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(71) Applicant *(for all designated States except US)*: **LORD CORPORATION** [US/US]; Attn: IP Legal Dept., 111 Lord Drive, Cary, North Carolina 27511 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **JOLLY, Mark** [US/US]; 909 W. Lenoir Street, Raleigh, North Carolina 27609 (US). **MILLER, Lane** [US/US]; 3328 Bentwillow Drive, Fuquay-Varina, North Carolina 27526 (US). **BADRE-ALAM, Askari** [US/US]; 205 Country Valley Court, Apex, North Carolina 27502 (US).

(74) Agent: MURPHY, III, Edward F.; Lord Corporation, 111 Lord Drive, Cary, North Carolina 27511 (US).

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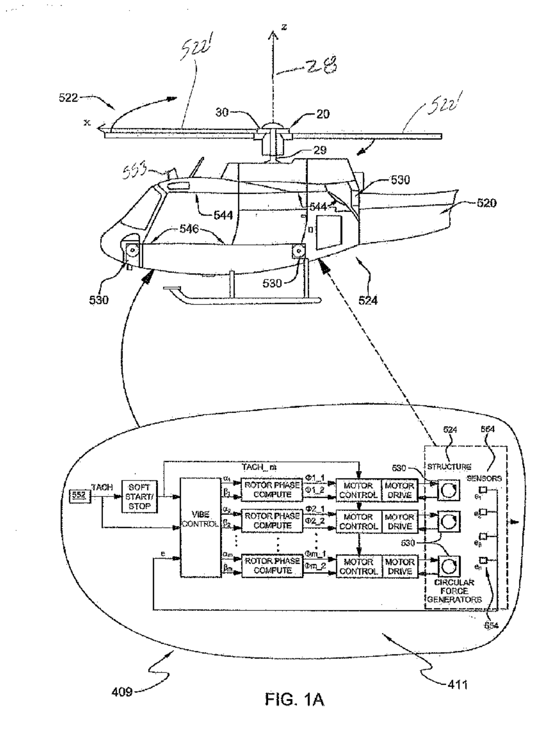

FIG. 1A

(57) Abstract: Rotary wing aircraft electronic control system including a tachometer and a plurality of nonrotating body vibration control sensors outputting at least first nonrotating body vibration sensor data correlating to vibrations. The system includes a plurality of nonrotating body force generators to input a vibration control force into said nonrotating aerostructure body. The system includes a data communications network link linking together the nonrotating body force generators the tachometer sensor, the vibration control sensors, and an actuating force generator rotor track balance electronic controller, the actuating force generator rotor track balance electronic controller including at least a first computer processor with the actuating force generator rotor track controller controlling the nonrotating body force generators to input vibration control forces into the nonrotating aerostructure body and computing a rotor track solution for aircraft rotor blades.

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REAL TIME ACTIVE HELICOPTER VIBRATION CONTROL AND ROTOR TRACK AND BALANCE SYSTEMS

This application claims the benefit of U.S. Provisional Application No. 61/348,489, filed May 26, 2010, which is herein incorporated by reference.

Field of the Invention

The invention relates to the field of vibration control systems for actively minimizing vibrations in structures. The invention relates to the field of methods/systems for actively controlling vibrations in vehicles. More particularly the invention relates to the field of controlling vibrations in aircraft vehicles having a nonrotating body and a rotating member, and more particularly the invention relates to helicopter vibration control systems.

Summary of the Invention

In embodiments the invention includes a rotary wing aircraft, the rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation, the rotary wing aircraft rotating hub having a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft preferably includes a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft preferably includes a plurality of nonrotating body vibration cancelling actuator force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically moving mass with the at least first nonrotating body force generator fixedly coupled with the nonrotating body. The rotary wing aircraft preferably includes a rotor plane tracker for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The rotary wing aircraft preferably includes a data communications network link, the data communications network link linking together the at least the nonrotating body force generators, the nonrotating body vibration control sensors, and the rotor plane tracker, wherein the nonrotating body force generators communicate force generation vibration control data through the force generation data communications network, with the first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the data communications network to provide a rotor track maintenance output.

In embodiments the invention includes a rotary wing aircraft electronic control system, the rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system preferably including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system preferably including a rotor plane tracker for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a data communications network link, the data communications system network link linking together the at least the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker, and an actuating force generator rotor track balance controller, the actuating force generator rotor track balance electronic controller including at least a first computer processor, the actuating force generator rotor track controller controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a rotary wing aircraft electronic control system, the rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system preferably including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system preferably including a data communications network link, the data communications system network link linking together the at least the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and an actuating force generator rotor track balance electronic controller, the actuating force generator rotor track balance electronic controller including at least a first computer processor, the actuating force generator rotor track balance controller controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a rotary wing aircraft control method for controlling a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The method preferably including providing a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, and fixedly coupling the at least first nonrotating body force generator with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes an aircraft control method for controlling an aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing an aircraft member tachometer sensor for outputting aircraft member data correlating to the relative rotation of the aircraft rotating hub rotor blades rotating relative to the nonrotating body. The method preferably including providing a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, and fixedly coupling the at least first nonrotating body force generator with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker for tracking the position of the aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass to inhibit vibrations in the nonrotating aerostructure body and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a rotary wing aircraft with an actuating force generator rotor track balance controller. =The rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub, the rotary wing aircraft including a vehicle vibration control system, a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body electromagnetically driven moving mass circular force generator, the at least a first nonrotating body electromagnetically driven moving mass circular force generator fixedly coupled with the nonrotating body, a data communications network link, the data communications system network link linking together at least the first nonrotating body electromagnetically driven moving mass circular force generator and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body electromagnetically driven moving mass circular force generator communicate force generation vibration control data through the data communications network, the at least first nonrotating body circular force generator controlled to produce a electromagnetically driven rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the actuating force generator rotor track balance controller controls the at least first electromagnetically moving mass force generator and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a aircraft vibration control system with an actuating force generator rotor track balance controller, for a aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub withal rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub. The aircraft vibration control system preferably includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body force generator with an electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body, a data communications network serial link, the data communications system network serial link linking together at least the first nonrotating body force generator and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate and share force generation vibration control data through the data communications network, the at least first nonrotating body force generator controlled with the actuating force generator rotor track balance controller to produce a force with a controllable magnitude and a controllable phase, the controllable force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body and the rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the actuating force generator rotor track balance controller controls the electromagnetically driven moving masses and produces a computed rotor track and balance solution for the rotor blades.

In embodiments the invention includes an aircraft vibration control system with an actuating force generator rotor track balance controller which controls electromagnetically driven moving masses and computes rotor track and balance solutions for the aircraft rotor blades. The aircraft vibration control system for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub, includes a rotating hub mounted means for controlling vibrations, the rotating hub mounted means for controlling vibrations mounted to the rotating rotary wing hub with the rotating hub mounted means for controlling vibrations rotating with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body force generator with an electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body, a means for linking together the actuating force generator rotor track balance controller, the sensors, the first nonrotating body force generator and the rotating hub mounted means for controlling vibrations wherein the rotating hub mounted means for controlling vibrations and the first nonrotating body force generator communicate and share force generation vibration control data through the means for linking, the at least first nonrotating body force generator is controlled to produce a force with a controllable magnitude and a controllable phase, the controllable force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body and, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced with the actuating force generator rotor track balance controller controlling the electromagnetically driven moving masses and producing a computed rotor track and balance solution for the rotor blades.

In embodiments the invention includes a vehicle vibration control system for controlling troublesome vibrations in a nonrotating vehicle body having a rotating machine member blades, the vehicle vibration control system including a vehicle vibration control system actuating force generator rotor track balance controller for controlling actuating force generator electromagnetically driven moving masses and producing a computed rotor track and balance solution for the vehicles blades. The system preferably includes a rotating machine member sensor, for inputting vehicle rotating machine member data correlating to a relative rotation of the rotating machine member rotating relative to the nonrotating body into the vehicle vibration control system controller, at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller, at least a first nonrotating vehicle body circular force generator with an electromagnetically driven moving mass, the at least a first nonrotating vehicle body circular force generator for fixedly mounting to the nonrotating vehicle body wherein the at least first nonrotating vehicle body circular force generator is controlled by the controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body with the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller, and a hub mounted vibration control system, the hub mounted vibration control system linked with the vehicle vibration control system controller with the actuating force generator rotor track balance controller controlling the electromagnetically driven moving masses and producing a computed rotor track and balance solution for the rotor blades.

In embodiments the invention includes a method of controlling vibration, the method including, providing at least a first nonrotating vehicle body circular force generator, fixedly mounting the at least first nonrotating vehicle body circular force generator to a nonrotating vehicle body, controlling the at least first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, providing a hub mounted vibration control system, fixedly mounting the hub mounted vibration control system to a rotatable hub of the nonrotating vehicle body, providing a communications network link and linking the hub mounted vibration control system together with the at least first nonrotating vehicle body circular force generator and an actuating force generator rotor track balance controller for controlling the actuating force generator and producing a computed rotor track and balance solution for the vehicles blades.

In an embodiment the invention includes a rotary wing aircraft vehicle, the vehicle having a nonrotating vehicle structure frame body and a rotating machine member, the vehicle including a vehicle vibration control system, the vehicle vibration control system including a vehicle vibration control system actuating force generator rotor track balance controller. The vehicle includes a vehicle rotating machine member sensor for inputting vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body into the vehicle vibration actuating force generator rotor track balance controller. The vehicle includes at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration actuating force generator rotor track balance controller. The vehicle includes at least a first nonrotating vehicle body circular force generator, the at least a first nonrotating vehicle body circular force generator fixedly coupled with the nonrotating vehicle body, the at least first nonrotating vehicle body circular force generator controlled by the controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body wherein the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor is reduced.

In an embodiment the invention includes a vehicle vibration control system for controlling troublesome vibrations in a nonrotating vehicle body having a rotating machine member. The vehicle vibration control system including a vehicle vibration control system actuating force generator rotor track balance controller. The vehicle vibration control system including a rotating machine member sensor, for inputting vehicle rotating machine member data correlating to a relative rotation of the rotating machine member rotating relative to the nonrotating body into the vehicle vibration control system actuating force generator rotor track balance controller. The vehicle vibration control system including at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system actuating force generator rotor track balance controller . The vehicle vibration control system including at least a first nonrotating vehicle body circular force generator, the at least a first nonrotating vehicle body circular force generator for fixedly mounting to the nonrotating vehicle body wherein the at least first nonrotating vehicle body circular force generator is controlled by the actuating force generator rotor track balance controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body with the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the actuating force generator rotor track balance controller .

In an embodiment the invention includes a method of controlling helicopter vibrations. The method includes providing a nonrotating helicopter body below a rotating helicopter rotor member. The method includes providing a vibration control system actuating force generator rotor track balance controller. The method includes providing a rotating helicopter rotor member sensor for inputting rotating member data correlating to a relative rotation of the rotating member rotating relative to the nonrotating body into the vibration control system actuating force generator rotor track balance controller. The method includes providing at least a first nonrotating body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating body vibration sensor data correlating to vehicle vibrations into the vibration control system actuating force generator rotor track balance controller. The method includes providing at least a first nonrotating vehicle body circular force generator. The method includes coupling the at least first nonrotating vehicle body circular force generator to the nonrotating helicopter body. The method includes controlling with the actuating force generator rotor track balance controller the coupled at least first nonrotating vehicle body circular force generator to produce a rotating force upon the nonrotating helicopter body with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotating member sensor data correlating to the relative rotation of the rotating member rotating relative to the nonrotating body with the vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the actuating force generator rotor track balance controller and an actuating force generator rotor track balance controller for controlling the actuating force generator and producing a computed rotor track and balance solution for the vehicles blades.

In an embodiment the invention includes a method of controlling vibrations. The method includes providing a nonrotating structure body having a rotating machine member. The method includes providing a vibration control system actuating force generator rotor track balance controller. The method includes providing a rotating machine member sensor, for inputting rotating member data correlating to a relative rotation of the rotating member rotating relative to the nonrotating body into the vibration control system actuating force generator rotor track balance controller. The method includes providing at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor inputting at least first nonrotating body vibration sensor data correlating to vibrations into the vibration control system actuating force generator rotor track balance controller. The method includes providing at least a first nonrotating body circular force generator. The method includes coupling the at least first nonrotating vehicle body circular force generator to the nonrotating structure body. The method includes controlling with the actuating force generator rotor track balance controller the coupled at least first nonrotating body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled relative to the rotating member sensor data correlating to the relative rotation of the rotating member rotating relative to the nonrotating body with the vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the actuating force generator rotor track balance controller and with the controller producing a computed rotor track and balance solution for the vehicles blades.

In an embodiment the invention includes a computer program product for a vibration control system. The computer program product comprising a computer readable medium. The computer program product comprising program instructions to monitor rotating machine member data correlating to a relative rotation of a rotating machine member rotating relative to a nonrotating body structure. The computer program product comprising program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations. The computer program product comprising program instructions to control an electromagnetically driven moving massforce generator mounted to the nonrotating body structure to control the force generator to output into the nonrotating body structure a force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations. The computer program product comprising program instructions to calculate a rotor track and balance solution for the rotor blades with the nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations and the rotating machine member data correlating to relative rotation of the rotating machine member rotating relative to the nonrotating body structure.

In an embodiment the invention includes a computer system for reducing vibrations in a vehicle with a nonrotating body structure and a rotating machine member rotating relative to the nonrotating body structure. The computer system comprising computer media with computer program instructions including program instructions to monitor rotating machine member data correlating to the relative rotation of the rotating machine member rotating relative to the nonrotating body structure. The computer system comprising computer media with computer program instructions including program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations measured by a plurality of nonrotating vehicle body vibration sensors. The computer system comprising computer media with computer program instructions including program instructions to control a circular force generator mounted to the nonrotating body structure to control the circular force generator to produce a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude and a controllable rotating force phase controlled in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations measured by the plurality of nonrotating vehicle body vibration sensors. The computer system comprising computer media with computer program instructions including calculating a rotor track and balance solution for the rotor blades with the nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations and the rotating machine member data correlating to relative rotation of the rotating machine member rotating relative to the nonrotating body structure.

In an embodiment the invention includes a vibration control system for controlling vibration on an aircraft structure responsive to a vibration disturbance at a given frequency. The vibration control system preferably includes a circular force generator for creating a controllable rotating force with controllable magnitude and phase. The vibration control system preferably includes a vibration sensor for generating a vibration signal indicative of vibration of the structure. The vibration control system preferably includes an actuating force generator rotor track balance controller with the controller producing a computed rotor track and balance solution for the structures rotating blades. The actuating force generator rotor track balance controller receives the vibration signal from the vibration sensor and commands the force generator to create the rotating force wherein such vibration of the structure sensed by the sensor is reduced. Preferably the vibration control system includes multiple circular force generators and multiple vibration sensors distributed throughout the structure, most preferably with the quantity of vibration sensors greater than the quantity of circular force generators. Preferably the vibration control system includes a reference sensor for generating a persistent signal indicative of the vibration disturbance, preferably wherein the reference sensor monitors a rotating blade machine member that are rotating relative to the structure and producing the vibrations. Preferably the controllable rotating force rotates at a given harmonic circular force generating frequency, preferably a harmonic of a rotating blade machine member that is rotating relative to the structure and producing the vibrations. Preferably the controllable rotating force is determined and calculated as circular force described as a real and imaginary part α and β, preferably with a circular force command signal generated with α and β. Preferably the controllable rotating force is generated with two corotating imbalance electromagnetically driven moving masses, which are preferably controlled with imbalance phasing Φ_1, Φ_2 with the actual imbalance phasing Φ_1, Φ_2 realizing the commanded α, β circular force.

In an embodiment the invention includes a vibration control system for controlling a vibration on a structure responsive to a vibration disturbance at a given frequency, said vibration control system including a circular force generator for creating a controllable rotating force with a controllable magnitude and controllable magnitude phase, said vibration control system including a vibration sensor for generating a vibration signal indicative of said vibration of said structure, said vibration control system including an actuating force generator rotor track balance controller that receives said vibration signal from said vibration sensor and commands said circular force generator to create said rotating force wherein such vibration of said structure sensed by said sensor is reduced and the actuating force generator rotor track balance controller producing a computed rotor track and balance solution.

In a preferred embodiment the rotary wing aircraft has a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation by an engine through a main gear box transmission and includes an actuating force generator rotor track balance controller with the controller producing a computed rotor track and balance solution for the structures rotating blades. The rotary wing aircraft includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors electromagnetically driven to rotate about the rotating hub center Z axis of rotation. The rotary wing aircraft includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The rotary wing aircraft includes at least a first nonrotating vibration sensor, the at least first nonrotating vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft includes a first nonrotating body force generator oriented and fixedly coupled with the nonrotating body proximate the gear box transmission and oriented relative to the rotating hub center Z axis of rotation. The rotary wing aircraft includes at least a second nonrotating body force generator oriented and fixedly coupled with the nonrotating body proximate the gear box transmission and oriented relative to the rotating hub center Z axis of rotation and the first nonrotating body force generator. The rotary wing aircraft includes a force generation data communications network link, the force generation data communications system network link linking together at least the first nonrotating body force generator, the second nonrotating body force generator, and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the nonrotating body force generators communicate force generation vibration control data through the force generation data communications network, the first nonrotating body force generator controlled to produce a first nonrotating body force generator force wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced with the actuating force generator rotor track balance controller with the controller producing a computed rotor track and balance solution for the structures rotating blades.

In a preferred embodiment the aircraft vibration control system is for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation by an engine through a main gear box transmission. The aircraft vibration control system includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The aircraft vibration control system includes a vibration sensor, the nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The aircraft vibration control system includes at least a first nonrotating body force generator and a second nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body force generator preferably has a first circular force generator rotating masses axis, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation. The second nonrotating body force generator preferably having a second circular force generator rotating masses axis, the at least second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation. Preferably the first circular force generator rotating masses axis is nonparallel to the second circular force generator rotating masses axis. The aircraft vibration control system preferably includes a data communications network link, the data communications network link linking together at least the first and second nonrotating body force generators and the rotating hub mounted vibration control system and an actuating force generator rotor track balance controller with the controller producing a computed rotor track and balance solution wherein the controller, the rotating hub mounted vibration control system and the first nonrotating body force generator communicate through the data communications network. The first nonrotating body circular force generator is controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body, and the second nonrotating body circular force generator controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body. The rotating hub mounted vibration control system preferably includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced and the actuating force generator rotor track balance controller producing a computed rotor track and balance solution for the structures rotating blades.

In a preferred embodiments the method of controlling aircraft vibrations in a rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation by an engine through a main gear box transmission includes providing a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation with the rotating rotary wing hub. The rotating hub mounted vibration control system includes a first hub mounted vibration control system rotor with a first imbalance mass concentration, and a second hub mounted vibration control system rotor with a second imbalance mass concentration. The method includes providing a first nonrotating body force generator; the first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. Preferably the first nonrotating body force generator having a first circular force generator rotating masses axis, with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation. The method preferably includes providing a second nonrotating body force generator having a second circular force generator rotating masses axis, the second nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation, with the first circular force generator rotating masses axis nonparallel to the second circular force generator rotating masses axis. The method preferably includes providing an actuating force generator rotor track balance controller with the controller producing a computed rotor track and balance solution for the structures rotating blades. The method includes controlling the first nonrotating vehicle body circular force generator with the actuating force generator rotor track balance controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method preferably includes controlling the second nonrotating vehicle body circular force generator with the actuating force generator rotor track balance controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method preferably includes driving the first hub mounted vibration control system rotor and the second hub mounted vibration control system rotor to control the vibrations. The method preferably includes producing a computed rotor track and balance solution with the actuating force generator rotor track balance controller.

It is to be understood that both the foregoing general description and the following detailed description are exemplary of the invention, and are intended to provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention and together with the description serve to explain the principals and operation of the invention.

Brief Description of the Drawings

FIG. 1A-B illustrates methods/systems for controlling helicopter vibrations.

FIG. 2 illustrates methods/systems for controlling helicopter vibrations with a communications bus and CFGs (Circular Force Generators) producing rotating force with controlled rotating force magnitude and controlled rotating force phase.

FIG. 3 illustrates circular force generation with two co-rotating imbalanced rotors creating a circular force with controllable magnitude and phase.

FIG. 4 illustrates Circular Force Generators (CFGs) with co-rotating imbalanced rotors.

FIG. 5A-G illustrates CFGs (Circular Force Generators) for producing rotating force with controlled rotating force magnitude and controlled rotating force phase.

FIG. 6A-F illustrates methods/systems with multiple oriented Circular Force Generators (CFGs).

FIG. 7A-E illustrates helicopter systems/methods for controlling vibration with control accelerometer sensors and CFGs located, mounted and oriented relative to a helicopter floor, sidewall, roof, and vehicle frames.

FIG. 8A-L illustrate helicopter Active Vibration Control with CFGs (Circular Force Generators) mounted on helicopter transmissions, with FIG. 8F-L illustrating computer modeled simulated performance of CFGs (Circular Force Generators) oriented with the axis of rotation of a rotating Hub Mounted Vibration control System (HMVS).

FIG. 9 illustrates a CFG (Circular Force Generator) with internal bearings, imbalance masses, motors, rotating mass sensor targets and sensors.

FIG. 10 illustrates methods/systems with multiple Circular Force Generators (CFGs) and accelerometers.

FIG. 11A-G illustrate CFGs (Circular Force Generators) with motor driven master rotating mass imbalance rotors and slave rotating mass imbalance rotors.

FIG. 12A-C illustrate CFGs (Circular Force Generators) with master rotating mass imbalance rotors and slave rotating mass imbalance rotors.

FIG. 13A-D illustrates methods/systems for controlling helicopter vibrations with a rotating Hub Mounted Vibration control System (HMVS), a communications bus and CFGs (Circular Force Generators).

FIG. 14 illustrates methods/systems for controlling helicopter vibrations with a HMVS, a communications bus and CFGs (Circular Force Generators).

FIG. 15 illustrates methods/systems for controlling helicopter vibrations with a HMVS, a communications bus and CFGs (Circular Force Generators).

FIG. 16 illustrates methods/systems for controlling helicopter vibrations with a HMVS, a communications bus and CFGs (Circular Force Generators).

FIG. 17 illustrates methods/systems for controlling helicopter vibrations with a HMVS, a communications bus and CFGs (Circular Force Generators) with a distributed master system control authority.

FIG. 18 illustrates methods/systems for controlling helicopter vibrations with a Dual Frequency HMVS, a communications bus and CFGs (Circular Force Generators).

FIG. 19A-B illustrates methods/systems for controlling helicopter vibrations with a communications bus and actuators.

FIG. 20A-C illustrates a dual frequency Hub Mounted Vibration control System (HMVS) with a 3P frequency stage and a 5P frequency stage.

FIG. 21 illustrates a dual frequency Hub Mounted Vibration control System (HMVS).

FIG. 22A-B illustrates HMVS imbalance rotors for generating a first rotating net force vector and a second rotating net force vector.

FIG. 23A-C illustrates dual frequency (3P and 5P) Hub Mounted Vibration control System (HMVS) control convergence properties, 3P and 5P rotor position commands, 3P and 5P tones.

FIG. 24A-B illustrates methods/systems for controlling helicopter vibrations with a dual frequency HMVS with 3 Rev and 5 Rev control.

FIG. 25A-C illustrates dual frequency (3P and 5P) HMVS for a helicopter rotor head.

FIG. 26A-B illustrates a single frequency (3P) HMVS for a helicopter rotor head.

FIG. 27A-B illustrates a dual frequency HMVS for a helicopter rotor head.

FIG. 28A-D illustrates HMVS imbalance rotors for generating two frequencies.

FIG. 29 illustrates HMVS control methods/systems.

FIG. 30A-B illustrates a dual frequency HMVS on a helicopter rotor head.

FIG. 31 illustrates an imbalance rotor with an imbalance mass concentration.

FIG. 32 illustrates an imbalance rotor with an imbalance mass concentration.

FIG. 33is a perspective view of an electromagnetic inertial actuator.

FIG. 34is a perspective view of a bottom half of the electromagnetic inertial actuator shown in FIG. 33.

FIG. 35is a perspective view of a flat voice coil motor.

FIG. 36 is a rear view of the flat voice coil motor shown in FIG. 35.

FIG. 37 is a perspective view of a left half of the flat voice coil motor shown in FIG. 35.

FIG. 38 shows the electromagnetic inertial actuator with the flat voice coil motor in a down position.

FIG. 39 shows the electromagnetic inertial actuator with the flat voice coil motor in an up position.

FIG. 40 shows magnetic flux in the flat voice coil motor.

FIG. 41 is a plot showing force generated by the flat voice coil motor versus stroke of the motor.

FIG. 42 is a perspective view of a flexure stack.

FIGS. 43A-N show voice coil/magnet arrangements for a voice coil motor of an electromagnetic inertial actuator.

FIG. 44 shows an aircraft including a vibration control system.

FIG. 45 is a perspective view of a variant of the electromagnetic inertial actuator shown in FIG. 33.

FIG. 46 is a perspective view of a variant of the electromagnetic inertial actuator shown in FIG. 33.

FIG. 47 illustrates a rotary wing aircraft with on-board aircraft control system hardware for real time active vibration control and rotor track and balance.

FIG. 48 illustrates a block diagram of a control system for actively controlling vibrations and providing rotor track and balance output solutions.

Detailed Description of the Preferred Embodiment

Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

In an embodiment the invention includes a rotary wing aircraft vehicle, the vehicle having a nonrotating vehicle structure frame body and a rotating machine member, the vehicle including a vehicle vibration control system, the vehicle vibration control system including a vehicle vibration control system controller. The vehicle includes a vehicle rotating machine member sensor for inputting vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body into the vehicle vibration control system controller. The vehicle includes at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller. The vehicle includes at least a first nonrotating vehicle body force generator, the at least a first nonrotating vehicle body force generator fixedly coupled with the nonrotating vehicle body, the at least first nonrotating vehicle body force generator controlled by the controller to produce a force with a controllable force magnitude and a controllable phase wherein the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor is reduced.

In an embodiment the rotary wing aircraft vehicle 520 includes a nonrotating vehicle body 524, preferably the helicopter structure frame, and a rotating machine member 522, preferably the helicopter rotating rotary wing hub with blades 522'. The rotating vehicle machine member 522 produces vibrations, with vibration disturbances at a vibration frequency, in the nonrotating vehicle body 524. The rotating machine member 522 rotating relative to the vehicle body 524 and producing troublesome vibrations in the vehicle body 524. The vehicle 520 includes a vehicle vibration control system 409, the vehicle vibration control system 409 including a vehicle vibration control system controller 411. Preferably the vehicle vibration control system controller 411 is comprised of at least one computer with inputs and outputs and at least one computer processor, with the vehicle vibration control system controller computer system for reducing vibrations preferably including computer media and utilizing computer programs with computer program instructions. Preferably the controller operates on one or more electronic devices connected and integrated together and communicating with each other. In an embodiment such as illustrated in FIG. 2, controller 411 operates within the system controller electronic devices and with the electronic modules (E-Modules) communicating through the communications bus network link. The vehicle 520 includes a vehicle rotating machine member sensor 552 for inputting vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524 into the vehicle vibration control system controller, preferably a tach output from a tachometer sensor 524 with tach inputs inputted into the controller 411. Preferably the vehicle rotating machine member sensor 552 is a reference sensor for generating a persistent signal indicative of the vibration disturbance, and senses a harmonic of the rotating speed of the rotating vehicle machine member 522 producing vibrations in the vehicle.

The vehicle 520 includes at least a first nonrotating vehicle body vibration sensor 554, the at least first nonrotating vehicle body vibration sensor 554 inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller 411, preferably the vibration sensors 554 are accelerometers coupled to the vehicle nonrotating body such that the accelerometers senses the vibrations and output vibrations signals into the vibration controller 411.

The vehicle 520 preferably includes at least a first nonrotating vehicle body circular force generator 530, the at least a first nonrotating vehicle body circular force generator 530 fixedly coupled with the nonrotating vehicle body 524 with the at least first nonrotating vehicle body circular force generator controlled by the controller 411 to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude. Preferably the at least a first nonrotating vehicle body circular force generator 530 is mechanically mounted to the frame structure body 524 of the vehicle 520 wherein the produced rotating force is transferred there into it with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body (tach input) wherein the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor is reduced. In preferred embodiments this includes producing 0 magnitude forces with 180° mass separations and maximum force magnitude with 0° mass separation controlled by the controller 411. Vibration is preferably reduced at a frequency correlating to rotating machine member 522, with vibrations preferably reduced at harmonics of the rotating machine member. Preferably methods include controlling harmonic vibrations of the rotating machine member with the generated rotating force emanating from the circular force generator 530, preferably the circular force generator 530 driving rotating moving masses at a harmonic of the vehicle rotating machine member. Preferably the system 409 generates rotating force as compared to linear component force, with the rotating force rotating at a harmonic of the vehicle rotating machine member 522, and preferably the rotating force phase is controlled relative to vehicle rotating machine member sensor persistent signal harmonic reference tachometer sine wave preferably utilized in the system controller 411 obtained from a sensor 552 input.

Preferably the vehicle 520 includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 wherein n>m. Preferably the rotating force is controlled to rotate at a vibration disturbance frequency, that is a harmonic of the rotating machine member 522 rotating speed with the system 409 and methods producing circular forces and not specifically or intentionally controlled to produce linear forces. Preferably in embodiments the methods/systems preferably inhibit and avoid calculating linear forces and outputting such. Preferably the vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body. Preferably the vehicle vibration control system controller 411 calculates in reference to the rotating reference signal the rotating force with a real part α and an imaginary part β. Preferably the systems/methods avoid and inhibit calculating linear forces for controlling the vibration, and preferably the vibration control system 409 controller 411 includes a vibe control subsystem (such as Vibe Control - FIG. 1B) which calculates real parts α_m and imaginary parts β_m in generating circular force command signals which command/describe desired rotating force vectors, such circular force command signals α_m β_m are preferably sent to rotor phase computer subsystem (such as Rotor Phase Compute - FIG. 1B) which in turn preferably computes mass phase signals, which are preferably sent to motor control/motor drive subsystem (such as Motor Control/Motor Drive - FIG. 1B) which generates motor drive signals that drive rotating masses around their circular paths, preferably with motor drive signals that drive the masses to generate the circular forces.

Preferably the vehicle 520 includes at least first nonrotating vehicle body circular force generator 530 including at least a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and at least a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}. As shown in FIG. 3, preferably axes 534' and 536' are overlapping, with the first (($mass_{m\_1}$) and second mass ($mass_{m\_2}$) (with m whole number equal to or greater than one) adjacent each other, preferably with duplicate mass arcs of duplicate arcuate shape and arcuate size oriented about the overlapping axes. Preferably the duplicate mass arcs of duplicate arcuate shape and arcuate size oriented about the overlapping axes adjacent each other, are preferably unnested rotating masses. The rotating mass arc preferably has an outer circumference curvature and an inner circular circumference curvature, and a center of mass. The circular force generator 530 preferably has two of the rotating mass arcs, with each rotating mass arc having a center of mass and a mass line going normal from the center of mass to its rotating mass axis providing a center of mass rotation axis track line, preferably with the first and second rotating mass arcs center of mass rotation axis track lines not crossing or intersecting but parallel, and preferably approximately adjacent.

Preferably the vehicle 520 includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 wherein n>m and (with m whole number equal to or greater than one). Preferably the vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. Preferably the first nonrotating vehicle body circular force generator 530 includes the first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534’ with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536’ with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. Preferably the m^{th} nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534’ with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536’ with a second rotating mass controllable rotating imbalance phase $\Phi_{m\_2,}$ the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal, preferably the rotating reference signal based on the tach input of the rotating machine rotor head member 522.

Preferably the first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}. Preferably the first rotating mass ($mass_{1\_1}$) is driven with a first motor and the second corotating mass ($mass_{1\_2}$) is driven with a second motor. As shown in FIG. 5, nonrotating vehicle body circular force generator 530 preferably includes the first rotating mass ($mass_{1\_1}$) 534 is driven with a first motor 538 and the second corotating mass ($mass_{1\_2}$) 536 is driven with a second motor 540.

Preferably the first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with a detent 576 linking between the first rotating mass ($mass_{m\_1}$) and the second corotating mass ($mass_{m\_2}$), and a single motor for driving the first rotating mass ($mass_{m\_1}$), wherein the first rotating mass ($mass_{m\_1}$) comprises a master rotating mass ($mass_{m\_1}$) with a master rotating mass controllable rotating imbalance phase Φ_{1_1}, and the second corotating mass ($mass_{m\_2}$) comprises a slave corotating mass ($mass_{m\_2}$) with a slave rotating mass controllable rotating imbalance phase Φ_{1_2} with the detent 576 controlling the slave rotating mass controllable rotating imbalance phase Φ_{1_2} relative to the master rotating mass controllable rotating imbalance phase Φ_{1_1}. As illustrated in FIG. 11, preferably one motor 571’’ with motor windings 571 drives both the master rotating mass 574 and the slave rotating mass 574. The motor windings 571 drive a motor rotor 571’ supported by bearings 572 with that motor rotor coupled with the master rotating mass imbalance rotor 574 (first rotating mass 534) with the second slave rotating mass imbalance rotor 573 coupled with the master rotor 574 with bearing 575 and detent 576 wherein the phase between the two rotors can be adjusted with controllably forcing slippage across the detent 576. Preferably the rotors are magnetically detented with a plurality of distributed magnets coupling the two rotors together, preferably with motor torque pulses controllably clocking the relative phases of the imbalance phases to control force magnitude with slipping of the detents 576. In embodiments detents 576 include magnetically detented magnets on magnets detent and magnets on steel. In embodiments the rotors are mechanically detented such as with mechanical ball detent, quill detent, and friction interface detent, preferably with elastomeric detents, preferably with engaging surface effect elastomers. FIG. 12 illustrates further embodiments of detented master and slave rotating masses. As shown in FIG. 12A-B, the master slave rotating mass rotor is preferably compliantly coupled and driven by the motor 571'', preferably with a compliance member 576'. Preferably compliance, preferably a compliance member 576', is provided between the motor and the master rotor imbalance. In preferred embodiments the compliance member 576' is a spring member. As shown in FIG. 12A, the compliance member 576' is an elastomeric spring member, preferably an elastomeric tubeform compliance member. As shown in FIG. 12B, the compliance member 576' is a magnetic detent spring and bearing member, preferably with the magnetic detents with lower step resolution than the above existing detents 576 between the master and slave rotating mass rotors or preferably with the magnetic detents with higher step maximum torque than the above existing detents 576 between the master and slave rotating mass rotors. In additional embodiments the compliance member 576' is a metal spring member, such as a spoke style metal spring, or other flexing metal spring member. In additional embodiments the compliance member 576' is a torsional spring member. Preferably the compliance member 576' is provided between the motor 571'' and the master rotating imbalance rotor and then the detent 576 is provided between the compliant master rotating imbalance mass and the detented slave rotor. FIG. 12C show the detent torque versus relative angular displacement for two detents.

Preferably the vehicle 520 includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530, with $m \geq 2$ and wherein $n>m$. Preferably the vehicle vibration control system controller 411 calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524, and the first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first circular force generator axis 530' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about the first circular force generator axis 530' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. The vehicle 520 includes a second nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{2\_1}$) 534 controllably driven about a second circular force generator axis 530'' with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) 536 controllably driven about the second circular force generator axis 530'' with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, with the imbalance phase Φ_{2_1} and the imbalance phase Φ_{2_2} controlled in reference to the rotating reference signal, the second nonrotating vehicle body circular force generator 530 oriented relative to the first nonrotating vehicle body circular force generator 530 wherein the second circular force generator axis 530'' is nonparallel with the first circular force generator axis 530'. In a preferred embodiment the second nonrotating vehicle body circular force generator 530 oriented relative to the first nonrotating vehicle body circular force generator 530 wherein the second circular force generator axis 530'' is oriented orthogonally with the first circular force generator axis 530'. Preferably $m \geq 3$, and a third nonrotating vehicle body circular force generator 530 first rotating mass ($mass_{3\_1}$) 534 is controllably driven about a third circular force generator axis 530''' with a first rotating mass controllable rotating imbalance phase Φ_{3_1} and a second corotating mass ($mass_{3\_2}$) 536 is controllably driven about the third circular force generator axis 530''' with a second rotating mass controllable rotating imbalance phase Φ_{3_2}, with the imbalance phase Φ_{3_1} and the imbalance phase Φ_{3_2} controlled in reference to the rotating reference signal, the third circular force generator axis oriented relative to the second circular force generator axis 530'' and the first circular force generator axis 530'. In preferred embodiments the axis 530', 530'', 530''' are nonparallel, and more preferably are oriented orthogonally. In embodiments at least two circular force generator axes are parallel, and preferably at least one nonparallel, preferably orthogonal. FIG. 6 illustrate embodiments of circular force generator axis 530',530'', 530''',530'''' orientation. In embodiments preferably the three axis 530', 530'', 530''' form a three-dimensional basis whereby controllable force components are created in three dimensions.

Preferably the vehicle 520 is a rotary wing aircraft with a vehicle ceiling and a vehicle floor. Preferably the vehicle nonrotating vehicle body 524 includes a vehicle ceiling 544 and a distal vehicle floor 546, the distal vehicle floor below 546 the vehicle ceiling 544 under normal parking, use and flight of the vehicle in the presence of gravity. Preferably the vehicle 520 includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with n>m. The vehicle vibration control system controller 411 calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator mounted to the vehicle body 524 proximate the vehicle ceiling 544. The vehicle with nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal, the mth nonrotating vehicle body circular force generator mounted to the vehicle body 524 proximate the vehicle floor 546. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the floor 546, and preferably under the floor 546, and preferably proximate the vehicle nose, and preferably proximate the vehicle tail. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the ceiling 544, and preferably above the ceiling 544, preferably proximate the vehicle tail, preferably mounted to a vehicle tailcone frame. FIG. 7 illustrates a vehicle vibration control system 409 with two force generators 530 mounted to the tailcone frame 7 proximate the ceiling 544 of a helicopter 520 and with two circular force generators 530 mounted under the floor 546 in the nose of the helicopter below the pilot and copilot area and with two circular force generators 530 mounted under the floor 546 to the helicopter frame 5. Preferably the two circular force generators 530 are mounted to the frame as shown in FIG. 7B with shear mounts as shown in FIG. 7D. In an embodiment the two circular force generators 530 in the nose area are mounted under the floor with base mounts as shown in FIG.7E. In an embodiment such as illustrated in FIG.7C, preferably a first forward controller 411 (1 FG Controller) controls the two circular force generators 530 which are mounted under the floor in the forward of the vehicle and a second aft controller 411 (2 FG Controller) controls the four circular force generators 530 mounted proximate the aft of the vehicle.

Preferably the rotary wing aircraft 520 includes a gear box transmission 526 for transmitting rotational power to the rotating machine member 522. Preferably vehicle engine energy force is transmitted through the transmission 526 to the vehicle motive force propeller helicopter rotor to move it and in turn move the vehicle, preferably with the transmission connected to rotor and transmitting rotating force to the rotor so the rotor turns at the relative rotation rate to the vehicle nonrotating body. The vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass (mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass (mass_{1_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 mounted proximate to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted adjacent to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. FIG. 8 illustrates embodiments with nonrotating vehicle body circular force generators 530 mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522. Most preferably with the circular force generator axis 530' are oriented non-parallel with the rotating machine member rotor hub axis of rotation 28. FIG. 8B-L illustrate preferred embodiments with the force generator axis 530', 530'', 530''', and 530'''' are oriented non-parallel with the helicopter rotary wing member rotor hub axis of rotation 28.

In preferred embodiments the rotary wing aircraft has a nonrotating aerostructure body 524 and a rotating rotary wing hub 522 driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission 526. The rotary wing aircraft includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system 20 mounted to the rotating rotary wing hub 522 with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors 38,44,38',44' driven to rotate about the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The rotary wing aircraft includes at least a first nonrotating vibration sensor, the at least first nonrotating vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft includes a nonrotating body circular force generator 530 having a first circular force generator rotating masses axis 530', the at least first nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the first circular force generator rotating masses axis 530' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes at least a second nonrotating body circular force generator 530 having a second circular force generator rotating masses axis 530'', the at least second nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the second circular force generator rotating masses axis 530'' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a data communications network link, preferably a distributed force generation data communications system network link linking together at least the first nonrotating body circular force generator 530, the second nonrotating body circular force generator 530, and the rotating hub mounted vibration control system 20 wherein the rotating hub mounted vibration control system and the nonrotating body circular force generators communicate force generation vibration control data through the distributed force generation data communications network, the first nonrotating body circular force generator controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

Preferably the circular force generator rotating masses axis 530', 530'', 530''', and 530'''' are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis. Preferably the circular force generators generate a force plane oriented in an YZ or XZ plane, preferably with the force plane oriented perpendicular to the XY plane of the rotating hub mounted vibration control system 20. Preferably the first and second circular force generator rotating masses axis 530' and 530'' are non-parallel to each other, preferably with their axis intersecting each other. Preferably the second nonrotating body circular force generator is controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotary wing aircraft includes a third nonrotating body circular force generator having a third circular force generator rotating masses axis 530''', the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis 530''' perpendicular to the rotating hub center Z axis of rotation 28. The third nonrotating body circular force generator is controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis 530''' with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotating hub mounted vibration control system, the first nonrotating body circular force generator, second nonrotating body circular force generator, and the third nonrotating body circular force generator are controlled together to provide five degrees of freedom control, preferably with the HMVS rotors rotating in XY planes, and the CFGs rotated in ZY and ZX planes normal to the XY planes. Preferably the rotating hub mounted vibration control system including a first rotating body vibration sensor, the rotating hub mounted vibration control system first rotating body vibration sensor outputting first rotating body vibration sensor data into the distributed force generation data communications network link. Preferably the aircraft includes a master controller connected to the distributed force generation data communications network link controls the rotating hub mounted vibration control system and the first nonrotating body circular force generator wherein vibrations sensed by the at least first nonrotating body vibration sensor are minimized. Preferably the distributed force generation data communications network link is a serial communications network link. Preferably the rotating rotary wing hub has an operational rotation frequency and the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a third hub mounted vibration control system rotor with a third imbalance mass concentration, the third hub mounted vibration control system rotor driven to rotate at a second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a fourth hub mounted vibration control system rotor with a fourth imbalance mass concentration, the fourth hub mounted vibration control system rotor driven to rotate at the second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotor speed greater than an operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at a second rotor speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the first circular force generator includes a first rotating mass (mass_{1_1}) controllably driven about the first circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass (mass_{1_2}) controllably driven about the first circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, and the second circular force generator including a first rotating mass ($mass_{2\_1}$) controllably driven about the second circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) controllably driven about the second circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, the second circular force generator oriented relative to the first circular force generator wherein the second circular force generator rotating masses axis is nonparallel with the first circular force generator rotating masses axis.

In a preferred embodiment the aircraft vibration control system is for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission. The aircraft vibration control system includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The aircraft vibration control system includes a vibration sensor, the nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The aircraft vibration control system includes at least a first nonrotating body force generator and a second nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator has a first circular force generator rotating masses axis, the at least first nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The second nonrotating body circular force generator having a second circular force generator rotating masses axis, the at least second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The first circular force generator rotating masses axis is nonparallel to the second circular force generator rotating masses axis. The aircraft vibration control system includes a distributed force generation data communications network link, the distributed force generation data communications network link linking together at least the first and second nonrotating body force generators and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate through the data communications network link. The first nonrotating body circular force generator is controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body, and the second nonrotating body circular force generator controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body. The rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the circular force generator rotating masses axis are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis, with force planes in a YZ or XZ plane, preferably force planes perpendicular to the XY HMVS plane. Preferably the first and second circular force generator rotating masses axis are non-parallel to each other, preferably with the axis intersecting each other. Preferably the third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, the third nonrotating body circular force generator controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In a preferred embodiment the method of controlling aircraft vibrations in a rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission includes providing a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The rotating hub mounted vibration control system includes a first hub mounted vibration control system rotor with a first imbalance mass concentration, and a second hub mounted vibration control system rotor with a second imbalance mass concentration. The method includes providing a first nonrotating body force generator; the first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator having a first circular force generator rotating masses axis, with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The method includes providing a second nonrotating body circular force generator having a second circular force generator rotating masses axis, the second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, with the first circular force generator rotating masses axis nonparallel to the second circular force generator rotating masses axis. The method includes controlling the first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes controlling the second nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes driving the first hub mounted vibration control system rotor and the second hub mounted vibration control system rotor to control the vibrations. Preferably the method includes providing a third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, and controlling the third nonrotating body circular force generator to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to a rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein a vibration sensed by an the at least first nonrotating body vibration sensor is reduced.

FIG. 5 illustrates preferred embodiments of a nonrotating vehicle body circular force generator 530 including first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534’ colined with circular force generator axis 530’ rotated by motor 538 (with the nonrotating motor winding preferably between the rotating motor rotor and the rotating mass 534) with first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536’ colined with circular force generator axis 530’ rotated by motor 540 (with the nonrotating motor winding preferably between the rotating motor rotor and the rotating mass 536) with first rotating mass controllable rotating imbalance phase Φ_{1_2}. Preferably a nonrotating vehicle body circular force generator circuit board 550 is positioned between the first rotating mass ($mass_{1\_1}$) 534 and the second corotating mass ($mass_{1\_2}$) 536, preferably a substantially planar is disposed and aligned between the rotating masses and motors, preferably with the circuit board comprised of a sealed circuit board with a sealed exterior overcoating, preferably with the circuit board plane oriented substantially normal to the circular force generator axis 530’ with the board preferably equal distances between the first rotating mass ($mass_{1\_1}$) 534 and the second corotating mass ($mass_{1\_2}$) 536. Preferably the circular force generator circuit board 550 extends with an electric lead end into an electronic housing, with the electric lead end connecting the circuit board with at least a first system connector with the outside and the controller 411 and the system 409. Preferably the circuit board includes wiring paths to the motor windings and to first and second rotating mass sensors 548 mounted on the circuit board 550. The first and second rotating mass sensors 548 mounted on the circuit board monitor the rotational position of the rotating mass sensor target 556 on the rotor being driven by the motors 538, 540 such that the controller 411 knows the rotational phase position of the rotating masses 534, 536, in preferred embodiments the first and second rotating mass sensors 548 are comprised of Hall sensor integrated sensor chips for sensing the rotation of a magnetic rotating mass sensor target 556 to provide out through the circuit board to the system controller the rotational position of the rotating mass. In an embodiment the rotating moving mass electronic noncontacting magnetic sensor 548 preferably comprises an integrated circuit semiconductor sensor chip which outputs through the circuit board 550 into the system 409 and controller 411 the rotational angle phase position of the rotating moving mass that the sensor target 556 is coupled with that the motor driven by the controller is driving. In a preferred embodiment the electronic noncontacting magnetic sensor integrated circuit semiconductor sensor chip has at least two dies, preferably the at least two dies are ASICs (Application Specific Integrated Circuits), in a preferred embodiment the at least two dies are side by side dies in the integrated circuit semiconductor sensor chip, in a preferred embodiment the at least two dies are vertically stacked dies in the integrated circuit semiconductor sensor chip. In a preferred embodiment the integrated circuit semiconductor sensor chip ASIC die include a magnetoresistive material, preferably with electrical resistance changes in the presence of the magnetic target magnetic field of target 556, preferably with magnetoresistive elements arranged in a Wheatstone bridge. In a preferred embodiment the integrated circuit semiconductor sensor chip ASIC die include a Hall Effect element, preferably a plurality of oriented Hall Effect elements, preferably silicon semiconductor Hall effect elements which detect the magnetic target magnetic field of target 556. The first electronic noncontacting magnetic sensor 548 sensor plane is integrated substantially normal to the circular force generator axis 530'. The second electronic noncontacting magnetic sensor 548 second sensor plane is integrated substantially normal to the circular force generator axis 530'. Preferably the motor driven rotor includes a fan magnetic coupling drive for driving air cooling fans, preferably with the magnetic coupling drive provided with a magnetic coupling drive ratio to drive the fan at a predetermined fan speed, preferably such as a 4/rev to provide forced air cooling of the force generator 530. FIG. 9 illustrates a further embodiment of a circular force generator axis 530' with the circuit board 550 oriented between the motor driven imbalance masses 534 and 536 with circuit board mounted axis oriented sensor plane chips 548 tracking the rotational position of the motor driven imbalance masses 534 and 536.

FIG. 10 illustrates a further vibration control system with a block diagram with six circular force generators 530 controlled by a controller 411 with a plurality of accelerometer nonrotating body vibration sensors 554 and an engine tachometer input sensor 552 for the rotating machine member sensor for inputting vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body into the vehicle vibration control system controller. The vehicle vibration control system controller 411 controls the rotation of the corotating masses rotating about circular force generator axes (530’, 530’’, …, 530’’’’’’) to create the controllable rotating forces which rotationally emanate out from the nonrotating vehicle body circular force generators 530 to reduces the vehicle vibrations sensed by the nonrotating body vibration sensors 554.

In embodiments the vehicle 520 is a helicopter with the vehicle rotating machine member 522 the helicopter rotating rotary wing hub above the nonrotating vehicle body helicopter fuselage frame below, and the helicopter rotating rotary wing hub includes hub mounted vibration control system 20 with at least a first hub mounted motor driven hub mass and at least a second hub mounted motor driven hub mass housed within a hub housing 30, with the mounted vibration control system 20 at least a first hub mounted motor driven hub mass and at least a second hub mounted motor driven hub mass driven to rotate relative to the rotary wing hub while the system 409 generates rotating forces in the body 524 with the circular force generators 530.

Preferably the circular force generator 530 includes at least a first rotating externally housed cooling fan having a rotation motion for cooling said circular force generator, said cooling fan rotation motion linked with the rotation of said rotating force. Preferably the circular force generator 530 includes at least a first rotating externally housed cooling fan having a rotation motion for cooling the circular force generator 530, the cooling fan rotation motion linked with a rotation of said first rotating mass (mass$_{1\_1}$) or said second corotating mass (mass$_{1\_2}$). Preferably the circular force generator 530 includes a magnetically coupled forced air cooling fan magnetically coupled to the rotation of the mass rotor within the generator housing such that no external power is needed to rotate the fan, preferably with a plurality of spaced magnets providing a rotation coupling to power the fan rotation.

In an embodiment the invention includes a vehicle vibration control system for controlling troublesome vibrations in a nonrotating vehicle body having a rotating machine member. The vehicle vibration control system including a vehicle vibration control system controller. The vehicle vibration control system including a rotating machine member sensor, for inputting vehicle rotating machine member data correlating to a relative rotation of the rotating machine member rotating relative to the nonrotating body into the vehicle vibration control system controller. The vehicle vibration control system including at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller. The vehicle vibration control system including at least a first nonrotating vehicle body circular force generator, the at least a first nonrotating vehicle body circular force generator for fixedly mounting to the nonrotating vehicle body wherein the at least first nonrotating vehicle body circular force generator is controlled by the controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body with the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller.

The vehicle vibration control system 409 includes a rotary wing aircraft vehicle vibration control system for controlling troublesome vibrations in a nonrotating vehicle body 524 having a rotating machine member 522, preferably the aircraft vehicle structure frame. Preferably the rotating vehicle machine member rotating component 522 producing vibrations and the vibration disturbance at a vibration frequency in the nonrotating vehicle body 524 is preferably the aircraft rotating rotary wing hub. The vehicle vibration control system 409 includes a vehicle vibration control system controller 411 with a vehicle vibration control system processor, with a computer processor with inputs and outputs, and with the control system preferably comprised of multiple connected subsystems. The system includes a vehicle rotating machine member sensor 552, for inputting vehicle rotating machine member data correlating to a relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body (tach input) into the vehicle vibration control system controller. Preferably the rotating machine member sensor 552 is a reference sensor for generating a persistent signal indicative of the vibration disturbance, and preferably senses a harmonic of the rotating speed of the rotating vehicle machine member 522 producing vibrations, and in preferred embodiments is a tachometer sensor providing a tach input. The system includes at least a first nonrotating vehicle body vibration sensor 554, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller, preferably with the system having a plurality of vibration sensors 554 distributed throughout the body 524, and in preferred embodiments the sensors 554 are accelerometers providing accel inputs. The system includes at least a first nonrotating vehicle body circular force generator 530, the at least a first nonrotating vehicle body circular force generator 530 for fixedly mounting to the nonrotating vehicle body 524 wherein the at least first nonrotating vehicle body circular force generator 530 is controlled by the controller 411 to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, (preferably 0 magnitude force when masses have a 180° separation opposed position) (preferably maximum force magnitude when masses have a 0° separation position), and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body (preferably in reference to the tach input) with the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller. Preferably the system includes a plurality of nonrotating vehicle body circular force generators 530 controlled by the controller 411 to produce a plurality of rotating forces with the vibration preferably reduced at a frequency correlating to rotating machine member 522, with troublesome vibrations in the body 524 preferably reduced at harmonics of rotating machine member 522, preferably with the method and system controlling harmonic vibrations of the rotating machine member 522 with the generated rotating forces emanating from the circular force generators 530, preferably with the circular force generators driven rotating moving masses 534 and 536 rotated at a harmonic of the vehicle rotating machine member 522. Preferably the system includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 wherein n>m. Preferably wherein the rotating forces generates are controlled by the controller 411 to rotate at a harmonic of the rotating machine member 522 rotating speed, preferably with the system/method producing circular forces and not calculating for or intentionally producing linear forces, with the method/system preferably inhibiting and avoiding calculating linear forces and outputting such.

Preferably the vehicle vibration control system controller generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body. Preferably the vehicle vibration control system controller 411 calculates in reference to a rotating reference signal the rotating force to be generated with a real part α and an imaginary part β. Preferably the vibe control subsystem calculates real parts α_m and imaginary parts β_m in generating circular force command signals which command/describe desired rotating force vectors, such circular force command signals α_m β_m are preferably sent to the rotor phase compute subsystem which in turn preferably computes mass phase signals, which are preferably sent to the motor control/motor drive subsystem which generates motor drive signals that drive the masses around their rotating circular paths, preferably motor drive signals that drive the masses to generate the circular forces preferably motor drive signals for motors 538, 540 to drive the masses 534, 536.

Preferably the at least first nonrotating vehicle body circular force generator 530 including at least a first rotating mass(mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and at least a second corotating mass (mass_{1_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, preferably with the axes are overlapping, with masses adjacent each other, preferably duplicate mass arcs of duplicate arcuate shape and arcuate size oriented about the overlapping axes. Preferably the system includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with n>m, the vehicle vibration control system controller generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524, and the first nonrotating vehicle body circular force generator 530 includes a first rotating mass (mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass (mass_{1_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. Preferably the mth nonrotating vehicle body circular force generator 530 includes a first rotating mass (mass_{m_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass (mass_{m_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase

Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal.

Preferably the first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}. Preferably the first rotating mass ($mass_{1\_1}$) 534 is driven with a first motor 538 and the second corotating mass ($mass_{1\_2}$) is driven with a second motor 540.

Preferably the first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2} with a detent 576 linking between the first rotating mass ($mass_{m\_1}$) and the second corotating mass ($mass_{m\_2}$), and a single motor for driving the first rotating mass ($mass_{m\_1}$), wherein the first rotating mass ($mass_{m\_1}$) comprises a master rotating mass ($mass_{m\_1}$) with a master rotating mass controllable rotating imbalance phase Φ_{1_1}, and the second corotating mass ($mass_{m\_2}$) comprises a slave corotating mass ($mass_{m\_2}$) with a slave rotating mass controllable rotating imbalance phase Φ_{1_2} with the detent controlling the slave rotating mass controllable rotating imbalance phase Φ_{1_2} relative to the master rotating mass controllable rotating imbalance phase Φ_{1_1}.

Preferably the system includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530, with $m \geq 2$ and $n>m$, and preferably the vehicle vibration control system controller calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first circular force generator axis 530' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about the first circular force generator axis 530' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. The system includes a second nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{2\_1}$) 534 controllably driven about a second circular force generator axis 530'' with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) 536 controllably driven about the second circular force generator axis 530'' with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, with the imbalance phase Φ_{2_1} and the imbalance phase Φ_{2_2} controlled in reference to the rotating reference signal, with the second nonrotating vehicle body circular force generator 530 oriented relative to the first nonrotating vehicle body circular force generator 530 wherein the second circular force generator axis 530'' is nonparallel with the first circular force generator axis 530'. In preferred embodiments the axes 530' and 530'' are oriented orthogonally. Preferably $m \geq 3$, and a third nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{3\_1}$) 534 controllably driven about a third circular force generator axis 530''' with a first rotating mass controllable rotating imbalance phase Φ_{3_1} and a second corotating mass ($mass_{3\_2}$) 536 controllably driven about the third circular force generator axis 530''' with a second rotating mass controllable rotating imbalance phase Φ_{3_2}, with the imbalance phase Φ_{3_1} and the imbalance phase Φ_{3_2} controlled in reference to the rotating reference signal, the third circular force generator axis oriented relative to the second circular force generator axis and the first circular force generator axis.

Preferably the system provides for the placement of nonrotating vehicle body circular force generators 530 proximate the vehicle ceiling and floor. Preferably the vehicle nonrotating vehicle body 524 includes a vehicle ceiling 544 and a distal vehicle floor 546, the distal vehicle floor below 546 the vehicle ceiling 544 under normal parking, use and flight of the vehicle in the presence of gravity. Preferably the system includes n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with $n>m$. The vehicle vibration control system controller 411 calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 preferably provided for mounting to the vehicle body 524 proximate the vehicle ceiling 544. The vehicle m^{th} nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal, the mth nonrotating vehicle body circular force generator 530 preferably provided for mounting to the vehicle body 524 proximate the vehicle floor 546. Preferably a plurality of circular force generators 530 are provided for mounting to the vehicle body frame 524 proximate the floor 546, and preferably under the floor 546, and preferably proximate the vehicle nose, and preferably proximate the vehicle tail. Preferably a plurality of circular force generators 530 are preferably provided for mounting to the vehicle body frame 524 proximate the ceiling 544, and preferably above the ceiling 544, preferably proximate the vehicle tail, preferably to a vehicle tailcone frame.

Preferably the system includes controlling vehicle transmission 526 vibrations. Preferably the vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 mounted proximate to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted adjacent to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. Preferably the nonrotating vehicle body circular force generators 530 are mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522. Preferably the rotary wing aircraft 520 includes a gear box transmission 526 for transmitting rotational power to the rotating machine member 522. Preferably vehicle engine energy force is transmitted through the transmission 526 to the vehicle motive force propeller helicopter rotor to move it and in turn move the vehicle, preferably with the transmission connected to rotor and transmitting rotating force to the rotor so the rotor turns at the relative rotation rate to the vehicle nonrotating body. The vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 mounted proximate to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted adjacent to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. FIG. 8 illustrates embodiments with nonrotating vehicle body circular force generators 530 mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522. Most preferably with the circular force generator axis 530' are oriented non-parallel with the rotating machine member rotor hub axis of rotation 28. FIG. 8B-L illustrate preferred embodiments with the circular force generator axis 530', 530'', 530''', and 530'''' are oriented non-parallel with the helicopter rotary wing member rotor hub axis of rotation 28.

In preferred embodiments the rotary wing aircraft has a nonrotating aerostructure body 524 and a rotating rotary wing hub 522 driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission 526. The rotary wing aircraft includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system 20 mounted to the rotating rotary wing hub 522 with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors 38,44,38',44' driven to rotate about the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The rotary wing aircraft includes at least a first nonrotating vibration sensor, the at least first nonrotating vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft includes a nonrotating body circular force generator 530 having a first circular force generator rotating masses axis 530', the at least first nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the first circular force generator rotating masses axis 530' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes at least a second nonrotating body circular force generator 530 having a second circular force generator rotating masses axis 530'', the at least second nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the second circular force generator rotating masses axis 530'' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a distributed force generation data communications network link, the distributed force generation data communications system network link linking together at least the first nonrotating body circular force generator 530, the second nonrotating body circular force generator 530, and the rotating hub mounted vibration control system 20 wherein the rotating hub mounted vibration control system and the nonrotating body circular force generators communicate force generation vibration control data through the distributed force generation data communications network, the first nonrotating body circular force generator controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

Preferably the circular force generator rotating masses axis 530', 530'', 530''', and 530'''' are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis. Preferably the circular force generators generate a force plane oriented in an YZ or XZ plane, preferably with the force plane oriented perpendicular to the XY plane of the rotating hub mounted vibration control system 20. Preferably the first and second circular force generator rotating masses axis 530' and 530'' are non-parallel to each other, preferably with their axis intersecting each other. Preferably the second nonrotating body circular force generator is controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotary wing aircraft includes a third nonrotating body circular force generator having a third circular force generator rotating masses axis 530''', the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis 530''' perpendicular to the rotating hub center Z axis of rotation 28. The third nonrotating body circular force generator is controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis 530''' with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotating hub mounted vibration control system, the first nonrotating body circular force generator, second nonrotating body circular force generator, and the third nonrotating body circular force generator are controlled together to provide five degrees of freedom control, preferably with the HMVS rotors rotating in XY planes, and the CFGs rotated in ZY and ZX planes normal to the XY planes. Preferably the rotating hub mounted vibration control system including a first rotating body vibration sensor, the rotating hub mounted vibration control system first rotating body vibration sensor outputting first rotating body vibration sensor data into the distributed force generation data communications network link. Preferably the aircraft includes a master controller connected to the distributed force generation data communications network link controls the rotating hub mounted vibration control system and the first nonrotating body circular force generator wherein vibrations sensed by the at least a first nonrotating body vibration sensor are minimized. Preferably the data communications network link is a serial communications network link. Preferably the rotating rotary wing hub has an operational rotation frequency and the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a third hub mounted vibration control system rotor with a third imbalance mass concentration, the third hub mounted vibration control system rotor driven to rotate at a second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a fourth hub mounted vibration control system rotor with a fourth imbalance mass concentration, the fourth hub mounted vibration control system rotor driven to rotate at the second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotor speed greater than an operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at a second rotor speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the first circular force generator includes a first rotating mass ($mass_{1\_1}$) controllably driven about the first circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) controllably driven about the first circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, and the second circular force generator including a first rotating mass ($mass_{2\_1}$) controllably driven about the second circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) controllably driven about the second circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, the second circular force generator oriented relative to the first circular force generator wherein the second circular force generator rotating masses axis is nonparallel with the first circular force generator rotating masses axis.

In a preferred embodiment the aircraft vibration control system is for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission. The aircraft vibration control system includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The aircraft vibration control system includes a vibration sensor, the nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The aircraft vibration control system includes at least a first nonrotating body force generator and a second nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator has a first circular force generator rotating masses axis, the at least first nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The second nonrotating body circular force generator having a second circular force generator rotating masses axis, the at least second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The first circular force generator rotating masses axis is nonparallel to the second circular force generator rotating masses axis. The aircraft vibration control system includes a distributed force generation data communications network link, the distributed force generation data communications network link linking together at least the first and second nonrotating body force generators and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate through the distributed force generation data communications network. The first nonrotating body circular force generator is controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body, and the second nonrotating body circular force generator controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body. The rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the circular force generator rotating masses axis are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis, with force planes in an YZ or XZ plane, preferably force planes perpendicular to the XY HMVS plane. Preferably the first and second circular force generator rotating masses axis are non-parallel to each other, preferably with the axis intersecting each other. Preferably the third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, the third nonrotating body circular force generator controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In a preferred embodiment the method of controlling aircraft vibrations in a rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission includes providing a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The rotating hub mounted vibration control system includes a first hub mounted vibration control system rotor with a first imbalance mass concentration, and a second hub mounted vibration control system rotor with a second imbalance mass concentration. The method includes providing a first nonrotating body force generator, the first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator having a first circular force generator rotating masses axis, with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The method includes providing a second nonrotating body circular force generator having a second circular force generator rotating masses axis, the second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, with the first circular force generator rotating masses axis nonparallel to the second circular force generator rotating masses axis. The method includes controlling the first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes controlling the second nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes driving the first hub mounted vibration control system rotor and the second hub mounted vibration control system rotor to control the vibrations. Preferably the method includes providing a third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, and controlling the third nonrotating body circular force generator to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to a rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein a vibration sensed by an at least first nonrotating body vibration sensor is reduced.

In an embodiment the invention includes a method of controlling helicopter vibrations. The method includes providing a nonrotating helicopter body below a rotating helicopter rotor member. The method includes providing a vibration control system controller. The method includes providing a rotating helicopter rotor member sensor for inputting rotating member data correlating to a relative rotation of the rotating member rotating relative to the nonrotating body into the vibration control system controller. The method includes providing at least a first nonrotating body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating body vibration sensor data correlating to vehicle vibrations into the vibration control system controller. The method includes providing at least a first nonrotating vehicle body circular force generator. The method includes coupling the at least first nonrotating vehicle body circular force generator to the nonrotating helicopter body. The method includes controlling with the controller the coupled at least first nonrotating vehicle body circular force generator to produce a rotating force upon the nonrotating helicopter body with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotating member sensor data correlating to the relative rotation of the rotating member rotating relative to the nonrotating body with the vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller.

The method of controlling helicopter vibrations includes providing a nonrotating helicopter body 524 below a rotating helicopter rotor member 522, preferably the helicopter rotating rotary wing hub. The method preferably includes providing a vehicle vibration control system controller 411, preferably with control system subsystems communicating within the vibration control system 409. The method preferably includes providing a vehicle rotating helicopter rotor member sensor 552, for inputting vehicle rotating member data correlating to a relative rotation of the vehicle rotating member rotating relative to the nonrotating vehicle body (preferably a tach input) into the vibration control system controller 411. The method preferably includes providing at least a first nonrotating body vibration sensor 554, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating body vibration sensor data correlating to vibrations into the vibration control system controller 411. The method preferably includes providing at least a first nonrotating vehicle body circular force generator 530. The method preferably includes coupling the at least first nonrotating vehicle body circular force generator 530 to the nonrotating helicopter body 524. The method preferably includes controlling with the controller 411 the coupled at least first nonrotating vehicle body circular force generator 530 to produce a rotating force upon the nonrotating helicopter body 524 with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude (preferably 0 magnitude force when masses 180° separation opposed position and maximum force magnitude when masses 0° separation), and with the controllable rotating force phase controlled in reference to the rotating member sensor data correlating to the relative rotation of the rotating member 522 rotating relative to the nonrotating body 524 with the vibration sensed by the at least first nonrotating vehicle body vibration sensor 554 reduced by the controller 411.

The method preferably includes providing then nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with n>m.

The method preferably includes the controlling of the rotating force to rotate at a harmonic of the rotating machine member rotating speed, preferably with the system/method producing circular forces while avoiding the calculation and generation of linear forces.

The method preferably includes generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524.

The method preferably includes calculating, with the controller, in reference to a rotating reference signal, the rotating force with a real part α and an imaginary part β. Preferably the method avoids and inhibits calculating linear forces for controlling the vibrations, preferably with the vibe control subsystem calculating real parts α_m and imaginary parts β_m in generating circular force command signals which command/describe desired rotating force vectors, such circular force command signals α_m β_m are preferably sent to the rotor phase compute subsystem which in turn preferably computes mass phase signals, which are preferably sent to motor control/motor drive subsystem which generates motor drive signals that drive the masses around their circular paths, preferably motor drive signals that drive the masses to generate the circular forces with the motor drive signals driving the motors 538, 540 of the circular force generator 530.

The method preferably includes providing the at least first nonrotating vehicle body circular force generator 530 with at least a first rotating mass (mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and at least a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}.

The method preferably includes providing then nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with n>m, with the vehicle vibration control system controller 411 generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body. The first nonrotating vehicle body circular force generator 530 including first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. The m^{th} nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal.

The method preferably includes providing the first nonrotating vehicle body circular force generator 530 which includes the first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and the second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}. Preferably the first rotating mass ($mass_{1\_1}$) 534 is driven with the first motor 538 and the second corotating mass ($mass_{1\_2}$) 536 is driven with the second motor 540.

In an embodiment, preferably the circular force generator 530 which includes the first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and the second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with a detent 576 linking between the first rotating mass ($mass_{m\_1}$) and the second corotating mass ($mass_{m\_2}$), and a motor for driving the first rotating mass ($mass_{m\_1}$), wherein the first rotating mass ($mass_{m\_1}$) comprises a master rotating mass ($mass_{m\_1}$) with a master rotating mass controllable rotating imbalance phase Φ_{1_1}, and the second corotating mass ($mass_{m\_2}$) comprises a slave corotating mass ($mass_{m\_2}$) with a slave rotating mass controllable rotating imbalance phase Φ_{1_2} with the detent controlling the slave rotating mass controllable rotating imbalance phase Φ_{1_2} relative to the master rotating mass controllable rotating imbalance phase Φ_{1_1}.

Preferably the method includes providing the n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530, with $m \geq 2$ and $n>m$, with the vehicle vibration control system controller generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body, with the first nonrotating vehicle body circular force generator 530 including a first rotating mass (mass_{1_1}) 534 controllably driven about a first circular force generator axis 530' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass (mass_{1_2}) 536 controllably driven about the first circular force generator axis 530' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. Preferably a second nonrotating vehicle body circular force generator 530 is provided including a first rotating mass (mass_{2_1}) 534 controllably driven about a second circular force generator axis 530'' with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass (mass_{2_2}) 536 controllably driven about the second circular force generator axis 530'' with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, with the imbalance phase Φ_{2_1} and the imbalance phase Φ_{2_2} controlled in reference to the rotating reference signal, with the second nonrotating vehicle body circular force generator 530 oriented relative to the first nonrotating vehicle body circular force generator 530 wherein the second circular force generator axis 530'' is nonparallel with the first circular force generator axis 530'. In embodiments the axes are preferably oriented orthogonally. Preferably $m \geq 3$, and a third nonrotating vehicle body circular force generator 530 is provided including a first rotating mass (mass_{3_1}) 534 controllably driven about a third circular force generator axis 530''' with a first rotating mass controllable rotating imbalance phase Φ_{3_1} and a second corotating mass (mass_{3_2}) 536 controllably driven about the third circular force generator axis 530''' with a second rotating mass controllable rotating imbalance phase Φ_{3_2}, with the imbalance phase Φ_{3_1} and the imbalance phase Φ_{3_2} controlled in reference to the rotating reference signal, the third circular force generator axis oriented relative to the second circular force generator axis and the first circular force generator axis.

Preferably the method includes mounting the circular force generators proximate the vehicle ceiling 544 and the floor 546. Preferably the method mounts the nonrotating vehicle body circular force generators 530 proximate the vehicle ceiling and floor. Preferably the vehicle nonrotating vehicle body 524 includes a vehicle ceiling 544 and a distal vehicle floor 546, the distal vehicle floor below 546 the vehicle ceiling 544 under normal parking, use and flight of the vehicle in the presence of gravity. Preferably n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 are provided with n>m. The controller 411 preferably calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 includes a first rotating mass (mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass (mass_{1_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 preferably mounted to the vehicle body 524 proximate the vehicle ceiling 544. The vehicle mth nonrotating vehicle body circular force generator 530 including a first rotating mass (mass_{m_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass (mass_{m_2}) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal, the mth nonrotating vehicle body circular force generator 530 mounted to the vehicle body 524 proximate the vehicle floor 546. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the floor 546, and preferably under the floor 546, and preferably proximate the vehicle nose, and preferably proximate the vehicle tail. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the ceiling 544, and preferably above the ceiling 544, preferably proximate the vehicle tail, preferably to a vehicle tailcone frame.

Preferably the method includes controlling vehicle transmission 526 vibrations. Preferably the vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass (mass_{1_1}) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, method including mounting the first nonrotating vehicle body circular force generator 530 to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. Preferably the nonrotating vehicle body circular force generators 530 are mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522, most preferably with the circular force generator axis 530' oriented parallel with the rotating machine member rotor hub axis of rotation.

Preferably the rotary wing aircraft 520 includes a gear box transmission 526 for transmitting rotational power to the rotating machine member 522. Preferably vehicle engine energy force is transmitted through the transmission 526 to the vehicle motive force propeller helicopter rotor to move it and in turn move the vehicle, preferably with the transmission connected to rotor and transmitting rotating force to the rotor so the rotor turns at the relative rotation rate to the vehicle nonrotating body. The vehicle vibration control system controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 mounted proximate to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted adjacent to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. FIG. 8 illustrates embodiments with nonrotating vehicle body circular force generators 530 mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522. Most preferably with the circular force generator axis 530' are oriented non-parallel with the rotating machine member rotor hub axis of rotation 28. FIG. 8B-L illustrate preferred embodiments with the circular force generator axis 530’, 530’’, 530’’’, and 530’’’’ are oriented non-parallel with the helicopter rotary wing member rotor hub axis of rotation 28.

In preferred embodiments the rotary wing aircraft has a nonrotating aerostructure body 524 and a rotating rotary wing hub 522 driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission 526. The rotary wing aircraft includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system 20 mounted to the rotating rotary wing hub 522 with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors 38,44,38’,44’ driven to rotate about the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The rotary wing aircraft includes at least a first nonrotating vibration sensor, the at least first nonrotating vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft includes a nonrotating body circular force generator 530 having a first circular force generator rotating masses axis 530’, the at least first nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the first circular force generator rotating masses axis 530’ perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes at least a second nonrotating body circular force generator 530 having a second circular force generator rotating masses axis 530’’, the at least second nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the second circular force generator rotating masses axis 530’’ perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a distributed force generation data communications network link, the distributed force generation data communications system network link linking together at least the first nonrotating body circular force generator 530, the second nonrotating body circular force generator 530, and the rotating hub mounted vibration control system 20 wherein the rotating hub mounted vibration control system and the nonrotating body circular force generators communicate force generation vibration control data through the distributed force generation data communications network, the first nonrotating body circular force generator controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

Preferably the circular force generator rotating masses axis 530', 530'', 530''', and 530'''' are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis. Preferably the circular force generators generate a force plane oriented in an YZ or XZ plane, preferably with the force plane oriented perpendicular to the XY plane of the rotating hub mounted vibration control system 20. Preferably the first and second circular force generator rotating masses axis 530' and 530'' are non-parallel to each other, preferably with their axis intersecting each other. Preferably the second nonrotating body circular force generator is controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotary wing aircraft includes a third nonrotating body circular force generator having a third circular force generator rotating masses axis 530''', the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis 530''' perpendicular to the rotating hub center Z axis of rotation 28. The third nonrotating body circular force generator is controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis 530''' with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotating hub mounted vibration control system, the first nonrotating body circular force generator, second nonrotating body circular force generator, and the third nonrotating body circular force generator are controlled together to provide five degrees of freedom control, preferably with the HMVS rotors rotating in XY planes, and the CFGs rotated in ZY and ZX planes normal to the XY planes. Preferably the rotating hub mounted vibration control system including a first rotating body vibration sensor, the rotating hub mounted vibration control system first rotating body vibration sensor outputting first rotating body vibration sensor data into the distributed force generation data communications network link. Preferably the aircraft includes a master controller connected to the data communications network link controls the rotating hub mounted vibration control system and the first nonrotating body circular force generator wherein vibrations sensed by the at least a first nonrotating body vibration sensor are minimized. Preferably the data communications network link is a serial communications network link. Preferably the rotating rotary wing hub has an operational rotation frequency and the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a third hub mounted vibration control system rotor with a third imbalance mass concentration, the third hub mounted vibration control system rotor driven to rotate at a second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a fourth hub mounted vibration control system rotor with a fourth imbalance mass concentration, the fourth hub mounted vibration control system rotor driven to rotate at the second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotor speed greater than an operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at a second rotor speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the first circular force generator includes a first rotating mass ($mass_{1\_1}$) controllably driven about the first circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) controllably driven about the first circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, and the second circular force generator including a first rotating mass ($mass_{2\_1}$) controllably driven about the second circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) controllably driven about the second circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, the second circular force generator oriented relative to the first circular force generator wherein the second circular force generator rotating masses axis is nonparallel with the first circular force generator rotating masses axis.

In a preferred embodiment the aircraft vibration control system is for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission. The aircraft vibration control system includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The aircraft vibration control system includes a vibration sensor, the nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The aircraft vibration control system includes at least a first nonrotating body force generator and a second nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator has a first circular force generator rotating masses axis, the at least first nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The second nonrotating body circular force generator having a second circular force generator rotating masses axis, the at least second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The first circular force generator rotating masses axis is nonparallel to the second circular force generator rotating masses axis. The aircraft vibration control system includes a data communications network link, the g data communications network link linking together at least the first and second nonrotating body force generators and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate through the data communications network. The first nonrotating body circular force generator is controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body, and the second nonrotating body circular force generator controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body. The rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the circular force generator rotating masses axis are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis, with force planes in an YZ or XZ plane, preferably force planes perpendicular to the XY HMVS plane. Preferably the first and second circular force generator rotating masses axis are non-parallel to each other, preferably with the axis intersecting each other. Preferably the third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, the third nonrotating body circular force generator controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In a preferred embodiment the method of controlling aircraft vibrations in a rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission includes providing a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The rotating hub mounted vibration control system includes a first hub mounted vibration control system rotor with a first imbalance mass concentration, and a second hub mounted vibration control system rotor with a second imbalance mass concentration. The method includes providing a first nonrotating body force generator, the first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body force generator preferably having a first circular force generator rotating masses axis, with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The method includes providing a second nonrotating body force generator preferably having a second circular force generator rotating masses axis, the second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, with the first circular force generator rotating masses axis nonparallel to the second circular force generator rotating masses axis. The method includes controlling the first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes controlling the second nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes driving the first hub mounted vibration control system rotor and the second hub mounted vibration control system rotor to control the vibrations. Preferably the method includes providing a third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, and controlling the third nonrotating body circular force generator to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to a rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein a vibration sensed by an at least first nonrotating body vibration sensor is reduced.

In an embodiment the invention includes a method of controlling vibrations. The method includes providing a nonrotating structure body having a rotating machine member. The method includes providing a vibration control system controller. The method includes providing a rotating machine member sensor, for inputting rotating member data correlating to a relative rotation of the rotating member rotating relative to the nonrotating body into the vibration control system controller. The method includes providing at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor inputting at least first nonrotating body vibration sensor data correlating to vibrations into the vibration control system controller. The method includes providing at least a first nonrotating body circular force generator. The method includes coupling the at least first nonrotating vehicle body circular force generator to the nonrotating structure body. The method includes controlling with the controller the coupled at least first nonrotating body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled relative to the rotating member sensor data correlating to the relative rotation of the rotating member rotating relative to the nonrotating body with the vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller.

The method of controlling vibrations, includes providing nonrotating structure body 524 having a rotating machine member 522. The method includes providing vibration control system controller 411 with a vibration control system processor, a computer with inputs and outputs, to control the control system preferably with communicating subsystems through the data communications network link. The method includes providing the rotating machine member sensor 552 for inputting rotating member data correlating to a relative rotation of the vehicle rotating member rotating relative to the nonrotating vehicle body (preferably a tach input) into the vibration control system controller 411. The method includes providing the nonrotating body vibration sensors 554, the first nonrotating body vibration sensors 554 inputting at vibration sensor data correlating to vehicle vibrations into the actuator force rotor track balance controller 411. The method preferably includes providing at least a first nonrotating vehicle body circular force generator 530. The method includes coupling the nonrotating vehicle body circular force generator 530 to the nonrotating structure body 524. The method includes controlling with the controller 411 the coupled at least first nonrotating body circular force generators 530 to produce rotating forces with controllable rotating force magnitude and controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude (0 magnitude force when masses 180° separation opposed position, maximum force magnitude when masses 0° separation), and with the controllable rotating force phase controlled relative to the rotating member sensor data correlating to the relative rotation of the rotating member rotating relative to the nonrotating body (tach input) with the vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller 411.

The method includes providing then nonrotating vehicle body vibration sensors and m nonrotating vehicle body circular force generators wherein n>m.

The method includes controlling the rotating force to rotate at a harmonic of the rotating machine member rotating speed.

The method includes generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body. The method preferably includes calculating in reference to a rotating reference signal the rotating force with a real part α and an imaginary part β. Preferably with the at least first nonrotating body circular force generators 530 , the method avoids and inhibits calculating linear forces for controlling vibrations, preferably with vibe control subsystem, preferably within the controller 411, calculating real parts α_m and imaginary parts β_m in generating circular force command signals which command/describe desired rotating force vectors, such circular force command signals α_m β_m are preferably sent to the rotor phase compute subsystem which in turn preferably computes mass phase signals, which are preferably sent to motor control/motor drive subsystem which generates motor drive signals that drive the masses around their circular paths, preferably motor drive signals that drive the motors 538, 540 that drive the masses 534, 536 to generate the circular forces.

Preferably providing the at least first nonrotating vehicle body circular force generators 530 includes providing the at least first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and the at least second corotating mass ($mass_{1\_2}$) 536 controllably driven about second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}.

Preferably n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 with n>m are provided, the first nonrotating vehicle body circular force generator 530 including first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to a rotating reference signal, and the mth nonrotating vehicle body circular force generator 530 including first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal.

Preferably the method includes providing nonrotating vehicle body circular force generators 530 with the first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2}. Preferably the method includes providing the motor 538 with the first rotating mass ($mass_{1\_1}$) 534 driven with the first motor 538 and providing the second motor 540 with the second corotating mass ($mass_{1\_2}$) 536 driven with the second motor 540.

Preferably the method includes providing nonrotating vehicle body circular force generators 530 with the first rotating mass ($mass_{1\_1}$) 534 with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 with a second rotating mass controllable rotating imbalance phase Φ_{1_2} with a detent 576 linking between the first rotating mass ($mass_{m\_1}$) and the second corotating mass ($mass_{m\_2}$), and a motor for driving the first rotating mass ($mass_{m\_1}$), wherein the first rotating mass ($mass_{m\_1}$) comprises a master rotating mass ($mass_{m\_1}$) with a master rotating mass controllable rotating imbalance phase Φ_{1_1}, and the second corotating mass ($mass_{m\_2}$) comprises a slave corotating mass ($mass_{m\_2}$) with a slave rotating mass controllable rotating imbalance phase Φ_{1_2} with the detent controlling the slave rotating mass controllable rotating imbalance phase Φ_{1_2} relative to the master rotating mass controllable rotating imbalance phase Φ_{1_1} with the one motor driving both, preferably magnetically detented.

Preferably the method includes providing the n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530, with $m \geq 2$ and $n>m$, with the vehicle vibration control system controller generating a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body, with the first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first circular force generator axis 530' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about the first circular force generator axis 530' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, with the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal. Preferably a second nonrotating vehicle body circular force generator 530 is provided including a first rotating mass ($mass_{2\_1}$) 534 controllably driven about a second circular force generator axis 530'' with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) 536 controllably driven about the second circular force generator axis 530'' with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, with the imbalance phase Φ_{2_1} and the imbalance phase Φ_{2_2} controlled in reference to the rotating reference signal, with the second nonrotating vehicle body circular force generator 530 oriented relative to the first nonrotating vehicle body circular force generator 530 wherein the second circular force generator axis 530'' is nonparallel with the first circular force generator axis 530'. In embodiments the axes are preferably oriented orthogonally. Preferably $m \geq 3$, and a third nonrotating vehicle body circular force generator 530 is provided including a first rotating mass ($mass_{3\_1}$) 534 controllably driven about a third circular force generator axis 530''' with a first rotating mass controllable rotating imbalance phase Φ_{3_1} and a second corotating mass ($mass_{3\_2}$) 536 controllably driven about the third circular force generator axis 530''' with a second rotating mass controllable rotating imbalance phase Φ_{3_2}, with the imbalance phase Φ_{3_1} and the imbalance phase Φ_{3_2} controlled in reference to the rotating reference signal, the third circular force generator axis oriented relative to the second circular force generator axis and the first circular force generator axis.

Preferably the method includes mounting the circular force generators proximate the vehicle ceiling 544 and the floor 546. Preferably the method mounts the nonrotating vehicle body circular force generators 530 proximate the vehicle ceiling and floor. Preferably the vehicle nonrotating vehicle body 524 includes a vehicle ceiling 544 and a distal vehicle floor 546, the distal vehicle floor below 546 the vehicle ceiling 544 under normal parking, use and flight of the vehicle in the presence of gravity. Preferably n nonrotating vehicle body vibration sensors 554 and m nonrotating vehicle body circular force generators 530 are provided with n>m. The controller 411 preferably calculates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 includes a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 preferably mounted to the vehicle body 524 proximate the vehicle ceiling 544. The vehicle m^{th} nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{m\_1}$) 534 controllably driven about a first rotating mass axis 534' with a first rotating mass controllable rotating imbalance phase Φ_{m_1} and a second corotating mass ($mass_{m\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{m_2}, the imbalance phase

Φ_{m_1} and the imbalance phase Φ_{m_2} controlled in reference to the rotating reference signal, the mth nonrotating vehicle body circular force generator 530 mounted to the vehicle body 524 proximate the vehicle floor 546. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the floor 546, and preferably under the floor 546, and preferably proximate the vehicle nose, and preferably proximate the vehicle tail. Preferably a plurality of circular force generators 530 are mounted to the vehicle body frame 524 proximate the ceiling 544, and preferably above the ceiling 544, preferably proximate the vehicle tail, preferably to a vehicle tailcone frame.

Preferably the method includes controlling vehicle transmission 526 vibrations. Preferably the controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534’ with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536’ with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, method including mounting the first nonrotating vehicle body circular force generator 530 to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. Preferably the nonrotating vehicle body circular force generators 530 are mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530’ oriented relative to the rotation axis of the rotating machine member 522.

Preferably the rotary wing aircraft 520 includes a gear box transmission 526 for transmitting rotational power to the rotating machine member 522. Preferably vehicle engine energy force is transmitted through the transmission 526 to the vehicle motive force propeller helicopter rotor to move it and in turn move the vehicle, preferably with the transmission connected to rotor and transmitting rotating force to the rotor so the rotor turns at the relative rotation rate to the vehicle nonrotating body. The controller 411 generates a rotating reference signal from the vehicle rotating machine member data correlating to the relative rotation of the vehicle rotating machine member 522 rotating relative to the nonrotating vehicle body 524. The first nonrotating vehicle body circular force generator 530 including a first rotating mass ($mass_{1\_1}$) 534 controllably driven about a first rotating mass axis 534’ with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) 536 controllably driven about a second rotating mass axis 536' with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, the imbalance phase Φ_{1_1} and the imbalance phase Φ_{1_2} controlled in reference to the rotating reference signal, the first nonrotating vehicle body circular force generator 530 mounted proximate to the vehicle transmission 526. In an embodiment a plurality of nonrotating vehicle body circular force generators 530 are mounted adjacent to the transmission 526, and preferably the transmission is above the floor 546 and ceiling 544. FIG. 8 illustrates embodiments with nonrotating vehicle body circular force generators 530 mounted to the vehicle transmissions 526, preferably with the circular force generator axis 530' oriented relative to the rotation axis of the rotating machine member 522. Most preferably with the circular force generator axis 530' are oriented non-parallel with the rotating machine member rotor hub axis of rotation 28. FIG. 8B-L illustrate preferred embodiments with the circular force generator axis 530', 530'', 530''', and 530'''' are oriented non-parallel with the helicopter rotary wing member rotor hub axis of rotation 28.

In preferred embodiments the rotary wing aircraft has a nonrotating aerostructure body 524 and a rotating rotary wing hub 522 driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission 526. The rotary wing aircraft includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system 20 mounted to the rotating rotary wing hub 522 with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors 38,44,38',44' driven to rotate about the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The rotary wing aircraft includes at least a first nonrotating vibration sensor, the at least first nonrotating vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft includes a nonrotating body circular force generator 530 having a first circular force generator rotating masses axis 530', the at least first nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the first circular force generator rotating masses axis 530' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes at least a second nonrotating body circular force generator 530 having a second circular force generator rotating masses axis 530'', the at least second nonrotating body circular force generator 530 fixedly coupled with the nonrotating body 524 proximate the gear box transmission 526 with the second circular force generator rotating masses axis 530'' perpendicular to the rotating hub center Z axis of rotation 28. The rotary wing aircraft includes a data communications network link, preferably a distributed force generation data communications system network link linking together at least the first nonrotating body circular force generator 530, the second nonrotating body circular force generator 530, and the rotating hub mounted vibration control system 20 wherein the rotating hub mounted vibration control system and the nonrotating body circular force generators communicate force generation vibration control data through the distributed force generation data communications network, the first nonrotating body circular force generator controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

Preferably the circular force generator rotating masses axis 530', 530'', 530''', and 530'''' are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis. Preferably the circular force generators generate a force plane oriented in an YZ or XZ plane, preferably with the force plane oriented perpendicular to the XY plane of the rotating hub mounted vibration control system 20. Preferably the first and second circular force generator rotating masses axis 530' and 530'' are non-parallel to each other, preferably with their axis intersecting each other. Preferably the second nonrotating body circular force generator is controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

Preferably the rotary wing aircraft includes a third nonrotating body circular force generator having a third circular force generator rotating masses axis 530''', the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis 530''' perpendicular to the rotating hub center Z axis of rotation 28. The third nonrotating body circular force generator is controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis 530''' with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the rotating hub mounted vibration control system, the first nonrotating body circular force generator, second nonrotating body circular force generator, and the third nonrotating body circular force generator are controlled together to provide five degrees of freedom control, preferably with the HMVS rotors rotating in XY planes, and the CFGs rotated in ZY and ZX planes normal to the XY planes. Preferably the rotating hub mounted vibration control system including a first rotating body vibration sensor, the rotating hub mounted vibration control system first rotating body vibration sensor outputting first rotating body vibration sensor data into the distributed force generation data communications network link. Preferably the aircraft includes a master controller connected to the distributed force generation data communications network link controls the rotating hub mounted vibration control system and the first nonrotating body circular force generator wherein vibrations sensed by the at least a first nonrotating body vibration sensor are minimized. Preferably the distributed force generation data communications network link is a serial communications network link. Preferably the rotating rotary wing hub has an operational rotation frequency and the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a third hub mounted vibration control system rotor with a third imbalance mass concentration, the third hub mounted vibration control system rotor driven to rotate at a second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, a fourth hub mounted vibration control system rotor with a fourth imbalance mass concentration, the fourth hub mounted vibration control system rotor driven to rotate at the second rotation speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the rotating hub mounted vibration control system plurality of imbalance mass concentration rotors (38,44,38',44') include a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotor speed greater than an operational rotation frequency of the rotating rotary wing hub, a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at a second rotor speed greater than the operational rotation frequency of the rotating rotary wing hub. Preferably the first circular force generator includes a first rotating mass ($mass_{1\_1}$) controllably driven about the first circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{1_1} and a second corotating mass ($mass_{1\_2}$) controllably driven about the first circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{1_2}, and the second circular force generator including a first rotating mass ($mass_{2\_1}$) controllably driven about the second circular force generator rotating masses axis with a first rotating mass controllable rotating imbalance phase Φ_{2_1} and a second corotating mass ($mass_{2\_2}$) controllably driven about the second circular force generator rotating masses axis with a second rotating mass controllable rotating imbalance phase Φ_{2_2}, the second circular force generator oriented relative to the first circular force generator wherein the second circular force generator rotating masses axis is nonparallel with the first circular force generator rotating masses axis.

In a preferred embodiment the aircraft vibration control system is for an aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission. The aircraft vibration control system includes a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The aircraft vibration control system includes a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body. The aircraft vibration control system includes a vibration sensor, the nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The aircraft vibration control system includes at least a first nonrotating body force generator and a second nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator has a first circular force generator rotating masses axis, the at least first nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The second nonrotating body circular force generator having a second circular force generator rotating masses axis, the at least second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The first circular force generator rotating masses axis is nonparallel to the second circular force generator rotating masses axis. The aircraft vibration control system includes a distributed force generation data communications network link, the distributed force generation data communications network link linking together at least the first and second nonrotating body force generators and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate through the distributed force generation data communications network. The first nonrotating body circular force generator is controlled to produce a first nonrotating body circular force generator rotating force centered about the first nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body, and the second nonrotating body circular force generator controlled to produce a second nonrotating body circular force generator rotating force centered about the second nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body. The rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced. Preferably the circular force generator rotating masses axis are perpendicular to the rotating hub center Z axis of rotation 28 with the masses axis not intersecting the Z axis, with force planes in an YZ or XZ plane, preferably force planes perpendicular to the XY HMVS plane. Preferably the first and second circular force generator rotating masses axis are non-parallel to each other, preferably with the axis intersecting each other. Preferably the third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, the third nonrotating body circular force generator controlled to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In a preferred embodiment the method of controlling aircraft vibrations in a rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub driven to rotate about a rotating hub center Z axis of rotation 28 by an engine through a main gear box transmission includes providing a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating about the rotating hub center Z axis of rotation 28 with the rotating rotary wing hub. The rotating hub mounted vibration control system includes a first hub mounted vibration control system rotor with a first imbalance mass concentration, and a second hub mounted vibration control system rotor with a second imbalance mass concentration. The method includes providing a first nonrotating body force generator, the first nonrotating body force generator fixedly coupled with the nonrotating body adjacent the gear box transmission. The first nonrotating body circular force generator having a first circular force generator rotating masses axis, with the first circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28. The method includes providing a second nonrotating body circular force generator having a second circular force generator rotating masses axis, the second nonrotating body circular force generator fixedly coupled with the nonrotating body adjacent the gear box transmission with the second circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, with the first circular force generator rotating masses axis nonparallel to the second circular force generator rotating masses axis. The method includes controlling the first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes controlling the second nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase. The method includes driving the first hub mounted vibration control system rotor and the second hub mounted vibration control system rotor to control the vibrations. Preferably the method includes providing a third nonrotating body circular force generator having a third circular force generator rotating masses axis, the third nonrotating body circular force generator fixedly coupled with the nonrotating body proximate the gear box transmission with the third nonrotating body circular force generator rotating masses axis perpendicular to the rotating hub center Z axis of rotation 28, and controlling the third nonrotating body circular force generator to produce a third nonrotating body circular force generator rotating force centered about the third nonrotating body circular force generator rotating masses axis with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to a rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein a vibration sensed by an at least first nonrotating body vibration sensor is reduced.

In an embodiment the invention includes a computer program product for a vibration control system. The computer program product comprising a computer readable medium. The computer program product comprising program instructions to monitor rotating machine member data correlating to a relative rotation of a rotating machine member rotating relative to a nonrotating body structure. The computer program product comprising program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations. The computer program product comprising program instructions to control a circular force generator mounted to the nonrotating body structure to control the circular force generator to output into the nonrotating body structure a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude and a controllable rotating force phase controlled in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations.

Preferably the vibration control system computer program product includes a computer readable medium and first program instructions to monitor rotating machine member data correlating to a relative rotation of the rotating machine member 522 rotating relative to a nonrotating body structure 524. Preferably the vibration control system computer program product includes second program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations. Preferably the vibration control system computer program product includes third program instructions to control a force generator 530 mounted to the nonrotating body structure 524 to control the force generator 530 to output into the nonrotating body structure 524 a force with a controllable force magnitude controlled from a minimal force magnitude up to a maximum force magnitude and a controllable force phase controlled in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations.

Preferably the second program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations, include instructions to monitor a plurality of nonrotating vehicle body vibration sensors' outputs from a plurality of nonrotating vehicle body vibration sensors 554 distributed about the nonrotating body structure 524.

Preferably the third program instructions to control the force generator 530 include rotating the rotating force at a harmonic vibration disturbance frequency which is a harmonic of the rotating machine member rotating speed.

Preferably the third program instructions to control the circular force generator 530 include instructions to calculate in reference to the rotating machine member 522 the rotating force with a real part α and an imaginary part β.

Preferably the program instructions avoid and inhibit calculating linear forces for controlling vibration with the circular force generator 530.

Preferably vibe control subsystem includes instructions for calculating real parts α_m and imaginary parts β_m in generating circular force command signals which command/describe desired rotating force vectors, and instructions for sending such circular force command signals α_m β_m to rotor phase compute subsystem which in turn preferably includes instructions for computing mass phase signals, which are preferably includes instructions for sending such mass phase signals to the motor control/motor drive subsystem which generates motor drive signals that drive the masses around their circular paths, preferably motor drive signals that drive the masses to generate the circular forces.

Preferably the system includes instructions for rotating the rotating force at a harmonic vibration disturbance frequency which is a harmonic of the rotating machine member rotating speed.

Preferably the system includes instructions for controlling rotation of the first rotor mass 534 and a rotation of the second rotor mass 536.

In an embodiment the invention includes a computer system for reducing vibrations in a vehicle with a nonrotating body structure and a rotating machine member rotating relative to the nonrotating body structure. The computer system comprising computer media with computer program instructions including program instructions to monitor rotating machine member data correlating to the relative rotation of the rotating machine member rotating relative to the nonrotating body structure. The computer system comprising computer media with computer program instructions including program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations measured by a plurality of nonrotating vehicle body vibration sensors. The computer system comprising computer media with computer program instructions including program instructions to control a circular force generator mounted to the nonrotating body structure to control the circular force generator to produce a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude and a controllable rotating force phase controlled in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations measured by the plurality of nonrotating vehicle body vibration sensors.

Preferably the computer system for reducing vibrations in the vehicle 520 with nonrotating body structure 524 and the rotating machine member 522 rotating relative to the nonrotating body structure 524 includes computer media 1107 with computer program instructions including first program instructions to monitor rotating machine member data correlating to the relative rotation of the rotating machine member 522 rotating relative to the nonrotating body structure 524. The system includes second program instructions to monitor nonrotating body structure vibration sensor data correlating to nonrotating body structure vibrations measured by a plurality of nonrotating vehicle body vibration sensors 554. The system third program instructions to control a circular force generator 530 mounted to the nonrotating body structure 524 to control the circular force generator 530 to produce a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude and a controllable rotating force phase controlled in reference to the monitored rotating machine member data to minimize nonrotating body structure vibrations measured by the plurality of nonrotating vehicle body vibration sensors 554.

Preferably the system includes program instructions to rotate the rotating force at a harmonic vibration disturbance frequency which is a harmonic of the rotating machine member rotating speed.

Preferably the system includes program instructions to control the circular force generator 530 and to calculates in reference to the rotating machine member 522 the rotating force with a real part α and an imaginary part β.

Preferably the system includes program instructions to control the circular force generator 530 and to generate a plurality of circular force command signals, preferably with the vibe control subsystem generating circular force command signals which command/describe desired rotating force vectors, the circular force command signals α_m β_m are preferably sent to rotor phase compute subsystem.

Preferably the system includes program instructions to control the circular force generator 530 and to generate a plurality of mass phase signals ($\Phi_{m\_1,}$ $\Phi_{m\_2,}$ rotating mass controllable rotating imbalance phase signals Φ_{m_1} Φ_{m_2}, and imbalance phase Φ_{m_1} and imbalance phase Φ_{m_2} controlled in reference to rotating machine member reference signal, preferably rotor phase compute subsystem receives circular force command signals α_m β_m, and generates the mass phase signals $\Phi_{m\_1,}$ Φ_{m_2} for the two corotating mass imbalances 534, 536).

Preferably the system includes program instructions to control the circular force generator 530 and to generate a plurality of motor drive signals to drive a first mass 534 and a second mass 536 (rotating mass controllable rotating imbalance phase signals Φ_{m_1} Φ_{m_2} preferably received into motor control/motor drive subsystem from rotor phase compute subsystem receives, with motor drive signals driving the circular force generator mass imbalances 534, 536 to controllably rotate to produce the rotating force).

In an embodiment the invention includes a data communications network link with computer data signals. The computer data signals transmitted in the data communications network link and vibration reducing computer system for a vehicle with a nonrotating body structure and a rotating machine member rotating relative to the nonrotating body structure. The computer data signal comprising a circular force command signal including information for producing a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude into the nonrotating body structure and a controllable rotating force phase controlled in reference to the rotating machine member to minimize nonrotating body structure vibrations in the nonrotating body structure.

Preferably the computer data signals are transmitted in the vibration reducing computer system 409 through the data communications network link for the vehicle 520 with the nonrotating body structure 524 and rotating machine member 522 rotating relative to the nonrotating body structure 524. Preferably the data communications network link with the computer data signal includes a circular force command signal with information for producing a rotating force with a controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude into the nonrotating body structure 524 and a controllable rotating force phase controlled in reference to the rotating machine member 522 to minimize nonrotating body structure vibrations in the nonrotating body structure 524. Preferably the vibe control subsystem generates the circular force command data signals which command/describe desired rotating force vectors, circular force command data signals α_m β_m are preferably sent to rotor phase compute subsystem. Preferably the circular force command signal includes a real part α and an imaginary part β.

In an embodiment the invention includes a vibration control system for controlling vibration on a structure responsive to a vibration disturbance at a given frequency. The vibration control system preferably includes a circular force generator for creating a controllable rotating force with controllable magnitude and phase. The vibration control system preferably includes a vibration sensor for generating a vibration signal indicative of vibration of the structure. The vibration control system preferably includes a controller that receives the vibration signal from the vibration sensor and commands the force generator to create said rotating force wherein such vibration of the structure sensed by the sensor is reduced. Preferably the vibration control system includes multiple circular force generators and multiple vibration sensors distributed throughout the structure, most preferably with the quantity of vibration sensors greater than the quantity of circular force generators. Preferably the vibration control system includes a reference sensor for generating a persistent signal indicative of the vibration disturbance, preferably wherein the reference sensor monitors a rotating machine member that is rotating relative to the structure and producing the vibrations. Preferably the controllable rotating force rotates at a given harmonic circular force generating frequency, preferably a harmonic of a rotating machine member that is rotating relative to the structure and producing the vibrations. Preferably the controllable rotating force is determined and calculated as circular force described as a real and imaginary part α and β, preferably with a circular force command signal generated with α and β. Preferably the controllable rotating force is generated with two corotating imbalance moving masses, which are preferably controlled with imbalance phasing Φ_1, Φ_2 with the actual imbalance phasing Φ_1, Φ_2 realizing the commanded α, β circular force.

Preferably the vibration control system 409 for controlling vibration on structure 524 responsive to a vibration disturbance at a given frequency includes a force generator 530 for creating a controllable rotating force with controllable magnitude and phase, a vibration sensor 554 for generating a vibration signal indicative of vibration of the structure 524, a controller 411 that receives the vibration signal from the vibration sensor 554 and commands the force generator 530 to create a rotating force such that vibration is reduced. Preferably the system includes the plurality of force generator 530 and vibration sensor 554, with the number of sensors 554 greater than the number of force generators 530. Preferably the system includes a reference sensor for generating a persistent signal indicative of the vibration disturbance. Preferably the controllable rotating force rotates at the given frequency.

In an embodiment the invention include a vibration control system for controlling a vibration on a structure responsive to a vibration disturbance at a given frequency, said vibration control system including a circular force generator for creating a controllable rotating force with a controllable magnitude and controllable magnitude phase, said vibration control system including a vibration sensor for generating a vibration signal indicative of said vibration of said structure, said vibration control system including a controller that receives said vibration signal from said vibration sensor and commands said circular force generator to create said rotating force wherein such vibration of said structure sensed by said sensor is reduced. Preferably the vibration control system 409 includes a plurality of m circular force generators 530 and a plurality n vibration sensors 554 distributed throughout the structure 524, preferably n>m. Preferably the vibration control system 409 includes a reference sensor 552 for generating a persistent signal indicative of said vibration disturbance, preferably the reference sensor 552 monitors a rotating machine member 522 that is rotating relative to said structure 524 and producing said vibration. Preferably the controllable rotating force rotates at a given harmonic circular force generating frequency. Preferably the vibration control system 409 includes a reference sensor 552 which monitors a rotating machine member 522 that is rotating relative to the structure 524, and the given harmonic circular force generating frequency is a harmonic of a harmonic of the monitored rotating machine member 522. Preferably the controllable rotating force is determined and calculated with a real and an imaginary part (α and β). Preferably a circular force command signal is generated with a real and an imaginary part (α and β). Preferably the controllable rotating force is generated with two corotating imbalance moving masses 534 and 536.

In preferred method embodiments of controlling vibrations, preferably the method avoids creating linear forces, and instead creates rotating forces, preferably with the methods and systems including the calculation of rotating forces and avoiding the calculation of linear forces. The active vibration control systems preferably include a pair of co-rotating masses, preferably imbalanced rotors that are individually motorized or motorized as a master/slave phased pair, preferably a detented phase pair.

The vibration control actuators of the system/method create circular forces of controllable magnitude and temporal phase. Preferably system identification is conducted with circular forces, with parameters that describe a circular force propagating thru the control algorithm of the systems/methods. For example, as shown in FIG. 1, the parameters α and β describe the in-phase and out-of-phase components of a circular force. The parameters that describe a circular force are converted into two rotor phases before being sent to the motor control. The methods preferably computationally convert rotary forces into rotor phases. The control structure using circular force generators is shown in FIG 1, with FIG. 1B the adaptive circular force algorithm illustrating the operation of the systems and methods. Preferably the circular force generator actuators are distributed throughout the vehicle structure, with the circular force generators inputting circular forces into the vehicle nonrotating body structure to reduce vibration.

Consider two co-rotating, co-axial rotors (a circular force generator) with imbalance masses of magnitude *m* located at a radial distance *r* from the center of rotation. The angular positions of the masses are given by which are measured counter-clockwise from the positive x-axis. The rotors are independently controllable but are synchronized to rotate at the same speed, ω.

The net forces in the x and y directions are:

$$F_x(t) = F_0[\cos(\theta_1(t)) + \cos(\theta_2(t))]$$

$$F_y(t) = F_0[\sin(\theta_1(t)) + \sin(\theta_2(t))]$$

where.

Since the imbalances rotate at the same speed ω but different phase angles, their angular positions can be written as:

$$\theta_1 = \omega t + \phi_1 \text{ and } \theta_2 = \omega t + \phi_2$$

Because the actuator generates a circular force of varying magnitude, it is preferred to write the force output as a circular force. The angle, θ_{12} , and magnitude,, of this force can be independently controlled. The resultant force components in the x and y directions from this circular force can be written as:

$$F_x(t) = F_{12}\cos(\theta_{12}(t))$$

$$F_y(t) = F_{12}\sin(\theta_{12}(t))$$

where.

The above two formulations for the resultant x and y forces are equivalent. Setting them equal, yields:

$$\alpha = F_{12}\cos(\phi_{12}) = F_0[\cos(\phi_1) + \cos(\phi_2)]$$

$$\beta = F_{12}\sin(\phi_{12}) = F_0[\sin(\phi_1) + \sin(\phi_2)]$$

The new parameters, α and β, are the in-phase and out-of-phase components, respectfully, of the circular force. Preferably in these systems/methods, these components are the values that are adapted in the gradient-descent algorithm, preferably with resulting vehicle vibrations reduced. Adaptations are preferably conducted using these α and β force components associated with the circular force actuators.

The method/system preferably includes a saturation control algorithm method and system for saturation conditions when operating the circular force generators. The maximum magnitude of the force generated by a circular actuator is limited to $2F_0$. This limitation is placed within the LMS algorithm to prevent the forces from going beyond the limit of what the actuators can deliver. The magnitude of the force from each circular actuator is calculated as:

$$F_{12} = \sqrt{\alpha^2 + \beta^2}$$

The force components are then limited to what the actuator can actually output using the following equations:

$$\alpha_{out} = \frac{\min(F_{12,} 2F_0)}{F_{12}} \alpha_{in}$$

$$\beta_{out} = \frac{\min(F_{12,} 2F_0)}{F_{12}} \beta_{in}$$

The method/system preferably includes a computing rotor phases algorithm method and system for computing rotor phases when operating the circular force generators. Preferably given alpha and beta from adaptation, the corresponding rotor phase angles must be calculated. This calculation is done in the [Rotor Phase Compute] block in FIG. 1. To calculate these two phase angles, the following equations are preferably solved in the inverse.

$$\alpha = F_0[\cos(\phi_1) + \cos(\phi_2)]$$

$$\beta = F_0[\sin(\phi_1) + \sin(\phi_2)]$$

Squaring both sides and adding the equations yields:

$$\alpha^2 + \beta^2 = F_0^2(2 + 2(\cos(\phi_1)\cos(\phi_2) + \sin(\phi_1)\sin(\phi_2)))$$

$$\alpha^2 + \beta^2 = 4F_0^2\left(\frac{1}{2} + \frac{1}{2}(\cos(\phi_1 - \phi_2))\right)$$

$$\alpha^2 + \beta^2 = 4F_0^2 \cos^2\left(\frac{\phi_1 - \phi_2}{2}\right)$$

Another equation can be found by dividing the equations as shown below:

$$\frac{\beta}{\alpha} = \frac{\sin(\phi_1) + \sin(\phi_2)}{\cos(\phi_1) + \cos(\phi_2)} = \frac{2\sin\left(\frac{\phi_1 + \phi_2}{2}\right)\cos\left(\frac{\phi_1 - \phi_2}{2}\right)}{2\cos\left(\frac{\phi_1 + \phi_2}{2}\right)\cos\left(\frac{\phi_1 - \phi_2}{2}\right)}$$

$$\frac{\beta}{\alpha} = \tan\left(\frac{\phi_1 + \phi_2}{2}\right)$$

Rewriting these equations gives:

$$\frac{1}{2}\begin{bmatrix}1 & -1\\ 1 & 1\end{bmatrix}\begin{bmatrix}\phi_1\\ \phi_2\end{bmatrix}=\begin{bmatrix}\cos^{-1}\dfrac{\sqrt{\alpha^2+\beta^2}}{2F_0}\\ \tan^{-1}\dfrac{\beta}{\alpha}\end{bmatrix}$$

The solution to the inverse problem is then:

$$\begin{bmatrix}\phi_1\\ \phi_2\end{bmatrix}=\begin{bmatrix}1 & 1\\ -1 & 1\end{bmatrix}\begin{bmatrix}\cos^{-1}\dfrac{\sqrt{\alpha^2+\beta^2}}{2F_0}\\ \tan^{-1}\dfrac{\beta}{\alpha}\end{bmatrix}$$

The active vibration control system preferably uses actuators with two co-rotating imbalanced rotors, to create circular forces of controllable magnitude and temporal phase.

In embodiments the vehicle 520 is a helicopter with the vehicle rotating machine member 522 the helicopter rotating rotary wing hub above the nonrotating vehicle body helicopter fuselage frame below, and the helicopter rotating rotary wing hub includes hub mounted vibration control system (HMVS) 20 with at least a first hub mounted motor driven hub mass and at least a second hub mounted motor driven hub mass housed within a hub housing 30, with the mounted vibration control system 20 at least a first hub mounted motor driven hub mass and at least a second hub mounted motor driven hub mass driven to rotate relative to the rotary wing hub while the system 409 generates rotating forces in the below rotating hub helicopter aerostructure body 524 with the circular force generators 530. FIG. 1A-8 illustrate embodiments with helicopters having force generators 530 and the hub mounted vibration control system (HMVS) 20. FIG. 13A-D illustrate further preferred embodiments of the rotary wing aircraft vehicle vibration control system with the circular force generators 530 and the hub mounted vibration control system 20 with a communication bus (COM. BUS) network link 150 for preferably communicating and sending data, control system functions and functionality signals. Preferably the communications bus 150 is established to provided a communications link interconnection between the circular force generators 530 generating the circular forces in the nonrotating body 524 and the rotating hub mounted vibration control system at least first hub mounted motor driven hub mass and at least second hub mounted motor driven hub mass. In preferred embodiments the communication bus is a serial communication bus, preferred embodiments the communication bus is chosen from the communication bus group comprised of ARINC-429, ARINC-825(CANbus), and MIL-S-1553. Preferably vibration sensor accelerometers are mounted in both the airframe and the HMVS, and preferably vibration sensor demodulated acceleration data is shared and communicated on the communication bus. Preferably power for airframe body circular force generators 530 and the HMVS 20 does not come through a single power supply, and preferably the power to the circular force generators 530 and the HMVS 20 is provided separately with the communication bus communicating data separated from such electrical power supply delivery. Preferably a single system computer controlled controller coordinates both the rotating HMVS rotating hub mounted vibration control system and the airframe body circular force generators 530. Preferably the rotating HMVS includes local rotating hub mounted failure control computer controlled electronics for preventing local hub failure, preferably preventing over-speed control. Preferably the rotating HMVS and the airframe body circular force generators include local drive electronics, with the local drive electronics preferably acting as nodes on the communications bus. In preferred embodiments with the HMVS, including a dual frequency HMVS with four hub mounted motor driven hub masses, with two rotating clock-wise and two rotating counter-clock-wise, preferably the clock-wise rotating masses are a node on the bus and the counter-clock-wise rotating masses are another separate note on the bus. Preferably the HMVS system controller and the airframe body circular force generators system controllers each have their own system control capability, such that one system can operate without the other. In preferred embodiments the HMVS receives tachometer information signals from the communication bus, and preferably the HMVS includes a local tachometer signal sensor for locally sensing the tachometer as a backup to loss of the communication bus signal.

Further preferred embodiments of the rotary wing aircraft vehicle vibration control system with the circular force generators 530 and the hub mounted vibration control system 20 with a communication bus (COM. BUS) 150 are shown in FIG. 14-19. The rotary wing aircraft helicopter preferably includes an active vibration control system power converter source 26' for outputting electromagnetic force generator power outputs. The aerostructure nonrotating frame 524 includes a plurality of distributed active vibration control system nodal sites 28' for mounting of force generators wherein generated forces are inputted into the aerostructure to suppress the troublesome vibrations. Preferably the aircraft includes at least a first distributed active vibration electromagnetic force generator 530, the first distributed active vibration electromagnetic force generator 530 including a first distributed electronic control system 32 and a first electromagnetically driven mass 34, the first distributed active vibration electromagnetic force generator 530 fixed to the frame aerostructure 524 at a first distributed active vibration control system nodal site 28'. The aircraft includes a plurality of electrical power distribution lines 140, the electrical power distribution lines 140 connecting the electromagnetic force generators 530 with the power source 26' with the electromagnetic force generator power outputs outputted to the electromagnetic force generators. The aircraft includes a distributed expandable force generator data communications network 150, the distributed force generator data communications network 150 linking together the at least first and second distributed electronic control systems 32 wherein the distributed electronic control systems 32 communicate force generator vibration control data through the distributed force generator data communications network 150 independently of the electrical power distribution lines 140 to minimize the troublesome vibrations. Preferably each node has a unique address on the network 150, with the force generating data distributed through the network 150 with the unique network address, preferably the unique node address# along with the force data, such as a magnitude and phase of a force to be generated by the electromagnetic force generator 530 having the unique data communications node network address (or the unique data communications node network address with a real and imaginary force generation values). In preferred embodiments the distributed expandable force generator data communications network 150 is a wired data communications network, and preferably is comprised of a communication bus and with a harness interface connector connecting each electromagnetic force generator's distributed electronic control system 32 with the network 150, with the distributed electronic control systems 32 both sending and receiving force generating system data through the network 150. In preferred embodiments the distributed expandable force generator data communications network 150 is a Controller Area Network, with the distributed electronic control systems 32 including microcontrollers communicating with each other through the network along with the microcontrollers in the system controller. Preferably the distributed electronic control systems 32 also communicate system health data such as whether a force generator 530 is healthy or not healthy. Preferably the force generator network node address and its accompanying force generation data (network node#_magnitude_phase) flows throughout the network 150 and is shared on the network with all network nodes and all electromagnetic force generators 530. In an embodiment the aircraft includes a master system controller 52, the master system controller 52 connected to the distributed force generator data communications network 150 wherein the master system controller 52 provides a plurality of authority commands to the at least first and second distributed electronic control systems 32, with the at least first and second distributed electronic control systems 32 executing a plurality of subordinate local force generator operation commands. Preferably the subordinate local force generator operation commands depend on the type of force generator. In preferred embodiments the force generators 530, are rotating mass force generators, preferably with the subordinate local force generator operation commands commanding electromagnetic motor rotations of corotating electromagnetically driven masses 34 and 36. In preferred embodiments an electromagnetic force generator's distributed electronic control system 32 receive its network node address and its accompanying force generation data (network node#_magnitude_phase) from which its microcontroller computes electromagnetic motor rotations for the corotating electromagnetically driven masses 34 and 36 to output a desired circular force into aerostructure 524 through the fixing base 38, with the force generators 530 preferably comprised of circular force generators outputting circular forces into aerostructure 524 at their respective fixing base nodal sites 28'. In an embodiment the aircraft includes a migrating master system control authority, the migrating master system control authority movable between the at least first and second distributed electronic control systems 32 of the plurality of force generators 530, with the migrating master system control authority providing a plurality of authority commands to the distributed electronic control systems 32 to execute a plurality of subordinate local force generator operation commands such as with a Migrating Master System Control Authority, preferably without a separate distinct physical head master System Controller. With the migrating master system control authority at any one point in time preferably the system has a master control authority taking up temporary residence in a distributed electronic control system 32, which includes executable software and/or firmware commands that provide a physically headless control system with distributed control of the system with the ability of backup command with migration movement of authority. Preferably the system includes distributed networked accelerometers 54, with the distributed networked accelerometers including microcontrollers having accelerometer network links 56 with the distributed expandable force generator data communications network 150. The accelerometers input and output vibration measurement data into the force generator data communications network, preferably with the plurality of accelerometers inputting data into the network (and receiving data from the network) with the accelerometers each having a unique network node address #, with the accelerometers including an accelerometer distributed network electronic control system for data interfacing with the network. In a preferred embodiment the accelerometer network links 56 are wired links, and preferably the accelerometers are powered through the communications bus wired network links 56. In an alternative embodiment the accelerometers are wireless networked accelerometers providing wireless transmission of accelerometer data measurements sent to the network 150 for determination on how to minimize troublesome vibrations with the accelerometers powered by alternative means such as with batteries or with power supplied from aircraft power supply outlets or power supply 26'. In an embodiment the aircraft includes a distributed master system control authority. The distributed master system control authority is distributed among the at least first and second distributed electronic control systems 32 utilizing the network 150 with the distributed master system control authority providing a plurality of authority commands to the individual distributed electronic control systems 32 to execute a plurality of subordinate local force generator operation commands, such as with a Distributed Master System Control Authority. Preferably at any one point in time the system has a master control authority spread out in at least two distributed electronic control systems 32, and includes executable software and/or firmware commands that provide a physically headless system with distributed control of the system with backup control with the plurality of distributed electronic control systems 32 on the network 150. Preferably the system includes distributed networked accelerometers 54, with the distributed networked accelerometers including microcontrollers having accelerometer network links 56 with the distributed expandable force generator data communications network 150. The accelerometers input and output vibration measurement data into the force generator data communications network, preferably with the plurality of accelerometers inputting data into the network (and receiving data from the network) with the accelerometers each having a unique network node address #, with the accelerometers including an accelerometer distributed network electronic control system for data interfacing with the network. In a preferred embodiment the accelerometer network links 56 are wired links, and preferably the accelerometers are powered through the communications bus wired network links 56. In an alternative embodiment the accelerometers are wireless networked accelerometers providing wireless transmission of accelerometer data measurements sent to the network 150 for determination on how to minimize troublesome vibrations with the accelerometers powered by alternative means such as with batteries or with power supplied from aircraft power supply outlets or power supply 26'. In an embodiment the aircraft includes at least a first distributed networked accelerometer 54. The accelerometer outputs can be inputted directly into the network 150 or into system controller 52. Preferably the at least first distributed networked accelerometer 54 has an accelerometer network link 56 with the distributed expandable force generator data communications network 150. The accelerometers are fixed to the aircraft, preferably fixed to the aerostructure 524, and measure vibrations in the aerostructure. The accelerometers sense and measure the troublesome vibrations created by the rotating machinery and the forces generated by the actuators and are measurable by the accelerometer.

The accelerometer measurements of vibrations are used as control inputs to drive down and minimize the troublesome vibrations. The accelerometers input and output vibration measurement data into the force generator data communications network, preferably with the plurality of accelerometers inputting data into the network (and receiving data from the network) with the accelerometers each having a unique network node address #, with the accelerometers including an accelerometer distributed network electronic control system for data interfacing with the network. In a preferred embodiment the accelerometer network links 56 are wired links, and preferably the accelerometers are powered through the communications bus wired network links 56. In an alternative embodiment the accelerometers are wireless networked accelerometers providing wireless transmission of accelerometer data measurements sent to the network 150 for determination on how to minimize troublesome vibrations with the accelerometers powered by alternative means such as with batteries or with power supplied from aircraft power supply outlets or power supply 26'. The accelerometer data measurements are shared through the network 150 and used in the system controllers, processors, and electronic control systems in the determination of controlling the electromagnetic driving of the moving masses to generate the forces to minimize the troublesome vibrations. In preferred embodiments the first distributed electronic control system 32 executes a plurality of local force generator operation rotating motor commands to rotate at least its first electromagnetic motor to move its at least first mass, and the second distributed electronic control system 32 executes a plurality of local force generator operation rotating motor commands to rotate at least its first electromagnetic motor to move its at least first mass. Preferably the plurality of distributed active vibration force generators 530 are circular force generating distributed active vibration force generators with the distributed electronic control systems 32 executing a plurality of local force generator operation rotating motor control commands. Preferably the distributed electronic control systems have a network bus interface with the data communications network bus through which force generation data is communicated, with the distributed electronic control systems executing a plurality of local force generator operation commands.

In an embodiment the invention includes a rotary blade rotary wing aircraft rotating hub mounted rotating assembly vibration control system for a rotary blade rotary wing aircraft rotating hub assembly experiencing a vibration of a plurality of vibration frequencies while rotating at an operational rotation frequency about a rotating assembly center axis of rotation. FIG. 13A-B illustrate a preferred rotary blade rotary wing aircraft rotating hub mounted rotating assembly vibration control system HMVS 20 for a rotary blade rotary wing aircraft rotating hub assembly 22 experiencing a vibration 24 of a plurality of vibration frequencies while rotating at an operational rotation frequency 26 (1P) about a rotating assembly center axis of rotation 28. (As illustrated and labeled the rotating hub assembly is rotating at 1P in a clockwise direction relative to non-rotating aircraft body/ground references).

FIG. 20A-C illustrates a hub mounted rotating assembly vibration control system 20 with about a quarter section cut away to reveal the internals housed inside the annular ring housing 30. The helicopter rotating hub mounted vibration control system preferably includes an annular ring housing 30 attachable to the helicopter rotary wing hub and rotating with the helicopter rotary wing hub at the helicopter operational rotation frequency. The helicopter rotating hub mounted vibration control system housing 30 including a first imbalance mass concentration rotor 38, a second imbalance mass concentration rotor 44, a third imbalance mass concentration rotor 38', and a fourth imbalance mass concentration rotor 44'. FIG. 21 illustrates a further rotating assembly vibration control system 20, with a cross section showing the four rotors housed in the housing 30. FIG. 22A-B illustrate the imbalance mass concentration rotors with their mass concentrations 40, 46, 40', 46'. Preferably the first imbalance mass concentration rotor 38 has a first imbalance mass concentration rotor center axis of rotation 136 centered on the rotating assembly center axis of rotation 28, the second imbalance mass concentration rotor 44 having a second imbalance mass concentration rotor center axis of rotation 142 centered on the rotating assembly center axis of rotation 28, the third imbalance mass concentration rotor 38' having a third imbalance mass concentration rotor center axis of rotation 136' centered on the rotating assembly center axis of rotation 28, and the fourth imbalance mass concentration rotor 44' having a fourth imbalance mass concentration rotor center axis of rotation 142' centered on the rotating assembly center axis of rotation 28. The first imbalance mass concentration rotor 38 and the second imbalance mass concentration rotor 44 are driven at a first rotation speed greater than the rotating assembly operational rotation frequency 26 (1P) while controlling the rotational position of the first imbalance mass concentration 40 and the second imbalance mass concentration 46 to produce a first rotating net force vector to inhibit a first vibration frequency. In preferred embodiments as illustrated in FIG. 20-22, the first imbalance mass concentration rotor 38 and the second imbalance mass concentration rotor 44 are driven at a four multiple vibration canceling rotation frequency (4P) counter rotating direction (rotation opposing rotation of the rotating hub assembly) (counter clockwise if hub is rotating clockwise as illustrated). The first and second rotor imbalance mass concentrations 40, 46 are driven at 4P opposing the direction of the rotating hub rotation while controlling the rotational position of the first imbalance mass concentration 40 and the second imbalance mass concentration 46 to produce a first rotating net force vector. The third imbalance mass concentration rotor 38' and the fourth imbalance mass concentration rotor 44' are driven at a second rotation speed greater than the rotating assembly operational rotation frequency 26 (P) while controlling the rotational position of the third imbalance mass concentration 40' and the fourth imbalance mass concentration 46' to produce a second rotating net force vector. The first and second rotating force vectors are controlled to inhibit vibration frequency (4P). In a preferred embodiment as illustrated in FIG. 20-22, the third imbalance mass concentration rotor 38' and the fourth imbalance mass concentration rotor 44' are driven at a four multiple vibration canceling rotation frequency (4P) co-rotating direction rotating with the rotation of the rotating hub assembly (4P rotating in same direction as rotating hub, clockwise if hub is rotating clockwise as illustrated) while controlling the rotational position of the third imbalance mass concentration and the fourth imbalance mass concentration to produce a second rotating net force vector to inhibit a second vibration frequency (5P) with respect to the 1P rotating frame. With the rotor hub rotating at P, and having N blades, preferably the first and second imbalance mass concentrations are rotated at a whole number multiple of P, most preferably NP in the direction opposing the rotor hub rotation, and preferably the third and fourth imbalance mass concentrations are rotated at a whole number multiple of P, most preferably NP in the same direction as the rotor hub rotation. Preferably the first imbalance mass concentration is opposingly oriented relative to the second imbalance mass concentration during a starting stopping rotation speed less than the first rotation speed. Preferably the third imbalance mass concentration is opposingly oriented relative to the fourth imbalance mass concentration during a starting stopping rotation speed less than the second rotation speed.

Preferably the first vibration frequency is a distinct rotating frame lower harmonic frequency from the second vibration frequency higher harmonic, and the first imbalance mass concentration rotor and the second imbalance mass concentration rotor is driven and controlled independently from the third imbalance mass concentration rotor and the fourth imbalance mass concentration rotor, preferably with the first imbalance mass concentration rotor and the second imbalance mass concentration rotor driven to rotate opposite of the hub assembly and the third and fourth rotors. Preferably the first vibration frequency lower harmonic is a distinct lower harmonic frequency 3P tone from the second vibration frequency higher harmonic 5P tone with respect to the 1P rotating frame. FIG. 23A-C show simulated test data showing with the vibration control on the system inhibited the two distinct frequencies; the test was simulated using a stationary helicopter body and rotor hub with vibrations inputted into the rotor hub using controlled linear actuator disturbance force generators to simulate the in-flight helicopter rotating hub vibrations.

Preferably the first vibration frequency is a distinct lower harmonic frequency tone from the second vibration frequency tone, and the first imbalance mass concentration rotor rotational position control and the second imbalance mass concentration rotor rotational position control is segregated from the third imbalance mass concentration rotor rotational position control and the fourth imbalance mass concentration rotor rotational position control. Preferably the first imbalance mass concentration rotor rotational position control and the second imbalance mass concentration rotor rotational position control is segregated from the third imbalance mass concentration rotor rotational position control and the fourth imbalance mass concentration rotor rotational position control, preferably with the electronics control system 50 comprised of separate subsystems 50’, 50’’.

Preferably the vibration control system includes a tachometer input and a first rotation speed rotors stage VC controller for controlling the first imbalance mass concentration rotor rotational position and the second imbalance mass concentration rotor rotational position, and a second rotation speed rotors stage VC controller for controlling the third imbalance mass concentration rotor rotational position and the fourth imbalance mass concentration rotor rotational position. FIG. 24A-B illustrates a vibration control system with a tachometer input and a first rotation speed rotors stage VC controller for controlling the first imbalance mass concentration rotor rotational position and the second imbalance mass concentration rotor rotational position with 3/Rev commands (3P commands) to a first motor control loop, and a second rotation speed rotors stage VC controller for controlling the third imbalance mass concentration rotor rotational position and the fourth imbalance mass concentration rotor rotational position with 5/Rev commands (5P commands) to a second motor control loop.

Preferably the vibration control system includes a first rotation speed electronics control system subsystem 50’ for controlling the first imbalance mass concentration rotor rotational position and the second imbalance mass concentration rotor rotational position, and a second rotation speed electronics control system subsystem 50’’ for controlling the third imbalance mass concentration rotor rotational position and the fourth imbalance mass concentration rotor rotational position. Preferably the vibration control system first rotation speed electronics control system subsystem 50’ is a first rotation speed rotors 3P stage VC controller for controlling the first imbalance mass concentration rotor rotational position and the second imbalance mass concentration rotor rotational position, and the second rotation speed electronics control system subsystem 50'' is a second rotation speed rotors 5P stage VC controller for controlling the third imbalance mass concentration rotor rotational position and the fourth imbalance mass concentration rotor rotational position.

Preferably the vibration control system includes a fault mode control protocol for controlling a rotation of the rotors during a sensed failure of the rotating assembly vibration control system, preferably with the system braking a failed rotor.

Preferably the first imbalance mass concentration is opposingly oriented to the second imbalance mass concentration during a first starting stopping rotation speed less than the first rotation speed and the third imbalance mass concentration is opposingly oriented to the fourth imbalance mass concentration during a second starting stopping rotation speed less than the second rotation speed.

In an embodiment the invention includes a computer program product in a storage medium for controlling a rotating vibration control system with a first imbalance mass concentration rotor, a second imbalance mass concentration rotor, a third imbalance mass concentration rotor, and a fourth imbalance mass concentration rotor. The computer program product includes a computer readable storage medium. The computer program product includes first program instructions for driving the first imbalance mass concentration rotor and the second imbalance mass concentration rotor at a first rotation speed vibration canceling rotation frequency while controlling the rotational position of the first imbalance mass concentration and the second imbalance mass concentration to produce a first net force vector to inhibit a first vibration frequency. Preferably the mass concentrations are controlled to inhibit a 3P lower harmonic. The computer program product includes second program instructions for driving the third imbalance mass concentration rotor and the fourth imbalance mass concentration rotor at a second rotation speed vibration canceling rotation frequency while controlling the rotational position of the first imbalance mass concentration and the second imbalance mass concentration separate from the controlling of the first imbalance mass concentration and the second imbalance mass concentration to produce a second net force vector to inhibit a second vibration frequency. Preferably the mass concentrations are controlled to inhibit a 5P higher harmonic. Preferably the computer program product includes program instructions opposingly orient the first imbalance mass concentration relative to the second imbalance mass concentration during a transitioning rotation speed, and the third imbalance mass concentration relative to the fourth imbalance mass concentration during a transitioning rotation speed. FIG. 20A and 24B illustrate the computer program product in a storage medium 1107, such as a storage medium 1107 readable by a computer 1106 and up loadable into the electronics control system 50 and subsystems 50', 50'', with the electronics control system 50 and subsystems 50', 50'' utilizing such instructions.

Preferably the computer program instructions include program instructions for calculating rotational positions of the third and fourth imbalance mass concentration rotors independently of the first and second imbalance mass concentration rotor positions.

Preferably the computer program instructions include program instructions for monitoring a tachometer input signal, and maintaining an opposing orientation of the first imbalance mass concentration and the second imbalance mass concentration.

Preferably a fault mode control protocol for controlling a rotation of the rotors during a sensed failure of the rotating vibration control system, preferably with instructions for braking a failed rotor. Preferably the fault mode control protocol includes instructions for monitoring a sensor signal and detecting a first rotor failure. Preferably the fault mode control protocol includes instructions for monitoring a sensor signal and detecting a second rotor failure. Preferably the fault mode control protocol includes instructions for monitoring a sensor signal and detecting a third rotor failure. Preferably the fault mode control protocol includes instructions for monitoring a sensor signal and detecting a fourth rotor failure.

Preferably the computer program instructions include program instructions to monitor a plurality of sensor signals. Preferably the computer program instructions include program instructions to monitor a plurality of accelerometers housed in the housing 30. Preferably the computer program instructions include program instructions to monitor a plurality of prefer position sensors housed in the housing a sensing the position of the rotors 38, 44, 38', 44', preferably Hall sensors. Preferably the computer program instructions include program instructions to monitor a plurality of fault sensors and health monitor sensors.

In an embodiment the invention includes computer program product in a storage medium for controlling a rotating assembly vibration control system. The computer program product including a computer readable storage medium. The computer program product including first program instructions to control a rotation of a first rotor and a rotation of a second rotor. The computer program product including second program instructions to monitor a plurality of sensor signals. The computer program product including third program instructions to control the rotation speed, rotation direction and phase of the first rotor and the rotation speed, rotation direction and phase of the second rotor to minimize a first monitored vibration frequency sensor signal. The computer program product including fourth program instructions to control a rotation of a third rotor and a rotation of a fourth rotor. The computer program product including fifth program instructions to monitor a plurality of sensor signals. The computer program product including sixth program instructions to control the rotation speed, rotation direction and phase of the third rotor and the rotation speed, rotation direction and phase of the fourth rotor to minimize a second monitored vibration frequency sensor signal.

Preferably the computer program product includes below speed program instructions, the below speed program instructions providing commands to opposingly orient the first rotor first imbalance mass concentration relative to the second rotor second imbalance mass concentration when the speed is below the vibration control rotation speed, preferably when starting and stopping the system. Preferably the computer program product includes below speed program instructions, the below speed program instructions providing commands to opposingly orient the third rotor first imbalance mass concentration relative to the fourth rotor second imbalance mass concentration when the speed is below the vibration control rotation speed, preferably when starting and stopping the system.

In an embodiment the invention includes a rotating vibration control system for a rotating assembly having at least a first vibration frequency operational vibration and at least a second vibration frequency operational vibration. The rotating vibration control system includes a first rotor with a first imbalance mass concentration, the first rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating assembly, preferably in a counter rotating direction, with rotation opposing rotation of the rotating assembly. The rotating vibration control system includes a second rotor with a second imbalance mass concentration, the second rotor driven to rotate at the first rotation speed greater than an operational rotation frequency of the rotating assembly, preferably in the counter rotating direction, opposing the rotation of the rotating assembly. The rotating vibration control system includes a third rotor with a third imbalance mass concentration, the third rotor driven to rotate at a second rotation speed greater than an operational rotation frequency of the rotating assembly, preferably in a co-rotating direction, rotating with the rotation of the rotating assembly. The rotating vibration control system includes a fourth rotor with a fourth imbalance mass concentration, the fourth rotor driven to rotate at the second rotation speed greater than an operational rotation frequency of the rotating assembly in the co-rotating direction with the rotation of the rotating assembly.

The rotating vibration control system includes at least a first vibration sensor for producing a plurality of first vibration sensor signals. The rotating vibration control system includes at least a second vibration sensor for producing a plurality of second vibration sensor signals. The rotating vibration control system includes a first rotor rotational position sensor. a second rotor rotational position sensor, a third rotor rotational position sensor, and a fourth rotor rotational position sensor, preferably Hall Effect sensors sensing the four rotor positions. The rotating vibration control system preferably includes a first motor control loop for controlling the rotation of the first rotor and the rotation of the second rotor and receives first stage VC controller motor commands. The rotating vibration control system preferably includes a first vibration control loop first rotation speed stage VC controller for controlling rotors and providing commands to the first motor control loop to minimize the first vibration sensor signals and the second vibration sensor signals. The rotating vibration control system preferably includes a second motor control loop for controlling the rotation of the third rotor and the rotation of the fourth rotor and receives second stage VC controller motor commands. The rotating vibration control system preferably includes a second vibration control loop second rotation speed stage VC controller for controlling rotors and providing commands to the second motor control loop to minimize the first vibration sensor signals and the second vibration sensor signals. Preferably the second vibration control loop second stage VC controller commands the second motor control loop independent of the first vibration control loop first stage VC controller.

Preferably the motor control loops close a control loop around the respective motors based on respective rotor position feedback derived from the rotor rotational position sensors. Preferably the system includes a soft start stop control subsystem, the soft start stop control subsystem providing commands to opposingly orient the first imbalance mass concentration relative to the second imbalance mass concentration, and the third imbalance mass concentration opposing the fourth.

Preferably the soft start stop control subsystem includes program instructions to opposingly orient the first imbalance mass concentration relative to the second imbalance mass concentration during a rotation speed ramp up, and the third imbalance mass concentration opposing the fourth.

Preferably the soft start stop control subsystem includes program instructions to opposingly orient the first imbalance mass concentration relative to the second imbalance mass concentration during a rotation speed ramp down, and the third imbalance mass concentration opposing the fourth.

In an embodiment the invention includes a rotary wing aircraft rotating hub mounted vibration control system for a rotary wing hub having at least a first and a second vibration frequency while rotating at a rotary wing operational rotation frequency. The rotating hub mounted vibration control system is comprised of: a system housing, the system housing attached to the rotary wing hub and rotating with the rotary wing hub at the operational rotation frequency. Preferably the housing has an electronics housing cavity subsystem and an adjacent coaxial rotor housing cavity subsystem, the rotor housing cavity subsystem containing the rotors.

The housing housing a first coaxial ring motor having a first rotor with a first imbalance mass concentration, a second coaxial ring motor having a second rotor with a second imbalance mass concentration.

The housing housing a third coaxial ring motor having a third rotor with a third imbalance mass concentration, a fourth coaxial ring motor having a fourth rotor with a fourth imbalance mass concentration.

The housing housing an electronics control system for controlling the vibration control system, preferably with computer electronics which utilize computer medium to operate and execute program instructions from computer program products, which are storagable on and loadable from computer storage medium.

The electronics control system includes a first rotation speed rotor stage VC controller electronics control subsystem for controlling a rotational position of the first imbalance mass concentration rotor and a rotational position of the second imbalance mass concentration rotor, the first rotation speed rotor stage VC controller electronics control subsystem controlling a speed and a phase of the first coaxial ring motor and the second coaxial ring motor such that the first imbalance mass concentration and the second imbalance mass concentration are directly driven at a whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency wherein the first rotary wing hub vibration frequency is reduced.

The electronics control system includes a second rotation speed rotor stage VC controller electronics control subsystem for controlling a rotational position of the third imbalance mass concentration rotor and a rotational position of the fourth imbalance mass concentration rotor, the second rotation speed rotor stage VC controller electronics control subsystem controlling a speed and a phase of the third coaxial ring motor and the fourth coaxial ring motor such that the third imbalance mass concentration and the fourth imbalance mass concentration are directly driven at a whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency wherein the second helicopter rotary wing hub vibration frequency is reduced.

Preferably first rotation speed rotor stage VC controller electronics control subsystem is separate from the second rotation speed rotor stage VC controller electronics control subsystem, preferably two subsystems control their rotors independently of the other rotors, preferably the location of the first and second rotors does not directly depend on the location of the third and fourth.

Preferably the first rotation speed rotor stage VC controller electronics control subsystem is physically separate from the second rotation speed rotor stage VC controller electronics control subsystem, preferably stacked in at least two electronics layers, preferably the electronics are housed proximate the center axis of rotation, proximate the housing ID, distal from housing OD. Preferably the rotors are stacked in layers, and the electronics subsystems are stacked in layers, the electronics proximate the housing ID and the rotors proximate the housing OD.

In an embodiment the invention includes a method of controlling a plurality of vibration frequencies of an aircraft with a rotary hub which rotates at an operational rotation frequency. The method includes providing an annular ring housing containing a first coaxial ring motor having a first rotor with a first imbalance mass concentration, a second coaxial ring motor having a second rotor with a second imbalance mass concentration, a third coaxial ring motor having a third rotor with a third imbalance mass concentration, a fourth coaxial ring motor having a fourth rotor with a fourth imbalance mass concentration, and an electronics control system for controlling the vibration control system. Preferably the electronics control system computer electronics execute program instructions from computer program products, which are storagable on and loadable from computer storage medium, the electronics control system including a first rotation speed rotor stage VC controller electronics control subsystem for controlling a rotational position of the first imbalance mass concentration rotor and a rotational position of the second imbalance mass concentration rotor, the electronics control system including a second rotation speed rotor stage VC controller electronics control subsystem for controlling a rotational position of the third imbalance mass concentration rotor and a rotational position of the fourth imbalance mass concentration rotor.

The method includes securing the annular ring housing to the rotary hub with the annular ring housing rotating at the operational rotation frequency with the rotary hub, driving the first rotor and the second rotor at a first whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency while controlling the rotational position of the first imbalance mass concentration and the second imbalance mass concentration in order to produce a first rotating net force vector to inhibit a first vibration frequency, and driving the third rotor and the fourth rotor at a second whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency while controlling the rotational position of the third imbalance mass concentration and the fourth imbalance mass concentration in order to produce a second rotating net force vector to inhibit a second vibration frequency.

Preferably the first rotation speed rotor stage VC controller electronics control subsystem controls a speed and a phase of the first coaxial ring motor and the second coaxial ring motor such that the first imbalance mass concentration and the second imbalance mass concentration are directly driven at a whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency wherein the first rotary wing hub vibration is reduced independent from the second rotation speed rotor stage VC controller electronics control subsystem controlling the speed and phase of the third coaxial ring motor and the fourth coaxial ring motor such that the third imbalance mass concentration and the fourth imbalance mass concentration are directly driven at a whole number multiple vibration canceling rotation frequency greater than the operational rotation frequency wherein the second helicopter rotary wing hub vibration is reduced.

FIG. 25A-C show the stacking of the imbalance rotors and motors, and the stacking of the separate electronics control subsystems 50’, 50’’. Preferably the stages are vertically stackable and separate, preferably with the electronics controls proximate the axis 28 and the housing ID and the rotor imbalance masses proximate the housing OD and distal from the axis 28. As a comparison between FIG. 25 and 26 shows, the vertically stackable stages are preferably separate, and in a preferred embodiment the first stage is used solely and separate as shown in FIG.25. FIG. 27A-B illustrates another embodiment of the invention with the stacking of the stages. FIG. 27B illustrates an embodiment of sensing the position of rotors and the imbalance mass with sensors 70, contained within the housing 30, with the sensors 70 position and mounted to provided position information regarding the rotational position of the imbalance mass being controlled. In an embodiment an inner motor control loop closes a control loop around the motors driving the rotors based on rotor motor position feedback derived from motor position sensors 70, preferably from the rotor magnetic encoder rotor position sensor read heads 70, preferably a Hall sensor. The inner loop servos the position of the motor to track commands sent from the vibration control stage VC controller such as the Rev Cmd. In FIG. 24 preferably these commands are in the form of a phase with respect to the provided tachometer signal input. FIG. 28A shows a first motor 36 with first imbalance rotor 38 with first imbalance rotor eccentric mass concentration 40. FIG. 28B shows a second motor 42 with second imbalance rotor 44 with second imbalance rotor eccentric mass concentration 46. FIG. 28C shows a third motor 36’ with third imbalance rotor 38’ with third imbalance rotor eccentric mass concentration 40’. FIG. 28D shows a fourth motor 42’ with fourth imbalance rotor 44’ with fourth imbalance rotor eccentric mass concentration 46’. FIG. 29 illustrates an embodiment of an electronics control system 50 for housing in the annular housing, with the electronics control system 50 circuit board including orthogonally positioned accelerometers 72, with the vibration sensor accelerometer hardware 72 providing orthogonal acceleration vibration signals. FIG. 30A-B illustrates another embodiment of the invention with the stacking of the rotor stages. In FIG. 30A the electronics control system 50 is shown stacked below the lower rotor. FIG. 31-32 illustrate further embodiments of imbalance rotors with imbalance mass concentrations.

In embodiments the invention includes a rotary wing aircraft, the rotary wing aircraft having a nonrotating aerostructure body and a rotating rotary wing hub, the rotary wing aircraft including a vehicle vibration control system, a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body circular force generator, the at least a first nonrotating body circular force generator fixedly coupled with the nonrotating body, a distributed force generation data communications network link, the distributed force generation data communications system network link linking together at least the first nonrotating body circular force generator and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body circular force generator communicate force generation vibration control data through the distributed force generation data communications network, the at least first nonrotating body circular force generator controlled to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In embodiments the invention includes a aircraft vibration control system, for a aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub, including, a rotating hub mounted vibration control system, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body, a distributed force generation data communications network serial link, the distributed force generation data communications system network serial link linking together at least the first nonrotating body force generator and the rotating hub mounted vibration control system wherein the rotating hub mounted vibration control system and the first nonrotating body force generator communicate and share force generation vibration control data through the distributed force generation data communications network, the at least first nonrotating body force generator controlled to produce a force with a controllable magnitude and a controllable phase, the controllable force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body and the rotating hub mounted vibration control system includes at least a first hub mounted vibration control system rotor with a first imbalance mass concentration, the first hub mounted vibration control system rotor driven to rotate at a first rotation speed greater than an operational rotation frequency of the rotating rotary wing hub, and at least a second hub mounted vibration control system rotor with a second imbalance mass concentration, the second hub mounted vibration control system rotor driven to rotate at the first rotation speed greater than the operational rotation frequency of the rotating rotary wing hub, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In embodiments the invention includes a aircraft vibration control system, for a aircraft vehicle having a nonrotating aerostructure body and a rotating rotary wing hub, including, a rotating hub mounted means for controlling vibrations, the rotating hub mounted means for controlling vibrations mounted to the rotating rotary wing hub with the rotating hub mounted means for controlling vibrations rotating with the rotating rotary wing hub, a rotary wing aircraft member sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotating rotary wing hub member rotating relative to the nonrotating body, at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations, at least a first nonrotating body force generator, the at least first nonrotating body force generator fixedly coupled with the nonrotating body, a means for linking together the first nonrotating body force generator and the rotating hub mounted means for controlling vibrations wherein the rotating hub mounted means for controlling vibrations and the first nonrotating body force generator communicate and share force generation vibration control data through the means for linking, the at least first nonrotating body force generator controlled to produce a force with a controllable magnitude and a controllable phase, the controllable force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable force phase controlled in reference to the rotary wing aircraft member sensor data correlating to the relative rotation of the rotating rotary wing hub rotating relative to the nonrotating body and, wherein the vibration sensed by the at least first nonrotating body vibration sensor is reduced.

In embodiments the invention includes a vehicle vibration control system for controlling troublesome vibrations in a nonrotating vehicle body having a rotating machine member, the vehicle vibration control system including a vehicle vibration control system controller, a rotating machine member sensor, for inputting vehicle rotating machine member data correlating to a relative rotation of the rotating machine member rotating relative to the nonrotating body into the vehicle vibration control system controller, at least a first nonrotating vehicle body vibration sensor, the at least first nonrotating vehicle body vibration sensor inputting at least first nonrotating vehicle body vibration sensor data correlating to vehicle vibrations into the vehicle vibration control system controller, at least a first nonrotating vehicle body circular force generator, the at least a first nonrotating vehicle body circular force generator for fixedly mounting to the nonrotating vehicle body wherein the at least first nonrotating vehicle body circular force generator is controlled by the controller to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, the controllable rotating force magnitude controlled from a minimal force magnitude up to a maximum force magnitude, and with the controllable rotating force phase controlled in reference to the vehicle rotating machine member sensor data correlating to the relative rotation of the vehicle rotating machine member rotating relative to the nonrotating vehicle body with the vehicle vibration sensed by the at least first nonrotating vehicle body vibration sensor reduced by the controller, and a hub mounted vibration control system, the hub mounted vibration control system linked with the vehicle vibration control system controller.

In embodiments the invention includes a method of controlling vibration, the method including, providing at least a first nonrotating vehicle body circular force generator, fixedly mounting the at least first nonrotating vehicle body circular force generator to a nonrotating vehicle body, controlling the at least first nonrotating vehicle body circular force generator to produce a rotating force with a controllable rotating force magnitude and a controllable rotating force phase, providing hub mounted vibration control system, fixedly mounting the hub mounted vibration control system to a rotatable hub of the nonrotating vehicle body, providing distributed force generation data communications network link and linking the hub mounted vibration control system together with the at least first nonrotating vehicle body circular force generator.

In an aspect of the invention, an electromagnetic driven moving mass inertial actuator includes a support part and a parallel arrangement of a first flexure part, a voice coil motor part, and a second flexure part, where the parallel arrangement is cantilevered from the support part.

In an aspect of the invention, an aircraft has an aircraft structure and a plurality of troublesome vibrations. The aircraft includes an electromagnetic inertial actuator support part, which is physically grounded to the aircraft structure. The aircraft further includes an electromagnetic inertial actuator parallel arrangement of a first flexure part, a voice coil motor part, and a second flexure part, where the electromagnetic inertial actuator parallel arrangement is cantilevered from the electromagnetic inertial actuator support part.

In an aspect of the invention, a method for controlling troublesome aircraft vibrations of an aircraft includes providing an electromagnetic inertial actuator, which includes a support part and a parallel arrangement of a first flexure part, a voice coil motor part, and a second flexure part, where the parallel arrangement is cantilevered from the support. The method further includes physically grounding the support part to an aircraft structure of the aircraft and electromagnetically driving the electromagnetic inertial actuator, wherein the parallel arrangement traces an arc relative to the support part.

In an embodiment the invention includes a method of making an electromagnetic actuator including providing a base, providing a coil, grounding the coil with the base, providing a parallel arrangement of flexures and a voice coil motor, and cantilevering the parallel arrangement from the base.

FIG. 33 shows an electromagnetic inertial actuator 1” according to embodiments of the invention. The electromagnetic driven moving mass inertial actuator 1” includes a support base 3”, which has an attachment plate 2” and mounting base 4”. The attachment plate 2” may be integrally formed or otherwise attached to the mounting base 4”. The bottom of the mounting base 4” can be attached to a structure, such as an aircraft structure, e.g., by bolts or other suitable attachment means. The electromagnetic inertial actuator 1” also includes a parallel arrangement 5” of a first flexure part 7”, a voice coil motor part 9”, and a second flexure part 11”. A “voice coil motor” is an electromagnetic positioning device that uses a coil of wire in a permanent magnetic field. In the parallel arrangement 5”, the first flexure part 7” is spaced apart from the second flexure part 11”, and the voice coil motor part 9” is disposed in the space between the flexure parts 7”, 11”. The parallel arrangement 5” is cantilevered from the support base 3”, i.e., the flexure parts 7”, 11” and the voice coil motor part 9” extend outward from the support base 3” in the manner of a cantilever. The ends 8”, 12” of the flexure parts 7”, 11”, respectively, which are coupled to the support base 3”, are the fixed or supported ends of the flexure parts 7”, 11”. The ends 10”, 14” of the flexure parts 7”, 11”, respectively, which are unattached to the support base 3”, are the moving or unsupported ends of the flexure parts 7”, 11”. The unsupported ends 10”, 14” of the flexure parts 7”, 11”, respectively, are coupled to a magnet part 13” of the voice coil motor part 9”. In addition to the magnet part 13”, the voice coil motor 9” also includes an interacting driving coil part (15” in FIGS. 34-35). The interacting driving coil part (15” in FIGS. 34-35) is preferably physically grounded to the support base 3”, with the interacting driving coil part (15” in FIGS. 34-35) being physically separated from the magnet part 13” and its associated cantilevered flexure-supported members, preferably with an air space gap. In the spring-mass actuator system, the cantilevered flexure-supported magnet part 13” and its associated cantilevered flexure-supported moving mass members represent a sprung moving mass, and the flexure parts 7”, 11” represent a spring. The magnet part 13” creates a magnetic field. When alternating current is supplied to the physically grounded non-sprung, non-moving coil part 15”, the coil part 15” interacts with the magnetic field created by the sprung moving mass magnet part 13” to generate an electromagnetic driving force that vibrates the cantilevered flexure-supported sprung moving mass magnet part 13”. The sprung moving mass magnet part 13” moves in an arc as it is electromagnetically driven (i.e., moves up and down) along a vertical direction in relation to the support base 3” (and the grounded coil 15”) and in and out relative to the support base 3” at the same time to trace an arc. If the frequency of the alternating current supplied to the coil part (15” in FIGS. 34-35) is the same as the natural frequency of the spring-mass system, the excursions of the magnet part 13” can become quite large. The larger the excursions, the higher the output force of the electromagnetic inertial actuator 1”.

FIG. 34 shows a cut through the electromagnetic inertial actuator 1”, which allows a view of the interior of the voice coil motor part 9”. In the embodiment shown in FIG. 34, the voice coil motor part 9” is a rectangular voice coil motor. The magnet part 13” includes permanent magnets 17”, 19”, 21”, 23”. Each of the permanent magnets 17”, 19”, 21”, 23” is flat (planar) and has a rectangular cross-section. In the embodiment of FIG. 34, the magnet part 13” has four permanent magnets. In alternate embodiments, the magnet part 13” could have more or fewer permanent magnets (as will be shown below with reference to FIGS. 43A-43N). In general, the four magnets provide a good balance between weight and magnetic gauss field. The permanent magnets 17”, 19”, 21”, 23” are in a parallel arrangement with each other and are spaced apart. Referring to FIG. 35, a gap 25” is defined between the adjacent permanent magnets 17”, 19”, and a gap 27” is defined between the adjacent permanent magnets 21”, 23”. A vertical plate 31” made of ferromagnetic material, such as low carbon steel, is disposed between the permanent magnets 19”, 21”. Vertical plates 33”, 35” made of ferromagnetic material are also disposed adjacent to the permanent magnets 17”, 23”. In FIG. 35, horizontal plates 37”, 39” made of ferromagnetic material are disposed adjacent to the tops and bottoms of the permanent magnets 17”, 19”, 21”, 23”. In FIG. 35, the ferromagnetic plates 31”, 33”, 35”, 37”, 39” are secured together, e.g., by means of bolts, to form an enclosure around the permanent magnets 17”, 19”, 21”, 23” and thereby direct the magnetic flux path. In alternate embodiments, the ferromagnetic plates 31”, 33”, 35”, 37”, 39” could be integrated together, i.e., instead of being provided as separate pieces, into a unitary housing. In FIG. 35, the permanent magnets 17”, 19”, 21”, 23” are held firmly in place, adjacent to the ferromagnetic plates 31”, 33”, 35”, 37”, 39”, by friction. In alternate embodiments, the permanent magnets could be bonded to the ferromagnetic plates to thereby secure the permanent magnets in place.

Still referring to FIG. 35, the coil part 15” of the voice coil motor part 9” includes a coil 41” positioned in the gaps 25”, 27”. In the embodiment shown in FIG. 35, the coil 41” is wound on a bobbin 43”. The coil 41” is wound in an oval or rectangular shape, as is best seen in FIG. 34. The coil 41” may be made of copper wire or other suitable conducting wire material. In FIG. 36, the bobbin 43” has flanges 45” with holes formed in them. The flanges 45” are used to attach the bobbin 43” to the support (3” in FIGS. 33 and 34). In FIG. 34, the bolts 46” indicate where the bobbin 43” is attached to the support base 3”. Other techniques for attaching the bobbin 43” to the support base 3” besides bolts and flanges may be used. In general, the bobbin 43” should be attached to the support base 3” such that it is cantilevered from the support base 3” and in parallel arrangement with the flexure parts 7”, 11”. In alternate embodiments, the bobbin 43” may be omitted and the coil 41” may be wound into the desired shape without the aid of a bobbin. In this case, the coil 41” will be free to move in the gaps 25”, 27”. In FIG. 34, it should be noted that there is an adjustable gap 47” between the distal ends of the coil 43” and magnet part 13”. The gap 47” allows the magnet part 13” to move curvilinearly relative to the support base 3”, preferably tracing an arc from the combination of a vertical movement and an axial in-and-out movement. Preferably, the electromagnetic inertial actuator curvilinearly arcing moving mass is electromagnetically driven to move curvilinearly to trace out an arc. Also, in FIG. 34, a yoke (i.e., a frame that couples together) 49” is coupled to the magnet part 13”. For example, such coupling could include bolting the yoke 49” to the ferromagnetic plates 33”, 35”. Other means of coupling the yoke 49” to the magnet part 13” could be used provided the integrity of the coupling remains intact as the magnet part 13” moves.

FIG. 37 shows a cut through the voice coil motor part 9”. In FIG. 375, B indicates the magnetic field created by the magnets 17”, 19”, 21”, 23” in the gaps 25”, 27”. When alternating current i is supplied to the coil 41”, the windings in the coil 41” interact with the magnetic field B in the gaps to exert a force f that drives (moves) the magnet part 13”. Returning to FIG. 33, the flexure parts 7”, 9” coupled to the magnet part 13” allow motion of the magnet part 13” along a vertical direction. Because of the cantilevered arrangement of the flexure parts 7”, 9”, the magnet part 13” moves in and out along an axial direction as it moves up and down along the vertical direction, thereby providing a curvilinear moving mass trace, preferably tracing an arc. FIG. 38 shows the magnet part 13” in a down position, with the flexure parts 7”, 11” deflected downwardly. FIG. 39 shows the magnet part 13” in an up position, with the flexure parts 7”, 11” deflected upwardly. The magnet part 13” moves in and out along the axial direction as it moves up and down along the vertical direction. As explained above, there is a gap (47” in FIG. 34) between the magnet part 13” and the coil (41” in FIG. 34) to accommodate axial motion of the magnet part 13” relative to the support base 3”. FIG. 40 shows magnetic flux path in the ferromagnetic plates 31”, 33”, 35”, 37”, 39” when the windings in the coil 41” interact with the magnetic field created in the gaps 25”, 27” by the permanent magnets 17”, 19”, 21”, 23”. FIG. 41 shows an example plot of force generated by the motor as a function of stroke of the motor. FIG. 41 shows that the force generated by the voice coil motor as described above is essentially linear, with very small force reduction at the ends of the stroke. In use, the force generated by the voice coil motor is transmitted to the support (3” in FIG. 33). With the support is attached to the aircraft structure, the force transmitted to the support is used to counteract vibrations of the structure.

Returning to FIG. 33, each of the flexure parts 7”, 11” is made up of two flexure stacks 50”. In alternate embodiments, more or fewer flexure stacks may be included in each of the flexure parts 7”, 11”. FIG. 42 shows a flexure stack 50” according to an embodiment of the invention. In the embodiment of FIG. 42, the flexure stack 50” includes flexures 52” interleaved with shims 54”. In a preferred embodiment the shims 54” are proximate the ends of the flexures 52” and do not extend along the flexure length with the middle of the stacks 50” free of the shims 54” (relatively short shims preferably bonded proximate ends of flexures and clamps 58” and do not extend the full length of the flexures through the mid-region of the flexure). Preferably each flexure 52” is in the form of a beam plate. The flexures 52” may be made of a non-elastomeric material, which may be metallic, non-metallic, or composite. Preferably, the flexures 52” are made of a composite or non-metallic material. In one embodiment, a composite material suitable for the flexures is comprised of reinforcing fibers in a polymer resin. In another embodiment, a composite material suitable for the flexures is comprised of a carbon-fiber reinforced composite. In another embodiment, the carbon-fiber reinforced composite is comprised of carbon fibers in a cured polymer matrix. In another embodiment, the carbon-reinforced fiber composite is comprised of carbon fibers in a cured epoxy matrix. In an embodiment the shims 54” are made of metal. In a preferred embodiment the shims 54” are made of an elastomer. In a preferred embodiment the elastomeric material for the shims is post-vulcanized rubber. The shims 54” in a preferred embodiment are bonded to the flexures 54” proximate their ends and the clamps 58”, with the shims inhibiting a fretting of the flexures as they move with the stroke of the voice coil motor. Preferably the bonded elastomeric shims 54” are provided to inhibit a fretting of the flexures 54”.

The distal ends of the flexure stack 50” are inserted into apertures 56” in flexure clamps 58” and held in the apertures 56”. The flexure clamps 58” have a double row bolt arrangement 60” (i.e., two rows of bolts, with the rows positioned on opposite sides of the clamps), and with this arrangement the flexure stack 50” can be firmly attached to the bracket

(49” in FIG. 33) and the vertical support (3” in FIG. 33). The double row bolt arrangement (60” in FIG. 42) improves the clamp stiffness and reduces the moment loads on the bolts (of the double row bolt arrangement) when the clamp 58” is secured to the bracket or vertical support. Returning to FIG. 33, the flexure stacks 50” span the full length of the inertial actuator 1”, thereby allowing large strokes of the voice coil motor part 9”. Large strokes result in large output forces of the actuator. The flexure stacks 50” are very stiff in five directions (lateral, longitudinal, and three rotations) but flexible in the vertical direction, allowing curvilinear movement of the magnet part 13” of the voice coil motor part 9”. The cantilevered arrangement of the flexure parts 7”, 11” and voice coil motor part 9” retains the parallel orientation of the voice coil motor part 9” relative to the flexure parts 7”, 11” throughout the stroke of the voice coil motor part 9”.

FIGS. 43A-43N show various examples voice coil/magnet arrangements usable in the voice coil motor part (9” in FIG. 33) of the electromagnetic inertial actuator (1” in FIG. 33). Preferably the arrangements include a ferromagnetic housing 34”, or a plurality of ferromagnetic plates 34”, defining a gap or a plurality of parallel gaps. Preferably the arrangements further include one or more permanent magnets 36” disposed in gap(s) and one or more coils 38” disposed adjacent to the permanent magnet(s) 36”. The coils 38” are typically annular or rectangular in shape as described above. Multiple coils 38” may be used in a stacked arrangement, such as shown in FIGS. 34K-N. The arrangement shown in FIG. 43A is similar to the one described above with reference to FIGS. 37 and 40.

FIG. 44 shows an aircraft 520 having a rotary wing system with at least one rotating blade rotating about a rotation axis. In use, the rotary wing system generates troublesome structural vibrations. A vibration control system for the aircraft 520 includes one or more vibration sensors 554 (e.g., accelerometers) mounted on the aircraft to sense the troublesome structural vibrations. The vibration control system also includes one or more nonrotating body force generator oriented electromagnetic inertial actuators 1” cantilever-mounted on the aircraft 520. The vibration control system also includes a controller 411. The controller 411 is shown outside of the aircraft for illustration purposes only. In practice, the controller 411 would be on-board the aircraft. The controller 411 receives signals from the vibration sensor(s) 554 representative of the troublesome structural vibrations. The controller 411 then sends signals to the nonrotating body force generator oriented electromagnetic inertial actuators 1”, instructing the nonrotating body force generator oriented electromagnetic inertial actuator(s) 1” to generate a force that counteracts the troublesome structural vibrations. Preferably the controller drives a plurality of nonrotating body force generator oriented electromagnetic inertial actuators with the actuators' sprung moving mass magnet part 13" tracing curvilinear arcs relative to their support bases, the support bases being physically grounded to the aircraft structure. Preferably the actuators' sprung moving mass magnet part 13" are cantilevered sprung supported with the composite flexures with the bonded elastomer end fret inhibiting shims.

FIG. 45 shows a variant 1A'' of the electromagnetic inertial actuator 1" of FIG. 33. In FIG. 45, weights 70", e.g., made of a metal such as steel, are coupled to the voice coil motor part 9". The weights 70" add mass to the sprung moving mass. Mounting base 4A" of the support base 3A" shown in FIG. 45 is different from the mounting base 4" shown in FIG. 33. The base 4A" of FIG. 45 has ears or flanges 72" that allows mounting of the base 4A" to a structure through a side of the base 4A". (In comparison, the base 4" of FIG. 33 can be mounted to a structure through a bottom of the base.) In FIG. 45, the flexure clamps 58A" at the support base 3A" are different from the flexure clamps 58" at the support base 3" shown in FIG. 33. Each of the flexure clamps 58A" shown in FIG. 45 can receive ends of multiple flexure stacks. The flexure clamps 58" shown in FIG. 33 preferably receive one end of a single flexure stack.

FIG. 46 shows a variant 1B" of the electromagnetic inertial actuator 1" of FIG. 33. The variant 1B" differs from the embodiment shown in FIG. 33 primarily in terms of the support base. In FIG. 46, the support base 3B" includes parallel plates 74", 76". The flexure stacks 50" at one end are coupled to the parallel plate 76", via attachment of the flexure clamps 58" to the parallel plate 76". The flexure stacks 50" at the other end are free to move and are not coupled to the parallel plate 74". The parallel plates 74", 76" are attached to a frame 78", thereby ensuring the rigidity of the support base 3B". The parallel plates 74", 76" include ears or flanges 74A", 76A" that can be connected to a structure. The support base 3B" allows the electromagnetic inertial actuator 1B" to be mounted sideways to a structure. The cantilevered parallel arrangement of the flexure stacks 50" and voice coil motor 9" is maintained by fixing the arrangement to only one of the parallel plates, i.e., parallel plate 76".

In embodiments the invention includes a rotary wing aircraft 520, the rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation, the rotary wing aircraft rotating hub having a plurality of rotor blades 522', the rotor blades including at least a first rotor blade 522' and at least a second rotor blade 522'. The rotary wing aircraft 520 preferably includes a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors 554 including at least a first nonrotating body vibration sensor 544, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft 520 preferably includes a plurality of nonrotating body vibration cancelling actuator force generators 530, 1'', the nonrotating body force generators including at least a first nonrotating body force generator 530 (1'') having at least a first electromagnetically moving mass 534 (13'')with the at least first nonrotating body force generator fixedly coupled with the nonrotating body 524. The rotary wing aircraft preferably includes a rotor plane tracker 553 for tracking the position of the rotary wing aircraft rotating hub rotor blades 522', the rotor plane tracker 553 for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The rotary wing aircraft preferably includes a data communications network link 150, the data communications network link linking together the at least the nonrotating body force generators, the nonrotating body vibration control sensors, and the rotor plane tracker, wherein the nonrotating body force generators communicate force generation vibration control data through the force generation data communications network, with the first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the data communications network to provide a rotor track maintenance output.

In embodiments the invention includes a rotary wing aircraft electronic control system 409, the rotary wing aircraft electronic control system 409 for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades 522', the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system 409 preferably including a rotary wing aircraft member tachometer sensor 552 for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor 522 and blades 522' rotating relative to the nonrotating body 524. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators 530,1'', the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass 534 , 13'', the at least first nonrotating body force generator fixedly coupled with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system 409 preferably including a rotor plane tracker 553 for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade 522' and the at least second rotor blade 522' relative to the nonrotating body 524. The rotary wing aircraft electronic control system preferably including a data communications network link 150, the data communications system network link linking together the at least the nonrotating body force generators 530,1'', the rotary wing aircraft member tachometer sensor 552, the nonrotating body vibration control sensors 554, and the rotor plane tracker 553, and an actuating force generator rotor track balance controller 411, the actuating force generator rotor track balance electronic controller 411 including at least a first computer processor 411', the actuating force generator rotor track controller controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a rotary wing aircraft electronic control system 409, the rotary wing aircraft electronic control system for a rotary wing aircraft 520 having a nonrotating aerostructure body 524 and a rotating hub 522 driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades 522', the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system 409 preferably including a rotary wing aircraft member tachometer sensor 552 for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades 522' rotating relative to the nonrotating body 524. The rotary wing aircraft electronic control system 409 preferably including a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors 554 including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system 409 preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators 530, 1'', the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass 534, 13'', the at least first nonrotating body force generator fixedly coupled with the nonrotating body 524 to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system 409 preferably including a data communications network link 150, the data communications system network link linking together the at least the nonrotating body force generators 530,1'', the rotary wing aircraft member tachometer sensor 552, the nonrotating body vibration control sensors 554 , and an actuating force generator rotor track balance electronic controller 411, the actuating force generator rotor track balance electronic controller 411 including at least a first computer processor 411', the actuating force generator rotor track balance controller 411 controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes a rotary wing aircraft control method for controlling a rotary wing aircraft 520 having a nonrotating aerostructure body 524 and a rotating hub 522 driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades 522', the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing a rotary wing aircraft member tachometer sensor 552 for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The method preferably including providing a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators 530, 1'', the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, and fixedly coupling the at least first nonrotating body force generator with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker 553 for tracking the position of the rotary wing aircraft rotating hub rotor blades 522', the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

In embodiments the invention includes an aircraft control method for controlling an aircraft 520 having a nonrotating aerostructure body 524 and a rotating hub 522 driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades 522', the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing an aircraft member tachometer sensor 552 for outputting aircraft member data correlating to the relative rotation of the aircraft rotating hub rotor blades 522' rotating relative to the nonrotating body 524. The method preferably including providing a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors 554 including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators 530,1'', the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass 534,13'', and fixedly coupling the at least first nonrotating body force generator with the nonrotating body 524 to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker 553 for tracking the position of the aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass to inhibit vibrations in the nonrotating aerostructure body and computing a rotor track and balance solution for the rotor blades.

Preferably the control systems and methods provide improved rotary wing aircraft 520. Preferably the control systems and methods actively control vibration in the aircraft 520 while monitoring the rotor track and balance of the rotating blades 522' to provide rotor track and balance solutions. Preferably the helicopter active vibration control with actuated force generators 530,1'' focuses on the vibration control of the aircraft 520 at the blade pass frequency N/Rev while the rotor track and balance monitors aircraft cabin vibration at the rotor frequency 1/Rev and blade tracking camera data to determine the track and balance solution for the helicopter 520. Preferably relatively low bandwidth (<1 kHz) rotor track and balance accelerometer vibration sensors 524 (RT&B accels) for the aircraft cabin vibration at the rotor frequency 1/Rev are located within the helicopter cabin. Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of controlling the force generators to minimize vibrations, receives and conditions cabin based accelerometer vibration sensors for use in controlling the active vibration force generators and calculation of the rotor track and balance solution outputs. Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of receiving and conditioning a rotor-synchronized tachometer signal from tachometer sensor 552 for use in controlling the active vibration force generators and calculation rotor track and balance solution outputs.

Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of receiving and conditioning a rotor tracking camera signal used to calculate the rotor track and balance solution (RT&B).

Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of computing the real-time active vibration control solution and creating force generator (FG) commands for controlling actuator force generator moving masses, as well as conducts other predetermined administrative functions associated with active vibration control.

Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of computing a rotor track and balance solution on a preferably continuous basis or as part of an initiated maintenance action and communicating the rotor track and balance solution to maintenance personnel through a maintenance interface output.

Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of providing an interface with the aircraft cockpit when required.

Preferably the electronic control system force generator rotor track balance electronic controller 411 performs the functions of amplifying FG force generation commands to drive the force generators. Alternatively, this is done in remote electronics proximate the force generators actuator fixed locations.

FIG. 47 and 48 illustrate the helicopter rotor track and balance and active vibration control system including the on-board aircraft hardware and a block diagram of the system/methods.

Preferably the electronic control system force generator rotor track balance electronic controller 411 utilizes cabin-based accelerometers 554 and a rotor tracking camera 553 as a tracker monitoring the rotary wing blades 522'. In trackerless embodiments the systems do not require the camera.

Preferably the system utilizes a Hub-Mounted Vibration Suppressor (HMVS) 20 to enable on-ground trim balancing of the blades with the electromagnetic positioning of the imbalance mass concentration rotors with their mass concentrations 40, 46, 40', 46'.

In embodiments the invention includes rotary wing aircraft 520, the rotary wing aircraft having nonrotating aerostructure body 524 and rotating hub 522 driven to rotate about a rotating hub center axis of rotation, the rotary wing aircraft rotating hub having a plurality of rotor blades 522', the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft preferably includes a plurality of nonrotating body vibration control sensors 554, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft preferably includes a plurality of nonrotating body vibration cancelling actuator force generators 530, 1'', the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically moving mass with the at least first nonrotating body force generator fixedly coupled with the nonrotating body. The rotary wing aircraft preferably includes a rotor plane tracker 553 for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The rotary wing aircraft preferably includes a data communications network link 150, the data communications network link linking together the at least the nonrotating body force generators, the nonrotating body vibration control sensors, and the rotor plane tracker, wherein the nonrotating body force generators communicate force generation vibration control data through the force generation data communications network, with the first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the data communications network to provide a rotor track maintenance output.

Preferably the provided rotor track maintenance output identifies the blade rotor plane tracking tab to be adjusted, and preferably the mass blade adjustment for a rotor blade 522'.

Preferably the system monitors rotor plane deflection positions of each blade 522' and provides rotor blade track adjustments and adjustments for balance blade masses while and cancelling/counteracting vibrations in the nonrotating helicopter aerostructure cabin with inputted electromagnetic actuator moving mass inertia forces. Preferably the system includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about the rotating hub center Z axis of rotation.

Preferably the system includes a rotary wing aircraft member tachometer sensor 552 for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body.

Preferably the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data are communicated through a distributed force generation data communications network 150 to provide a rotor track and balance maintenance output along with the active control of vibrations. Preferably the system monitors blade height and deflection relative to the nonrotating aerostructure body and the preferred rotor plane disk. Preferably the system monitors each blade 522' deflection from the rotor plane disk, and provides an output adjustment for tracking tab airfoil bend of each blade. Preferably the system provides an output adjustment for rotor balance mass of each blade. Preferably the system provides the output adjustment for the rotor mass by identifying each passing blade and correlating such with a vibration sensed with the passing of such blade.

Preferably the rotor plane tracker 553 is comprised of a rotor plane tracker camera. Preferably the rotor plane tracker camera 553 is mounted on the nonrotating aerostructure body relative to the rotary wing aircraft rotating hub to monitor the at least first rotor blade and at least second rotor blade.

Preferably the system includes an actuating actuator force generator rotor track balance controller 411, the actuating force generator rotor track balance controller including at least a first computer processor, the actuating force generator rotor track balance controller controlling the at least first electromagnetically moving mass inertia force with force generator commands and computes a rotor track and balance solution for the rotor blades.

Preferably the system includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, the rotating hub mounted vibration control system linked to the data communications network link 150.

Preferably the at least first nonrotating body force generator 530 is comprised of a nonrotating body circular force generator with the first electromagnetically moving mass rotated about an actuator axis.

Preferably the at least first nonrotating body force generator is comprised of a nonrotating body noncircular force generator 1'' with the first electromagnetically moving mass moved with a noncircular motion. Preferably the first electromagnetically moving mass is moved with an oscillating noncircular arc motion with the moving mass driven to oscillates back and forth.

In embodiments the invention includes the rotary wing aircraft electronic control system 409, the rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system preferably including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system preferably including a rotor plane tracker for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a data communications network link, the data communications system network link linking together the at least the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker, and an actuating force generator rotor track balance controller, the actuating force generator rotor track balance electronic controller including at least a first computer processor, the actuating force generator rotor track controller controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

Preferably the nonrotating body force generators communicate force generation vibration control data through distributed force generation data communications network link 150, with the first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the distributed force generation data communications network to provide a rotor track maintenance output. Preferably the system identifies a blade rotor plane tracking tab to be adjusted. Preferably the system identifies a blade rotor balance mass blade adjustment. Preferably the system monitors rotor plane deflection positions of each blade and outputs adjustments for blade mass balance and cancel/counteract vibrations in nonrotating helicopter aerostructure with inputted electromagnetic actuator forces.

Preferably the system includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about the rotating hub center Z axis of rotation.

Preferably the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data are communicated through the data communications network link 150 to provide a rotor track and balance maintenance output for adjusting a rotor blade airfoil and adjusting a rotor blade balance mass. Preferably blade height/ deflection relative to the nonrotating aerostructure body is monitored, with the system monitoring each blades deflection from the rotor plane disk, and outputting a maintenance adjustment for a tracking tab airfoil bend and an adjustment for the rotor balance mass. Preferably the rotor balance mass adjustment is provided by identifying the passing blade correlating with a vibration sensed with the passing of such blade.

Preferably the rotor plane tracker 553 is comprised of a rotor plane tracker camera. Preferably the rotary wing aircraft electronic control system rotor plane tracker camera is mounted on the nonrotating aerostructure body relative to the rotary wing aircraft rotating hub to monitor the at least first rotor blade and at least second rotor blade.

Preferably the rotary wing aircraft electronic control system includes a rotating hub mounted vibration control system 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, the rotating hub mounted vibration control system linked to the data communications network link.

In embodiments the at least first nonrotating body force generator is preferably comprised of a nonrotating body circular force generator 530 with the first electromagnetically moving mass rotated about an actuator axis.

In embodiments the at least first nonrotating body force generator is preferably comprised of a nonrotating body noncircular force generator 1'' with the first electromagnetically moving mass moved with a noncircular motion. Preferably the first electromagnetically moving mass is moved with a noncircular arc motion, preferably with the mass electromagnetically driven to oscillate back and forth tracing an arc.

In embodiments the invention includes a rotary wing aircraft electronic control system, the rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The rotary wing aircraft electronic control system preferably including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The rotary wing aircraft electronic control system preferably including a plurality of nonrotating body vibration cancelling actuator electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, the at least first nonrotating body force generator fixedly coupled with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The rotary wing aircraft electronic control system preferably including a data communications network link, the data communications system network link linking together the at least the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and an actuating force generator rotor track balance electronic controller, the actuating force generator rotor track balance electronic controller including at least a first computer processor, the actuating force generator rotor track balance controller controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

Preferably the nonrotating body force generators communicate force generation vibration control data through a distributed force generation data communications network link 150. Preferably the first nonrotating body force generator is controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the distributed force generation data communications network to provide a rotor track maintenance output. Preferably the system identifies the blade rotor plane tracking tab to be adjusted. Preferably the system identifies a mass blade adjustment. Preferably the system monitors the rotor plane deflection position of each blade and outputs blade mass balance adjustments and counteracts vibrations in the nonrotating helicopter aerostructure with inputted electromagnetic actuator forces.

Preferably the system includes a rotating hub mounted vibration control subsystem 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about the rotating hub center Z axis of rotation.

Preferably the system includes a data communications network linked rotor plane tracker 553 for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body, with the actuating force generator rotor track balance electronic controller computing a rotor track and balance maintenance output for adjusting a rotor blade airfoil and adjusting a rotor blade balance mass. Preferably the system monitors blade height/ deflection relative to the nonrotating aerostructure body, and monitors each blades deflection from the rotor plane disk, and outputs adjustments for tracking tab airfoil bends, and outputs adjustments for rotor balance mass. Preferably rotor mass adjustment is identified with a passing blade correlation to a vibration sensed with the passing of such blade.

Preferably the rotor plane tracker 553 is comprised of a rotor plane tracker camera. Preferably the rotor plane tracker camera is mounted on the nonrotating aerostructure body relative to the rotary wing aircraft rotating hub to optically monitor the at least first rotor blade and at least second rotor blade.

Preferably the rotary wing aircraft electronic control system includes a rotating hub mounted vibration control subsystem 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, the rotating hub mounted vibration control system linked to the data communications network link.

Preferably the at least first nonrotating body force generator 530 is comprised of a nonrotating body circular force generator with the first electromagnetically moving mass rotated about an actuator axis.

Preferably the at least first nonrotating body force generator is comprised of a nonrotating body noncircular force generator 1'' with the first electromagnetically moving mass moved with a noncircular motion, preferably with the first electromagnetically moving mass moved with a noncircular arc motion, with the mass electromagnetically driven to oscillate back and forth tracing an arc.

In embodiments the invention includes a rotary wing aircraft control method for controlling rotary wing aircraft 520 having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to the relative rotation of the rotary wing aircraft rotating hub rotor blades rotating relative to the nonrotating body. The method preferably including providing a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, and fixedly coupling the at least first nonrotating body force generator with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker for tracking the position of the rotary wing aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the rotary wing aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass and computing a rotor track and balance solution for the rotor blades.

Preferably the nonrotating body force generators communicate force generation vibration control data through a force generation data communications network link 150, with the first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by the nonrotating body vibration control sensors, with the rotor plane tracker first rotor blade data and second rotor blade data and the nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through the force generation data communications network to provide a rotor track maintenance output.

Preferably the rotor plane tracker 553 is comprised of a rotor plane tracker camera. Preferably the rotor plane tracker camera is mounted on the nonrotating aerostructure body relative to the rotary wing aircraft rotating hub to optically monitor the at least first rotor blade and at least second rotor blade.

Preferably the method includes providing a rotating hub mounted vibration control subsystem 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating rotary wing hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, the rotating hub mounted vibration control system controlled along with the nonrotating body force generators.

Preferably the at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator 530 with the first electromagnetically moving mass rotated about an actuator axis.

Preferably the at least first nonrotating body force generator is comprised of a nonrotating body noncircular force generator 1'' with the first electromagnetically moving mass moved with a noncircular motion, preferably the first electromagnetically moving mass is moved with a noncircular arc motion, preferably oscillating back and forth along an arc.

In embodiments the invention includes an aircraft control method for controlling aircraft 520 having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, the rotor blades including at least a first rotor blade and at least a second rotor blade. The method preferably including providing an aircraft member tachometer sensor for outputting aircraft member data correlating to the relative rotation of the aircraft rotating hub rotor blades rotating relative to the nonrotating body. The method preferably including providing a plurality of nonrotating body vibration control sensors, the nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, the at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations. The method preferably including providing a plurality of nonrotating body electromagnetic force generators, the nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, and fixedly coupling the at least first nonrotating body force generator with the nonrotating body to input a vibration control force into the nonrotating aerostructure body. The method preferably including providing a rotor plane tracker for tracking the position of the aircraft rotating hub rotor blades, the rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of the at least first rotor blade and the at least second rotor blade relative to the nonrotating body. The method preferably including linking together the nonrotating body force generators, the aircraft member tachometer sensor, the nonrotating body vibration control sensors, and the rotor plane tracker and controlling the at least first electromagnetically moving mass to inhibit vibrations in the nonrotating aerostructure body and computing a rotor track and balance solution for the rotor blades.

Preferably the rotor plane tracker 553 is comprised of a rotor plane tracker camera. Preferably the rotor plane tracker camera is mounted on the nonrotating aerostructure body relative to the aircraft rotating hub to optically monitor the at least first rotor blade and at least second rotor blade.

Preferably the method includes providing a rotating hub mounted vibration control subsystem 20, the rotating hub mounted vibration control system mounted to the rotating rotary wing hub with the rotating hub mounted vibration control system rotating with the rotating hub, the rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors rotatable about a rotating hub center axis of rotation, the rotating hub mounted vibration control system controlled along with the nonrotating body force generators.

Preferably the at least first nonrotating body force generator is comprised of a nonrotating body circular force generator 530 with the first electromagnetically moving mass rotated about an actuator axis.

Preferably the at least first nonrotating body force generator is comprised of a nonrotating body noncircular force generator 1'' with the first electromagnetically moving mass moved with a noncircular motion. Preferably the first electromagnetically moving mass is moved with a noncircular arc motion and oscillates back and forth tracing an arc.

It will be apparent to those skilled in the art that various modifications and variations can be made to the invention without departing from the spirit and scope of the invention. Thus, it is intended that the invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents. It is intended that the scope of differing terms or phrases in the claims may be fulfilled by the same or different structure(s) or step(s).

Claims:

1. A rotary wing aircraft, said rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation, said rotary wing aircraft rotating hub having a plurality of rotor blades, said rotor blades including at least a first rotor blade and at least a second rotor blade,

a plurality of nonrotating body vibration control sensors, said nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, said at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations,

a plurality of nonrotating body force generators, said nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically moving mass, said at least first nonrotating body force generator fixedly coupled with said nonrotating body,

a rotor plane tracker for tracking the position of said rotary wing aircraft rotating hub rotor blades, said rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said at least first rotor blade and said at least second rotor blade relative to said nonrotating body,

a data communications network link, said data communications system network link linking together said at least said nonrotating body force generators, said rotary wing aircraft member tachometer sensor, said nonrotating body vibration control sensors, and said rotor plane tracker,

wherein said nonrotating body force generators communicate force generation vibration control data through said distributed force generation data communications network,

said first nonrotating body force generator controlled to produce a first nonrotating body force generator force to minimize vibrations sensed by said nonrotating body vibration control sensors, with said rotor plane tracker first rotor blade data and second rotor blade data and said nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through said distributed force generation data communications network to provide a rotor track maintenance output.

2. An aircraft, as claimed in claim 1, with said rotor plane tracker first rotor blade data and second rotor blade data and said nonrotating body vibration control sensors first

nonrotating body vibration sensor data communicated through said distributed force generation data communications network to provide a rotor track and balance maintenance output.

3. An aircraft, as claimed in claim 2, wherein said rotor plane tracker is comprised of a rotor plane tracker camera.

4. An aircraft, as claimed in claim 3, wherein said rotor plane tracker camera is mounted on said nonrotating aerostructure body relative to said rotary wing aircraft rotating hub to monitor said at least first rotor blade and at least second rotor blade.

5. An aircraft, as claimed in claim 1, including an actuating force generator rotor track balance controller, said actuating force generator rotor track balance controller including at least a first processor, said actuating force generator rotor track balance controller controlling said at least a first electromagnetically moving mass and computes a rotor track and balance solution for said rotor blades.

6. An aircraft, as claimed in claim 1, includes a rotating hub mounted vibration control system, said rotating hub mounted vibration control system mounted to said rotating rotary wing hub with said rotating hub mounted vibration control system rotating with said rotating rotary wing hub, said rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, said rotating hub mounted vibration control system linked to said data communications network link.

7. An aircraft, as claimed in claim 1, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator with said first electromagnetically moving mass rotated about an actuator axis.

8. An aircraft, as claimed in claim 1, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular motion.

9. An aircraft, as claimed in claim 8, wherein comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular arc motion.

10. A rotary wing aircraft electronic control system, said rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, said rotor blades including at least a first rotor blade and at least a second rotor blade,

said rotary wing aircraft electronic control system including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to said relative rotation of said rotary wing aircraft rotating hub rotor blades rotating relative to said nonrotating body,

a plurality of nonrotating body vibration control sensors, said nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, said at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations,

a plurality of nonrotating body electromagnetic force generators, said nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, said at least first nonrotating body force generator fixedly coupled with said nonrotating body to input a vibration control force into said nonrotating aerostructure body,

a rotor plane tracker for tracking the position of said rotary wing aircraft rotating hub rotor blades, said rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said at least first rotor blade and said at least second rotor blade relative to said nonrotating body,

a data communications network link, said data communications system network link linking together said at least said nonrotating body force generators, said rotary wing aircraft member tachometer sensor, said nonrotating body vibration control sensors, and said rotor plane tracker, and an actuating force generator rotor track controller, said actuating force generator rotor track electronic controller including at least a first processor, said actuating force generator rotor track controller controlling said at least first electromagnetically moving mass and computing a rotor track solution for said rotor blades.

11. A rotary wing aircraft electronic control system, as claimed in claim 10, with said rotor plane tracker first rotor blade data and second rotor blade data and said nonrotating body vibration control sensors first nonrotating body vibration sensor data communicated through said data communications network to provide a rotor track and balance maintenance output for adjusting a rotor blade airfoil and adjusting a rotor blade balance mass.

12. A rotary wing aircraft electronic control system, as claimed in claim 10 wherein said rotor plane tracker is comprised of a rotor plane tracker camera.

13. A rotary wing aircraft electronic control system as claimed in claim 12, wherein said rotor plane tracker camera is mounted on said nonrotating aerostructure body relative to said rotary wing aircraft rotating hub to monitor said at least first rotor blade and at least second rotor blade.

14. A rotary wing aircraft electronic control system as claimed in claim 10, including a rotating hub mounted vibration control system, said rotating hub mounted vibration control system mounted to said rotating rotary wing hub with said rotating hub mounted vibration control system rotating with said rotating rotary wing hub, said rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, said rotating hub mounted vibration control system linked to said data communications network link.

15. A rotary wing aircraft electronic control system as claimed in claim 10, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator with said first electromagnetically moving mass rotated about an actuator axis.

16. A rotary wing aircraft electronic control system as claimed in claim 10, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular motion.

17. A rotary wing aircraft electronic control system as claimed in claim 16, wherein said first electromagnetically moving mass is moved with a noncircular arc motion.

18. A rotary wing aircraft electronic control system, said rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, said rotor blades including at least a first rotor blade and at least a second rotor blade,

said rotary wing aircraft electronic control system including a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to said relative rotation of said rotary wing aircraft rotating hub rotor blades rotating relative to said nonrotating body,

a plurality of nonrotating body vibration control sensors, said nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, said at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations,

a plurality of nonrotating body force generators, said nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, said at least first nonrotating body force generator fixedly coupled with said nonrotating body to input a vibration control force into said nonrotating aerostructure body,

a data communications network link, said data communications system network link linking together said at least said nonrotating body force generators, said rotary wing aircraft member tachometer sensor, said nonrotating body vibration control sensors, and an actuating force generator rotor track balance electronic controller, said actuating force generator rotor track balance electronic controller including at least a first computer processor, said actuating force generator rotor track controller controlling said at least first electromagnetically moving mass and computing a rotor track solution for said rotor blades.

19. A rotary wing aircraft electronic control system, as claimed in claim 18, including a data communications network linked rotor plane tracker for tracking the position of said rotary wing aircraft rotating hub rotor blades, said rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said at least first rotor blade and said at least second rotor blade relative to said nonrotating body, with said actuating force generator rotor track balance electronic controller computing a rotor

track and balance maintenance output for adjusting a rotor blade airfoil and adjusting a rotor blade balance mass.

20. A rotary wing aircraft electronic control system, as claimed in claim 19, wherein said rotor plane tracker is comprised of a rotor plane tracker camera.

21. A rotary wing aircraft electronic control system as claimed in claim 20, wherein said rotor plane tracker camera is mounted on said nonrotating aerostructure body relative to said rotary wing aircraft rotating hub to optically monitor said at least first rotor blade and at least second rotor blade.

22. A rotary wing aircraft electronic control system as claimed in claim 18, including a rotating hub mounted vibration control system, said rotating hub mounted vibration control system mounted to said rotating rotary wing hub with said rotating hub mounted vibration control system rotating with said rotating rotary wing hub, said rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, said rotating hub mounted vibration control system linked to said data communications network link.

23. A rotary wing aircraft electronic control system as claimed in claim 18, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator with said first electromagnetically moving mass rotated about an actuator axis.

24. A rotary wing aircraft electronic control system as claimed in claim 18, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular motion.

25. A rotary wing aircraft electronic control system as claimed in claim 24, wherein said first electromagnetically moving mass is moved with a noncircular arc motion.

26. A rotary wing aircraft control method for controlling a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center

axis of rotation with a plurality of rotor blades, said rotor blades including at least a first rotor blade and at least a second rotor blade,

said method including,

providing a rotary wing aircraft member tachometer sensor for outputting rotary wing aircraft member data correlating to said relative rotation of said rotary wing aircraft rotating hub rotor blades rotating relative to said nonrotating body,

providing a plurality of nonrotating body vibration control sensors, said nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, said at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations,

providing a plurality of nonrotating body electromagnetic force generators, said nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, fixedly coupling said at least first nonrotating body force generator with said nonrotating body to input a vibration control force into said nonrotating aerostructure body,

providing a rotor plane tracker for tracking the position of said rotary wing aircraft rotating hub rotor blades, said rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said at least first rotor blade and said at least second rotor blade relative to said nonrotating body,

linking together said nonrotating body force generators, said rotary wing aircraft member tachometer sensor, said nonrotating body vibration control sensors, and said rotor plane tracker and controlling said at least first electromagnetically moving mass and computing a rotor track and balance solution for said rotor blades.

27. A method as claimed in claim 26, wherein said rotor plane tracker is comprised of a rotor plane tracker camera.

28. A method as claimed in claim 27, wherein said rotor plane tracker camera is mounted on said nonrotating aerostructure body relative to said rotary wing aircraft rotating hub to optically monitor said at least first rotor blade and at least second rotor blade.

29. A method as claimed in claim 26, including providing a rotating hub mounted vibration control system, said rotating hub mounted vibration control system mounted to said rotating rotary wing hub with said rotating hub mounted vibration control system rotating

with said rotating rotary wing hub, said rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors driven to rotate about a rotating hub center axis of rotation, said rotating hub mounted vibration control system controlled along with said nonrotating body force generators.

30. A method as claimed in claim 26, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator with said first electromagnetically moving mass rotated about an actuator axis.

31. A method as claimed in claim 26, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular motion.

32. A method as claimed in claim 31 wherein said first electromagnetically moving mass is moved with a noncircular arc motion.

33. An aircraft control method for controlling an aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate about a rotating hub center axis of rotation with a plurality of rotor blades, said rotor blades including at least a first rotor blade and at least a second rotor blade,

said method including,

providing an aircraft member tachometer sensor for outputting aircraft member data correlating to said relative rotation of said aircraft rotating hub rotor blades rotating relative to said nonrotating body,

providing a plurality of nonrotating body vibration control sensors, said nonrotating body vibration control sensors including at least a first nonrotating body vibration sensor, said at least first nonrotating body vibration sensor outputting at least first nonrotating body vibration sensor data correlating to vibrations,

providing a plurality of nonrotating body electromagnetic force generators, said nonrotating body force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, fixedly coupling said at least first nonrotating body force generator with said nonrotating body to input a vibration control force into said nonrotating aerostructure body, providing a rotor plane tracker for tracking the position of said aircraft rotating hub rotor blades, said rotor plane tracker outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said at least first rotor blade and said at least second rotor blade relative to said nonrotating body,

linking together said nonrotating body force generators, said aircraft member tachometer sensor, said nonrotating body vibration control sensors, and said rotor plane tracker and controlling said at least first electromagnetically moving mass to inhibit vibrations in said nonrotating aerostructure body and computing a rotor track and balance solution for said rotor blades.

34. A method as claimed in claim 33, wherein said rotor plane tracker is comprised of a rotor plane tracker camera.

35. A method as claimed in claim 34, wherein said rotor plane tracker camera is mounted on said nonrotating aerostructure body relative to said aircraft rotating hub to optically monitor said at least first rotor blade and at least second rotor blade.

36. A method as claimed in claim 33, including providing a rotating hub mounted vibration control system, said rotating hub mounted vibration control system mounted to said rotating rotary wing hub with said rotating hub mounted vibration control system rotating with said rotating hub, said rotating hub mounted vibration control system including a plurality of imbalance mass concentration rotors rotatable about a rotating hub center axis of rotation, said rotating hub mounted vibration control system controlled along with said nonrotating body force generators.

37. A method as claimed in claim 33, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body circular force generator with said first electromagnetically moving mass rotated about an actuator axis.

38. A method as claimed in claim 33, wherein said at least a first nonrotating body force generator is comprised of a nonrotating body noncircular force generator with said first electromagnetically moving mass moved with a noncircular motion.

39. A method as claimed in claim 38 wherein said first electromagnetically moving mass is moved with a noncircular arc motion.

40. A rotary wing aircraft electronic control system, said rotary wing aircraft electronic control system for a rotary wing aircraft having a nonrotating aerostructure body and a rotating hub driven to rotate with a plurality of rotor blades,

a plurality of nonrotating body electromagnetic actuated force generators, said nonrotating body electromagnetic actuated force generators including at least a first nonrotating body force generator having at least a first electromagnetically driven moving mass, said at least first nonrotating body force generator for coupling with said nonrotating body to input an actuated vibration control force into said nonrotating aerostructure body,

a rotor plane tracker for tracking the position of said rotary wing aircraft rotating hub rotor blades, said rotor plane tracker for outputting at least first rotor blade data and at least second rotor blade data correlating to the relative position of said rotor blades relative to said nonrotating body,

and an actuating force generator rotor track balance controller said actuating force generator rotor track balance controller including a means for controlling said nonrotating body electromagnetic actuated force generators to reduce vibrations in said nonrotating aerostructure body and a means for computing a rotor track and balance solution for the rotor blades.

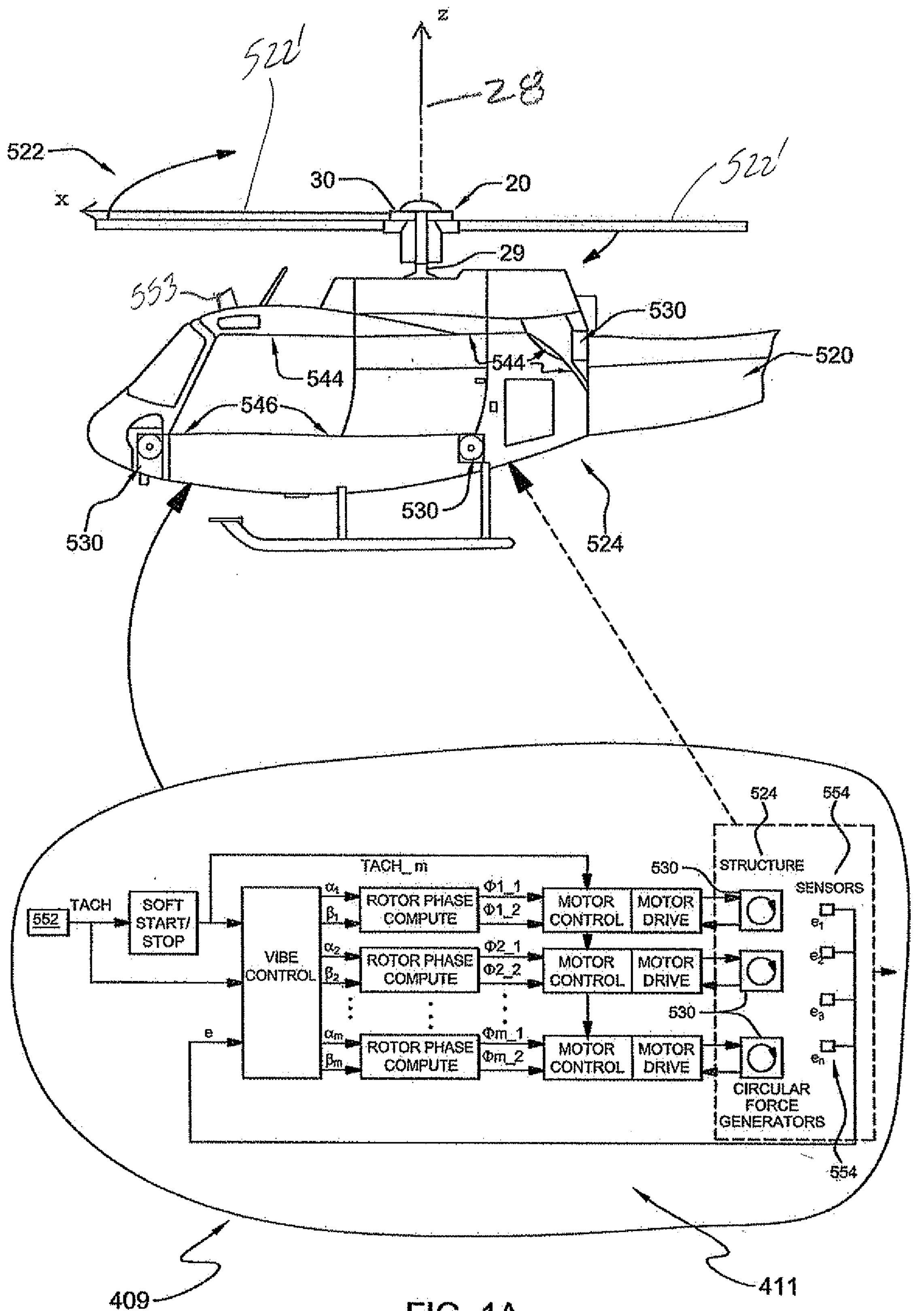

z
522'
28
522
x
30
20
522'
29
553
530
520
544
544
546
530
530
524
524
554
STRUCTURE
SENSORS
TACH_m
530
552
TACH
SOFT START/ STOP
VIBE CONTROL
α_1
β_1
α_2
β_2
α_m
β_m
e
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
Φ1_1
Φ1_2
Φ2_1
Φ2_2
Φm_1
Φm_2
MOTOR CONTROL
MOTOR DRIVE
MOTOR CONTROL
MOTOR DRIVE
MOTOR CONTROL
MOTOR DRIVE
e_1
e_2
e_3
e_n
530
CIRCULAR FORCE GENERATORS
554
409
411

FIG. 1A

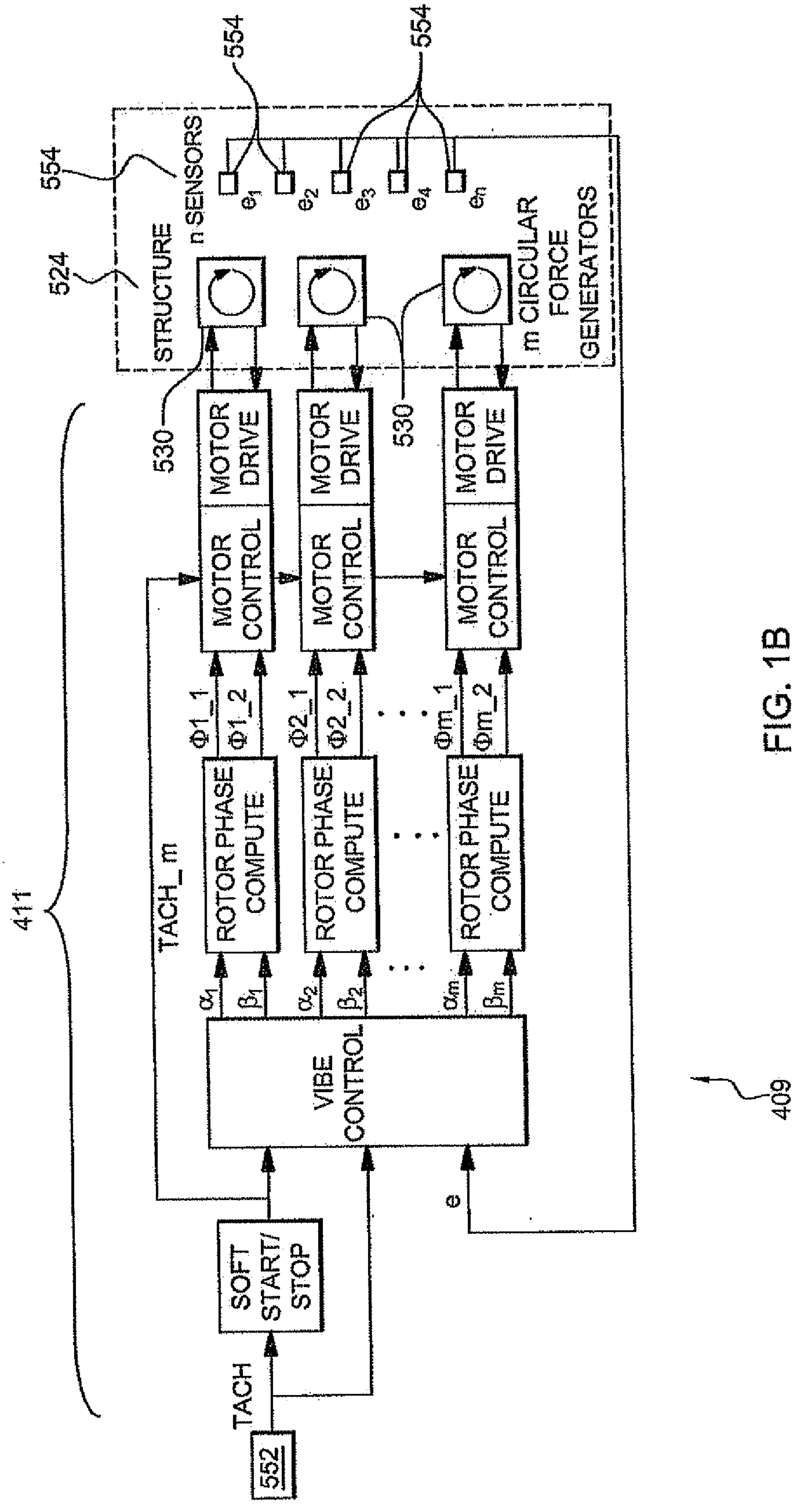
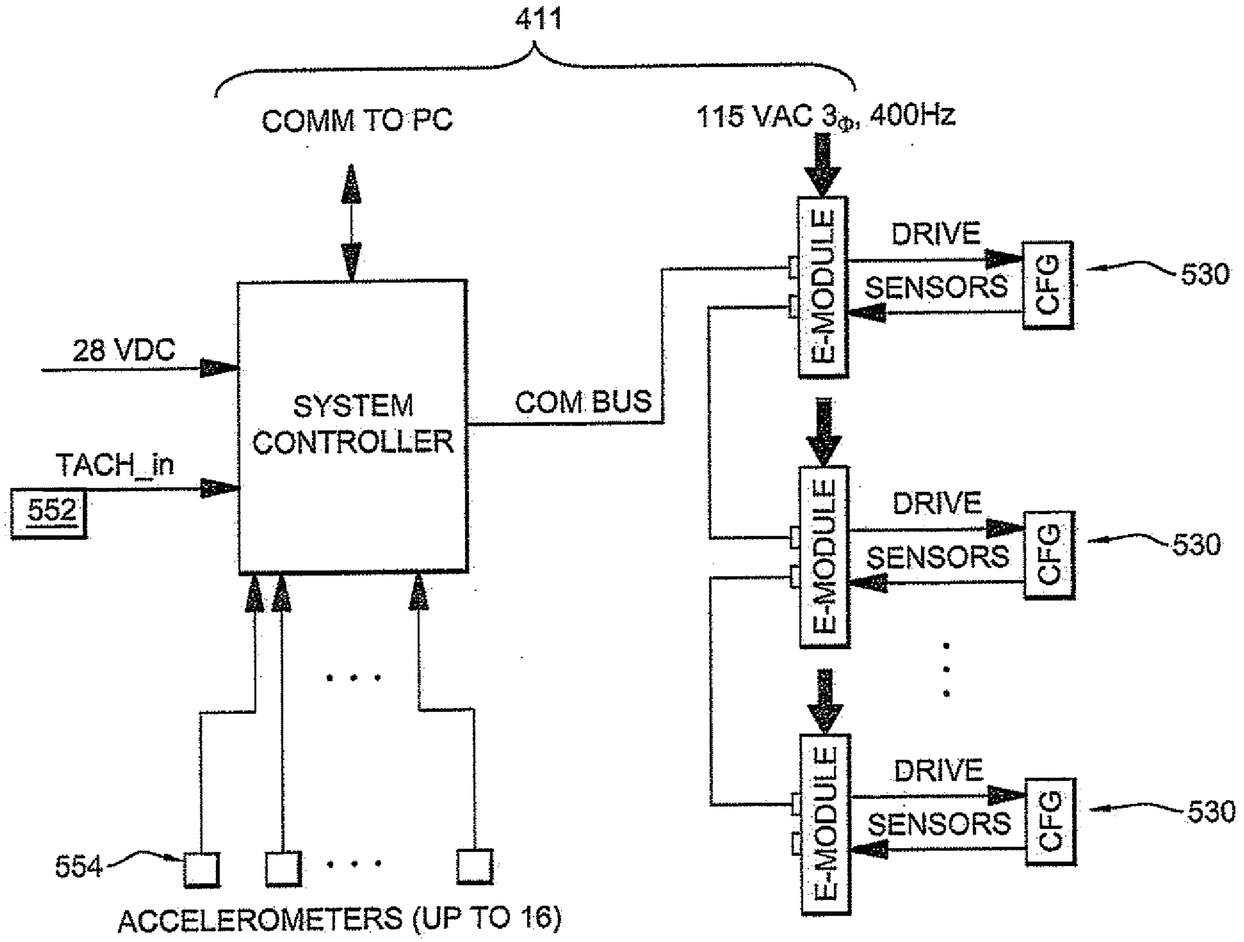

552
TACH
SOFT START/ STOP
TACH_m
VIBE CONTROL
e
α_1
β_1
α_2
β_2
α_m
β_m
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
Φ1_1
Φ1_2
Φ2_1
Φ2_2
Φm_1
Φm_2
MOTOR CONTROL
MOTOR CONTROL
MOTOR CONTROL
MOTOR DRIVE
MOTOR DRIVE
MOTOR DRIVE
530
530
STRUCTURE
524
m CIRCULAR FORCE GENERATORS
n SENSORS
554
554
554
e_1
e_2
e_3
e_4
e_n
411
409

FIG. 1B



COM. BUS PREFERABLY USES CANbus
CFG (CIRCULAR FORCE GENERATOR) PRODUCES ROTATING FORCE WITH CONTROLLED ROTATING FORCE MAGNITUDE AND CONTROLLED ROTATING FORCE PHASE

FIG. 2

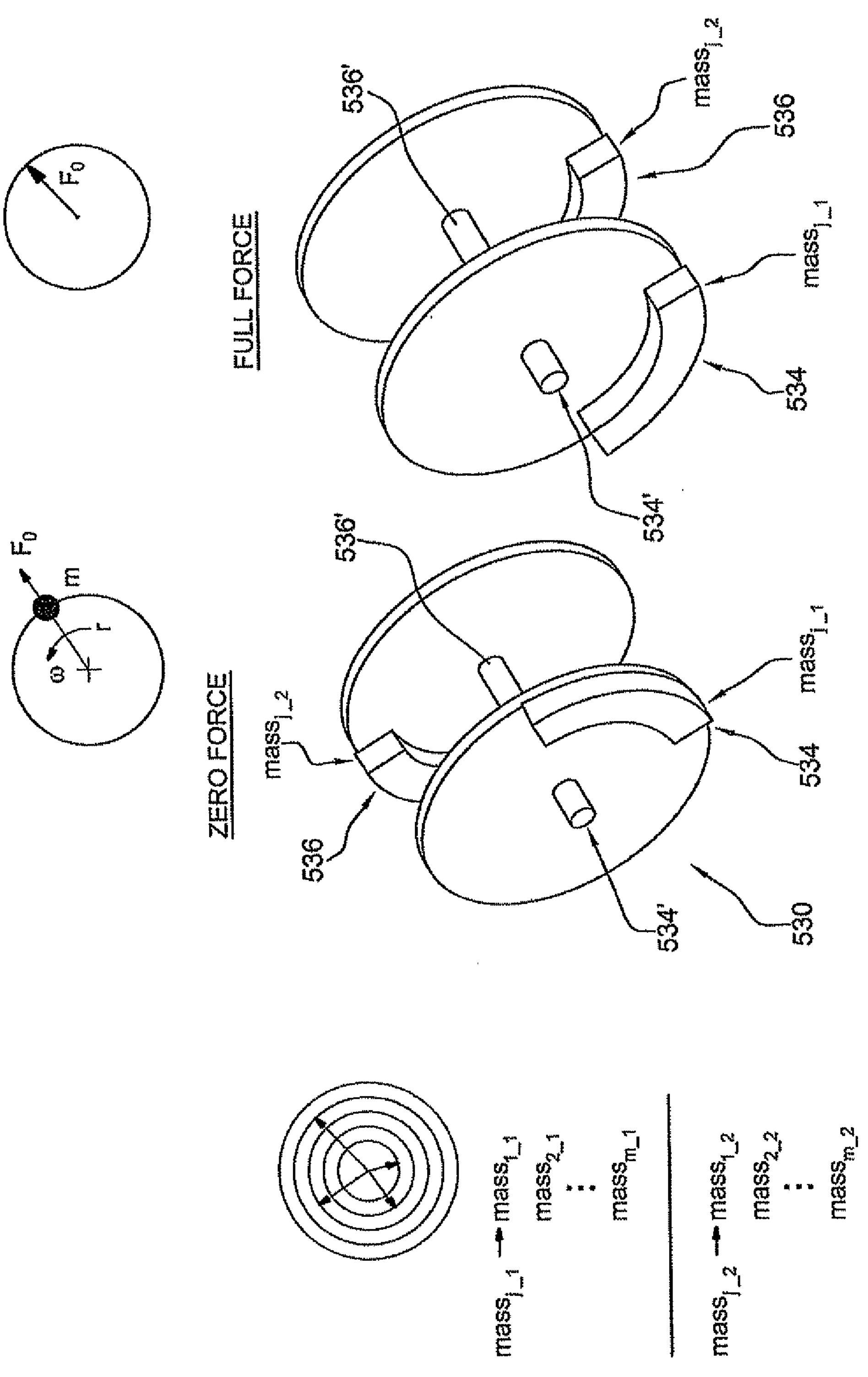

ZERO FORCE
FULL FORCE
F_0
m
r
ω
F_0
536'
536
mass_{j_2}
mass_{j_1}
534
534'
530
536'
536
mass_{j_2}
mass_{j_1}
534
534'
$\text{mass}_{j\_1} \rightarrow \text{mass}_{1\_1}$
mass_{2_1}
$\vdots$
mass_{m_1}
$\text{mass}_{j\_2} \rightarrow \text{mass}_{1\_2}$
mass_{2_2}
$\vdots$
mass_{m_2}

FIG. 3

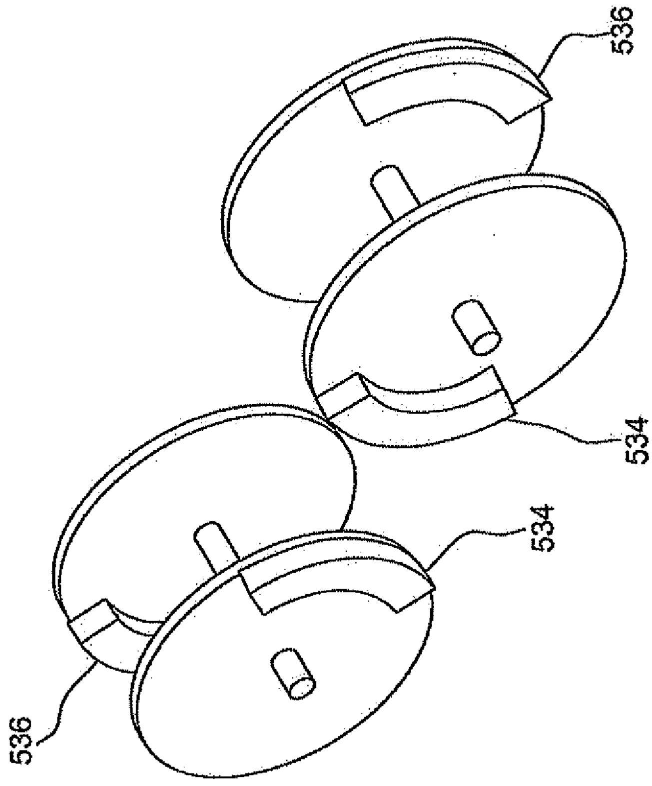


FIG. 4

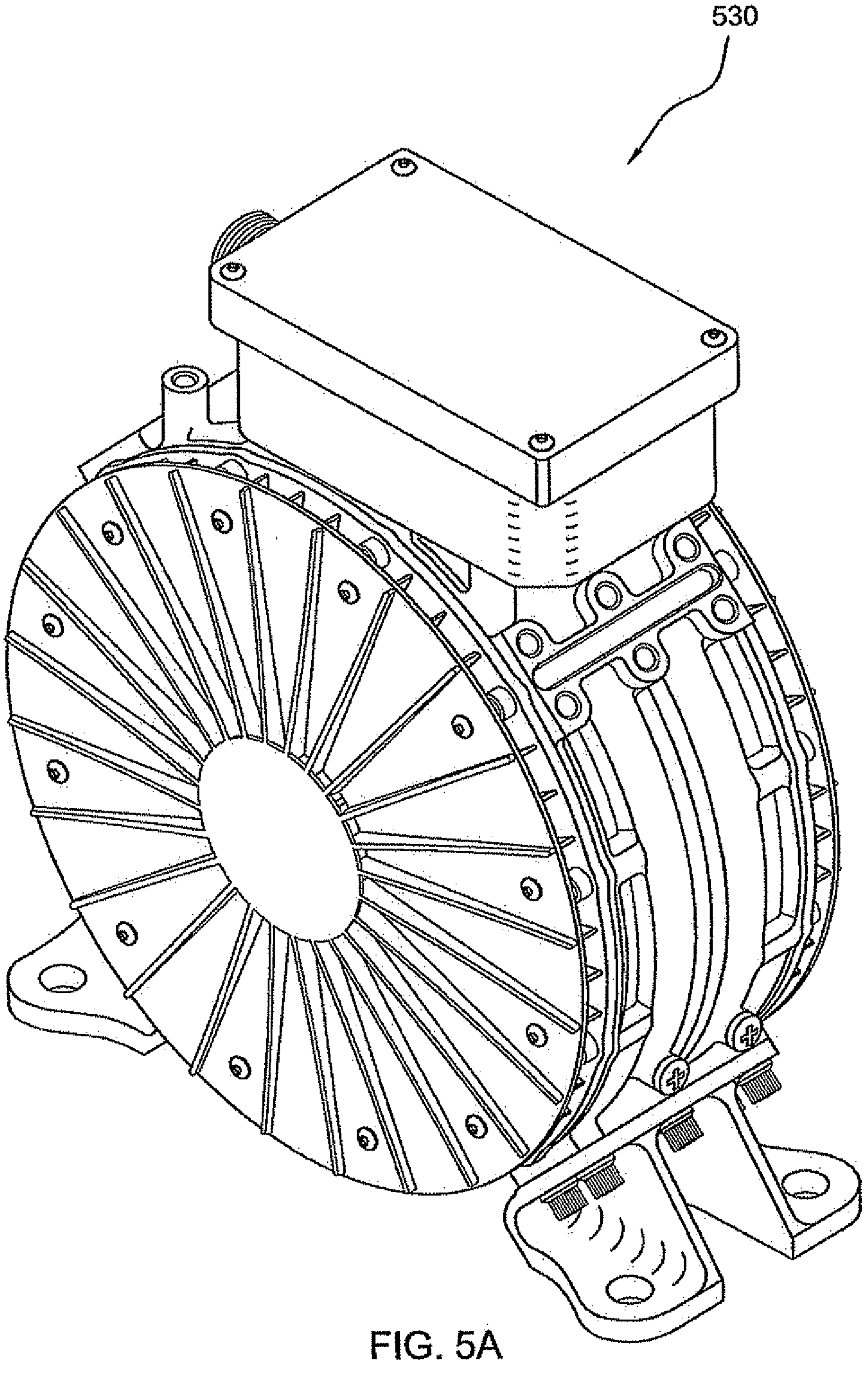


FIG. 5A

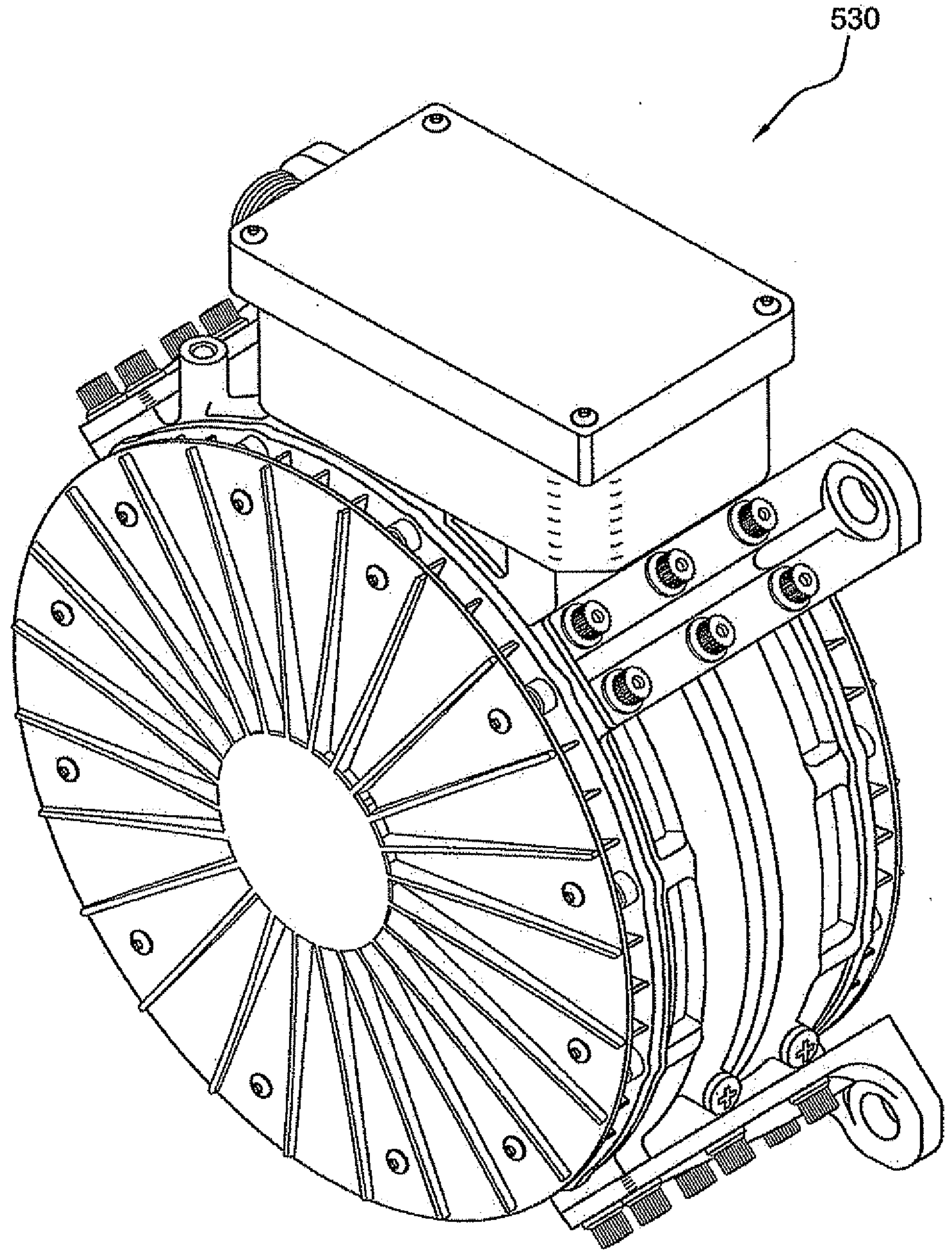


FIG. 5B

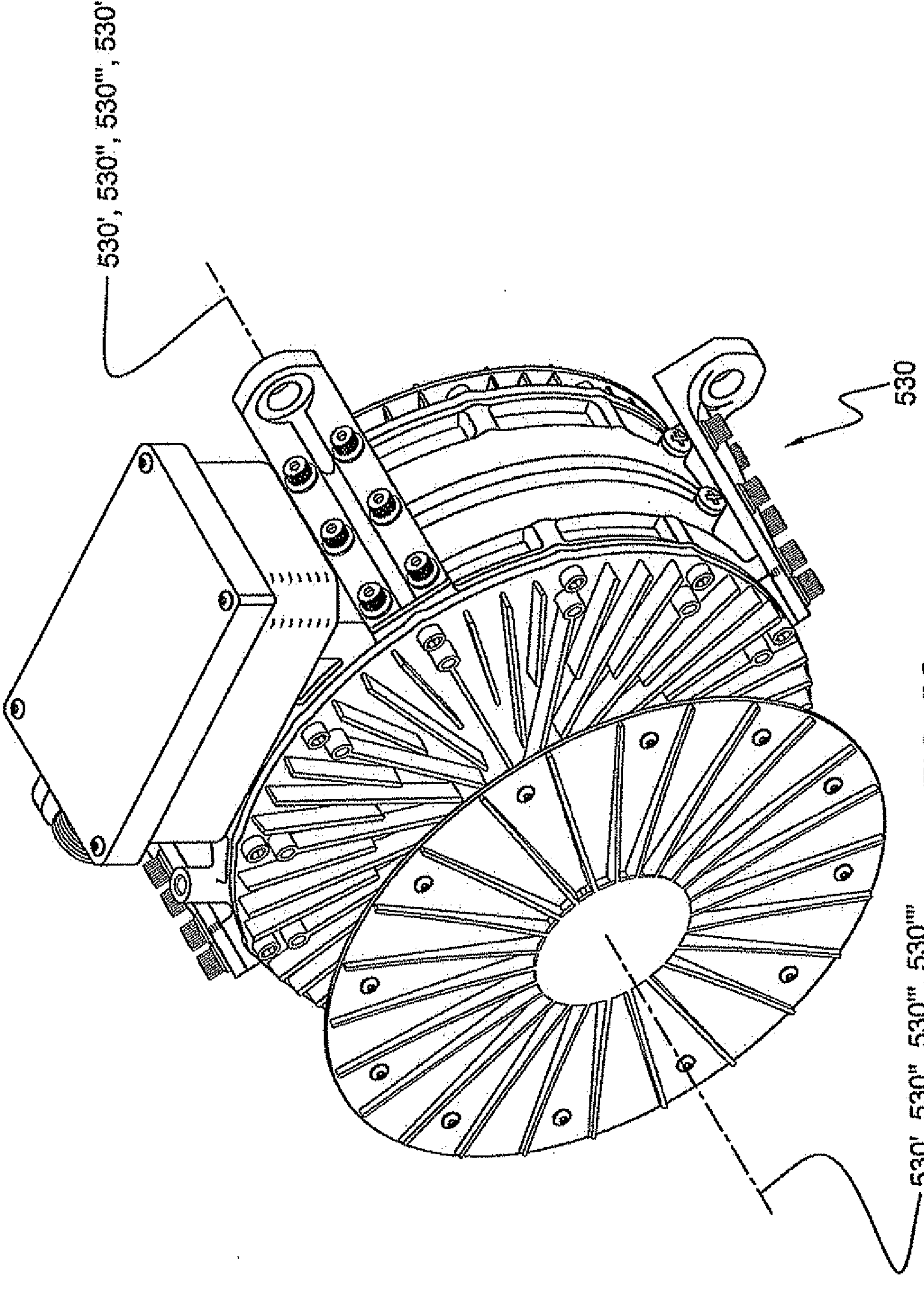


FIG. 5C

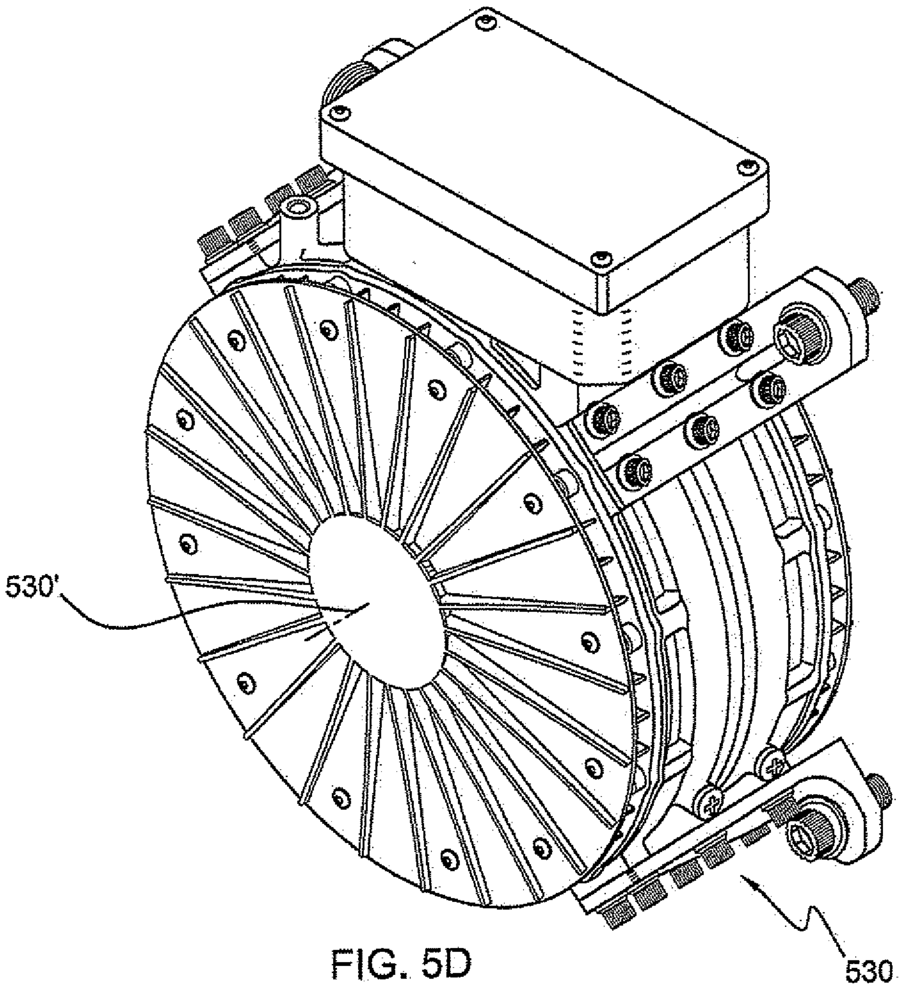


FIG. 5D

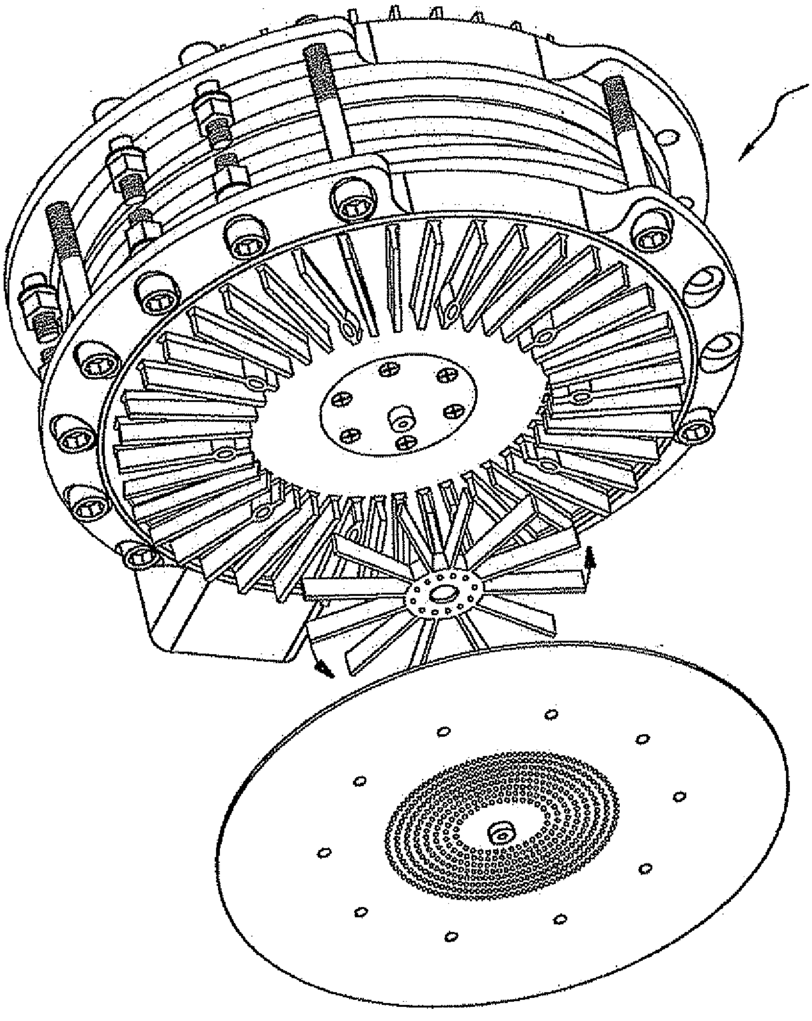


FIG. 5E

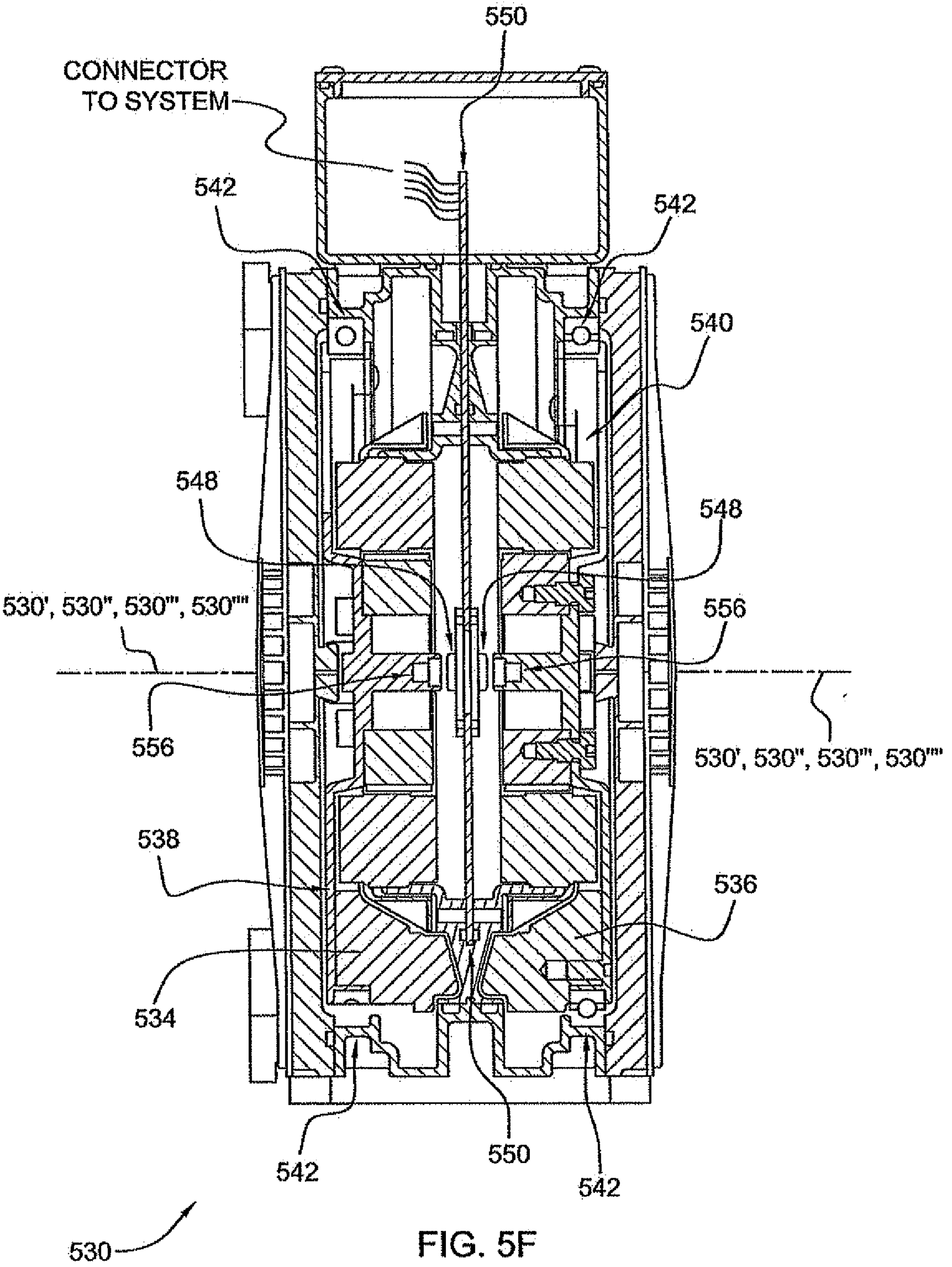

550
CONNECTOR
TO SYSTEM
542
542
540
548
548
530', 530", 530'", 530""
556
556
530', 530", 530'", 530""
538
536
534
542
550
542
530

FIG. 5F

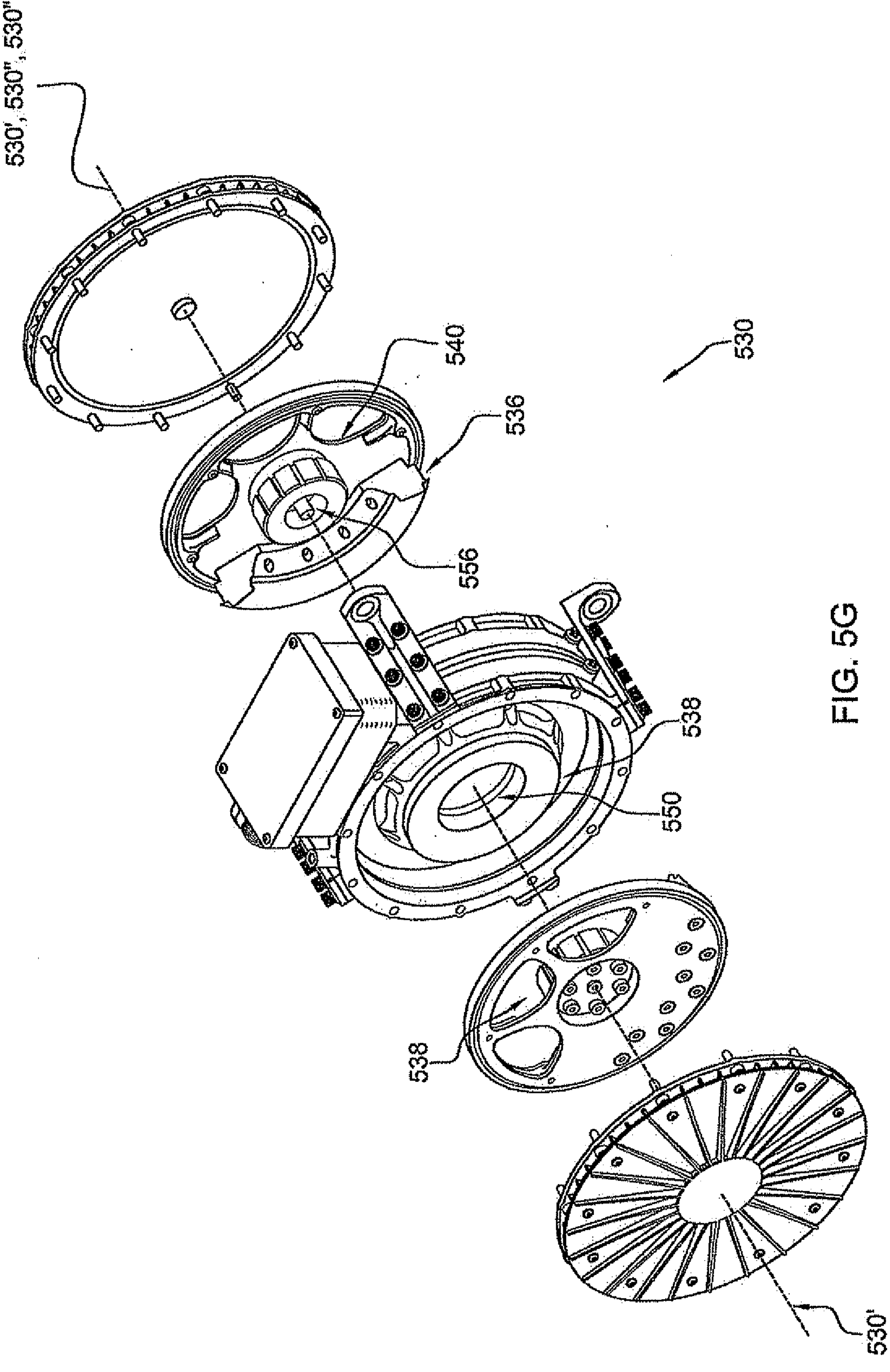


FIG. 5G

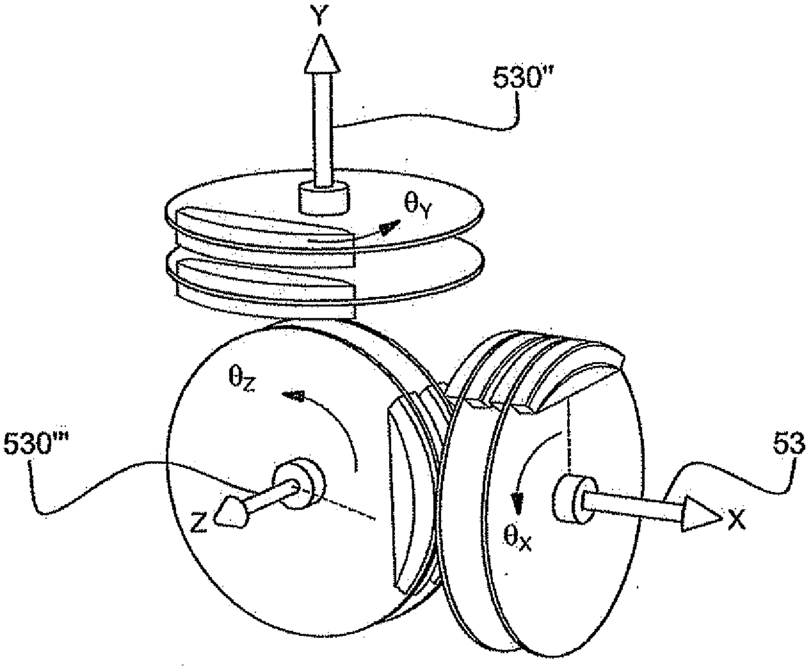


FIG. 6A

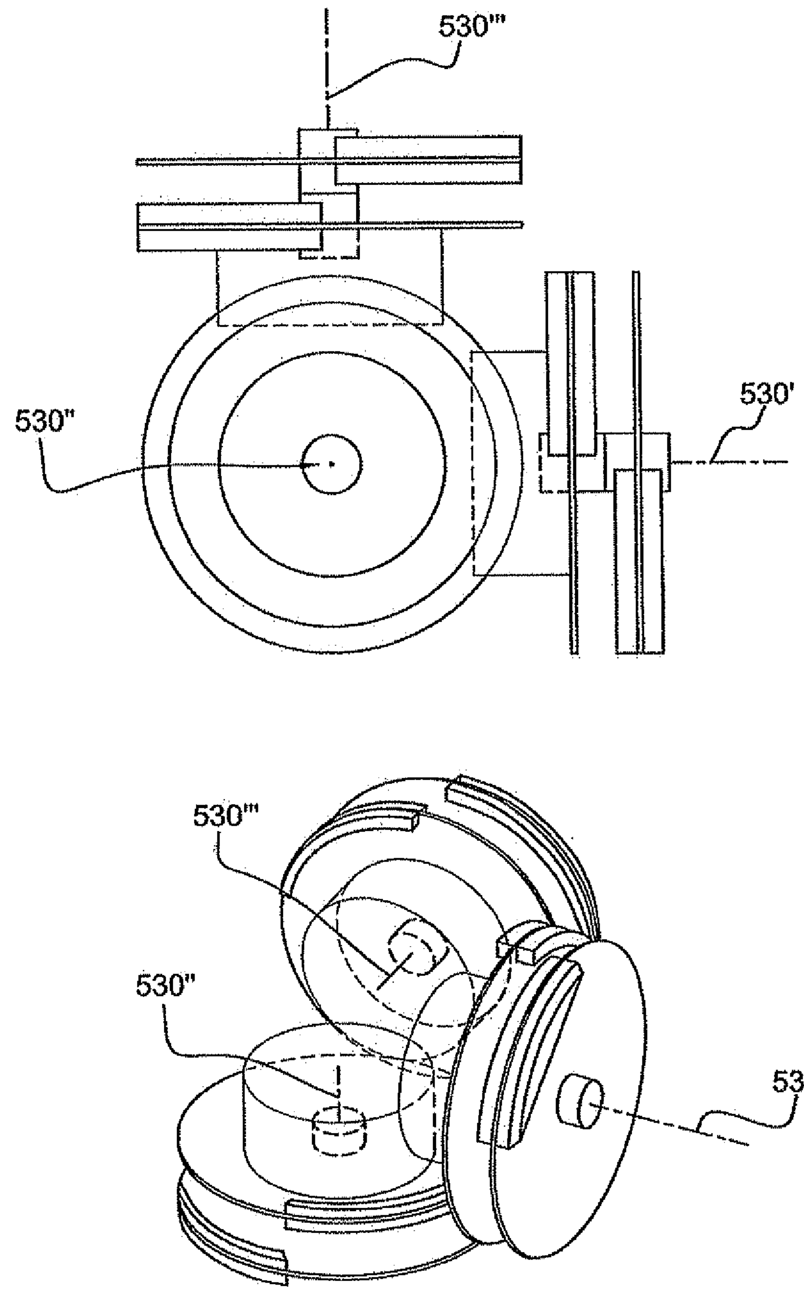


FIG. 6B

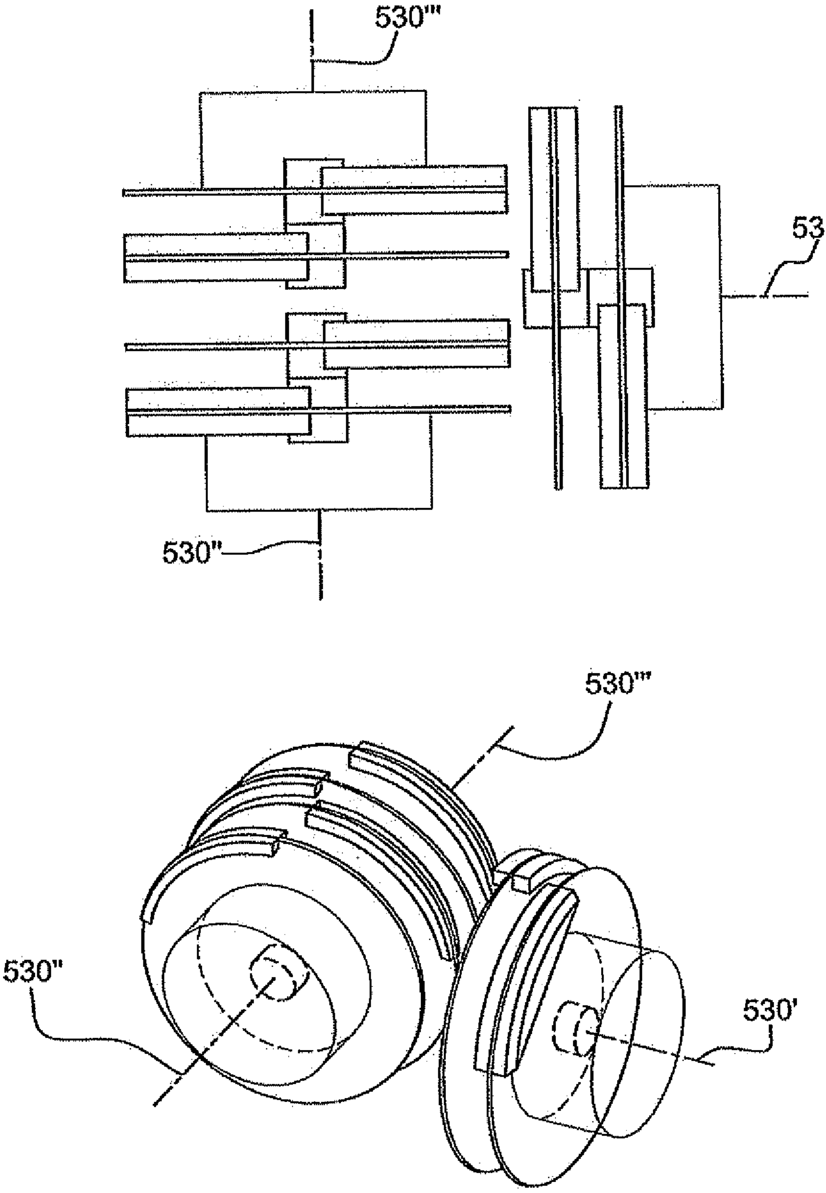


FIG. 6C

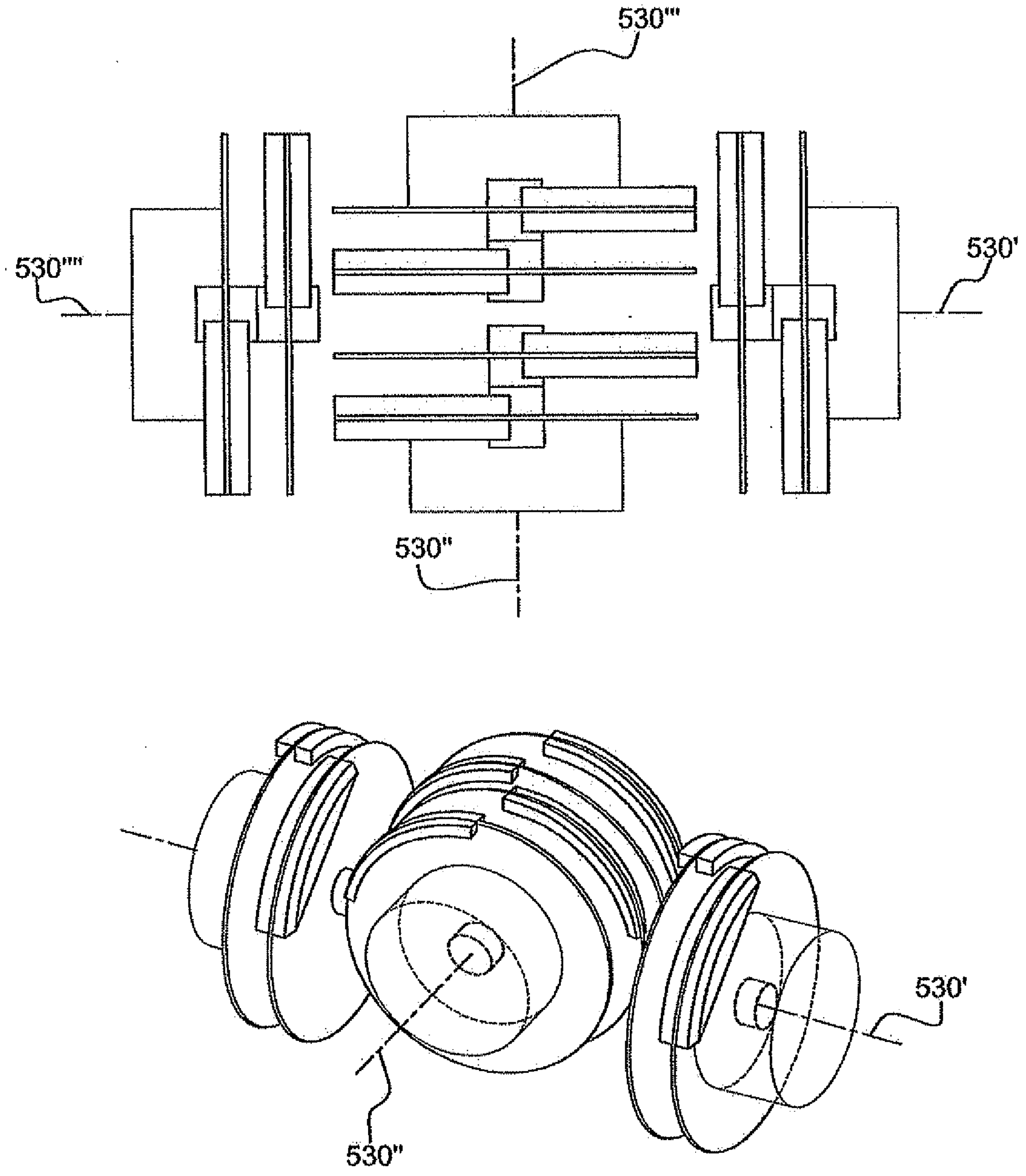


FIG. 6D

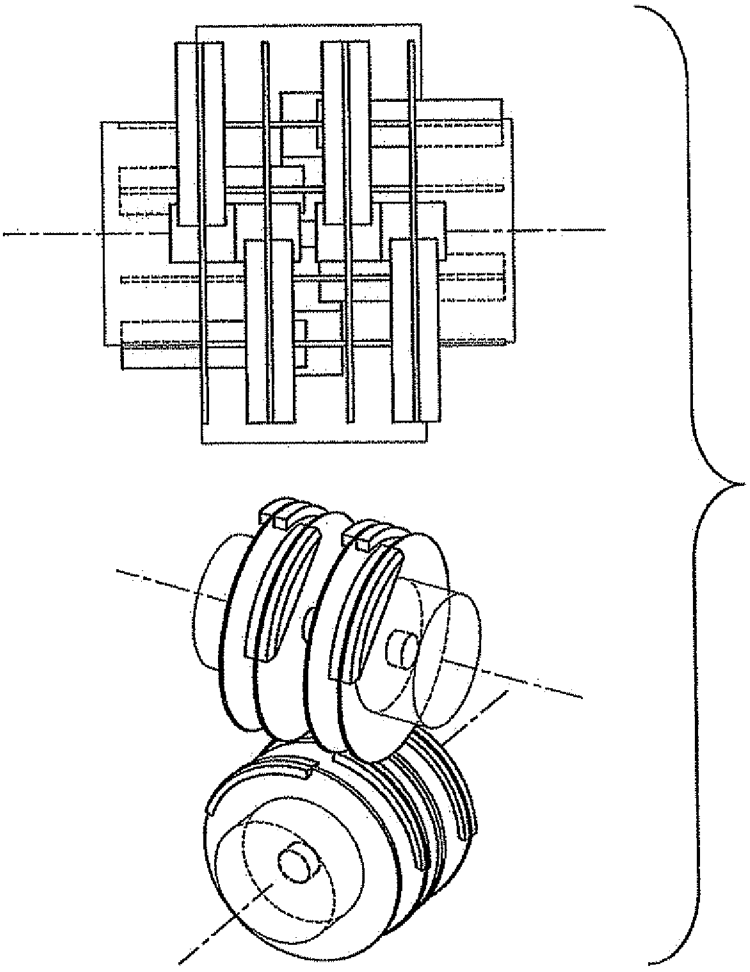


FIG. 6E

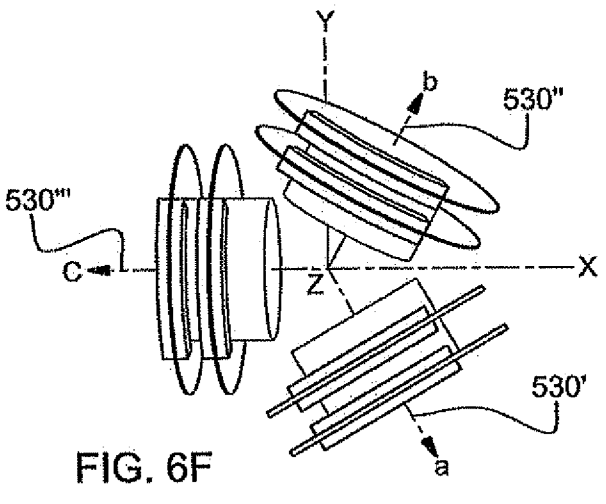
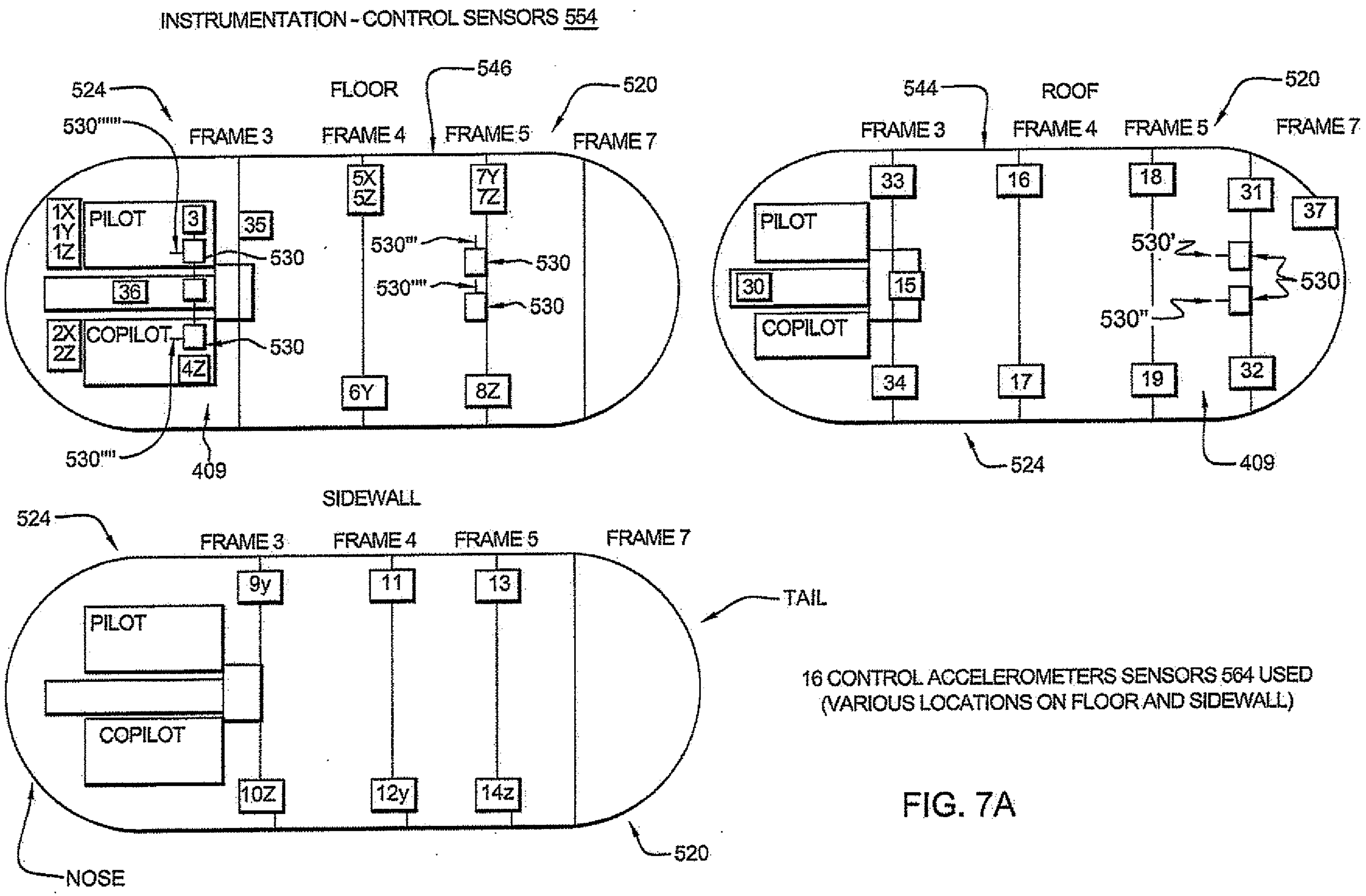


FIG. 6F



16 CONTROL ACCELEROMETERS SENSORS 564 USED
(VARIOUS LOCATIONS ON FLOOR AND SIDEWALL)

FIG. 7A

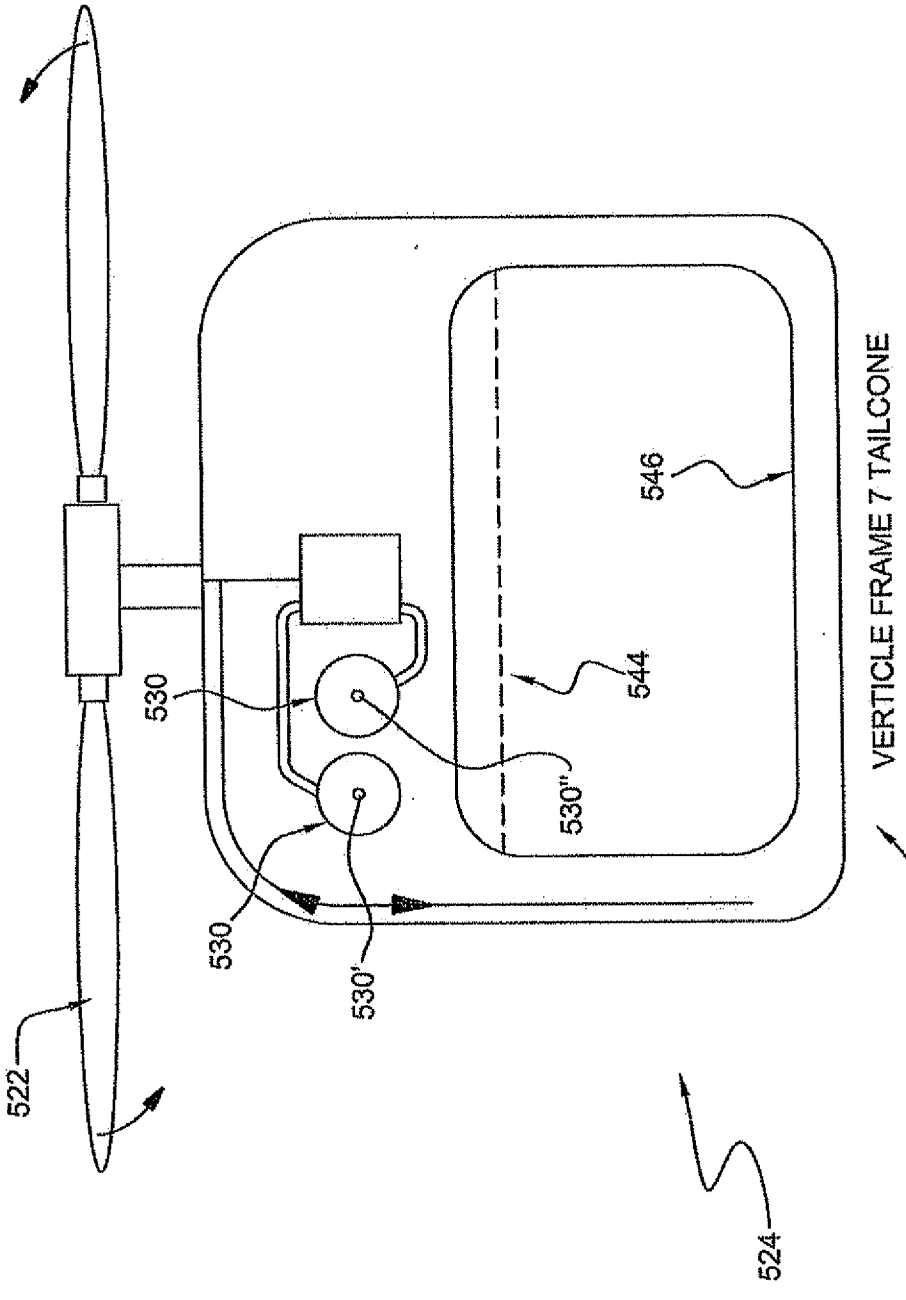


FIG. 7B

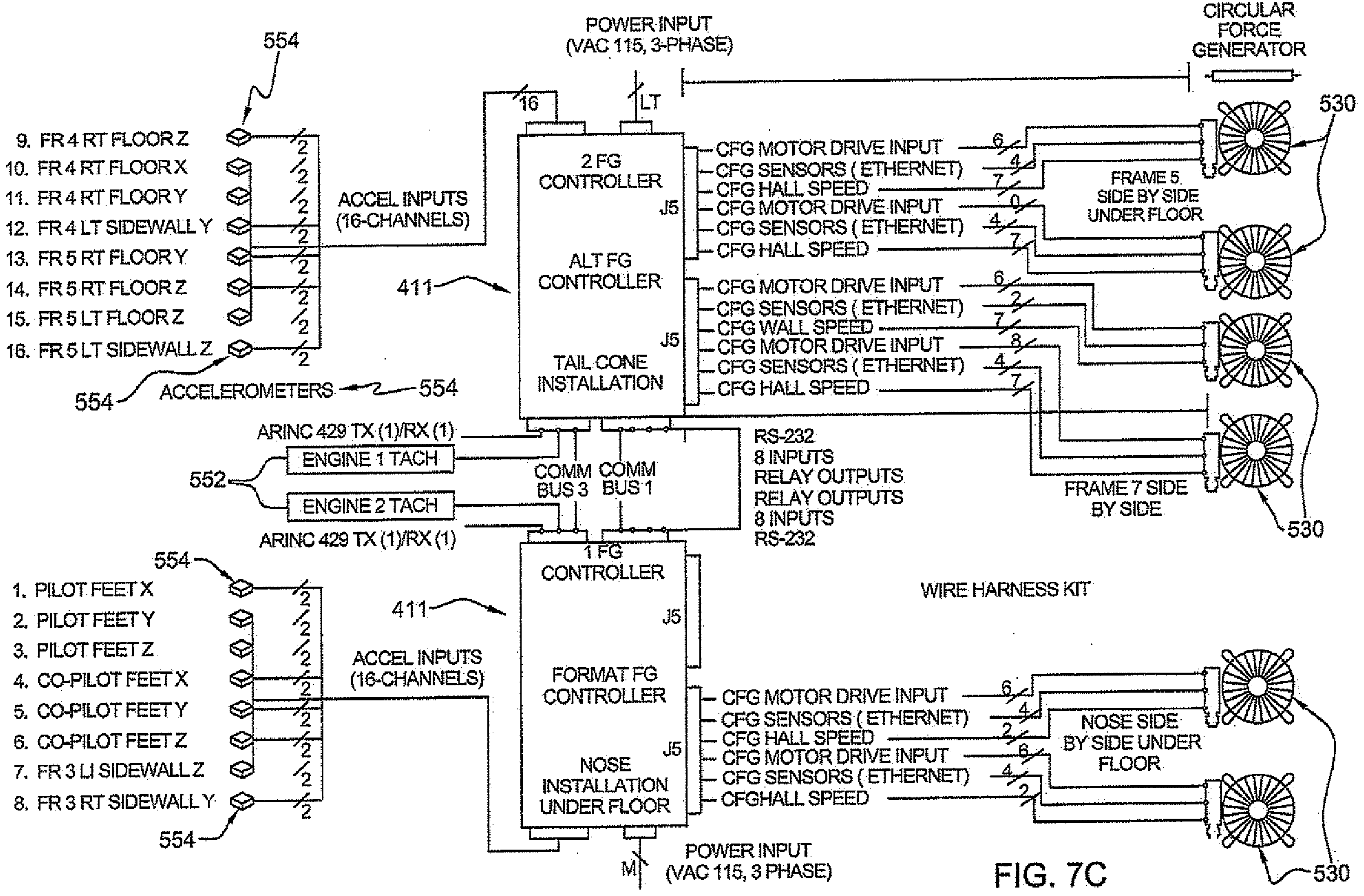
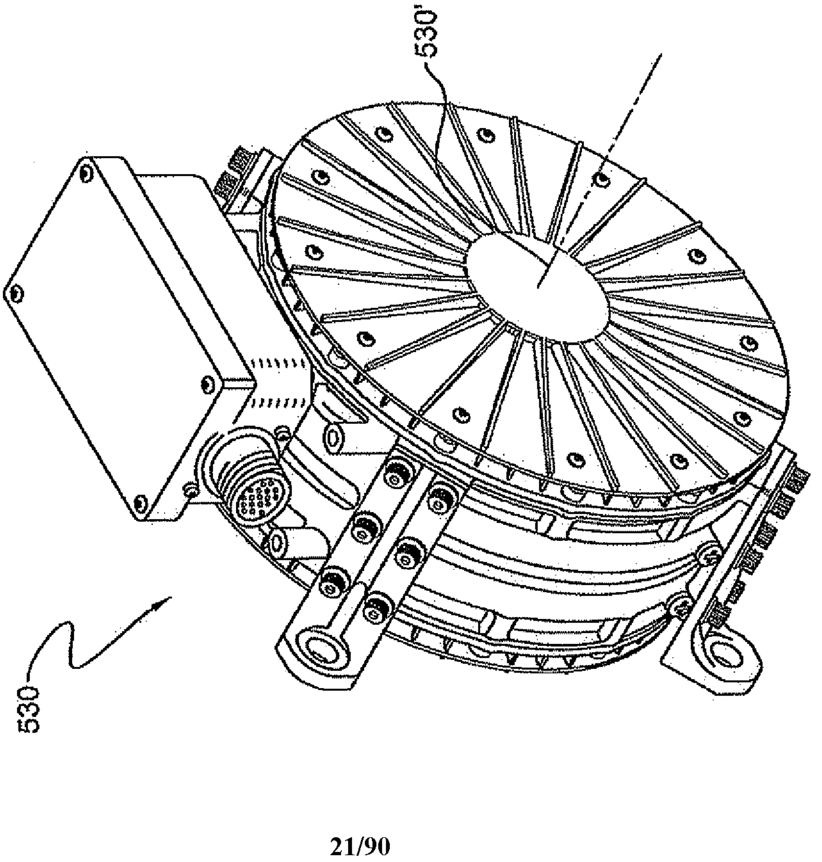
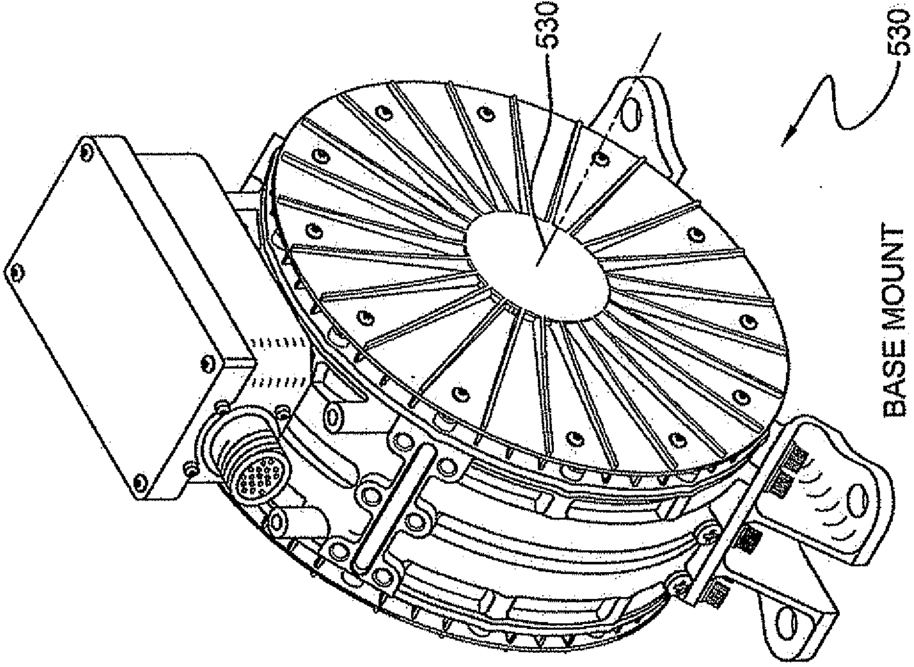

554
9. FR 4 RT FLOOR Z
10. FR 4 RT FLOOR X
11. FR 4 RT FLOOR Y
12. FR 4 LT SIDEWALL Y
13. FR 5 RT FLOOR Y
14. FR 5 RT FLOOR Z
15. FR 5 LT FLOOR Z
16. FR 5 LT SIDEWALL Z
554
ACCELEROMETERS
554
2
ACCEL INPUTS
(16-CHANNELS)
16
POWER INPUT
(VAC 115, 3-PHASE)
LT
CIRCULAR
FORCE
GENERATOR
530
2 FG
CONTROLLER
J5
ALT FG
CONTROLLER
J5
TAIL CONE
INSTALLATION
411
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFG HALL SPEED
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFG HALL SPEED
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFG WALL SPEED
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFG HALL SPEED
6
4
7
0
4
7
6
2
7
8
4
7
FRAME 5
SIDE BY SIDE
UNDER FLOOR
FRAME 7 SIDE
BY SIDE
530
530
ARINC 429 TX (1)/RX (1)
ENGINE 1 TACH
552
ENGINE 2 TACH
ARINC 429 TX (1)/RX (1)
COMM
BUS 3
COMM
BUS 1
RS-232
8 INPUTS
RELAY OUTPUTS
RELAY OUTPUTS
8 INPUTS
RS-232
WIRE HARNESS KIT
554
1. PILOT FEET X
2. PILOT FEET Y
3. PILOT FEET Z
4. CO-PILOT FEET X
5. CO-PILOT FEET Y
6. CO-PILOT FEET Z
7. FR 3 LI SIDEWALL Z
8. FR 3 RT SIDEWALL Y
554
ACCEL INPUTS
(16-CHANNELS)
411
1 FG
CONTROLLER
J5
FORMAT FG
CONTROLLER
J5
NOSE
INSTALLATION
UNDER FLOOR
M
POWER INPUT
(VAC 115, 3 PHASE)
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFG HALL SPEED
CFG MOTOR DRIVE INPUT
CFG SENSORS (ETHERNET)
CFGHALL SPEED
6
4
2
6
4
2
NOSE SIDE
BY SIDE UNDER
FLOOR
530

FIG. 7C



SHEAR MOUNT
FIG. 7D



BASE MOUNT
FIG. 7E

AVC WITH CIRCULAR FORCE GENERATORS (CFGs) ON HELICOPTER TRANSMISSIONS

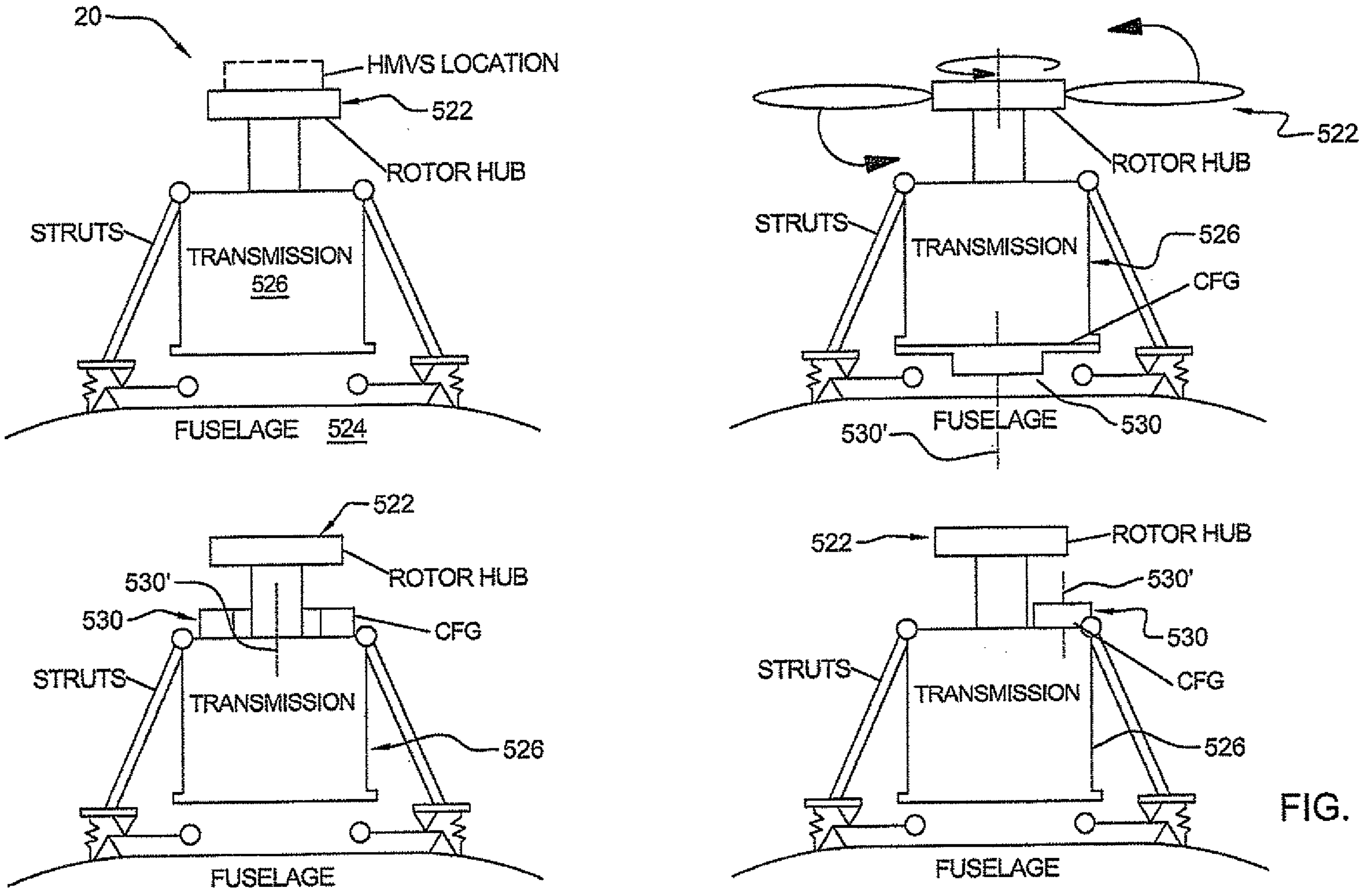


FIG. 8A

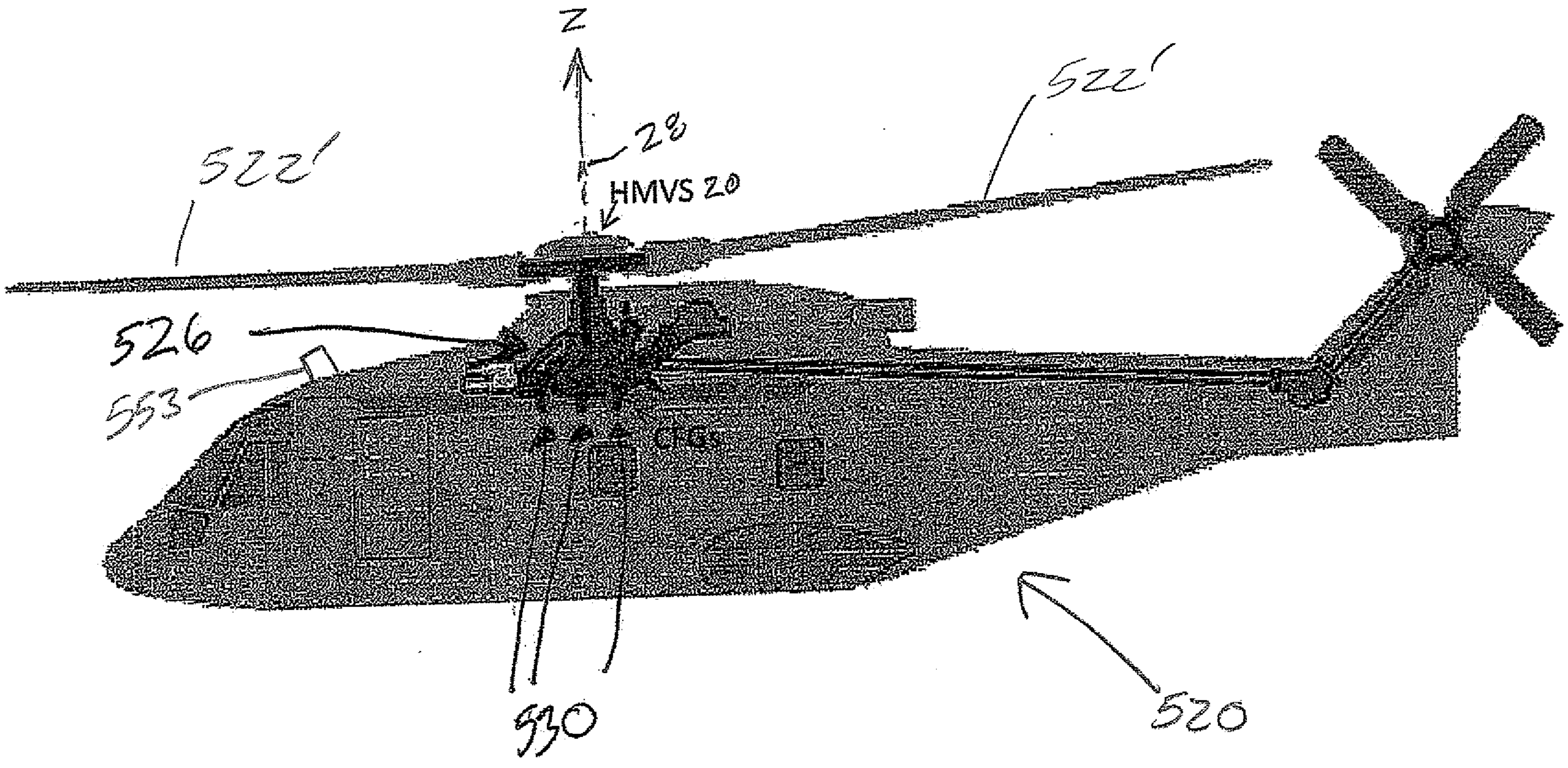


FIG. 8B

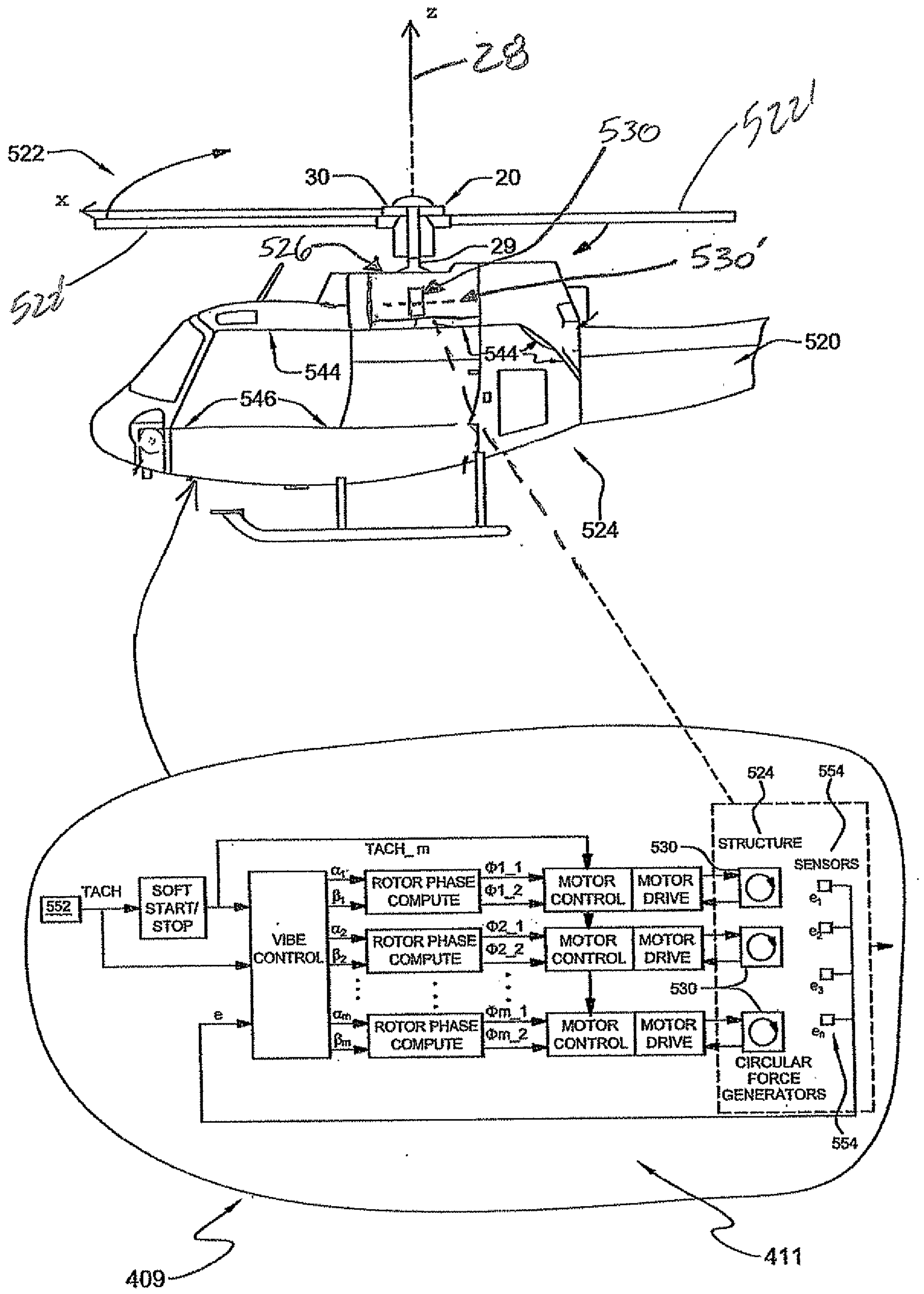

z
28
522
x
30
20
530
522
29
526
530'
522
544
544
520
546
524
TACH_m
552
TACH
SOFT START/ STOP
VIBE CONTROL
e
α_1
β_1
α_2
β_2
α_m
β_m
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
ROTOR PHASE COMPUTE
Φ1_1
Φ1_2
Φ2_1
Φ2_2
Φm_1
Φm_2
MOTOR CONTROL
MOTOR DRIVE
MOTOR CONTROL
MOTOR DRIVE
MOTOR CONTROL
MOTOR DRIVE
530
530
524
STRUCTURE
554
SENSORS
e_1
e_2
e_3
e_n
CIRCULAR FORCE GENERATORS
554
409
411

FIG. 8C

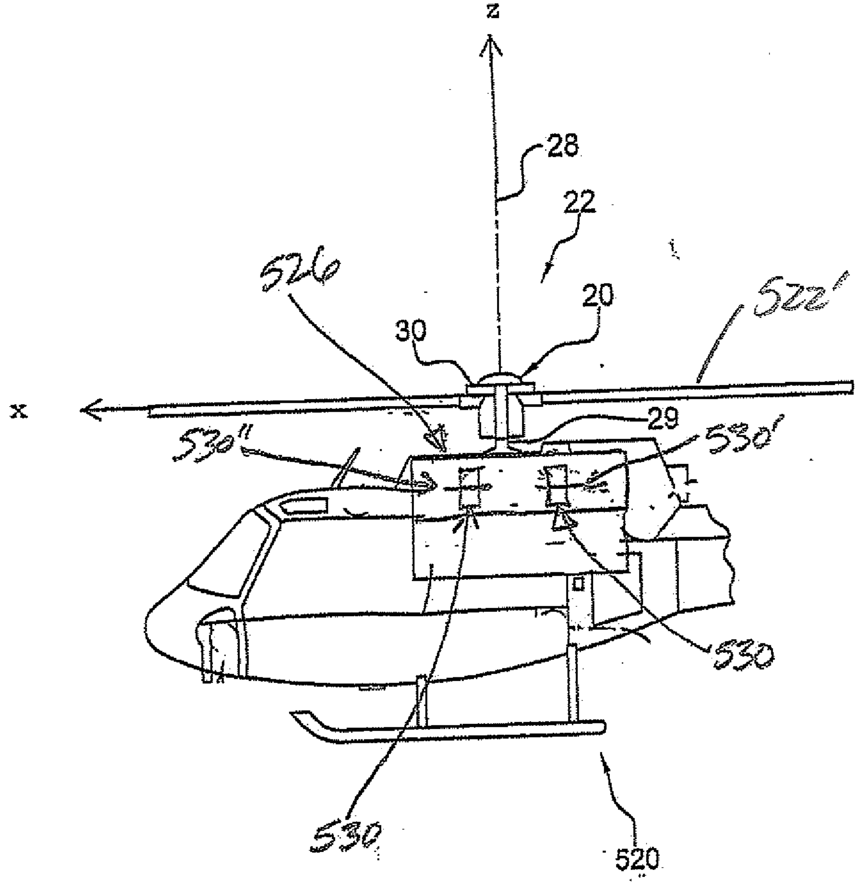

z
28
22
20
30
526
522'
x
29
530''
530'
530
530
520

FIG. 8D

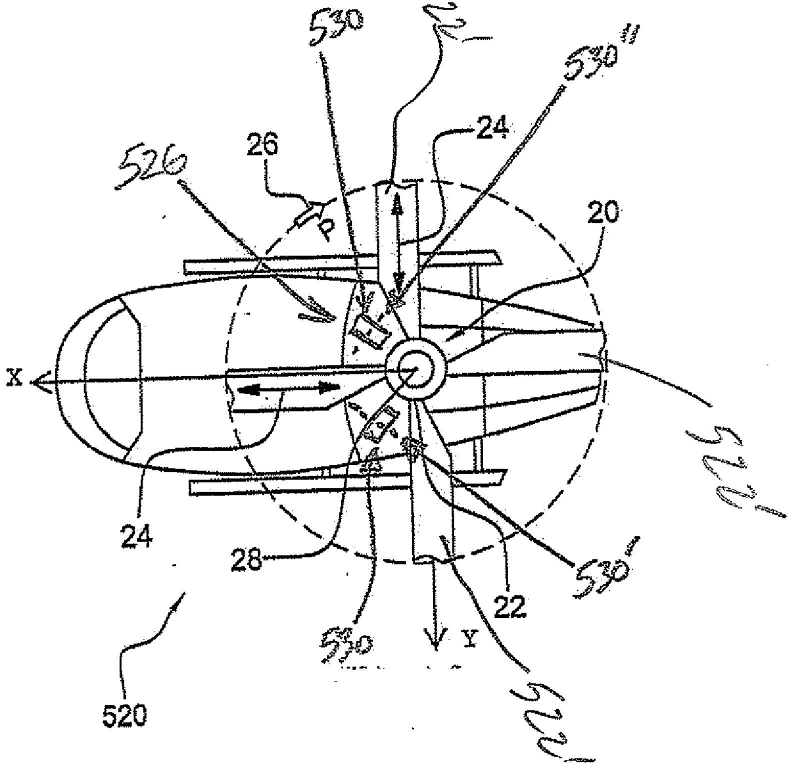

530
522'
530''
24
526
26
P
20
X
522'
24
28
530
Y
22
530'
522'
520

FIG. 8E

FIG. 8F

◆ 5 D.O.F. floating mass with an HMVS attached at the top and different arrangements of CFG's attached at the bottom.

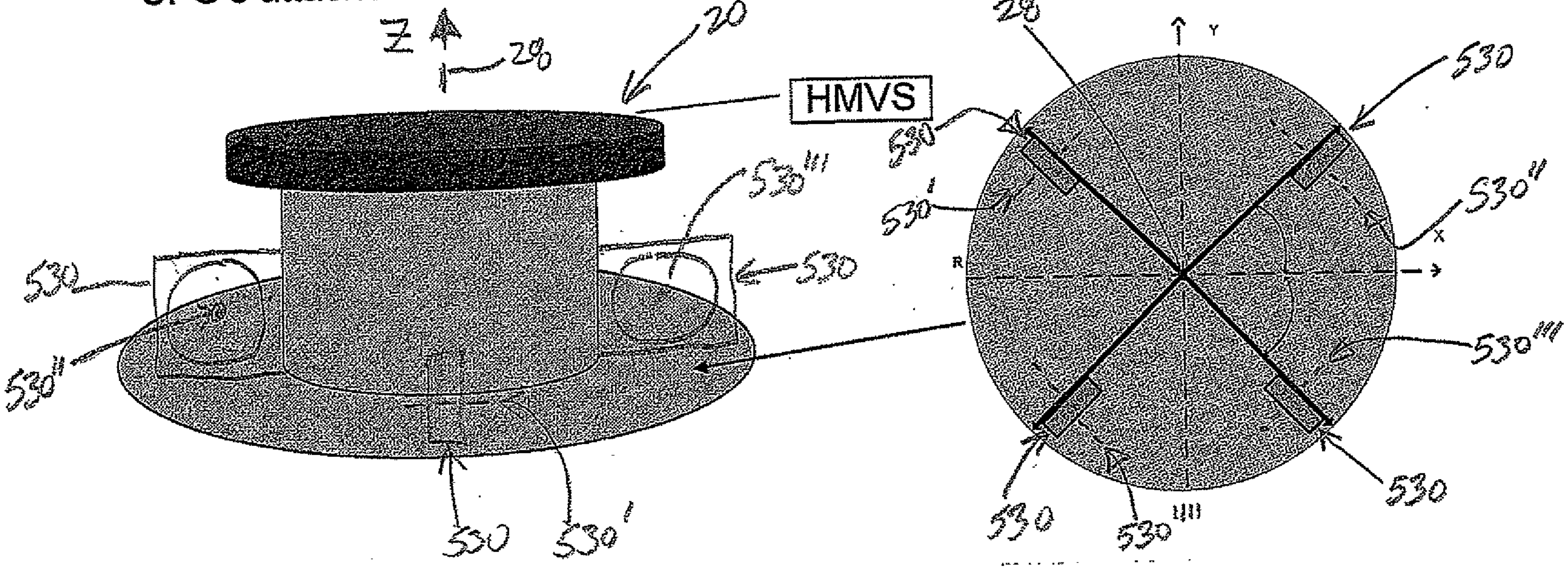


FIG. 86

HMVS & 6 Back to Back Circular Force Generators Producing Only Vertical Force

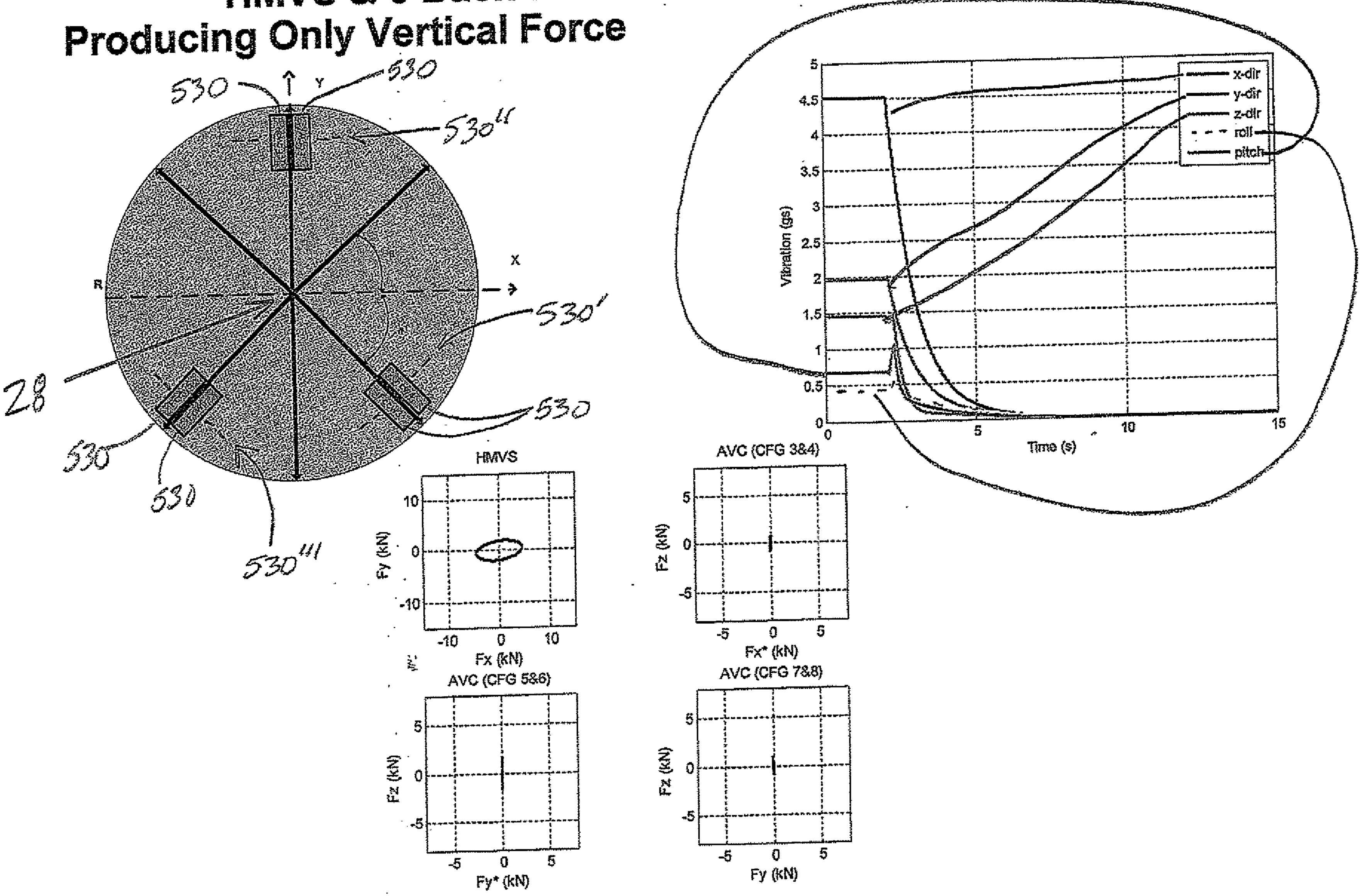


FIG. 8H

HMVS & 4 Back to Back Circular Force Generators Producing Only Vertical Force

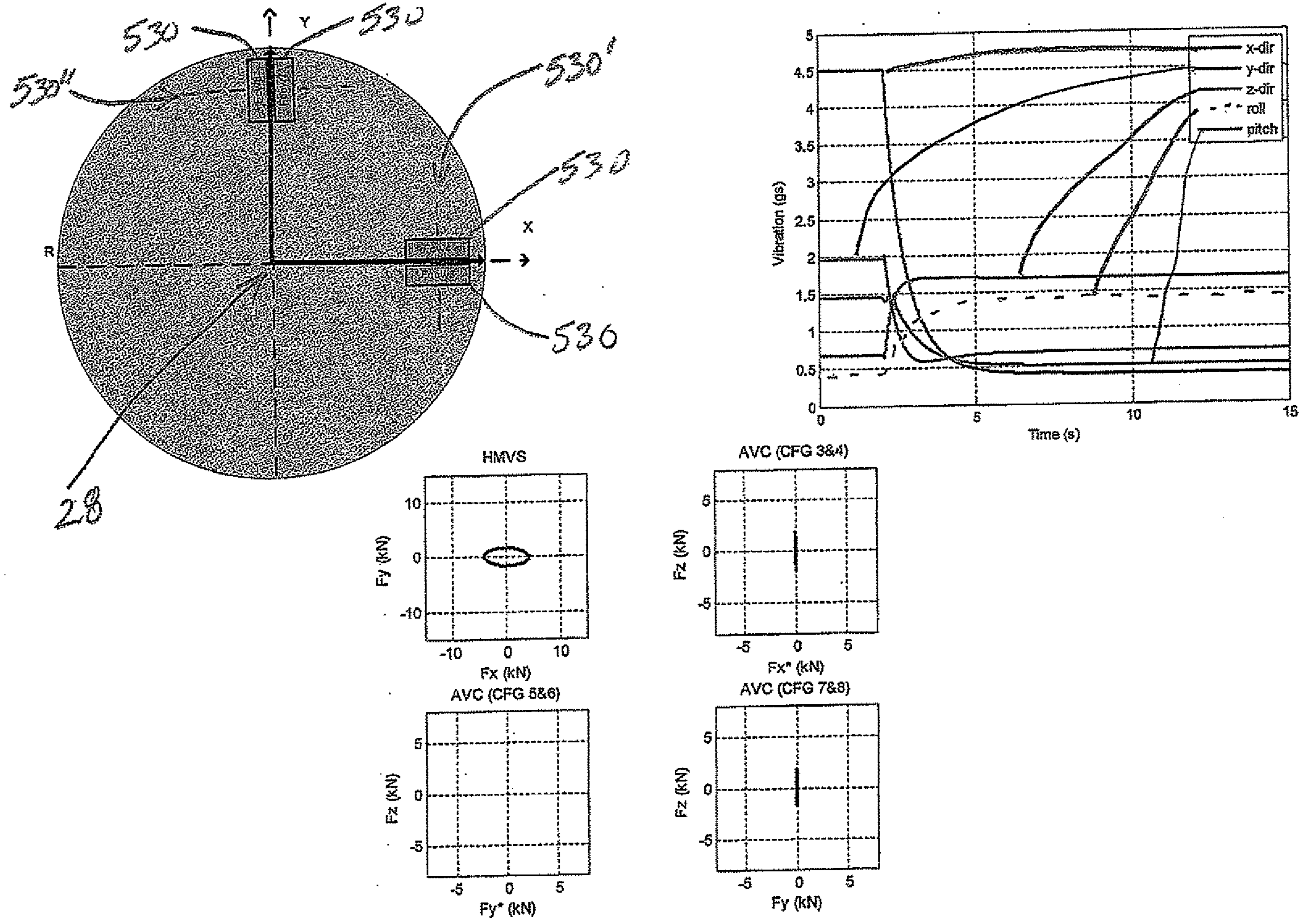


FIG. 8I

HMVS & 4 Independent Circular Force Generators

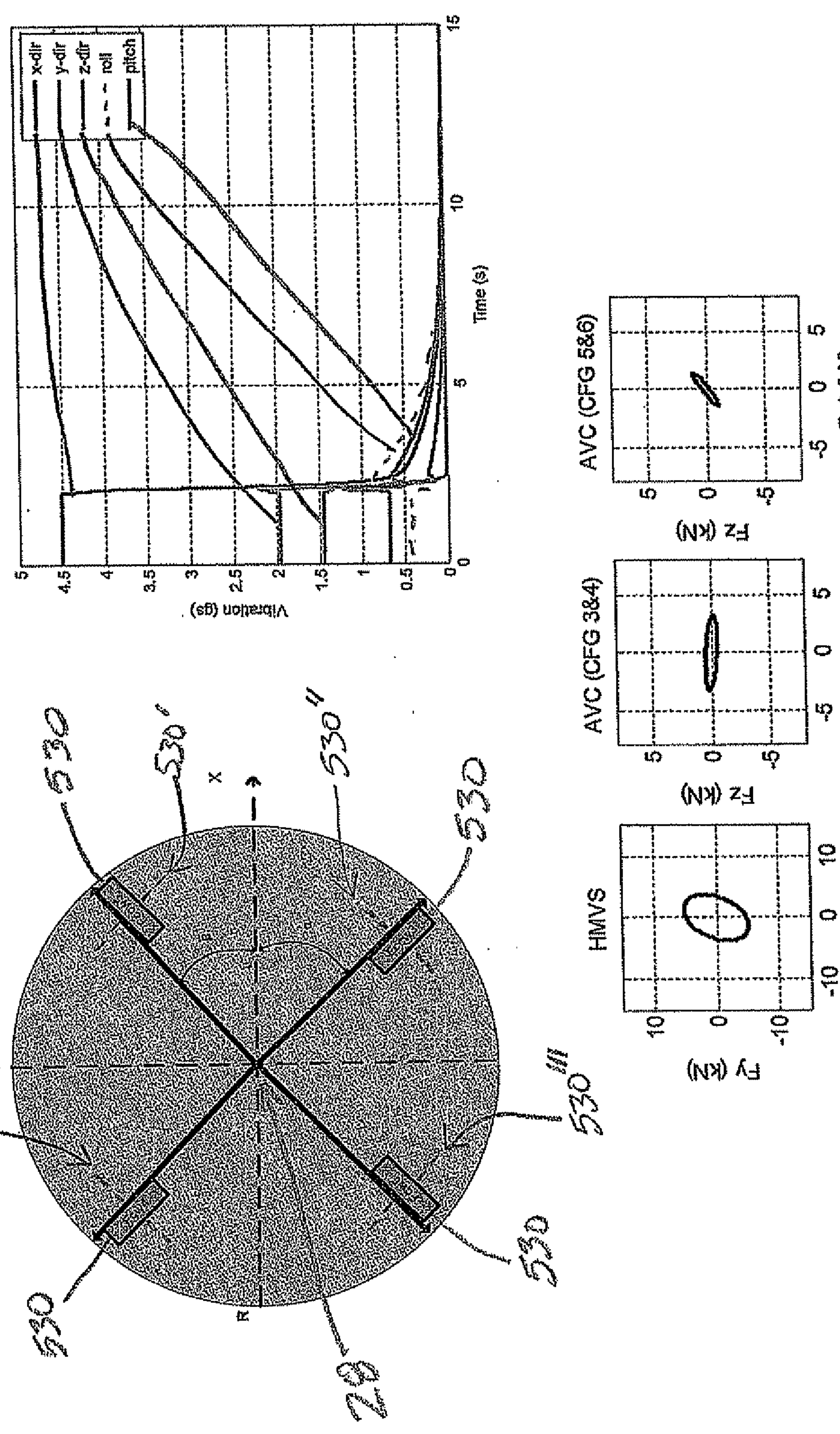


FIG. 8J

HMVS & 3 Independent Circular Force Generators

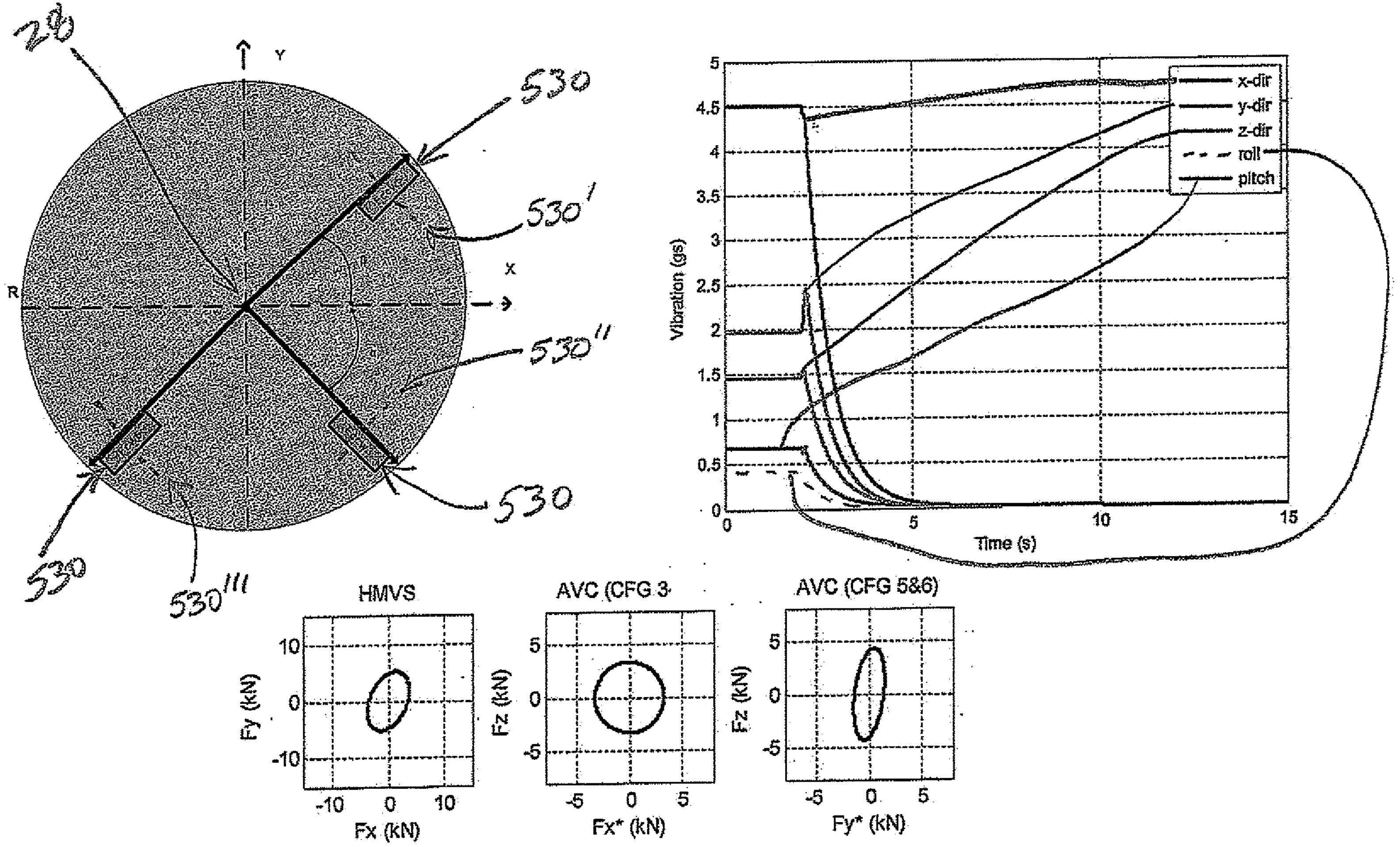


FIG. 8K

HMVS & 2 Independent Circular Force Generators

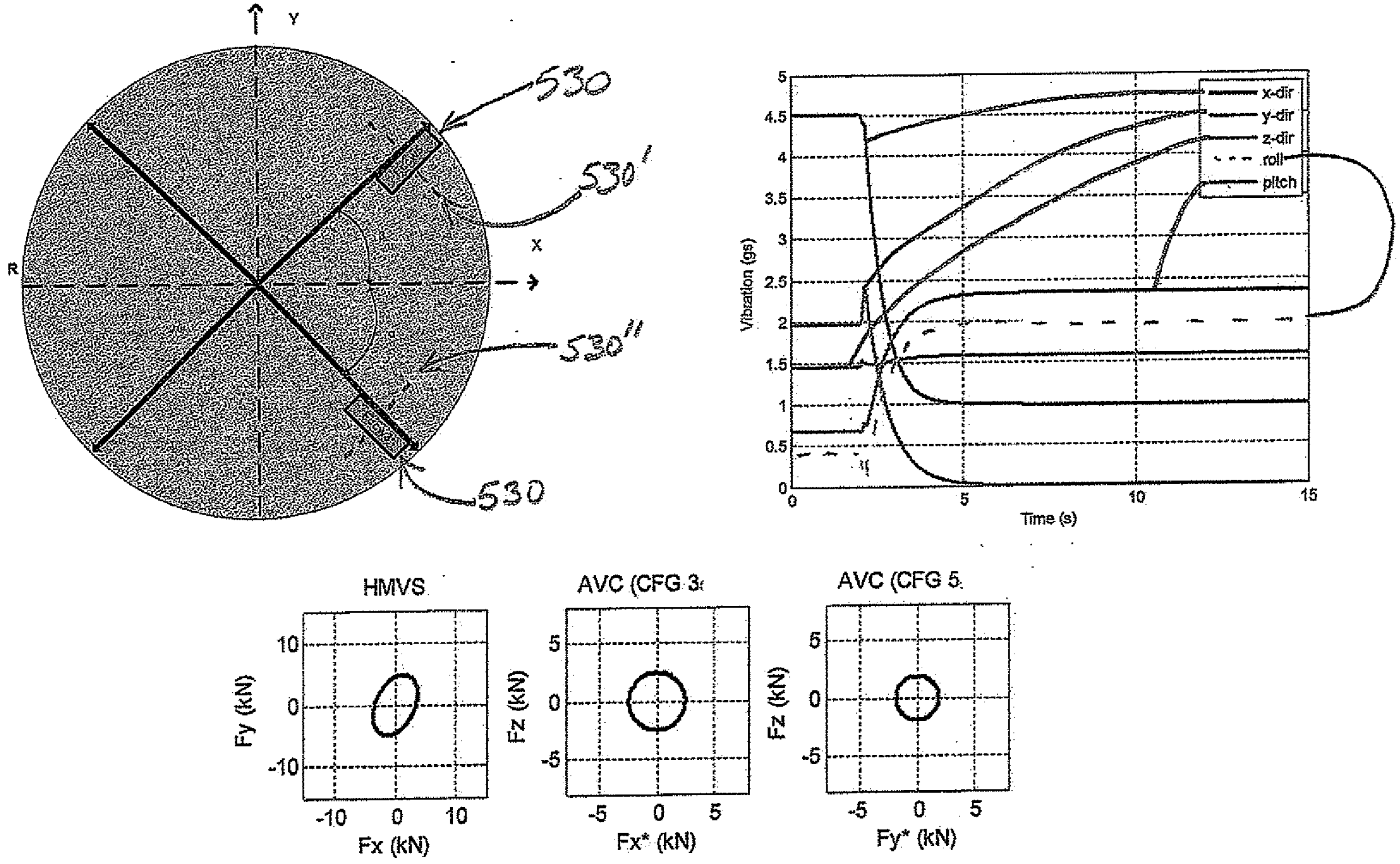
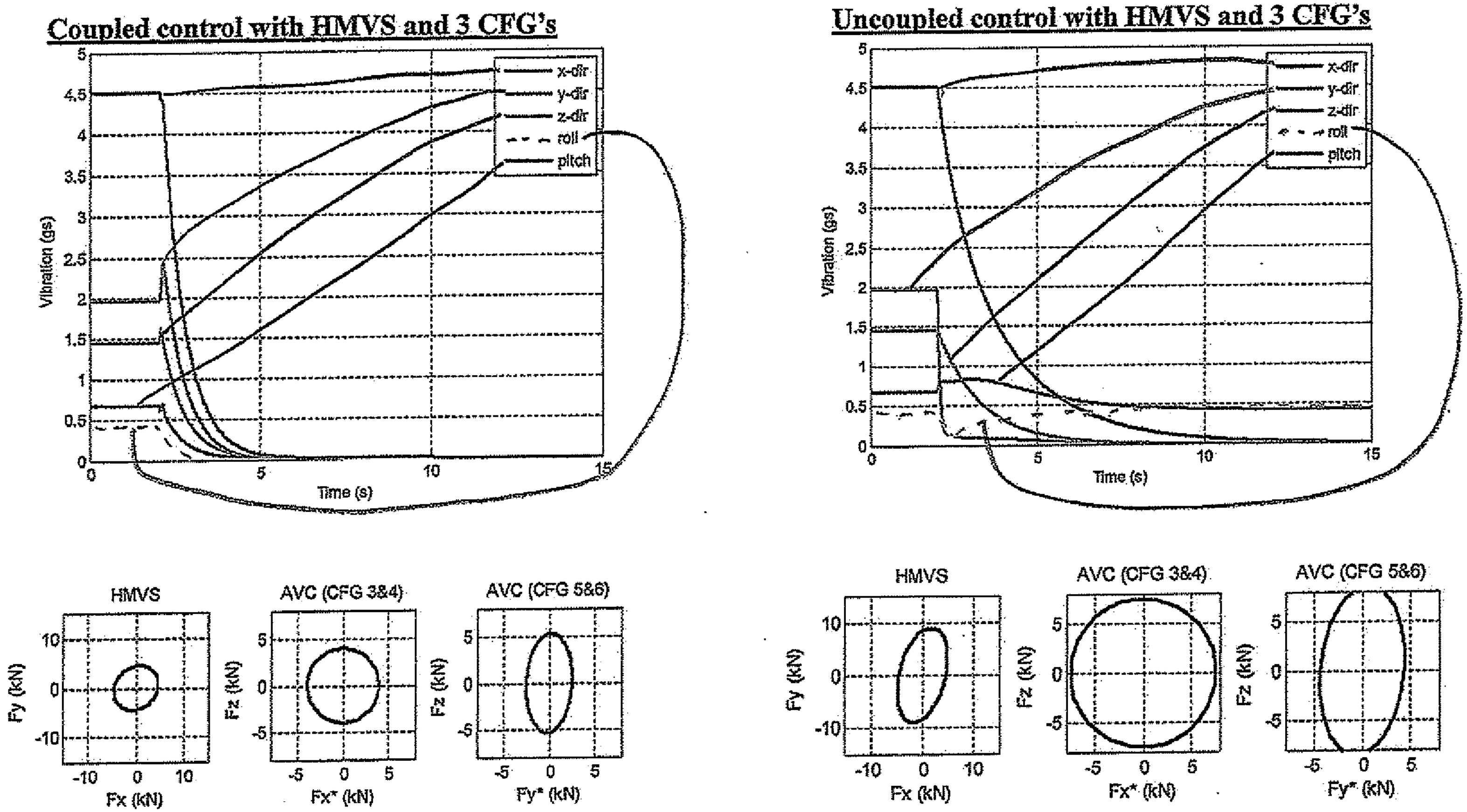


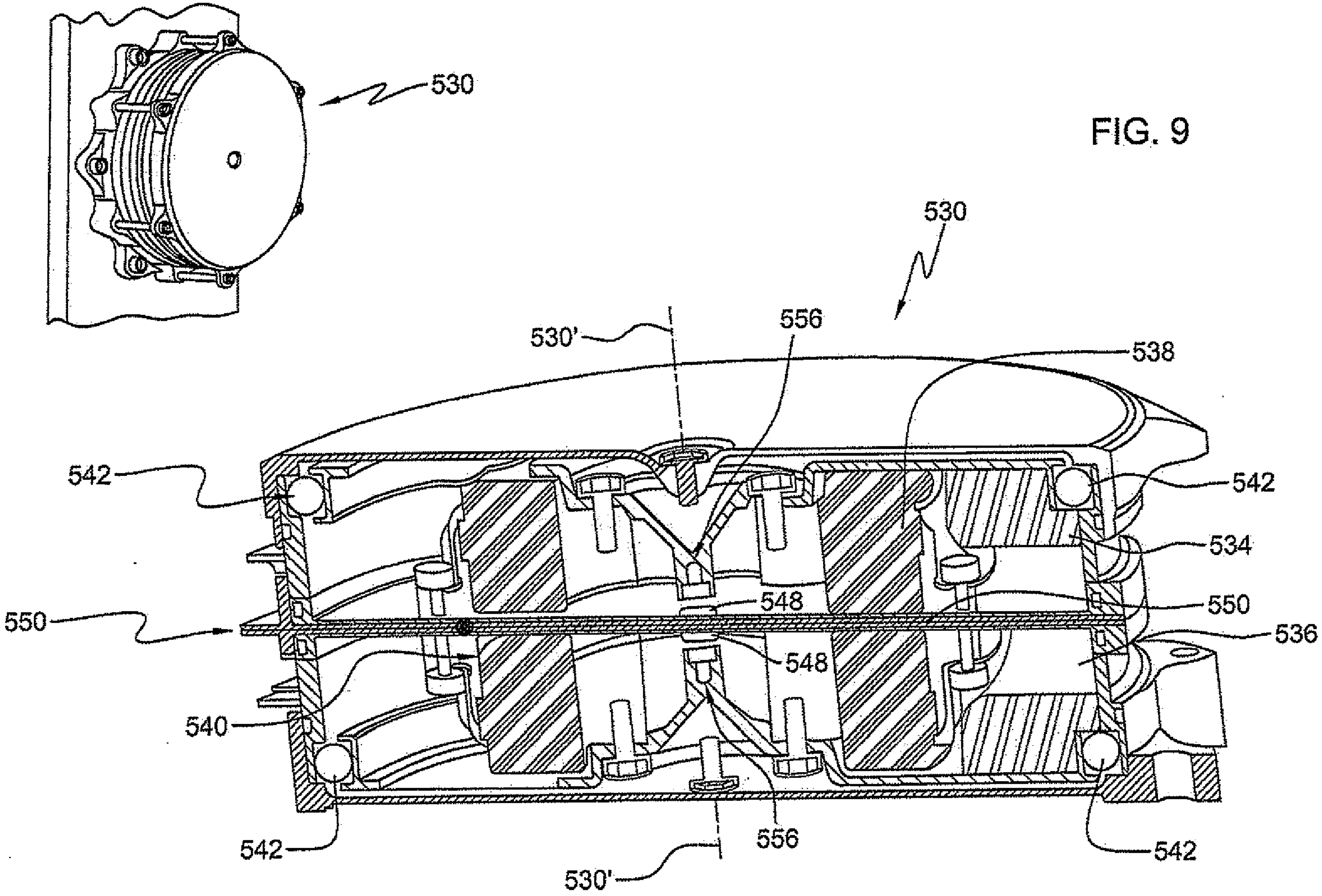
FIG. 8L

An uncoupled vibration control algorithm for the HMVS and AVC can result in degraded performance and actuators fighting each other


Coupled control with HMVS and 3 CFG's

Uncoupled control with HMVS and 3 CFG's

FIG. 9


530
530
530'
556
538
542
542
534
550
550
548
548
536
540
542
556
542
530'

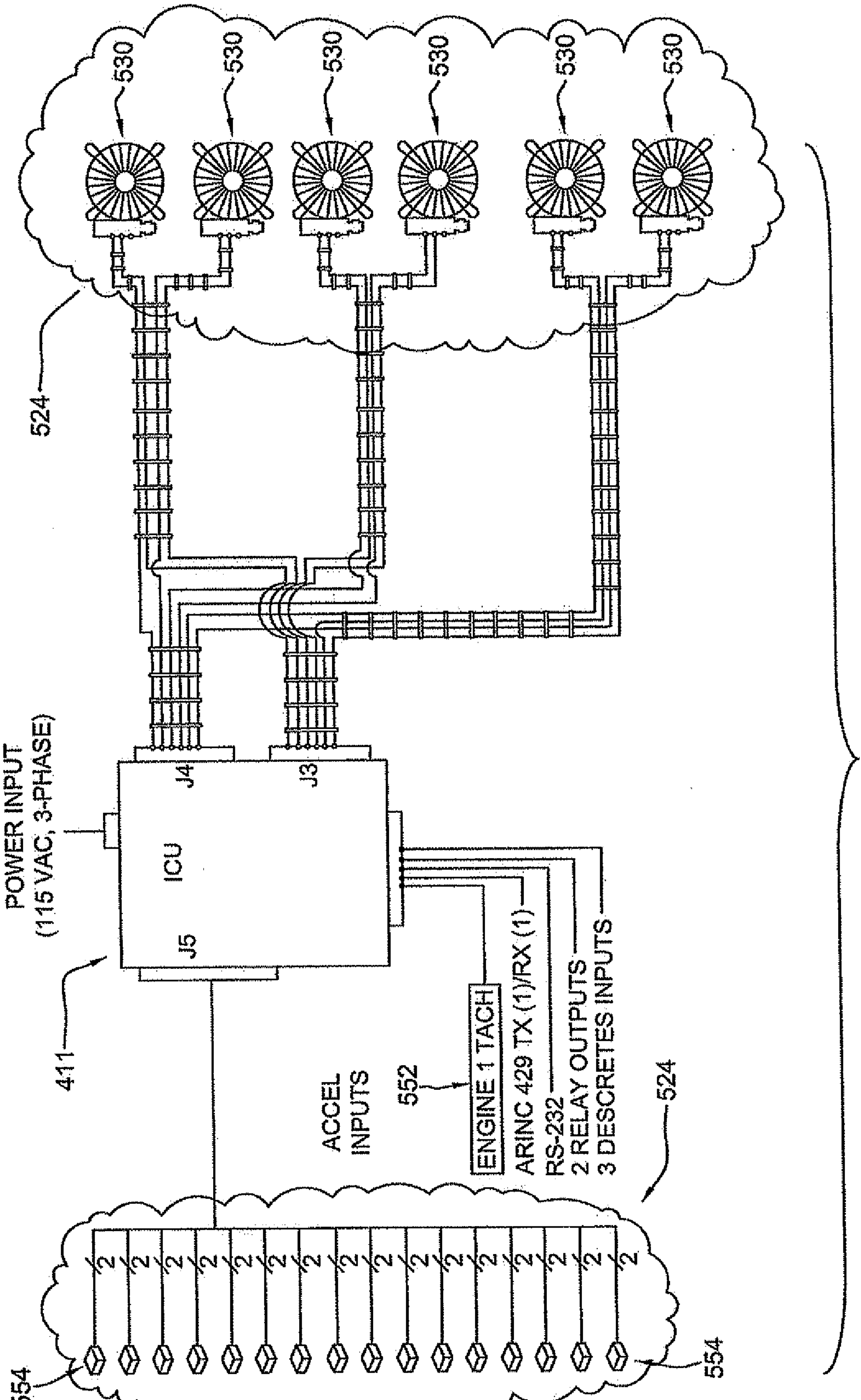

POWER INPUT
(115 VAC, 3-PHASE)
ICU
J4
J3
J5
411
530
530
530
530
530
530
524
524
409
ACCEL
INPUTS
552
ENGINE 1 TACH
ARINC 429 TX (1)/RX (1)
RS-232
2 RELAY OUTPUTS
3 DESCRETES INPUTS
2
554
554

FIG. 10

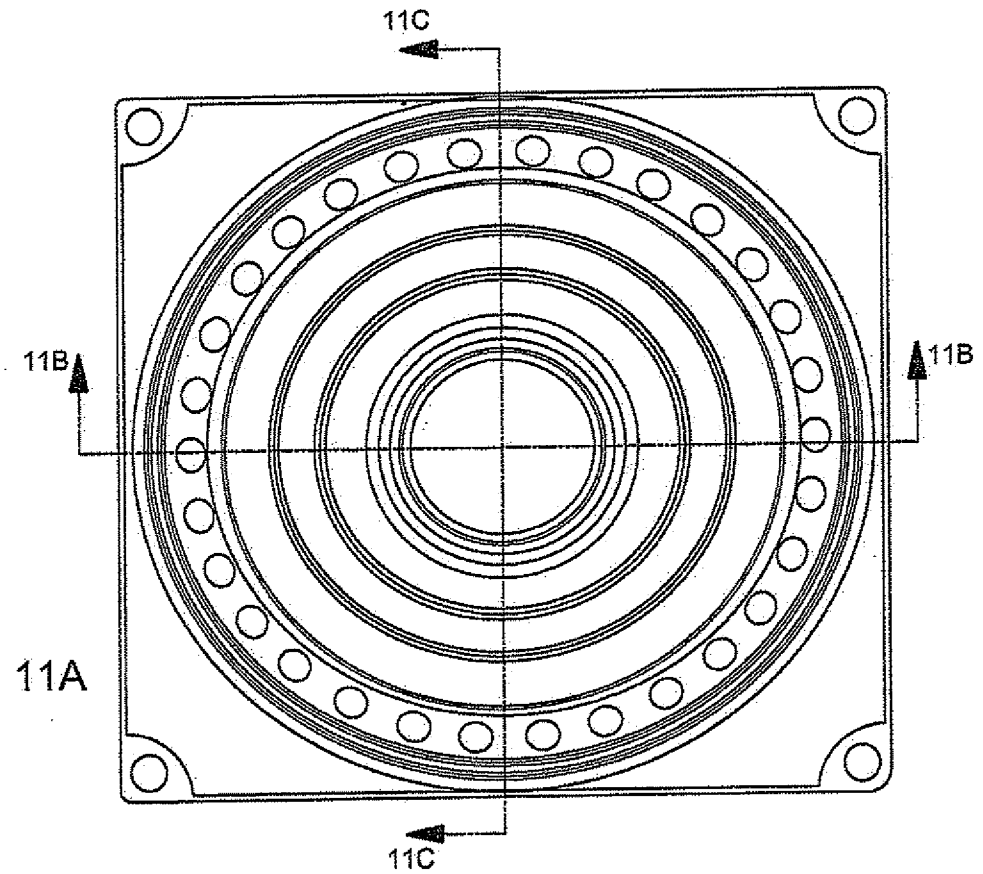


FIG. 11A

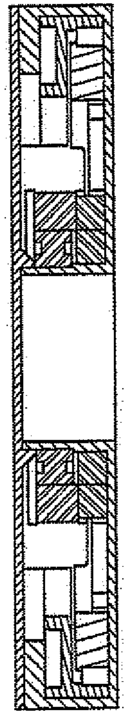


FIG. 11C

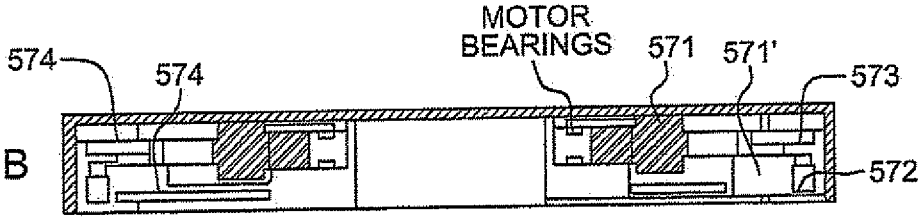


FIG. 11B

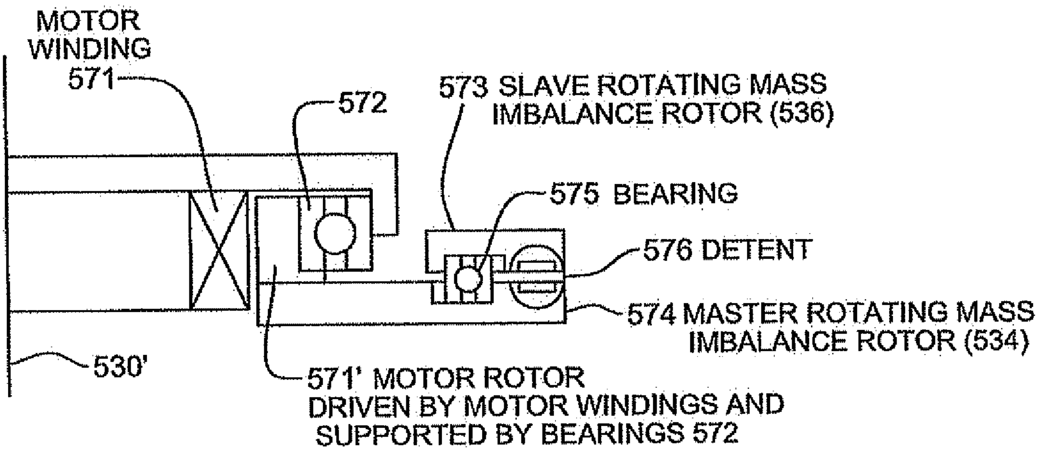

MOTOR
WINDING
571
572
573 SLAVE ROTATING MASS
IMBALANCE ROTOR (536)
575 BEARING
576 DETENT
574 MASTER ROTATING MASS
IMBALANCE ROTOR (534)
530'
571' MOTOR ROTOR
DRIVEN BY MOTOR WINDINGS AND
SUPPORTED BY BEARINGS 572

FIG. 11D

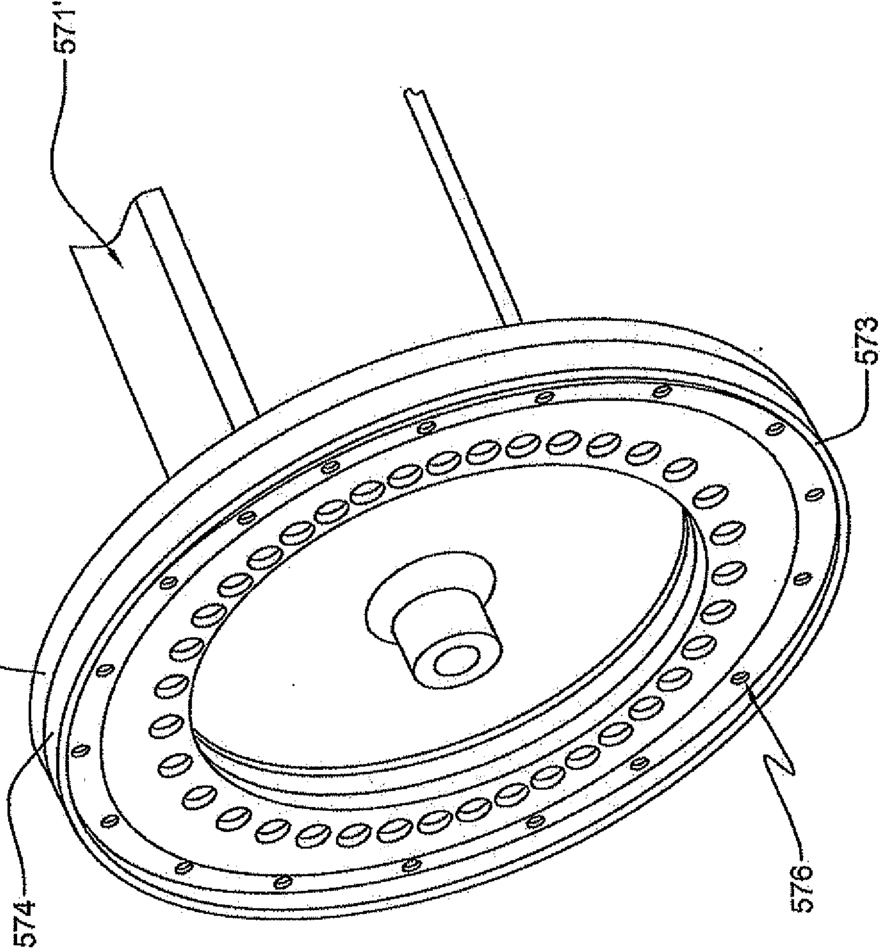


FIG. 11E

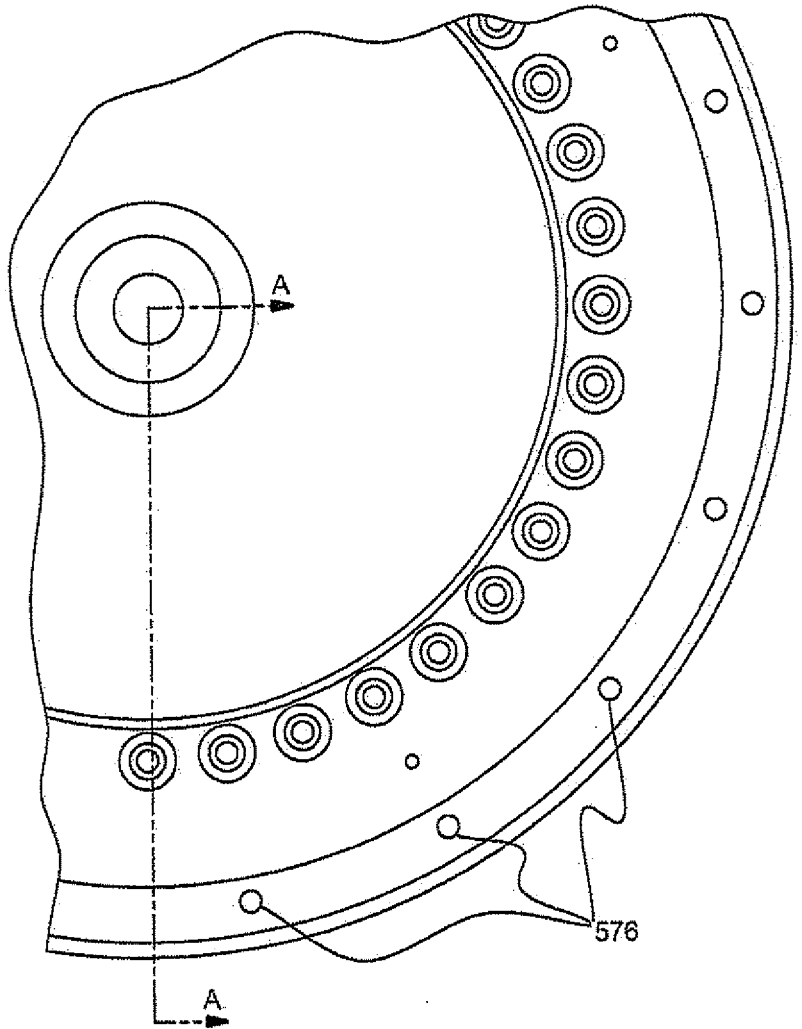


FIG. 11F

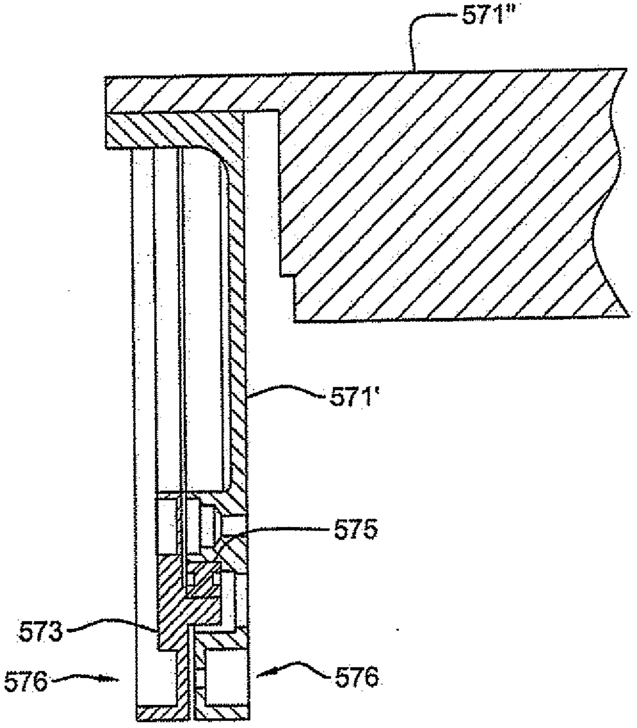


FIG. 11G

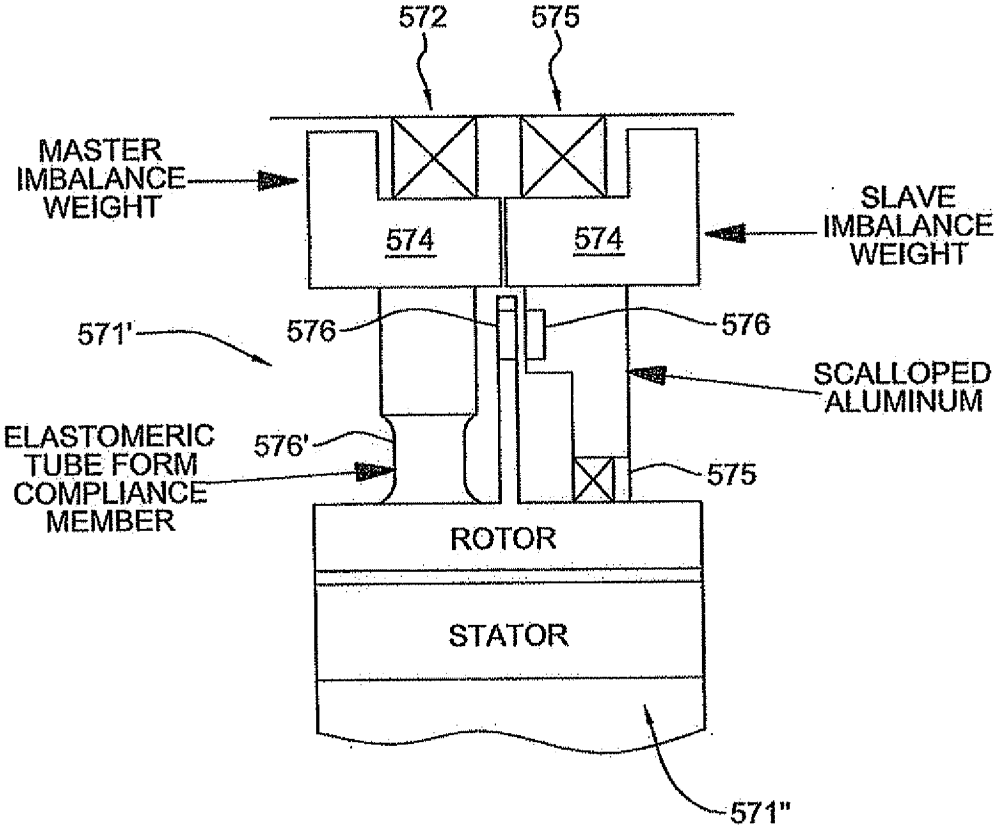

572
575
MASTER IMBALANCE WEIGHT
SLAVE IMBALANCE WEIGHT
574
574
571'
576
576
SCALLOPED ALUMINUM
ELASTOMERIC TUBE FORM COMPLIANCE MEMBER
576'
575
ROTOR
STATOR
571"

FIG. 12A

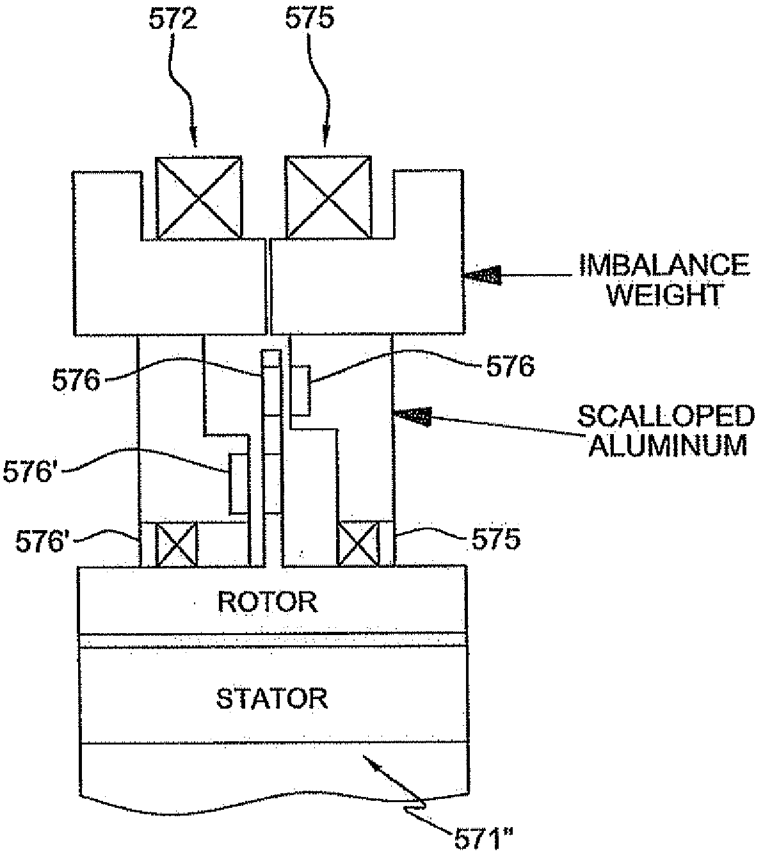

572
575
IMBALANCE WEIGHT
576
576
SCALLOPED ALUMINUM
576'
576'
575
ROTOR
STATOR
571"

FIG. 12B

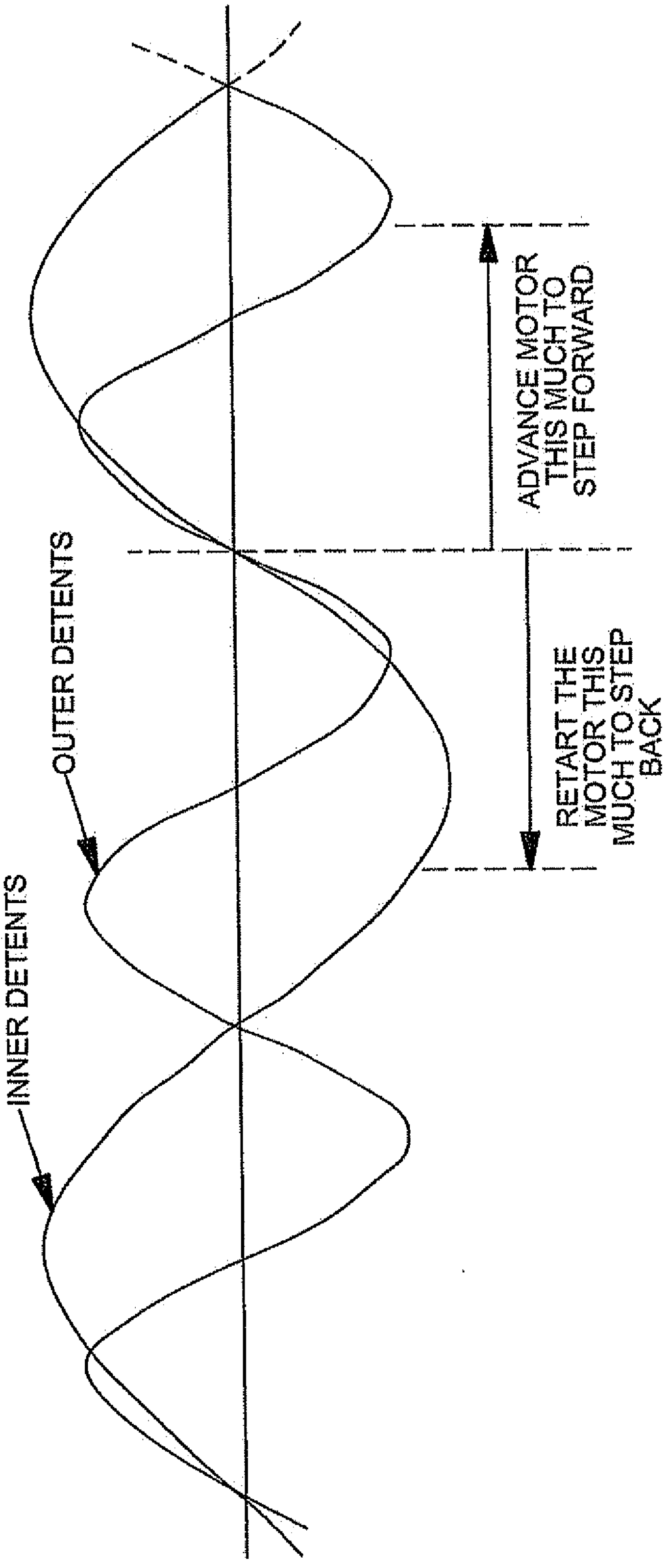

ADVANCE MOTOR THIS MUCH TO STEP FORWARD
RETART THE MOTOR THIS MUCH TO STEP BACK
OUTER DETENTS
INNER DETENTS

FIG. 12C

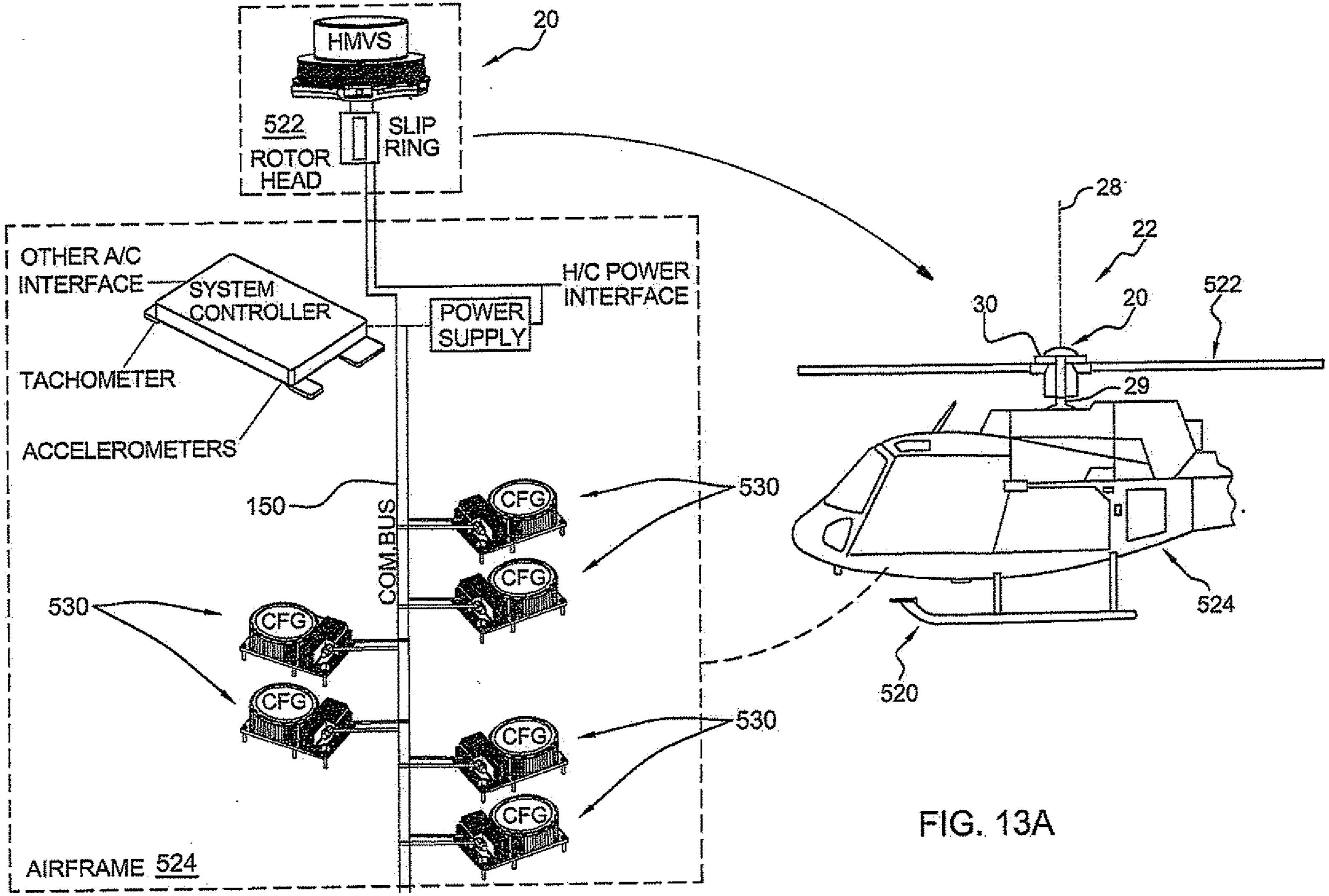

HMVS
20
522
ROTOR HEAD
SLIP RING
OTHER A/C INTERFACE
SYSTEM CONTROLLER
TACHOMETER
ACCELEROMETERS
POWER SUPPLY
H/C POWER INTERFACE
150
COM.BUS
CFG
530
530
530
AIRFRAME 524
28
22
30
20
522
29
524
520

FIG. 13A

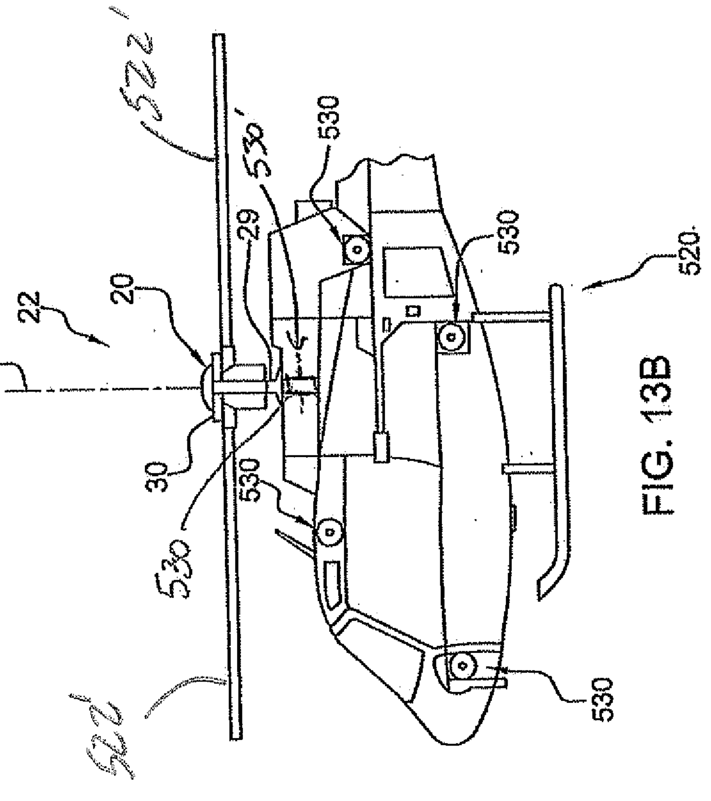


FIG. 13B

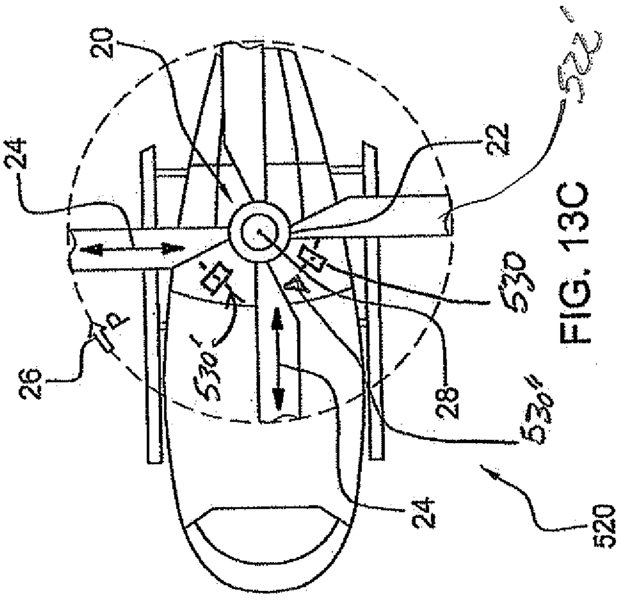


FIG. 13C

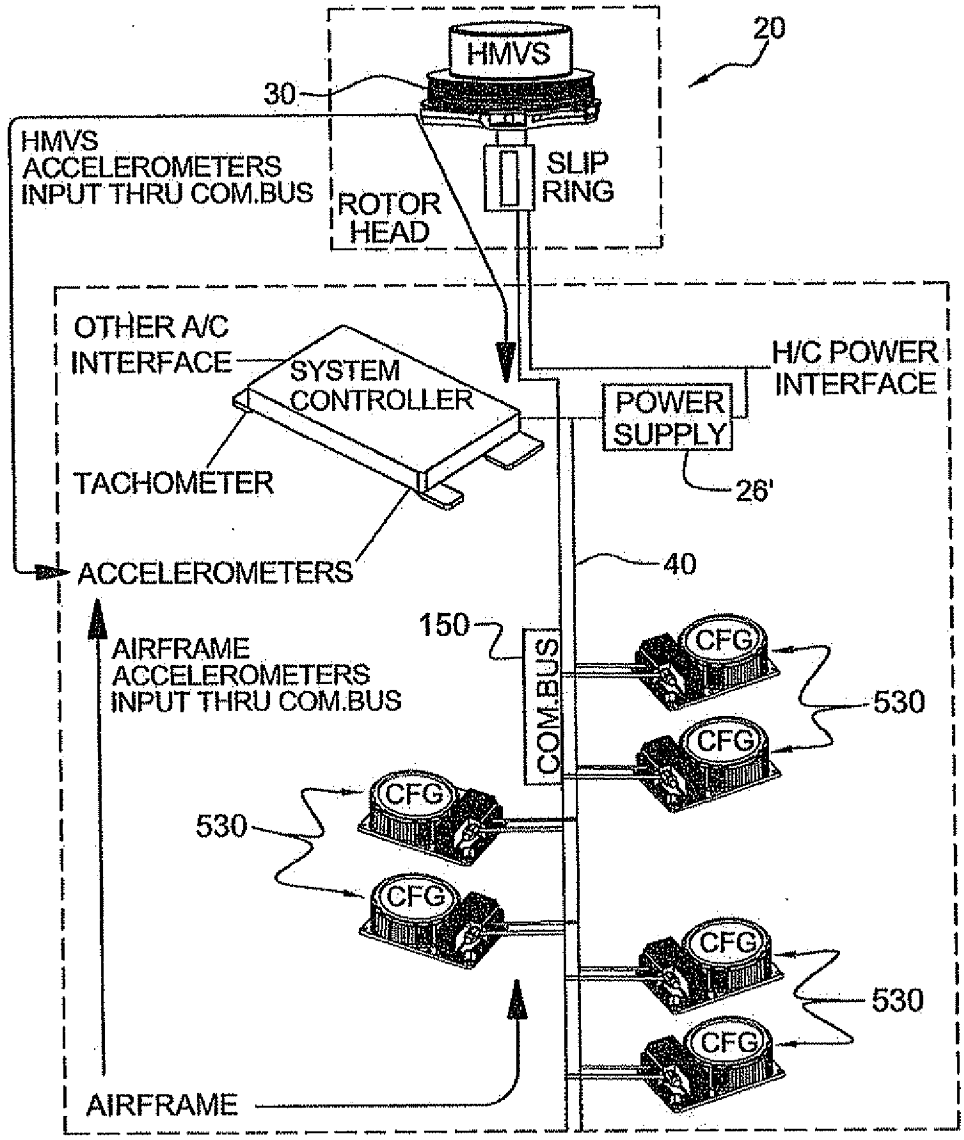

HMVS
20
30
HMVS ACCELEROMETERS INPUT THRU COM.BUS
ROTOR HEAD
SLIP RING
OTHER A/C INTERFACE
SYSTEM CONTROLLER
H/C POWER INTERFACE
POWER SUPPLY
26'
TACHOMETER
ACCELEROMETERS
40
150
COM.BUS
AIRFRAME ACCELEROMETERS INPUT THRU COM.BUS
CFG
530
AIRFRAME

FIG. 13D

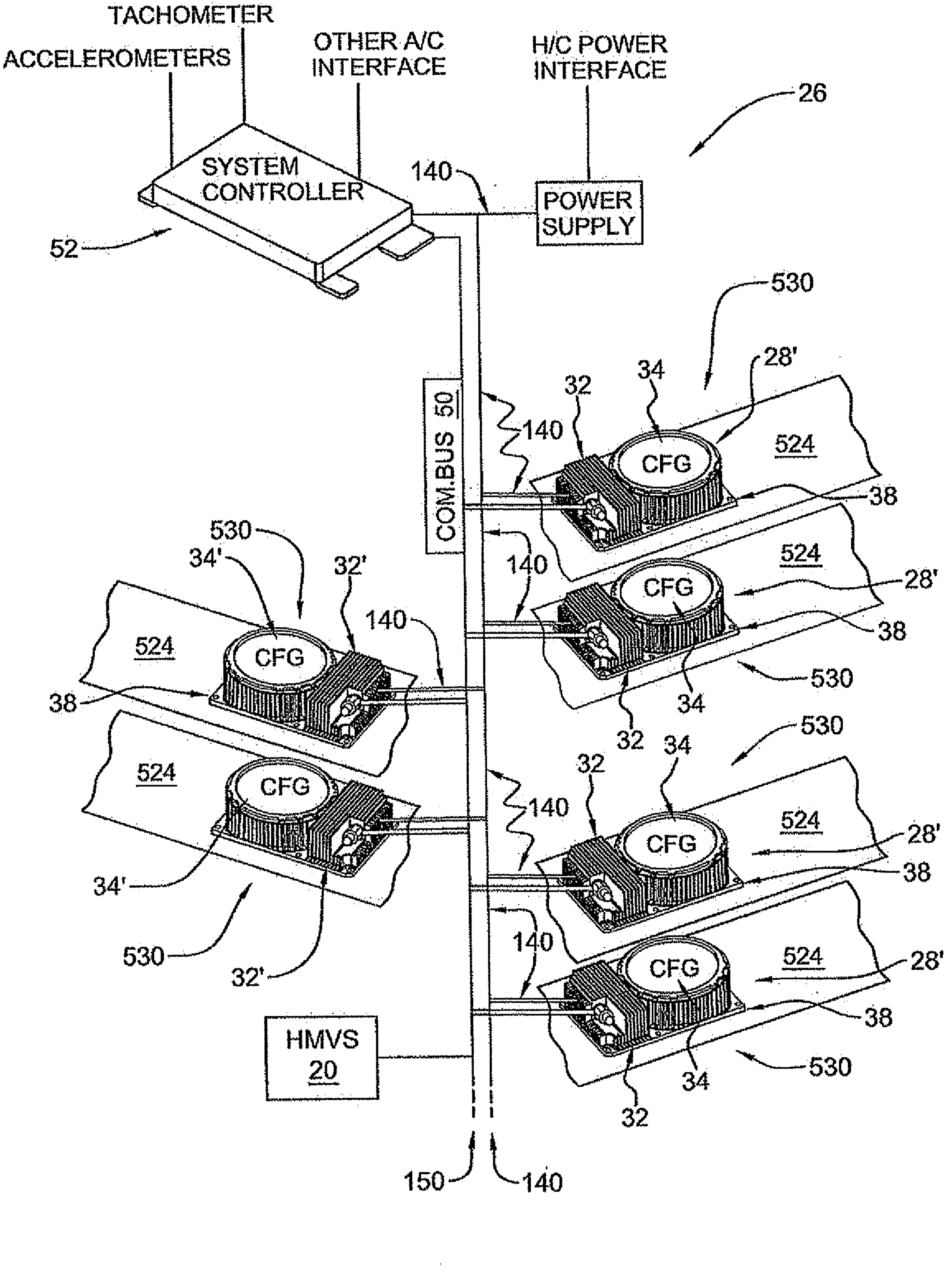

TACHOMETER
ACCELEROMETERS
OTHER A/C INTERFACE
H/C POWER INTERFACE
26
SYSTEM CONTROLLER
140
POWER SUPPLY
52
530
28'
34
32
COM.BUS 50
140
524
CFG
38
530
34'
32'
140
140
524
CFG
28'
38
524
CFG
38
530
34
32
530
524
CFG
32
34
140
140
524
CFG
28'
38
34'
530
32'
140
524
CFG
28'
38
530
34
32
HMVS 20
150
140

FIG. 14

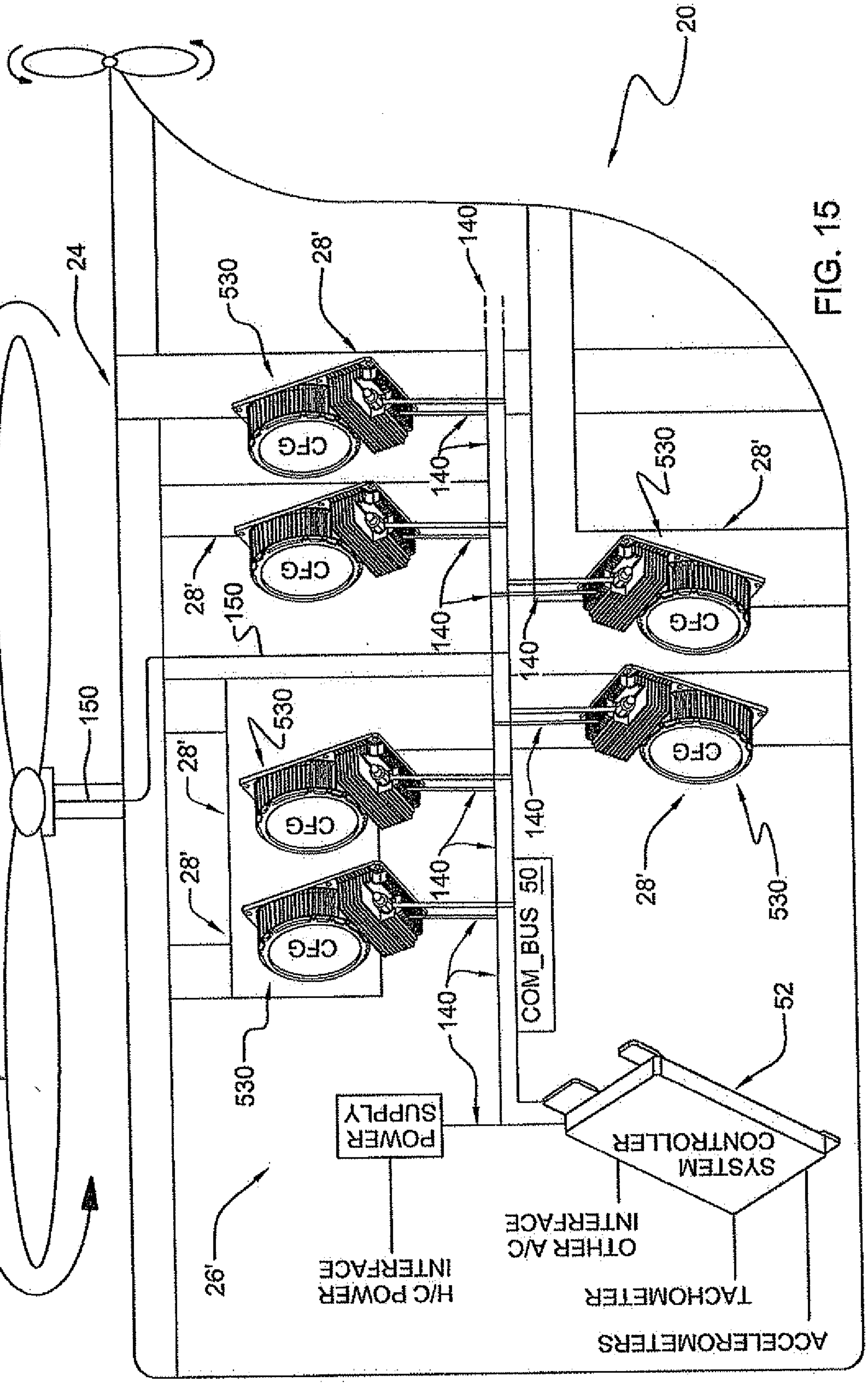

20
24
522'
522'
20
150
150
28'
530
140
CFG
COM_BUS 50
52
SYSTEM CONTROLLER
POWER SUPPLY
H/C POWER INTERFACE
OTHER A/C INTERFACE
TACHOMETER
ACCELEROMETERS
26'

FIG. 15

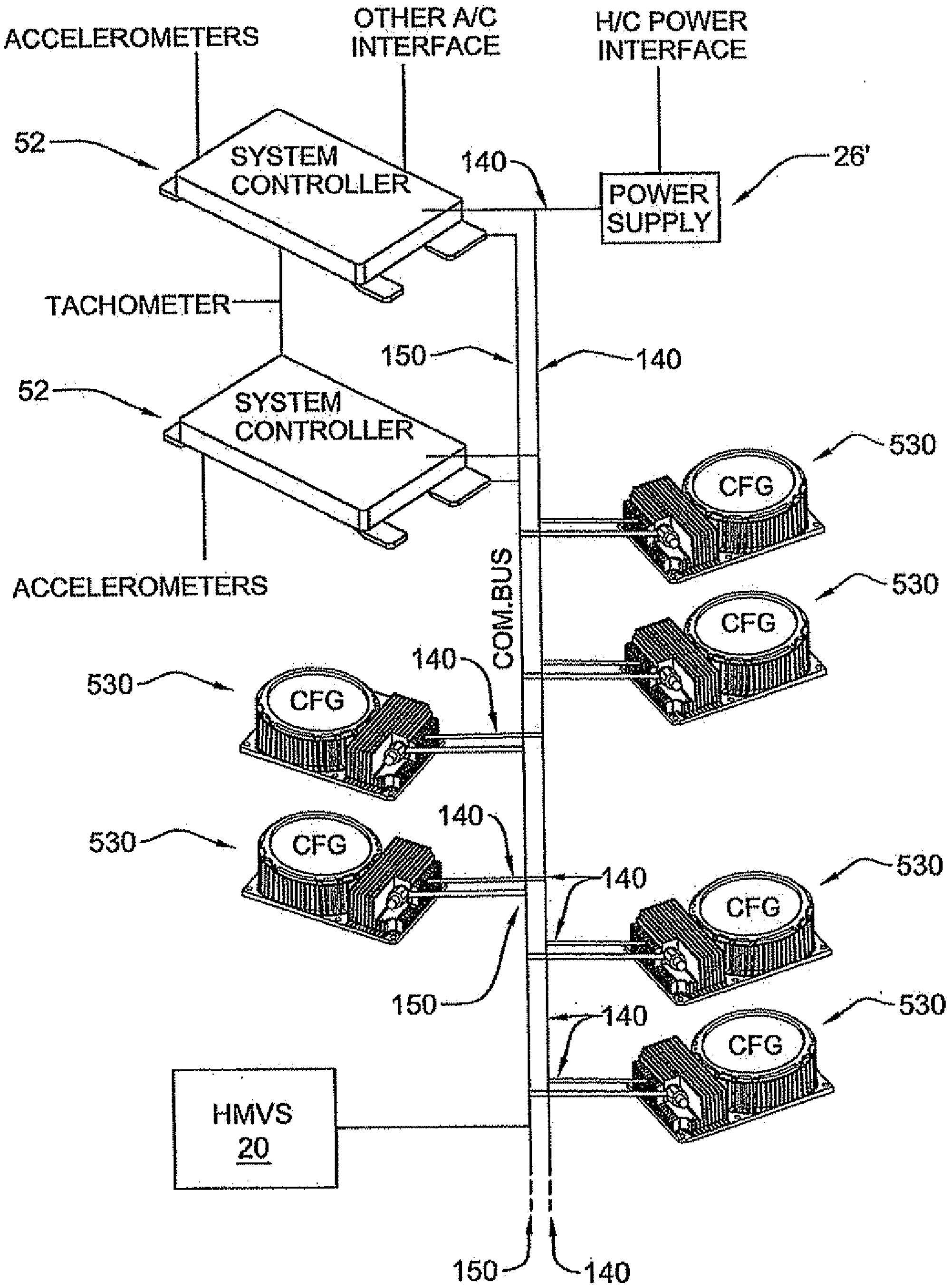
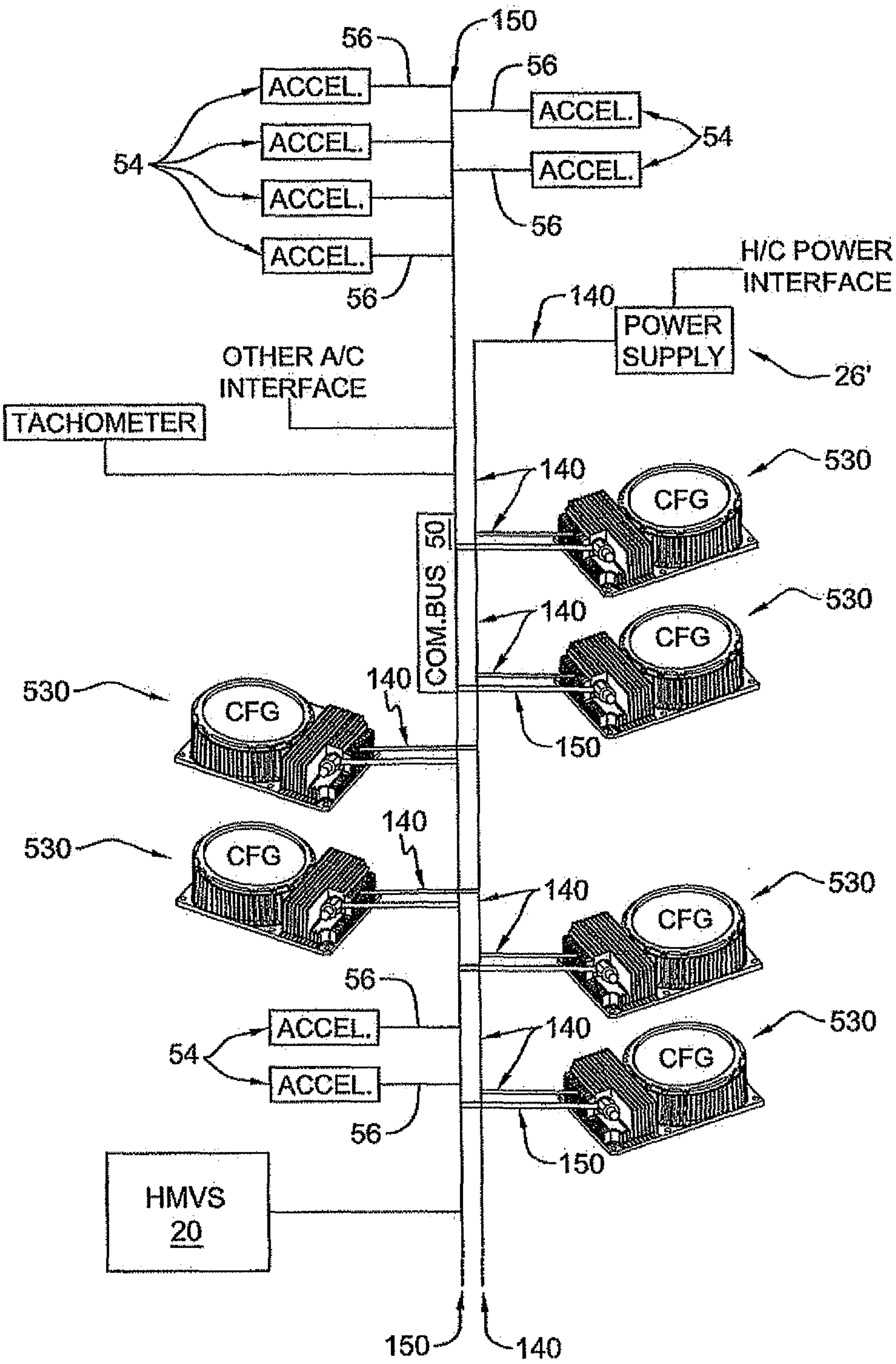
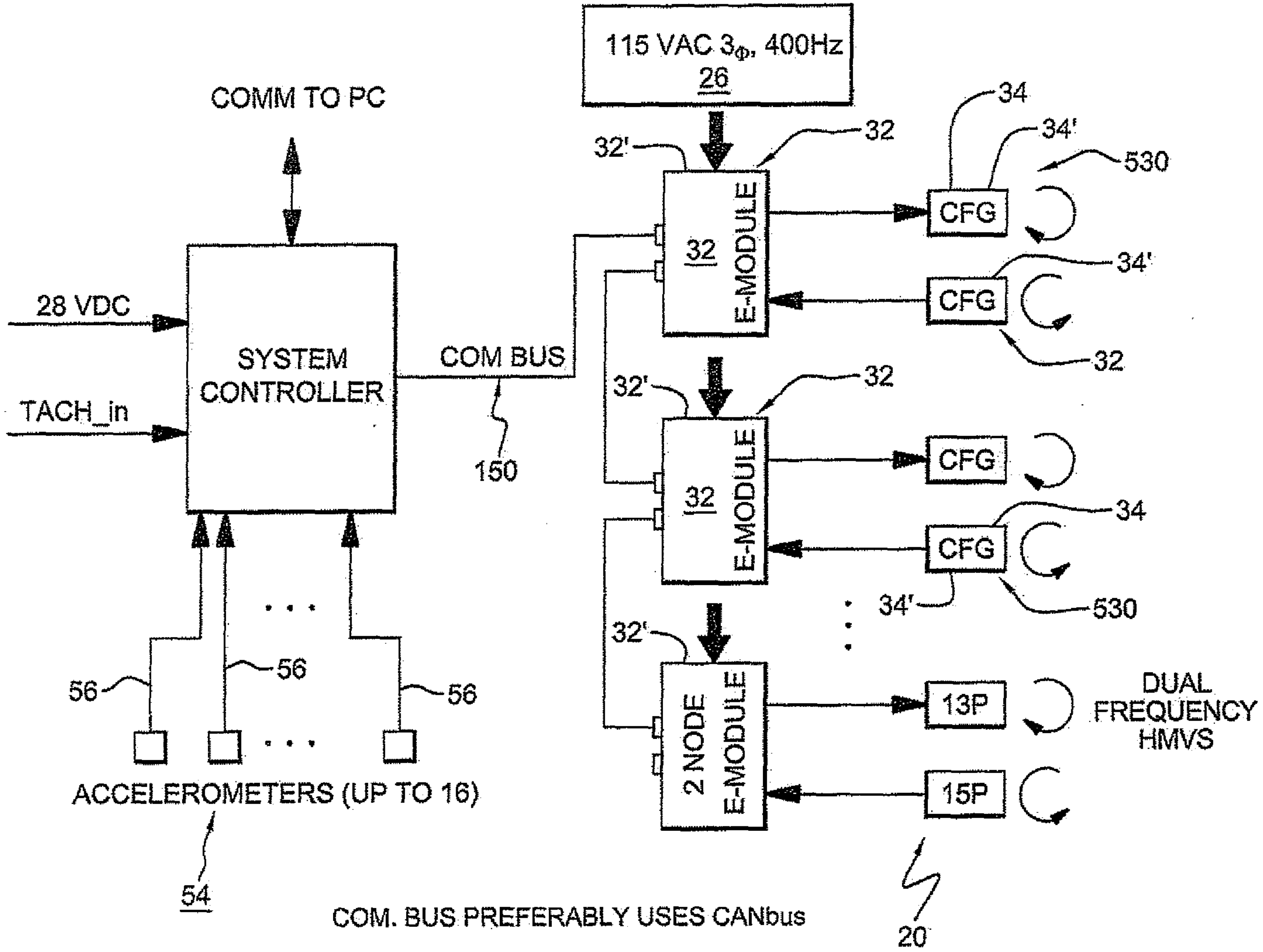

ACCELEROMETERS
OTHER A/C INTERFACE
H/C POWER INTERFACE
52
SYSTEM CONTROLLER
140
POWER SUPPLY
26'
TACHOMETER
150
140
52
SYSTEM CONTROLLER
530
CFG
ACCELEROMETERS
COM.BUS
530
CFG
530
CFG
140
530
CFG
140
140
530
CFG
150
140
530
CFG
HMVS
20
150
140

FIG. 16



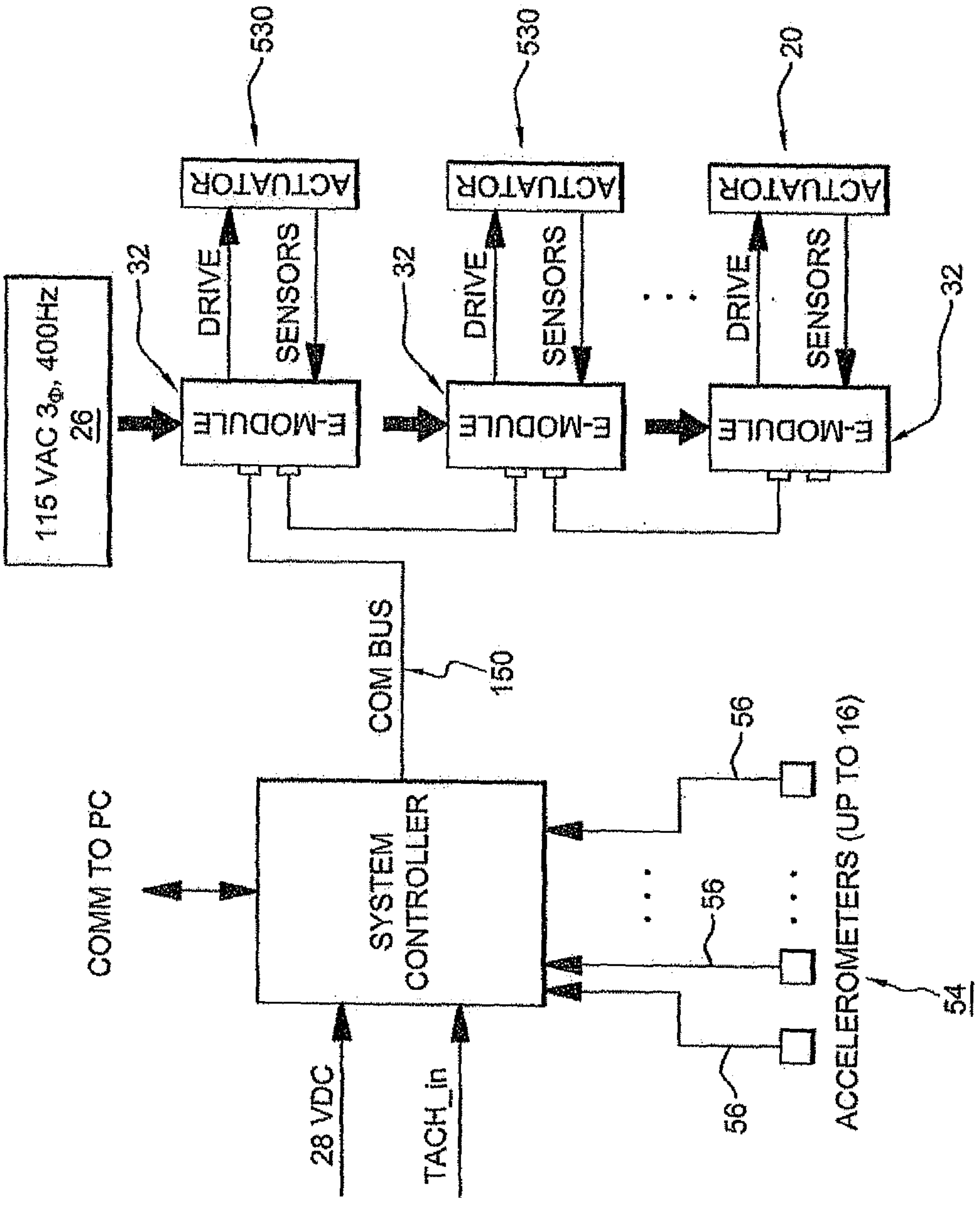
DISTRIBUTED MASTER SYSTEM CONTROL AUTHORITY

FIG. 17



COM. BUS PREFERABLY USES CANbus

FIG. 18



COM. BUS PREFERABLY USES CANbus

FIG. 19A

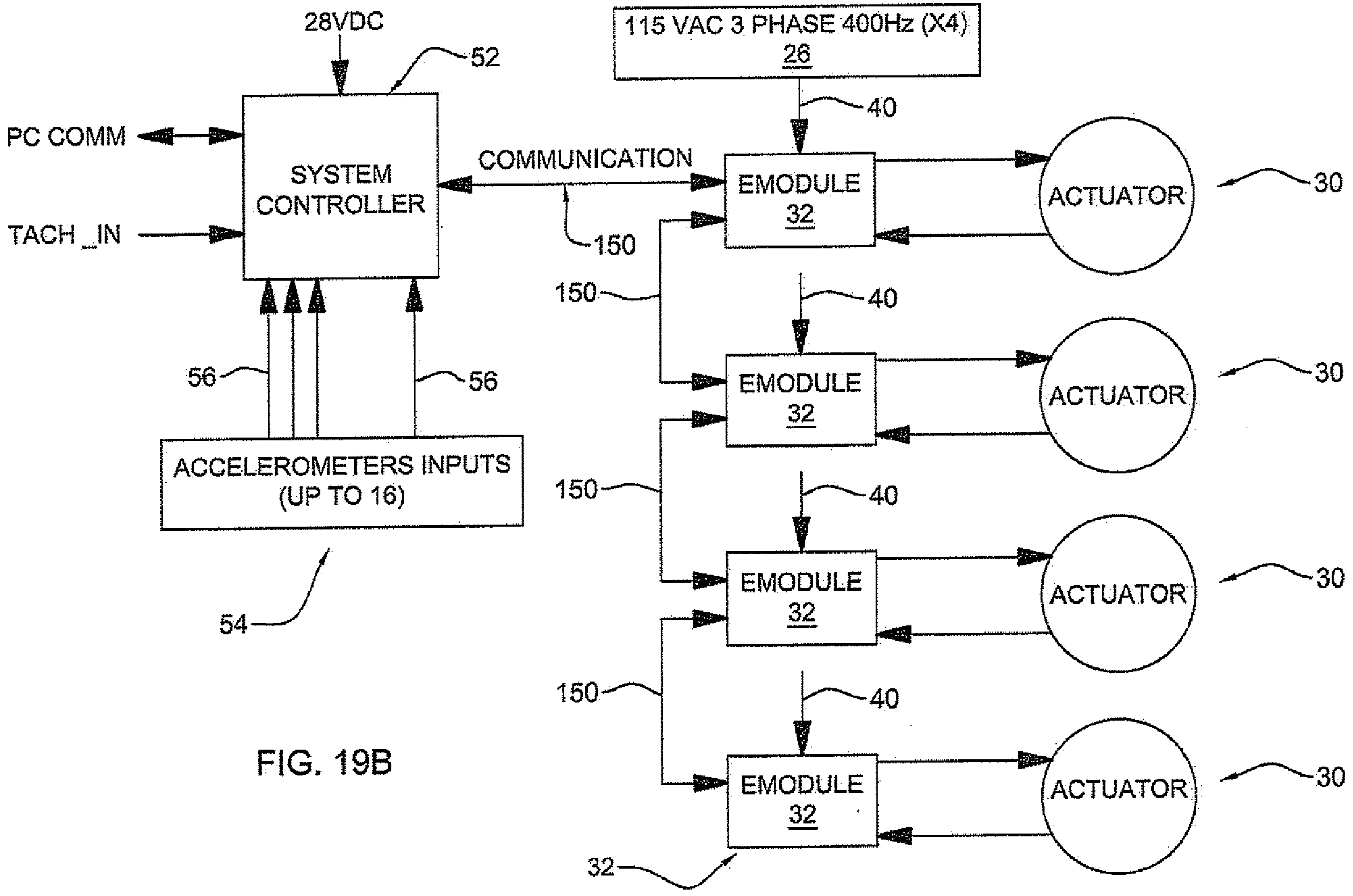

28VDC
52
PC COMM
SYSTEM CONTROLLER
TACH _IN
COMMUNICATION
150
56
56
ACCELEROMETERS INPUTS (UP TO 16)
54
115 VAC 3 PHASE 400Hz (X4)
26
40
EMODULE
32
ACTUATOR
30
150
40
EMODULE
32
ACTUATOR
30
150
40
EMODULE
32
ACTUATOR
30
150
40
EMODULE
32
ACTUATOR
30
32

FIG. 19B

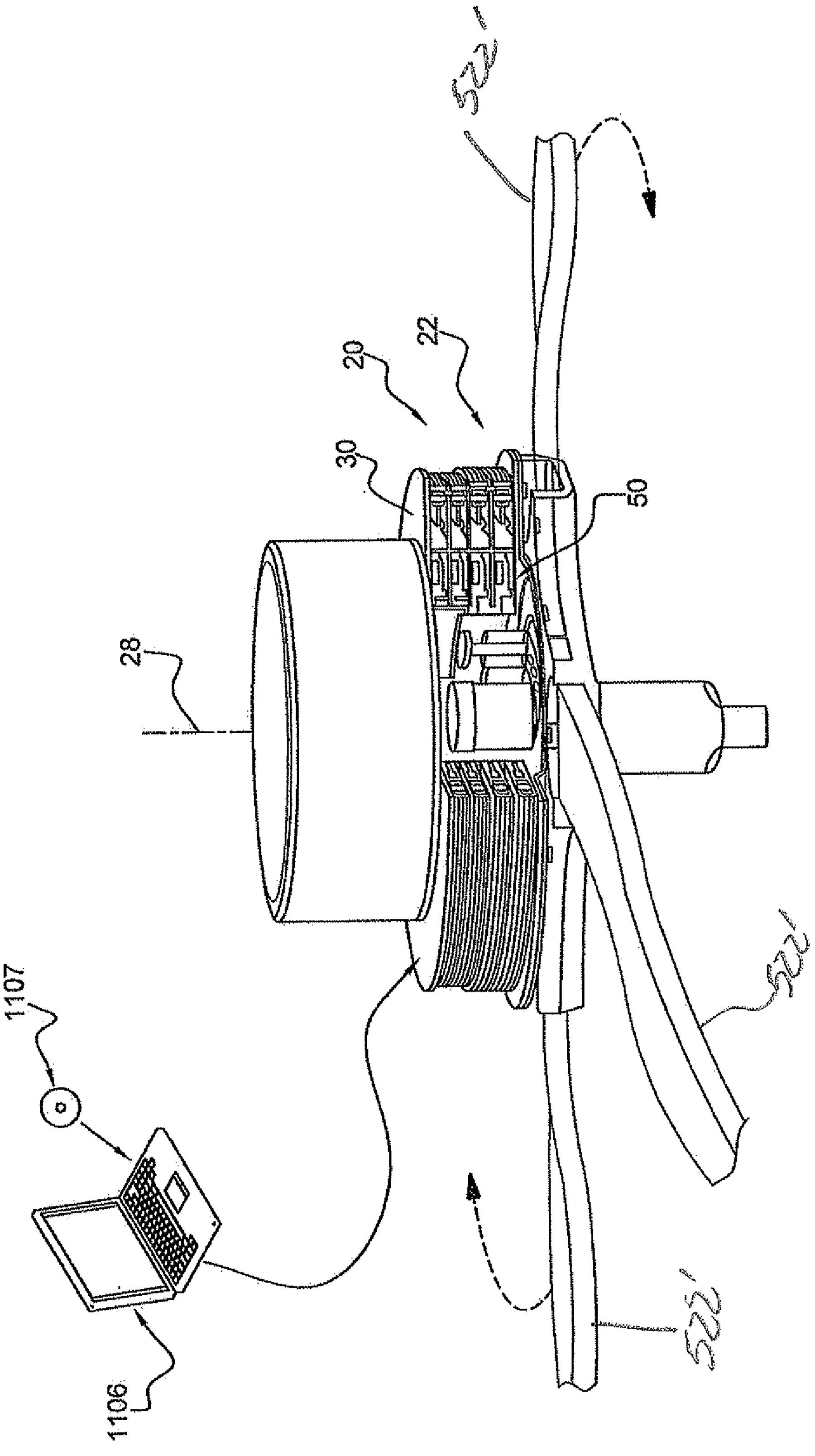


FIG. 20A

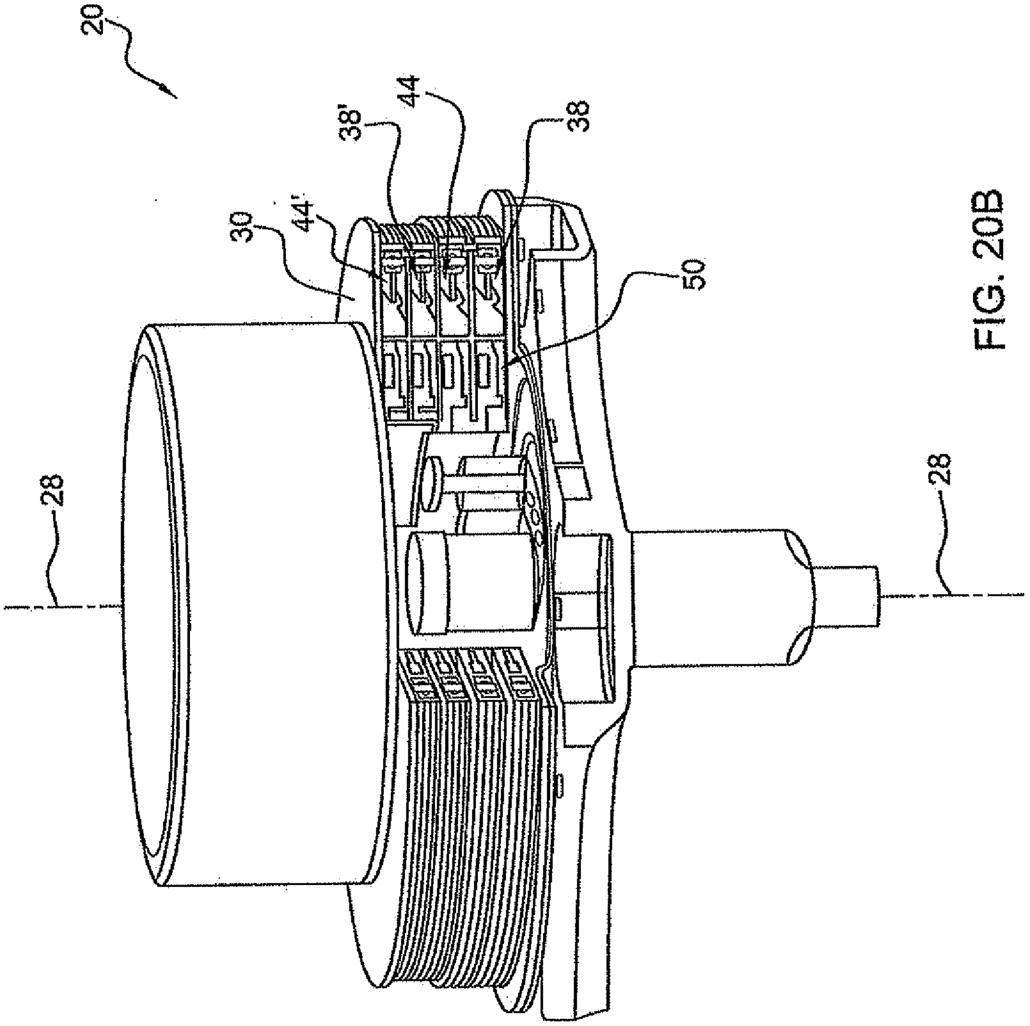


FIG. 20B

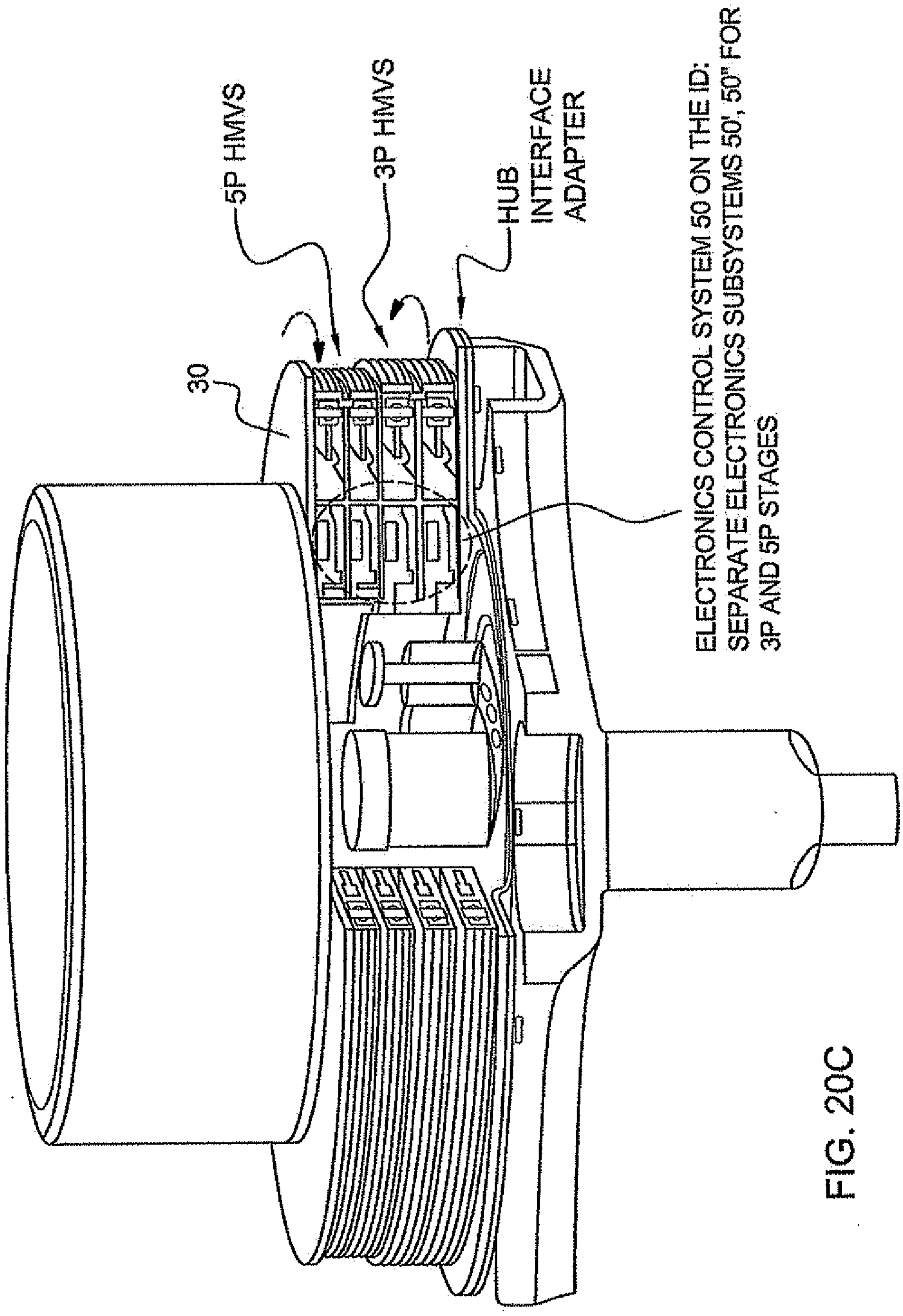

30
5P HMVS
3P HMVS
HUB INTERFACE ADAPTER
ELECTRONICS CONTROL SYSTEM 50 ON THE ID: SEPARATE ELECTRONICS SUBSYSTEMS 50', 50" FOR 3P AND 5P STAGES

FIG. 20C

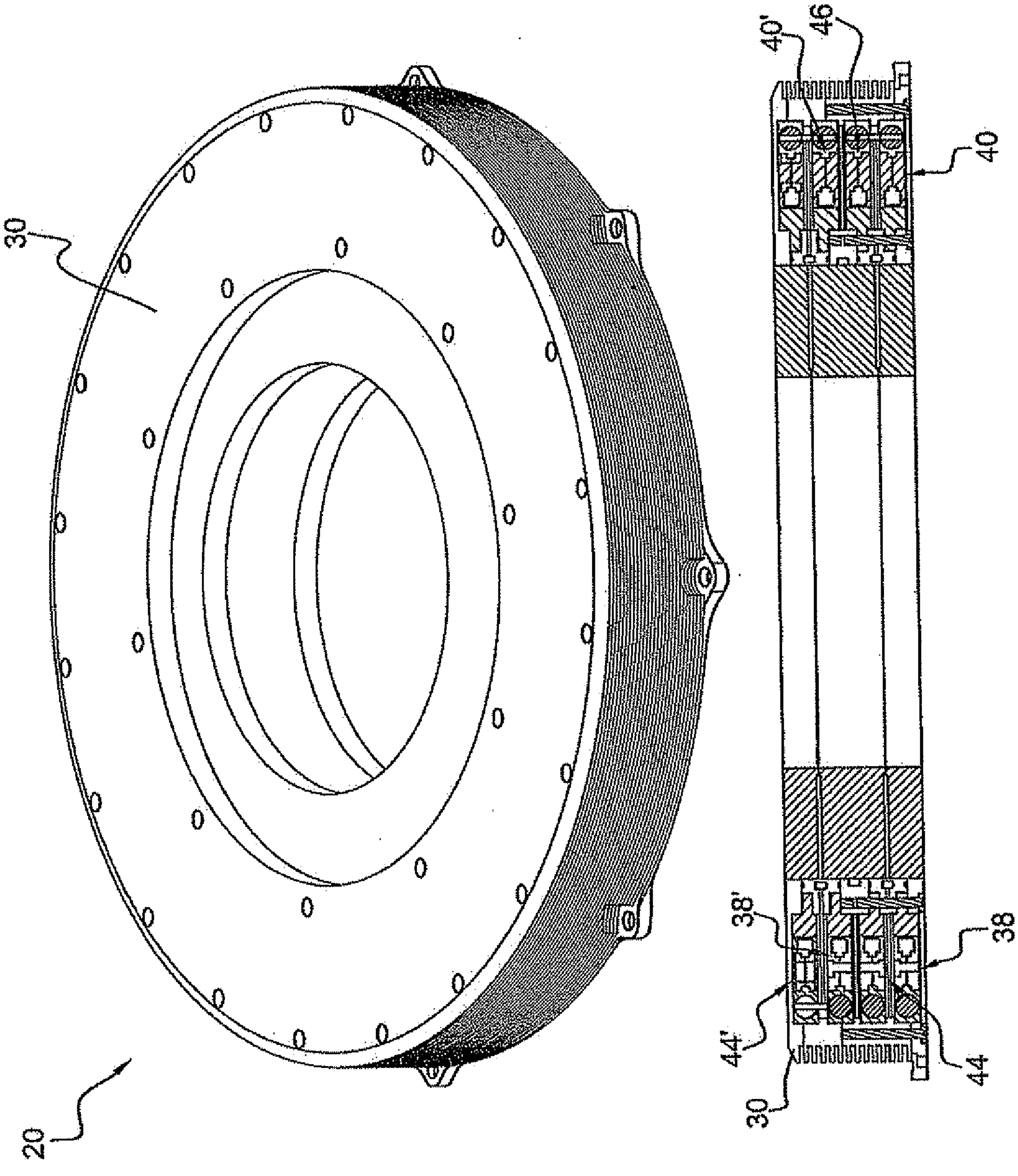


FIG. 21

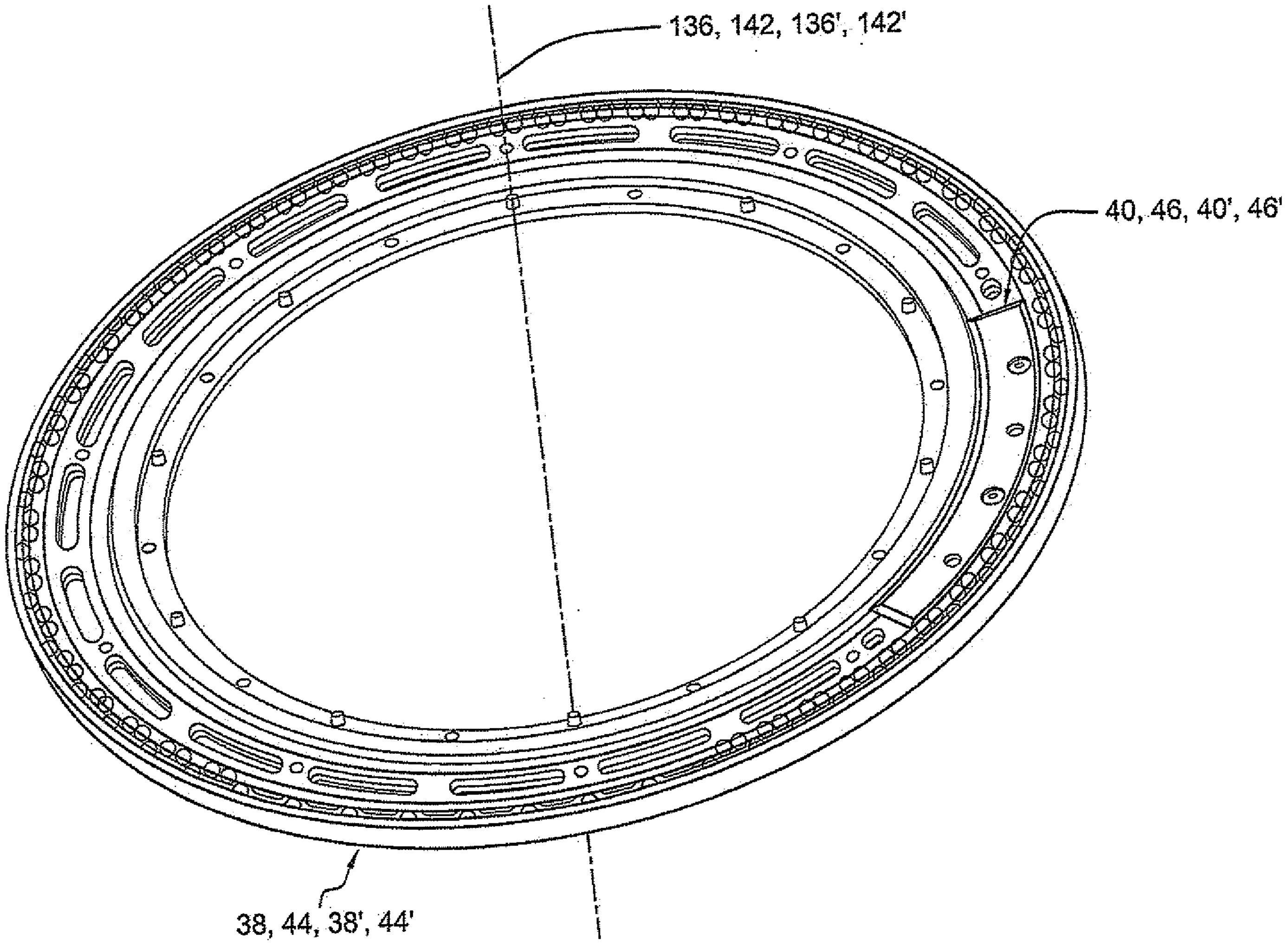


FIG. 22A

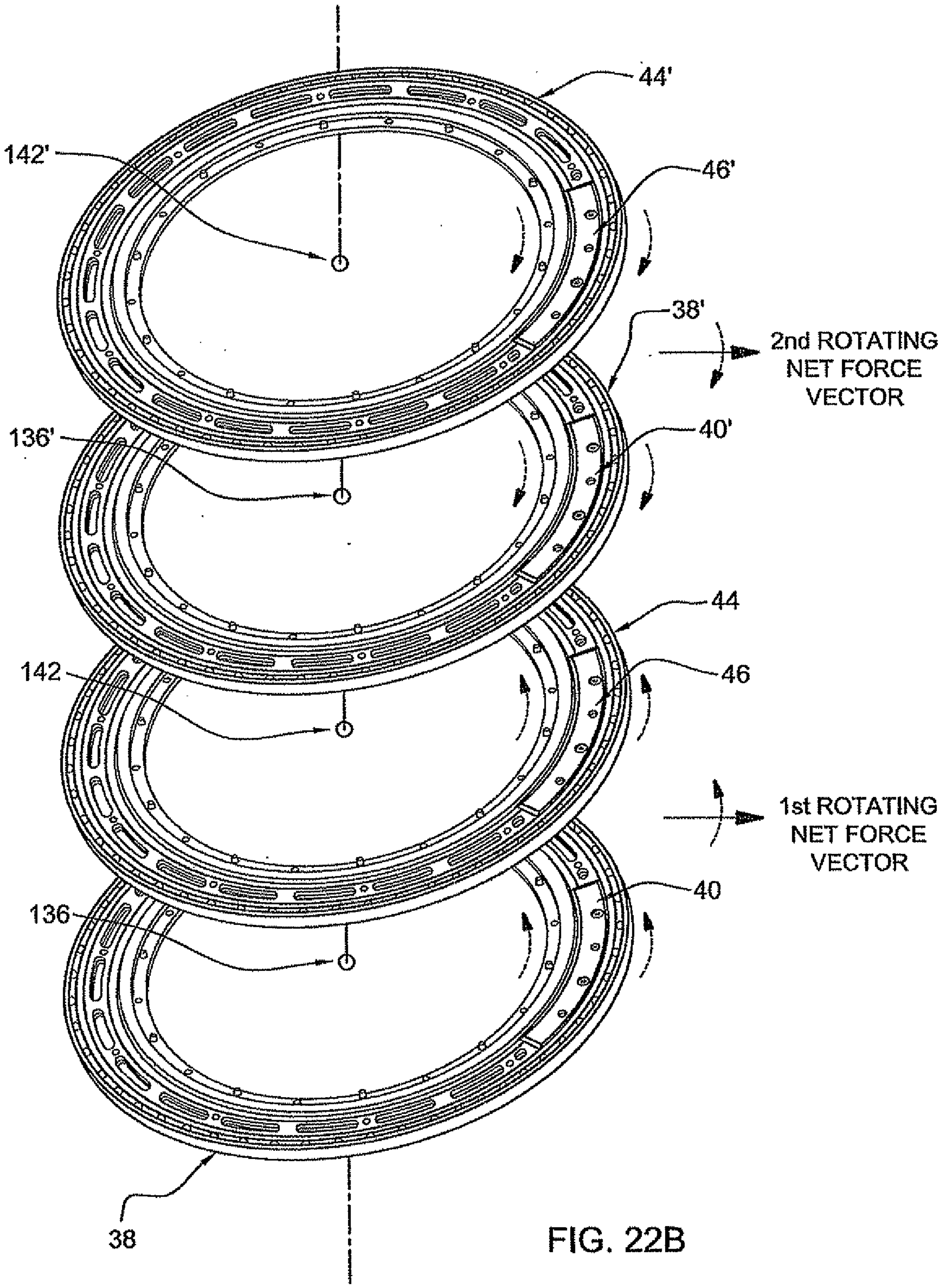

44'
142'
46'
38'
2nd ROTATING NET FORCE VECTOR
136'
40'
44
142
46
1st ROTATING NET FORCE VECTOR
136
40
38

FIG. 22B

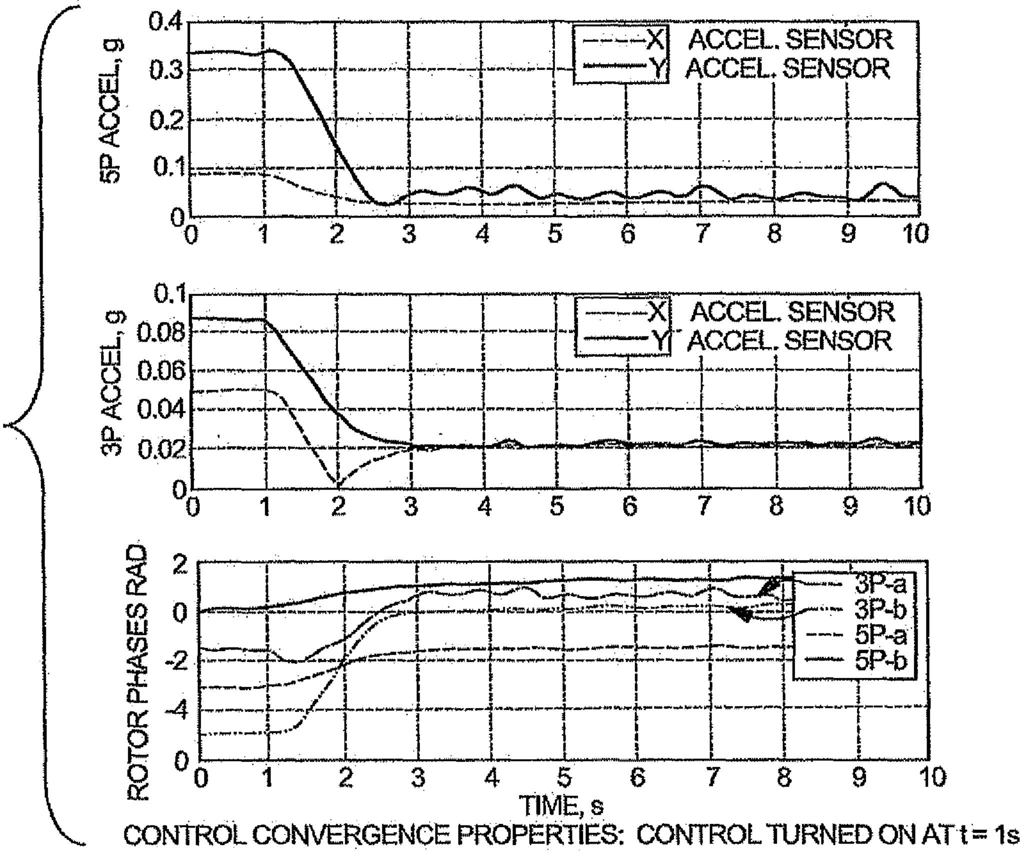


FIG. 23A

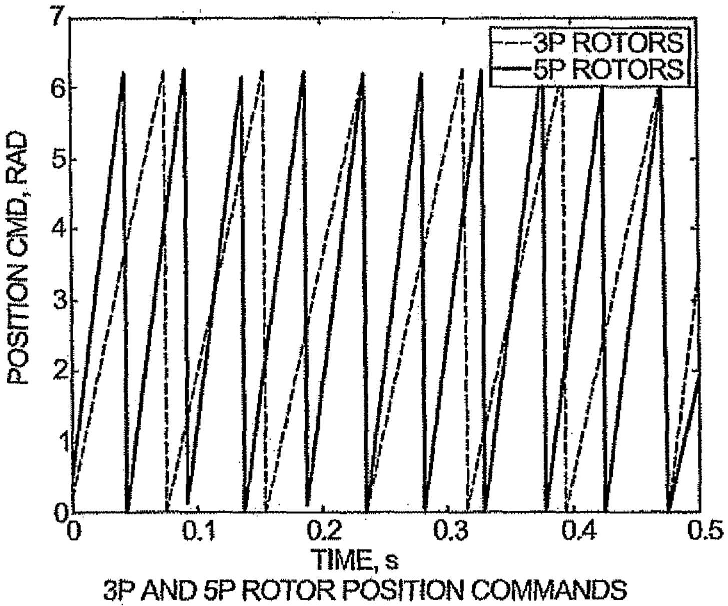


FIG. 23B

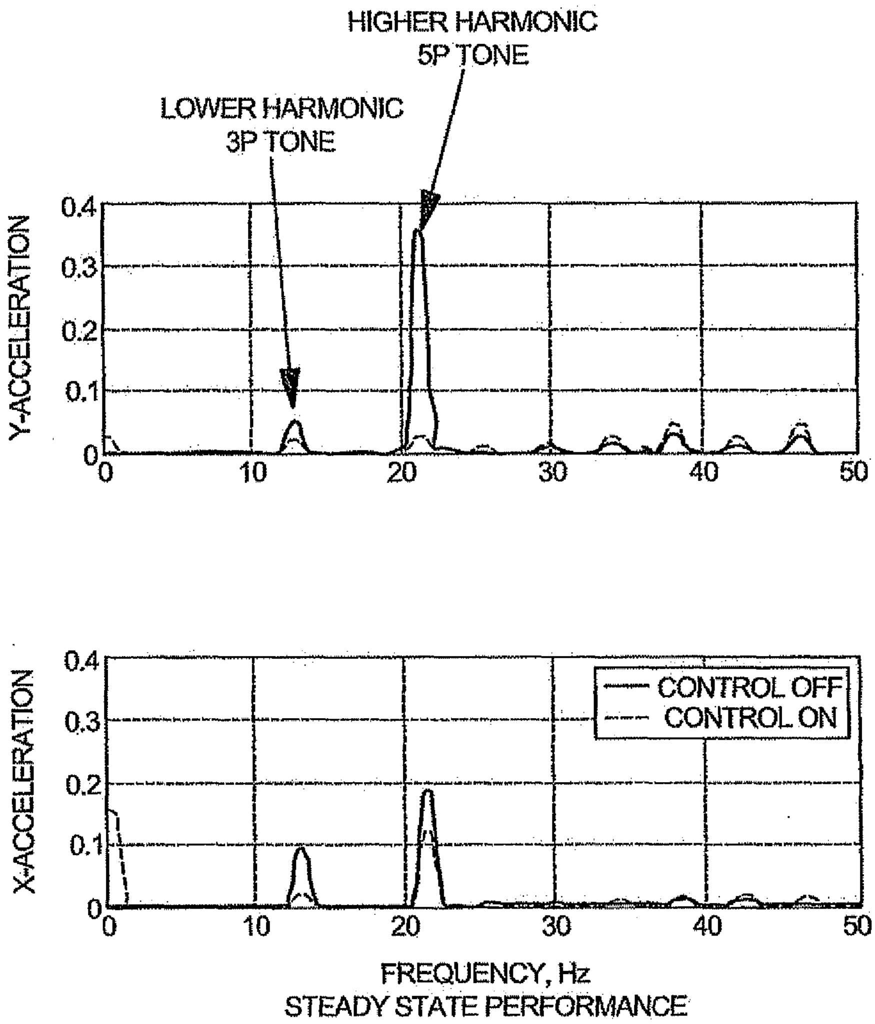

HIGHER HARMONIC
5P TONE
LOWER HARMONIC
3P TONE
Y-ACCELERATION
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
X-ACCELERATION
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
CONTROL OFF
CONTROL ON
FREQUENCY, Hz
STEADY STATE PERFORMANCE

FIG. 23C

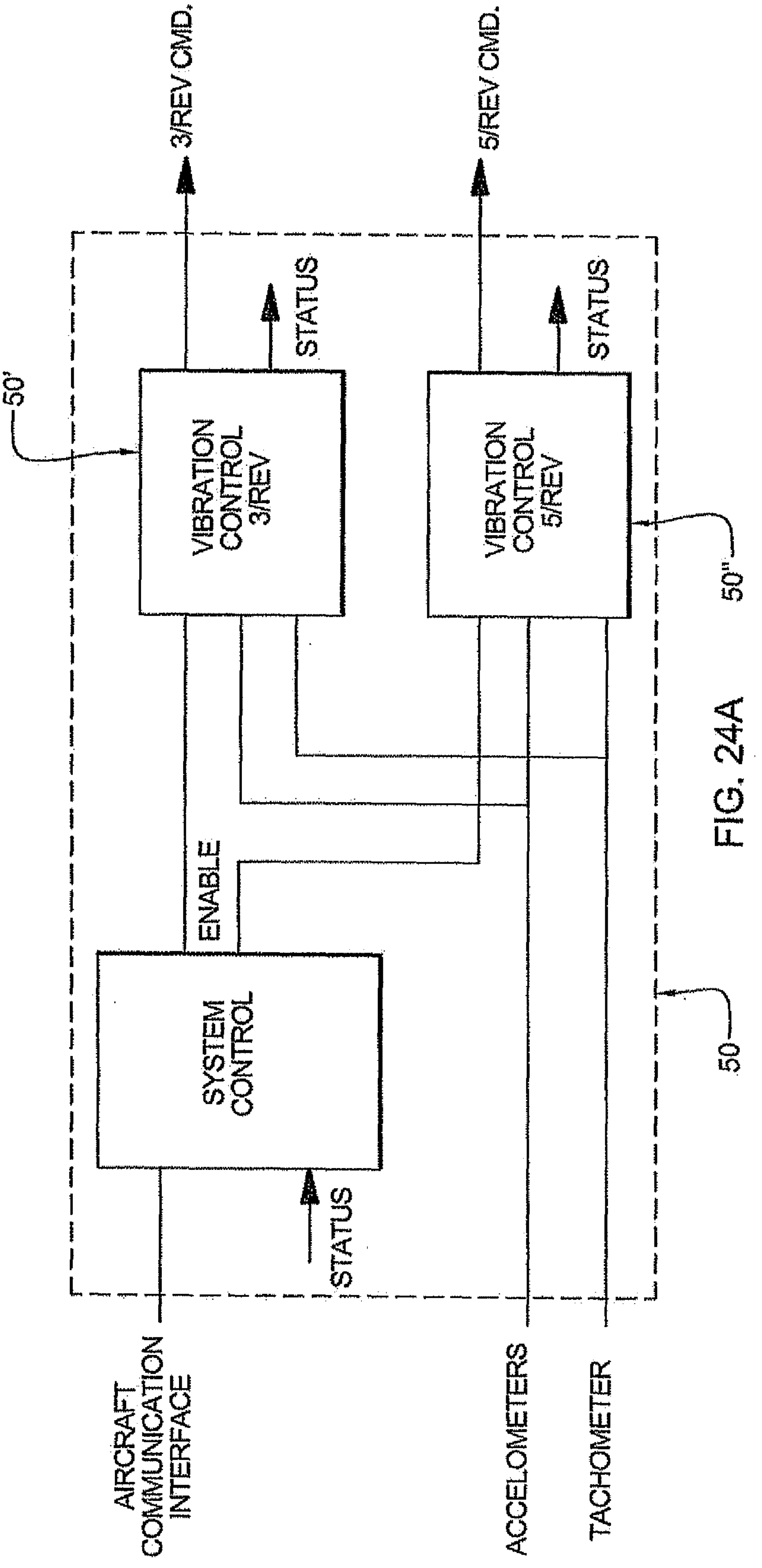

3/REV CMD.
5/REV CMD.
50'
STATUS
STATUS
VIBRATION CONTROL 3/REV
VIBRATION CONTROL 5/REV
50"
ENABLE
SYSTEM CONTROL
50
STATUS
AIRCRAFT COMMUNICATION INTERFACE
ACCELOMETERS
TACHOMETER

FIG. 24A

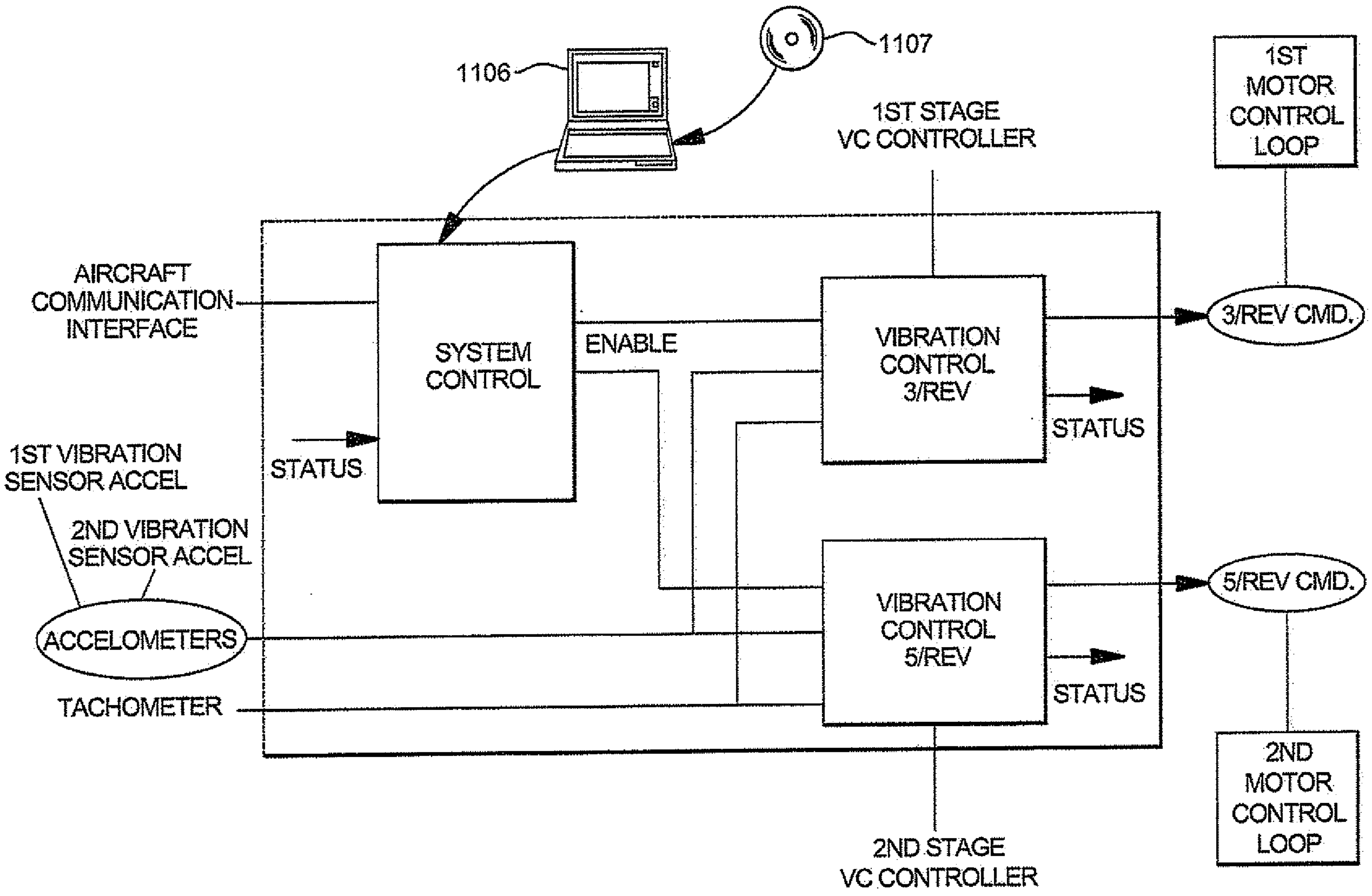
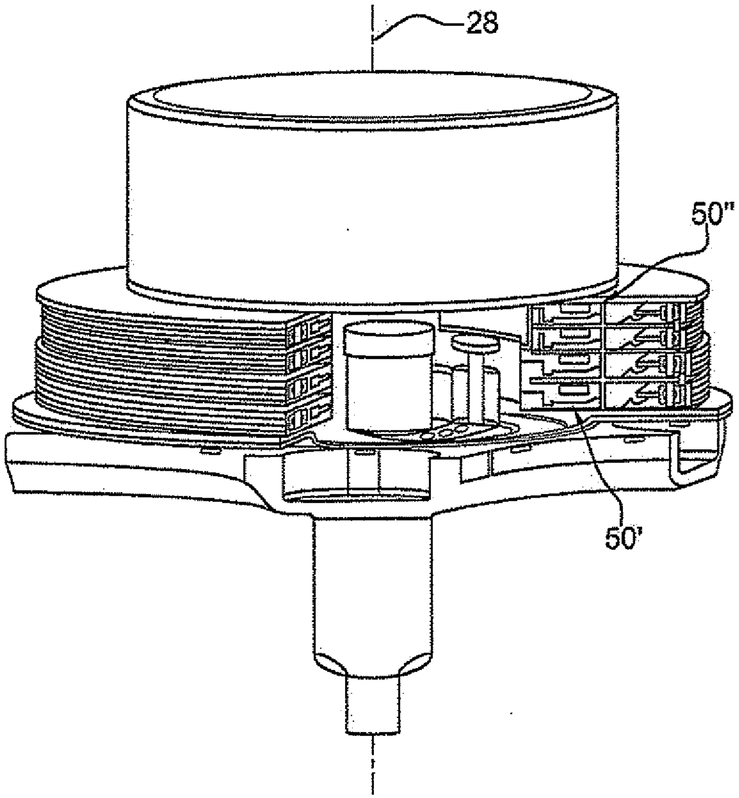
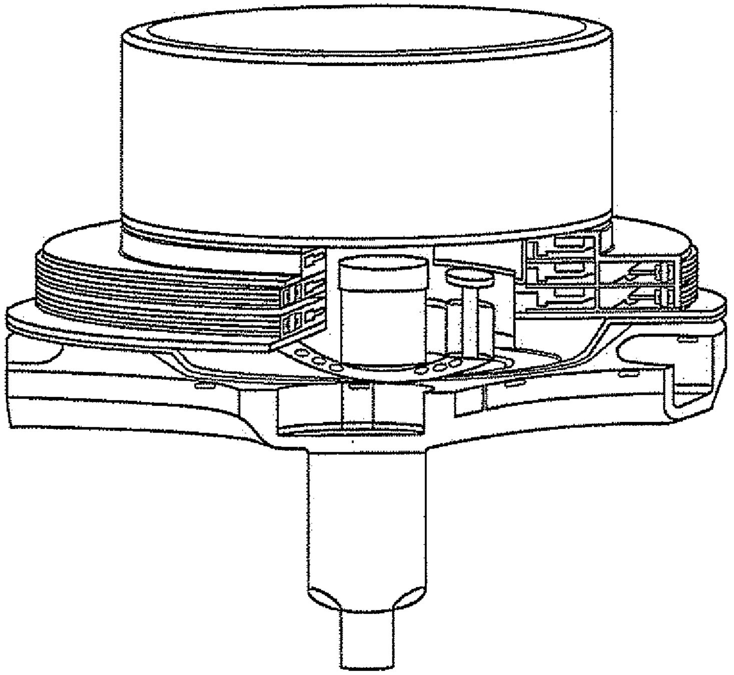

1106
1107
1ST STAGE VC CONTROLLER
1ST MOTOR CONTROL LOOP
AIRCRAFT COMMUNICATION INTERFACE
SYSTEM CONTROL
ENABLE
VIBRATION CONTROL 3/REV
3/REV CMD.
STATUS
STATUS
1ST VIBRATION SENSOR ACCEL
2ND VIBRATION SENSOR ACCEL
ACCELOMETERS
TACHOMETER
VIBRATION CONTROL 5/REV
5/REV CMD.
STATUS
2ND STAGE VC CONTROLLER
2ND MOTOR CONTROL LOOP

FIG. 24B



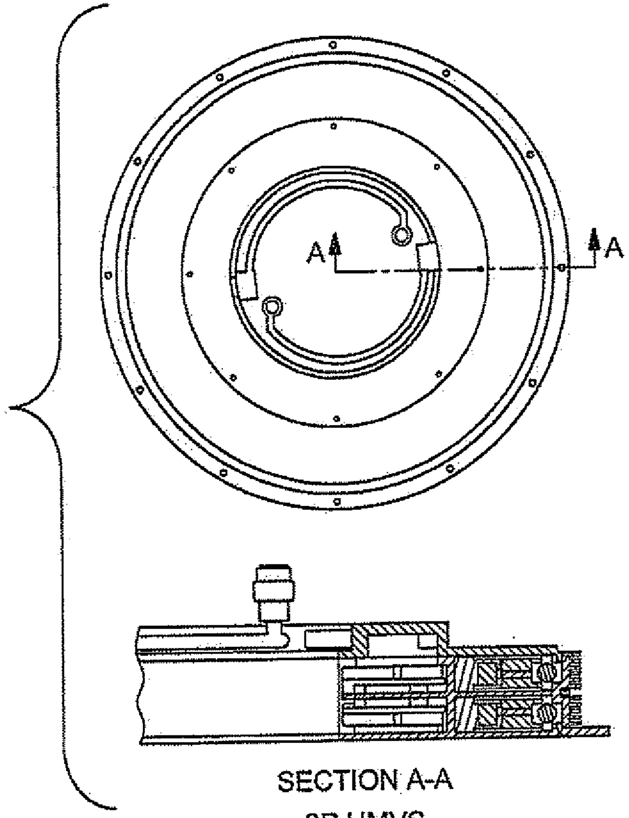
DUAL FREQUENCY HMVS

FIG. 25A



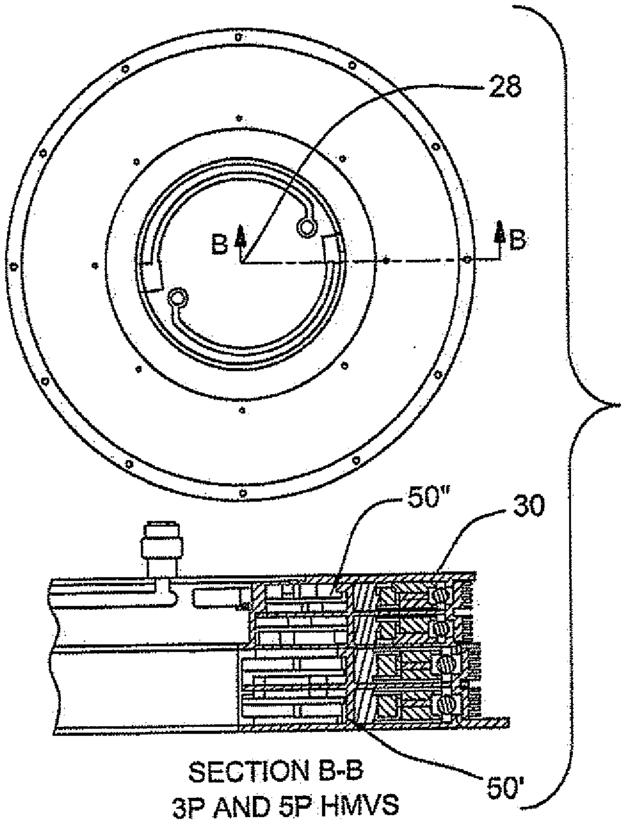
3P HMVS

FIG. 26A



SECTION A-A
3P HMVS

FIG. 26B



SECTION B-B
3P AND 5P HMVS

FIG. 25B

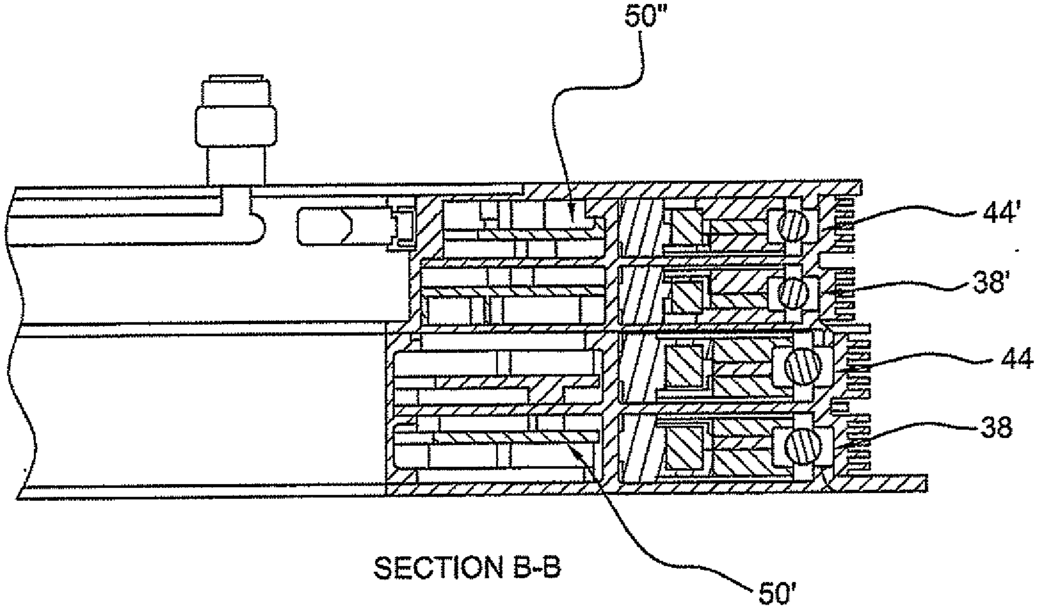


FIG. 25C

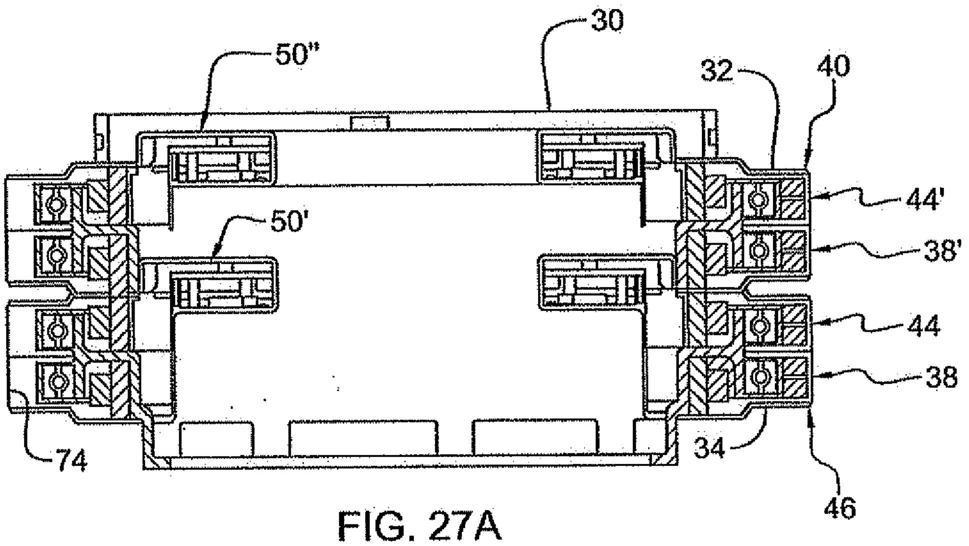


FIG. 27A

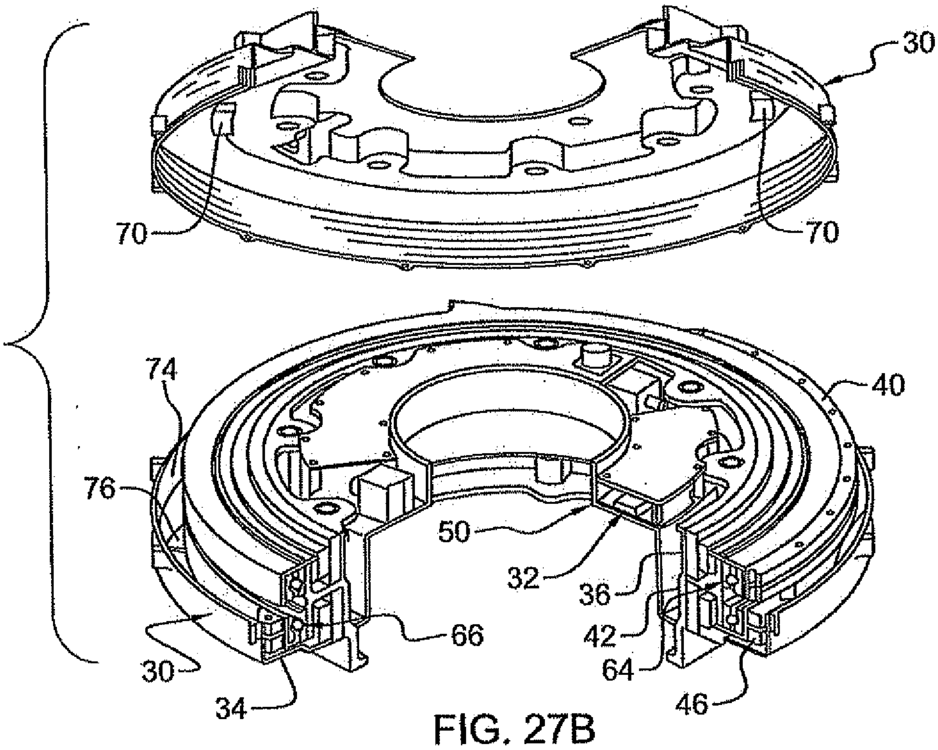


FIG. 27B

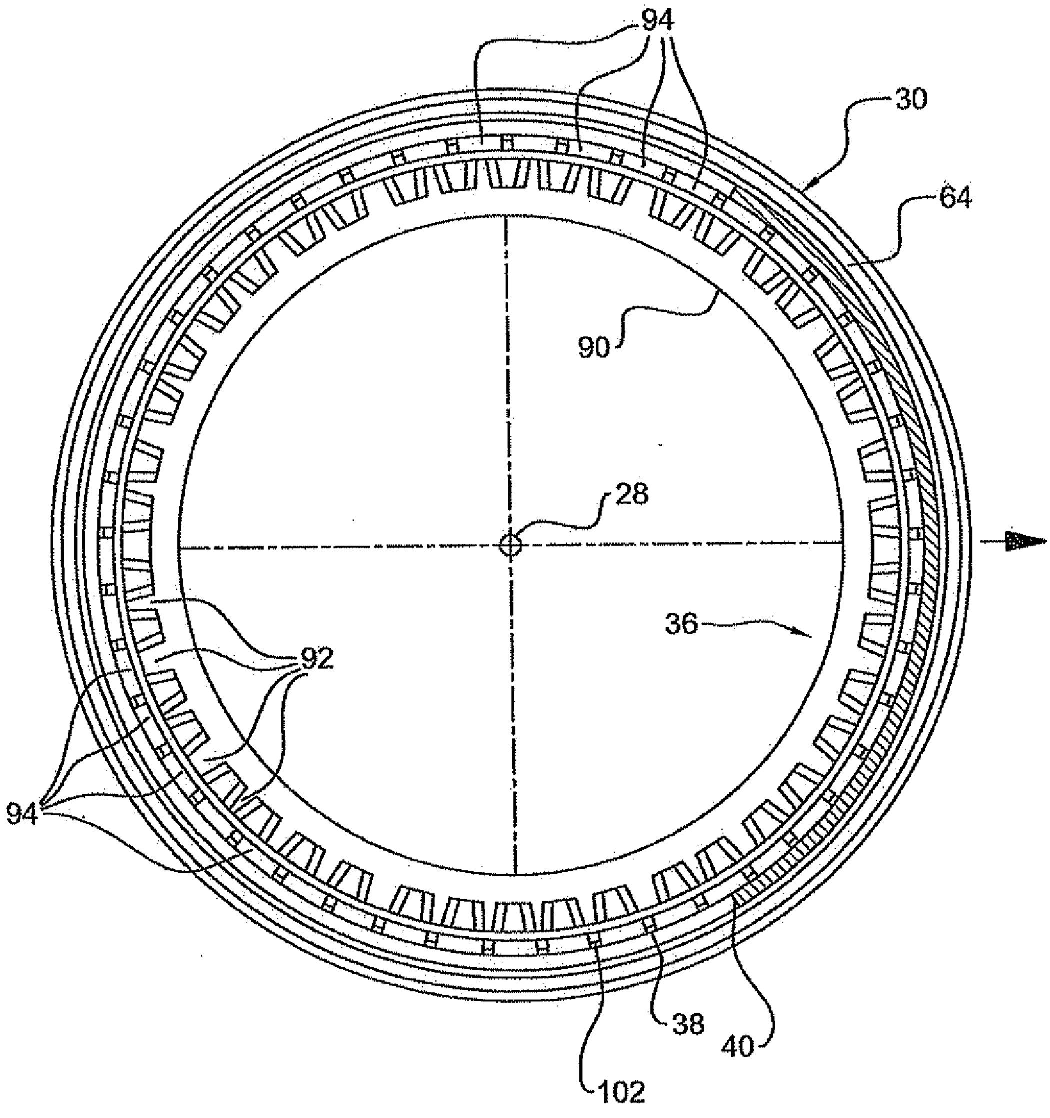


FIG. 28A

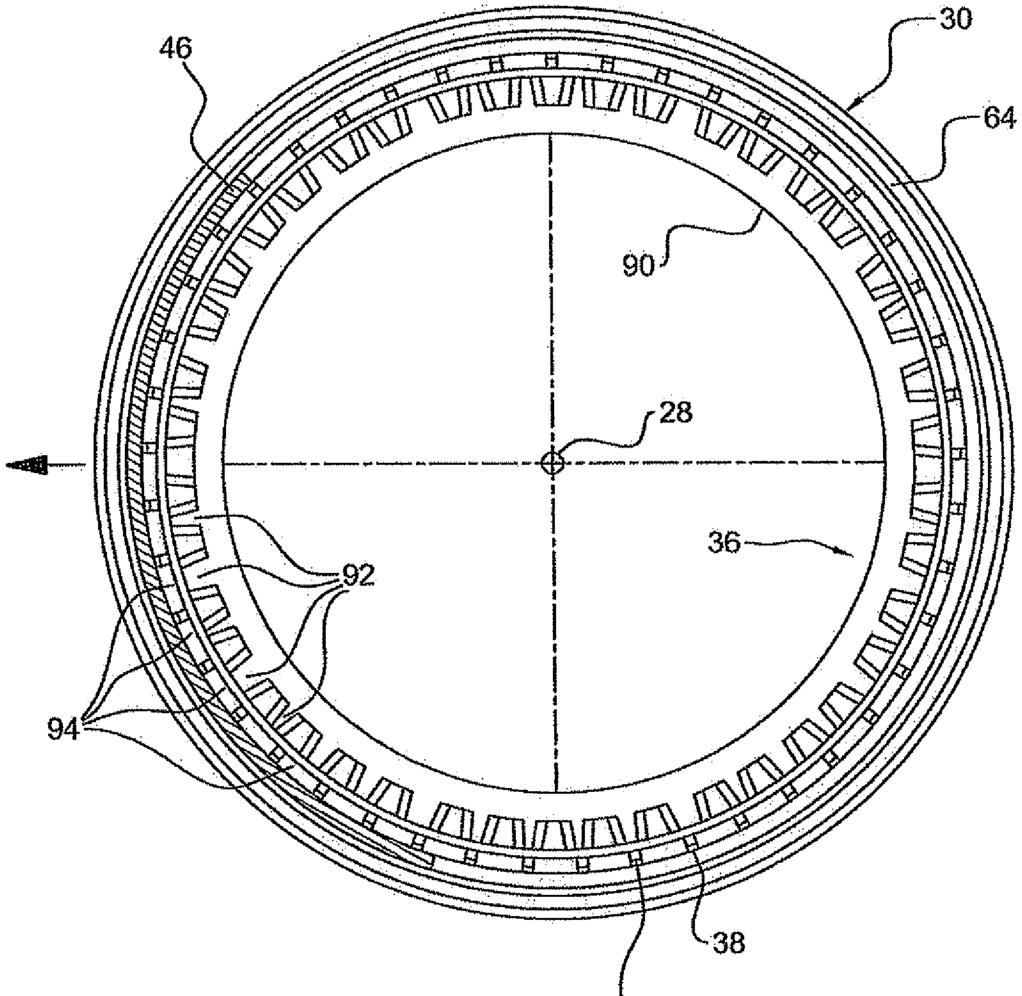


FIG. 28B

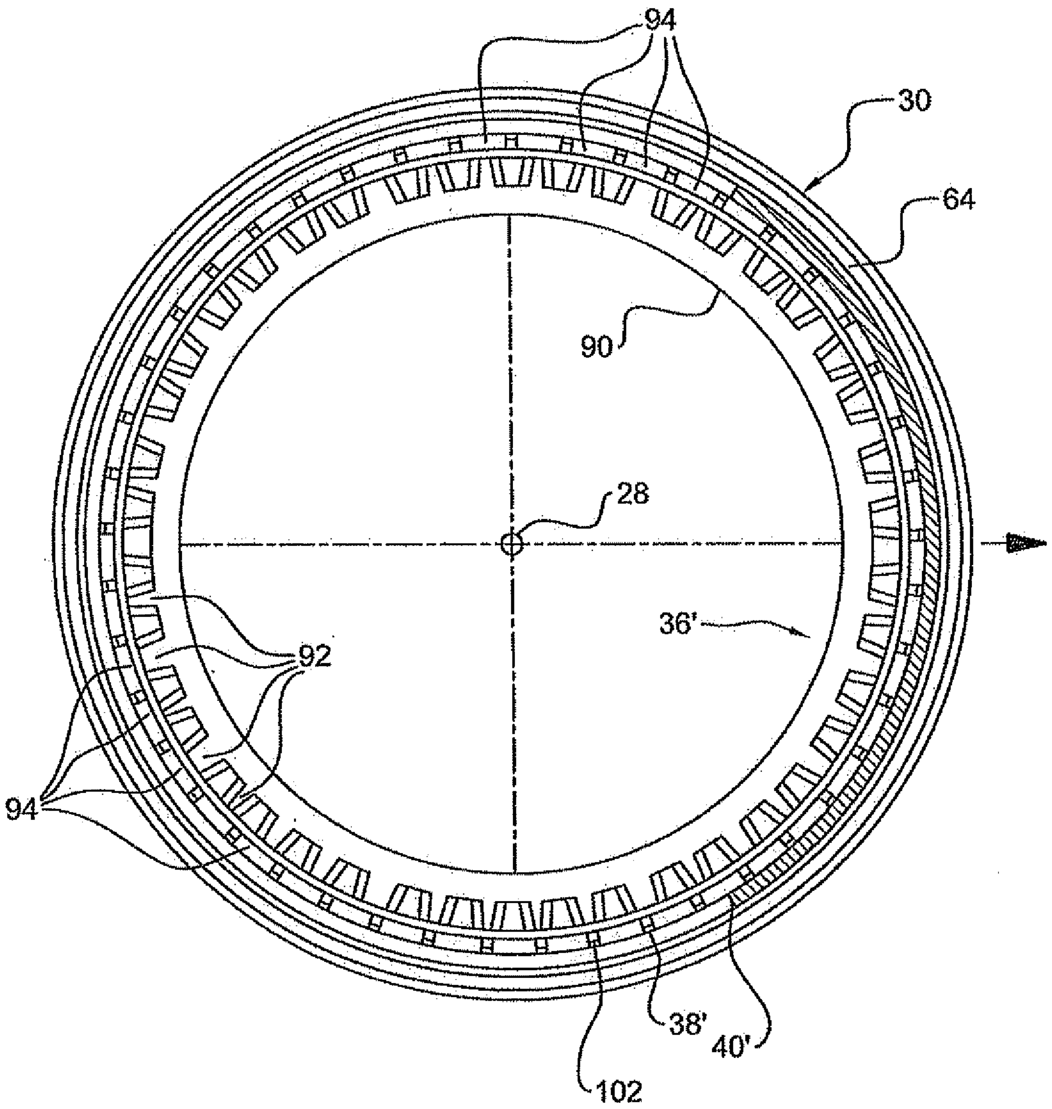


FIG. 28C

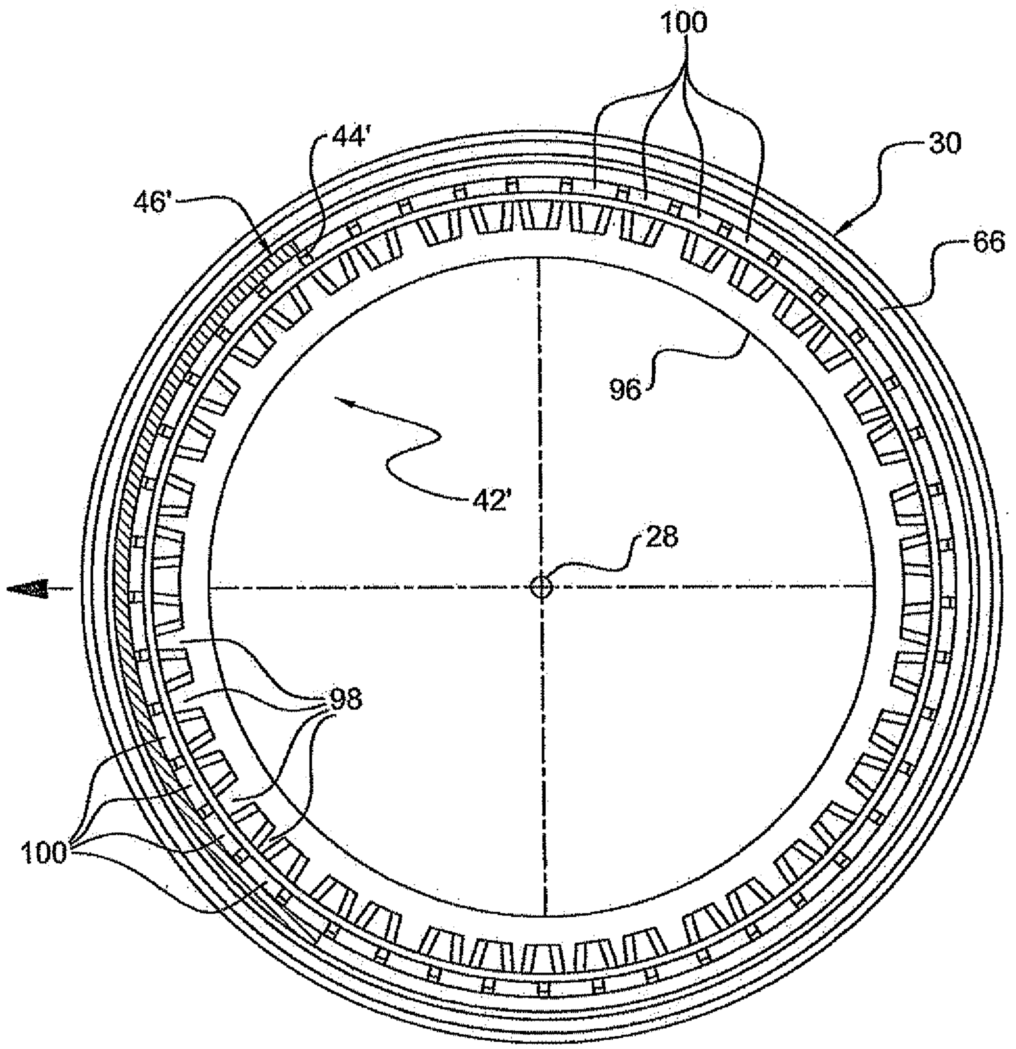


FIG. 28D

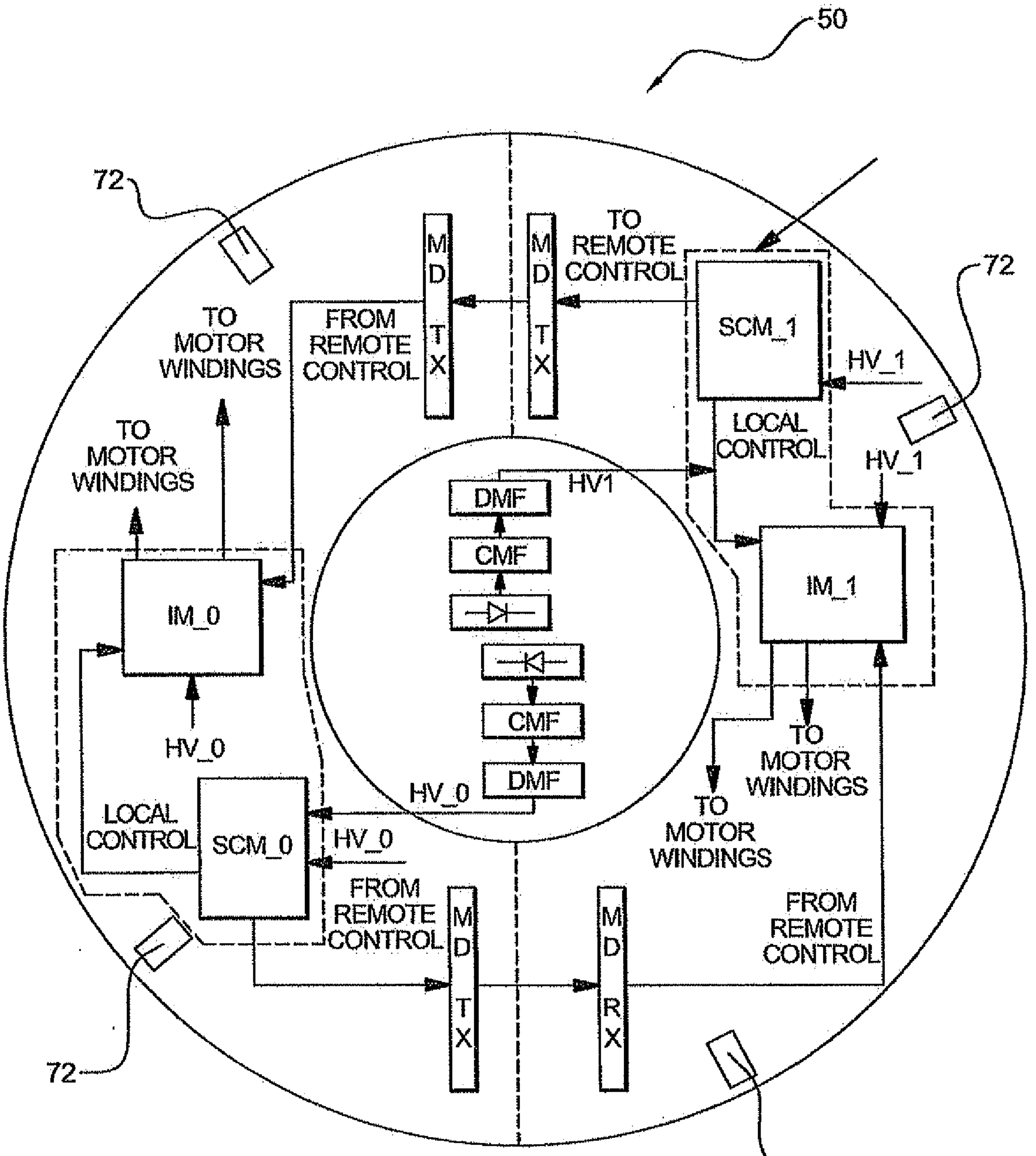

50
72
72
72
72
MD TX
MD TX
TO REMOTE CONTROL
SCM_1
HV_1
LOCAL CONTROL
HV_1
IM_1
TO MOTOR WINDINGS
TO MOTOR WINDINGS
FROM REMOTE CONTROL
MD RX
MD TX
FROM REMOTE CONTROL
SCM_0
HV_0
LOCAL CONTROL
HV_0
IM_0
TO MOTOR WINDINGS
TO MOTOR WINDINGS
FROM REMOTE CONTROL
DMF
HV1
CMF
CMF
DMF
HV_0

FIG. 29

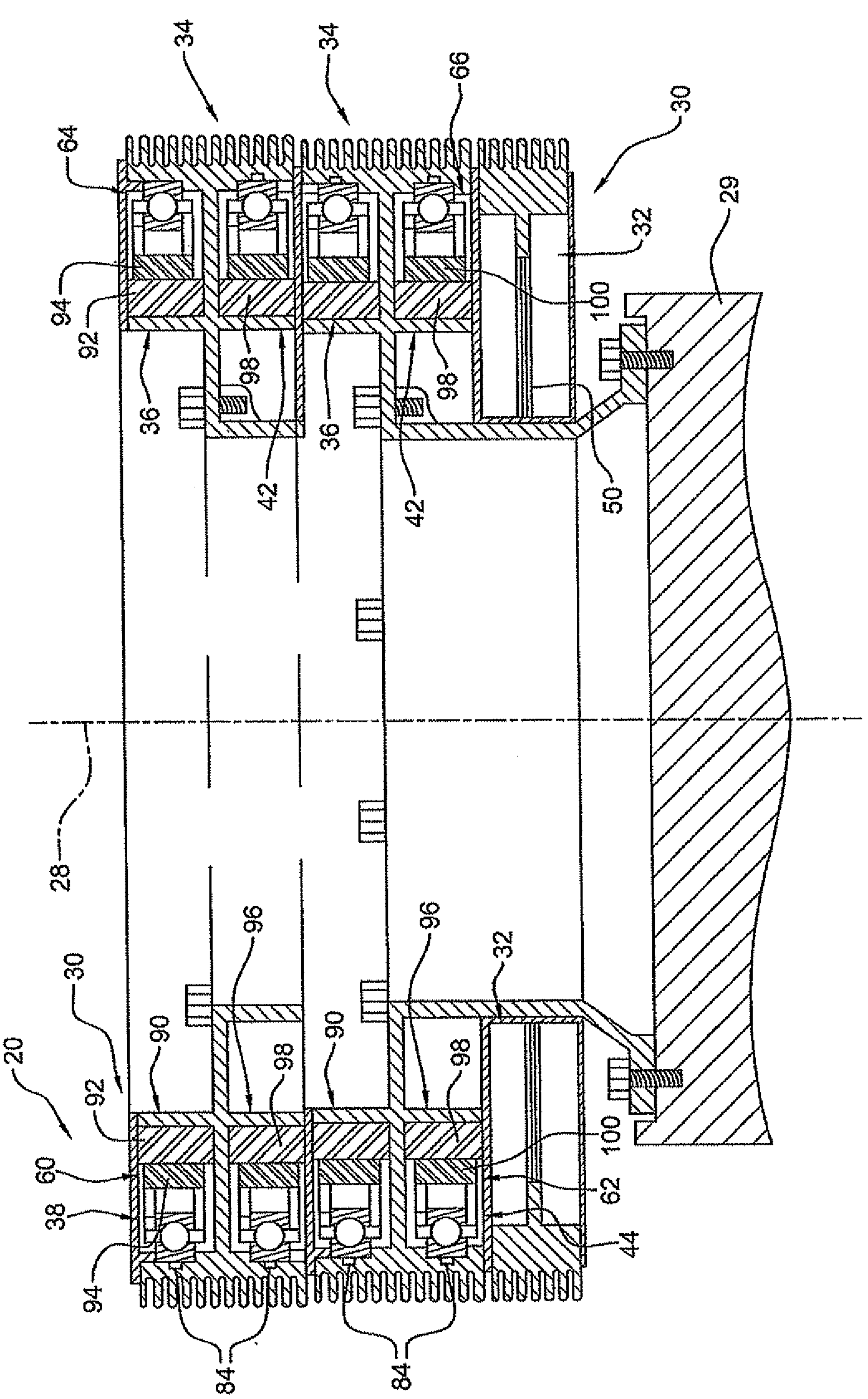

34
34
66
30
64
29
32
94
92
100
36
98
42
36
98
42
50
28
20
30
92
90
96
98
90
96
98
32
60
38
100
62
44
94
84
84

FIG. 30A

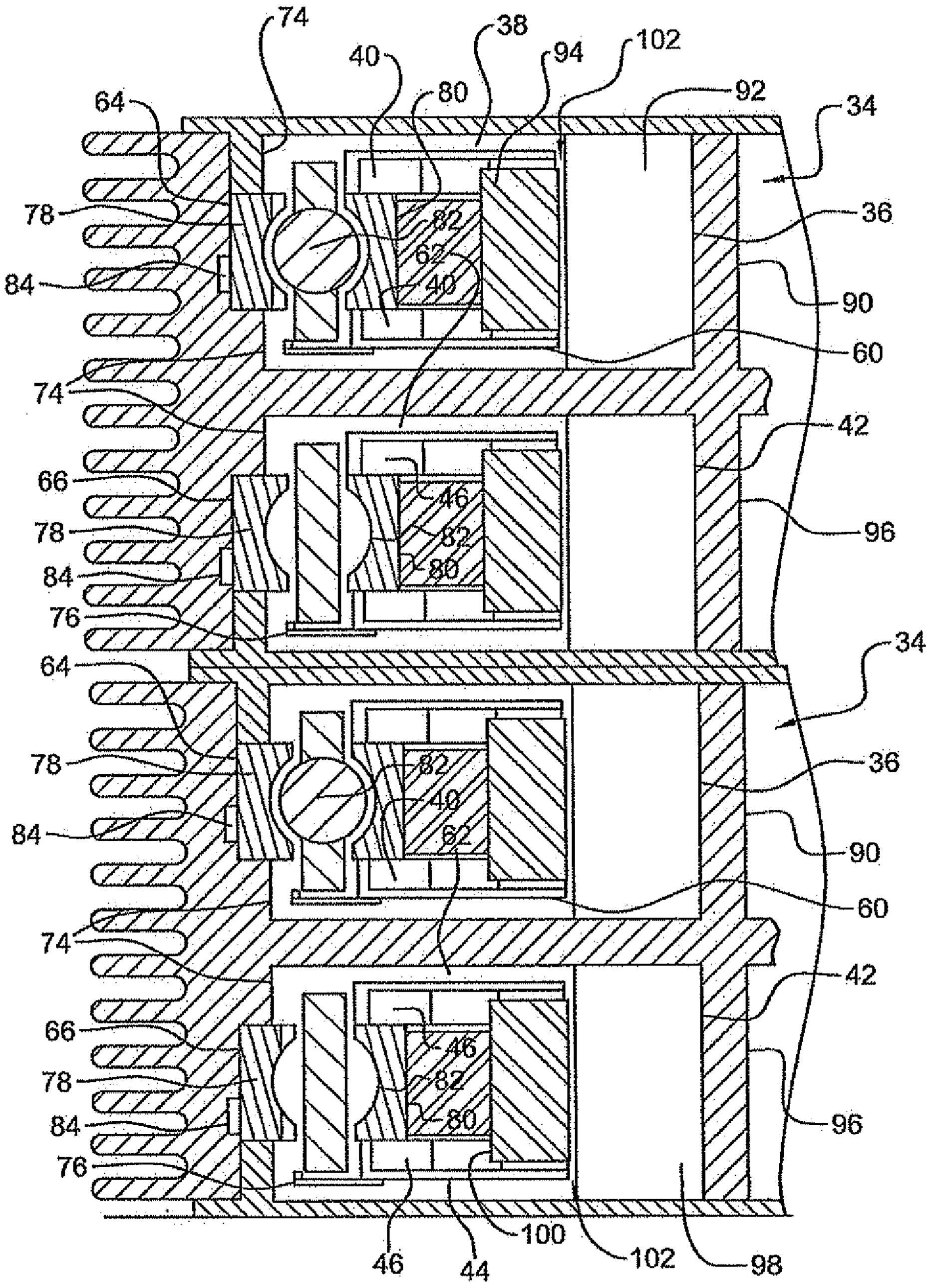

74
38
40
94
102
92
80
64
34
78
82
36
62
84
40
90
60
74
42
66
46
78
82
96
84
80
76
64
34
78
82
36
40
84
62
90
60
74
42
66
46
78
82
84
80
96
76
100
46
44
102
98

FIG. 30B

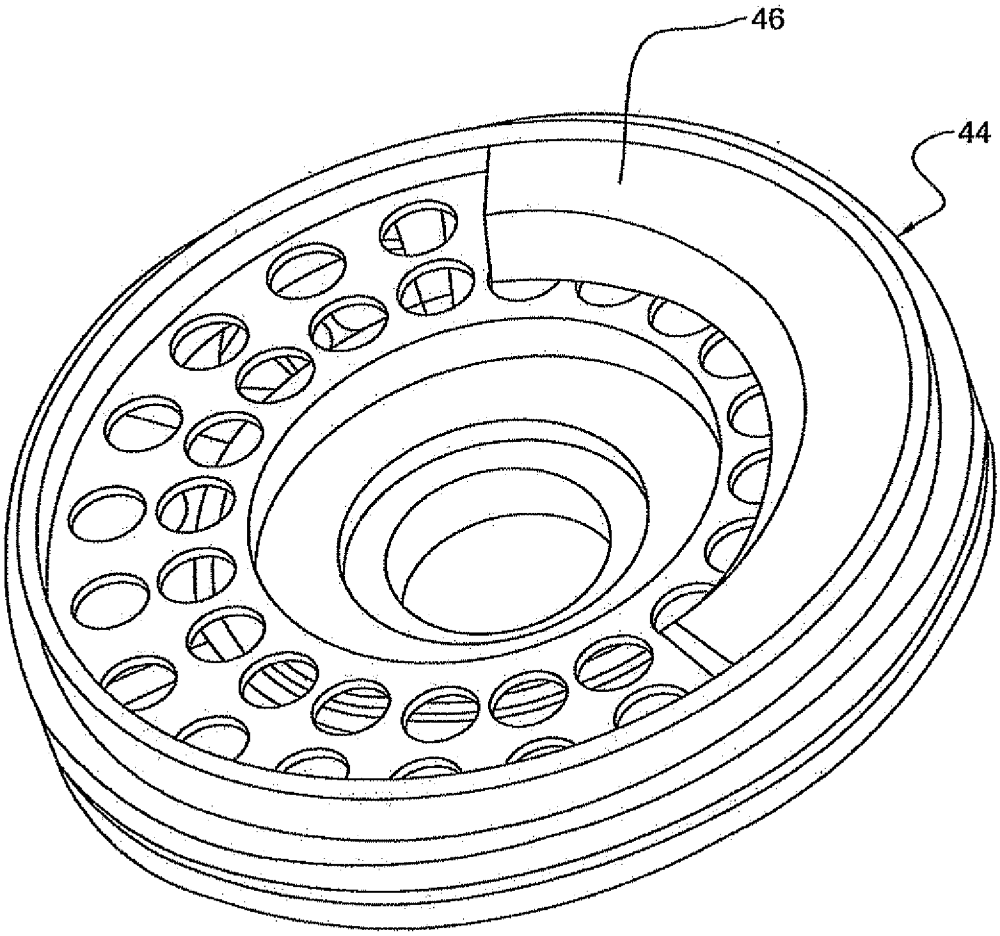


FIG. 31

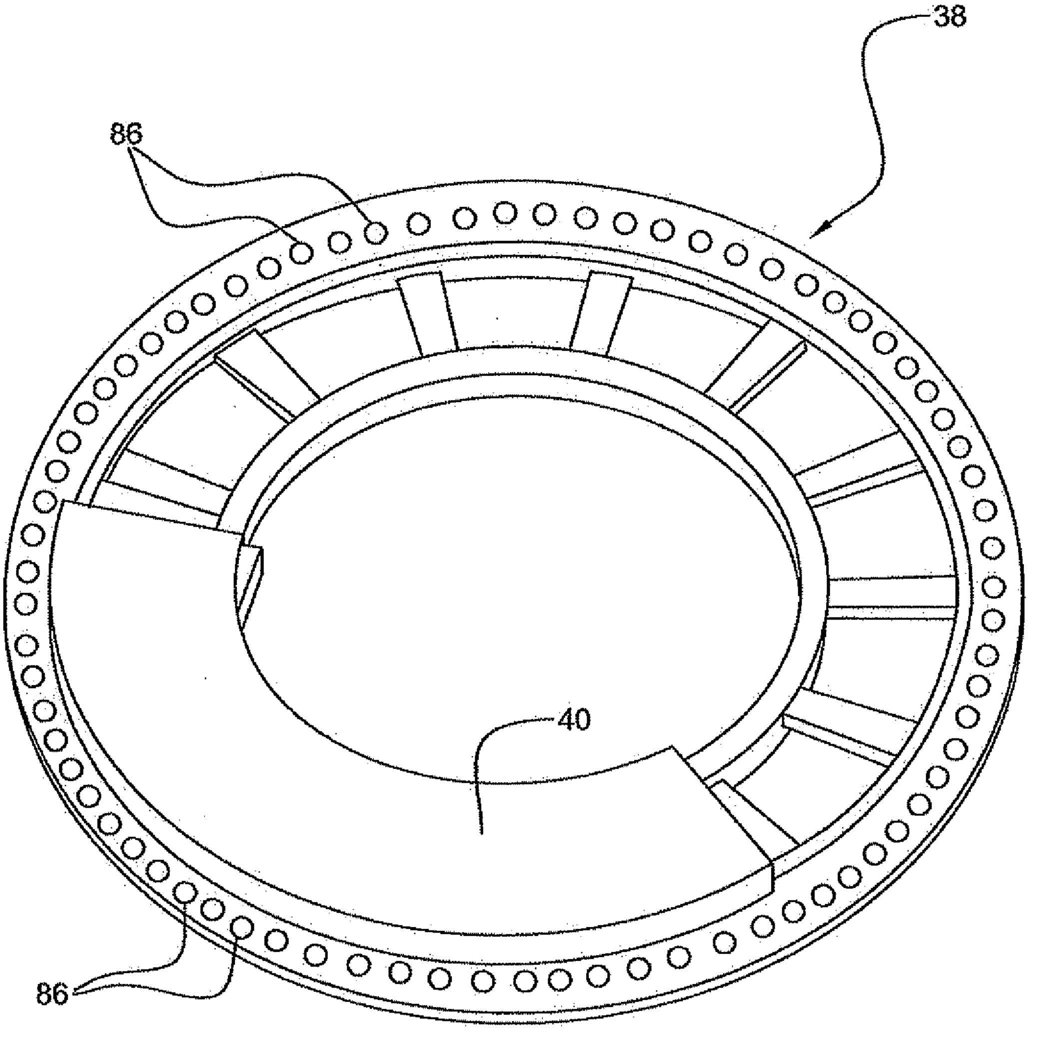


FIG. 32

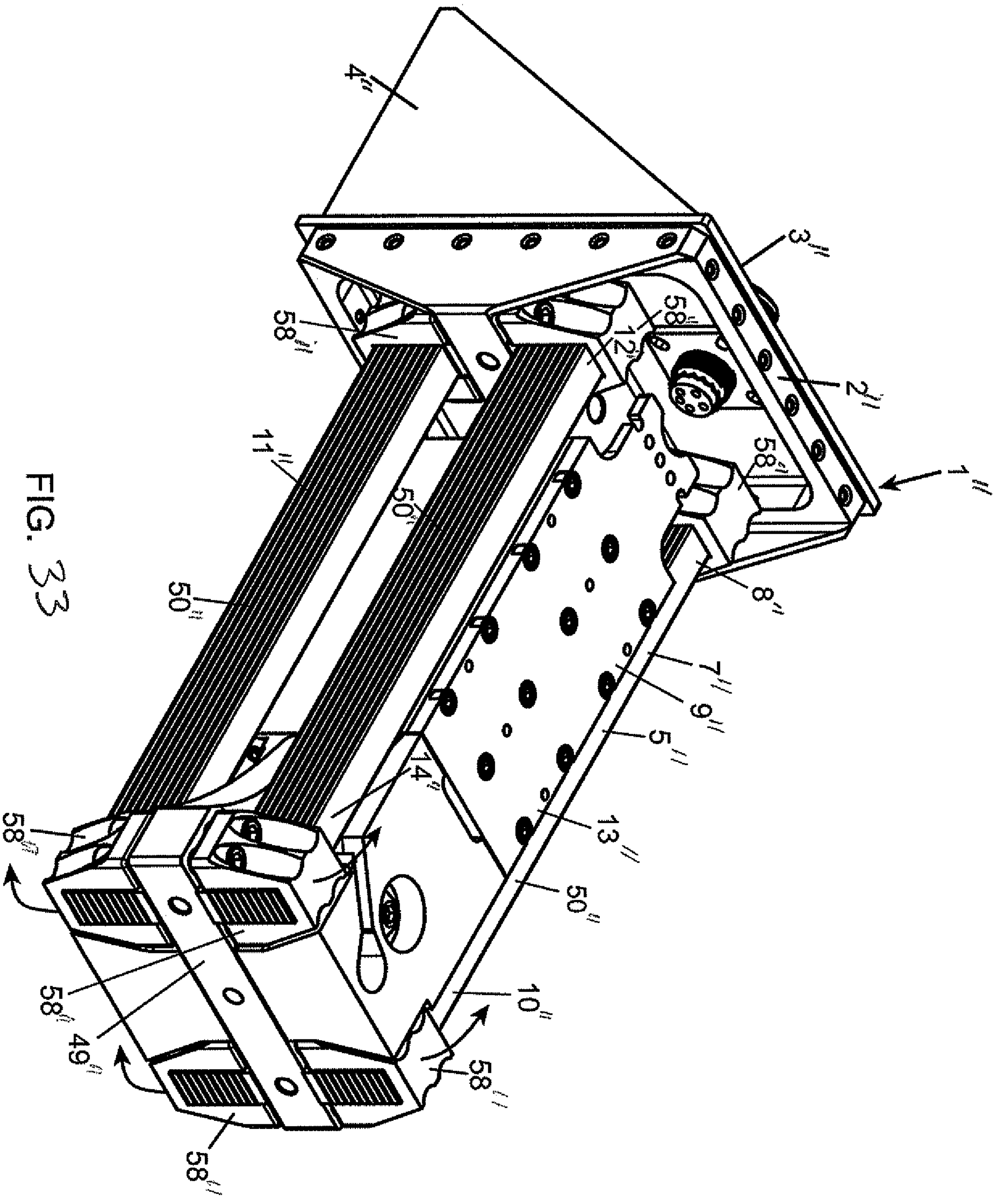


FIG. 33

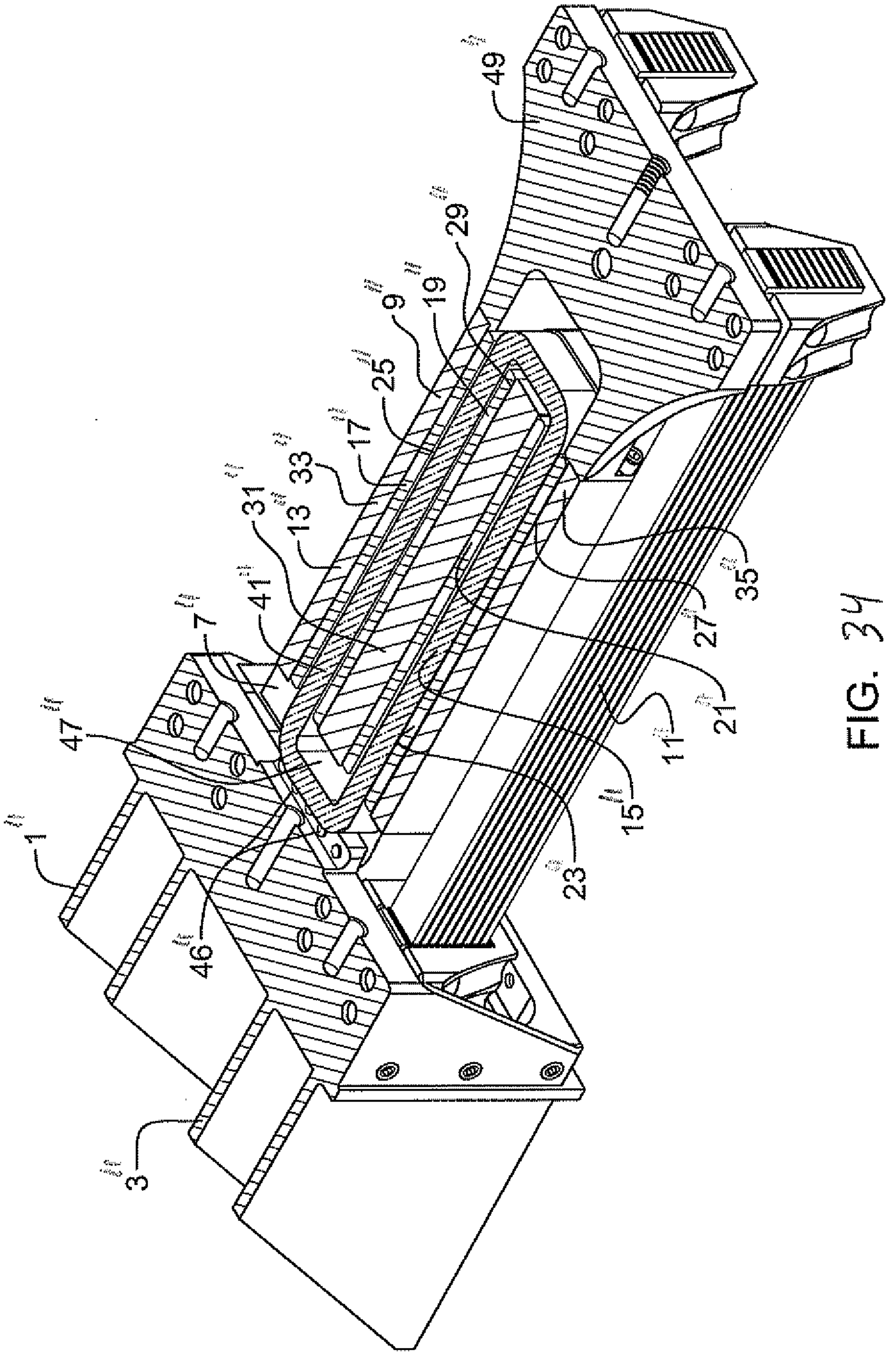


FIG. 34

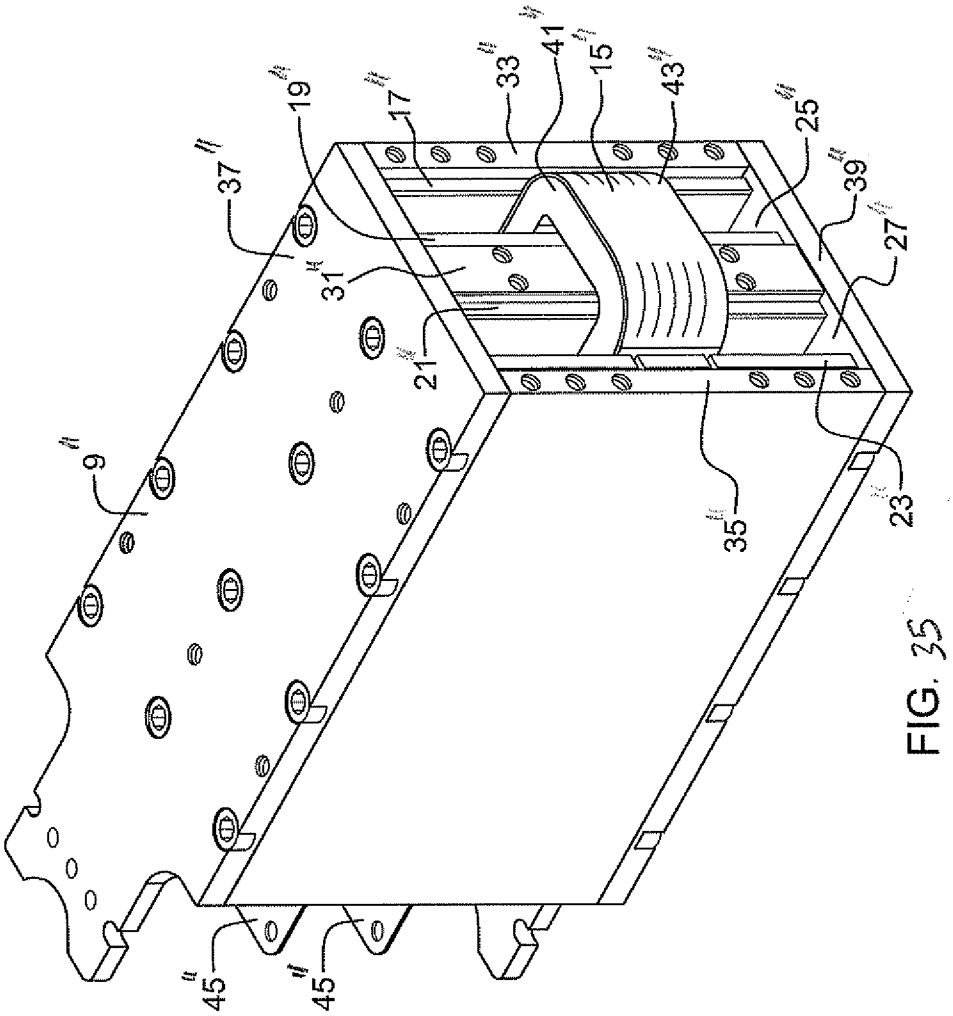


FIG. 35

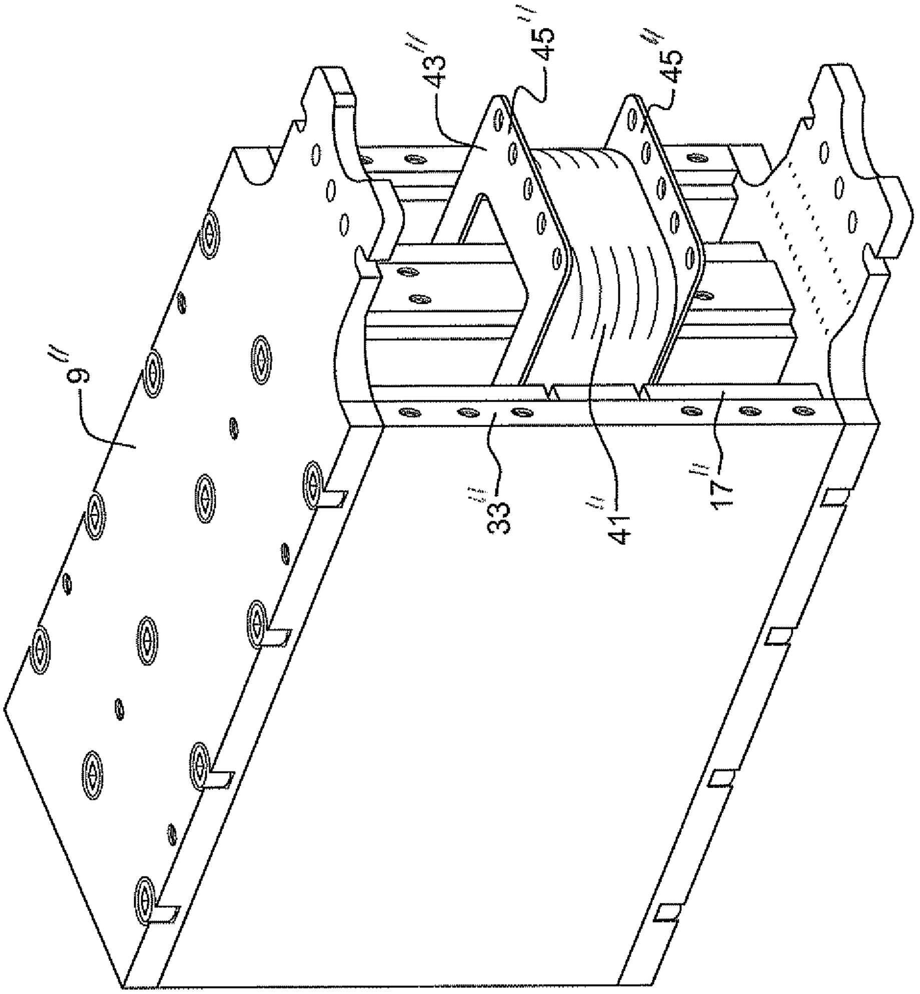


FIG. 36

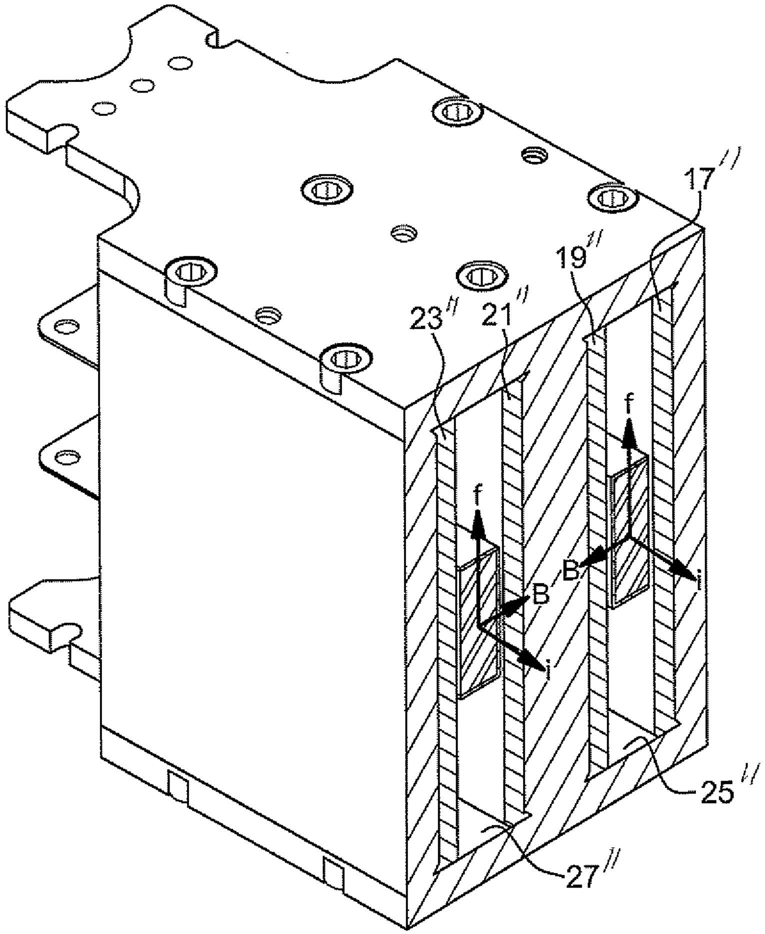


FIG 37

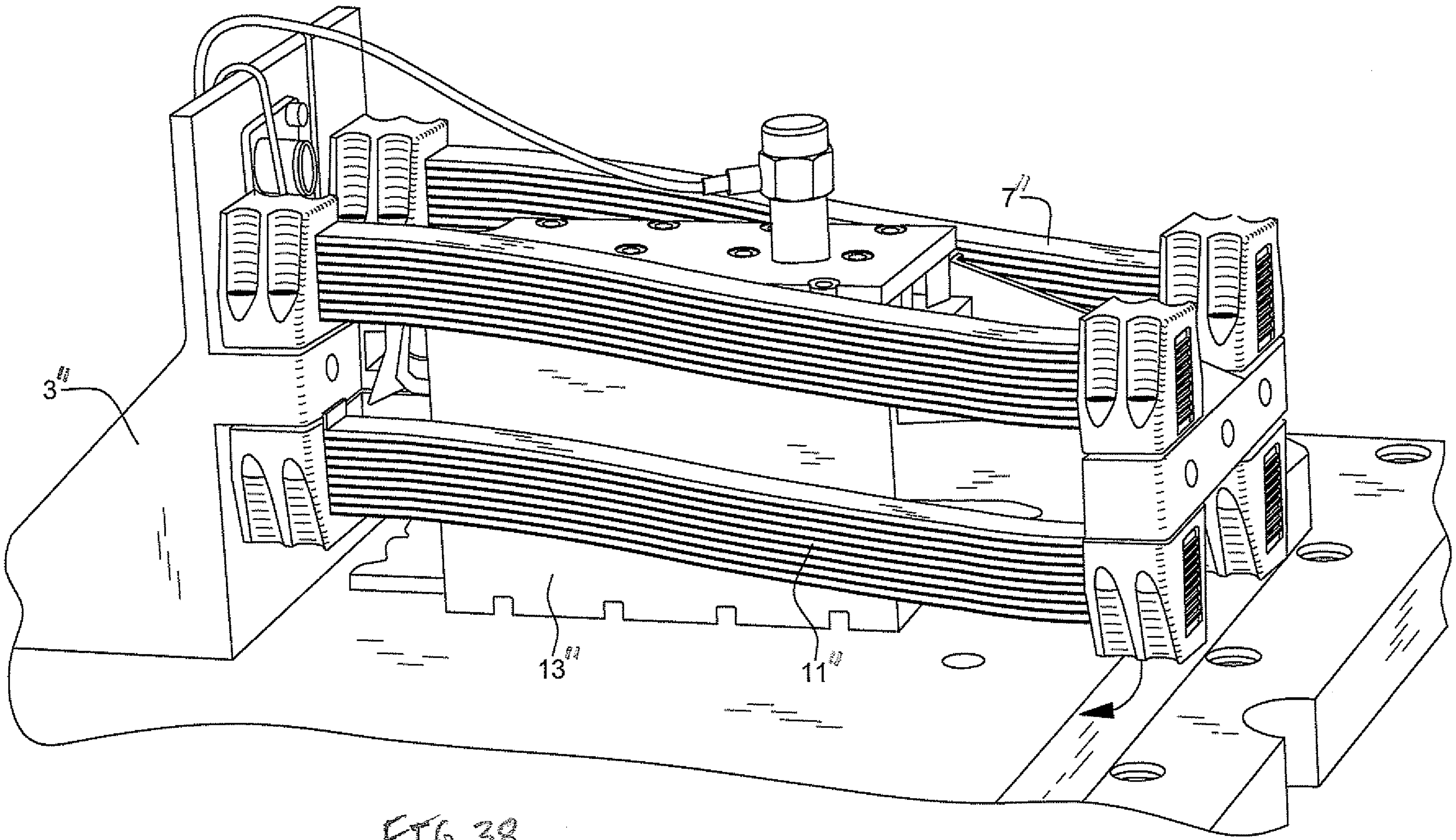


FIG. 38

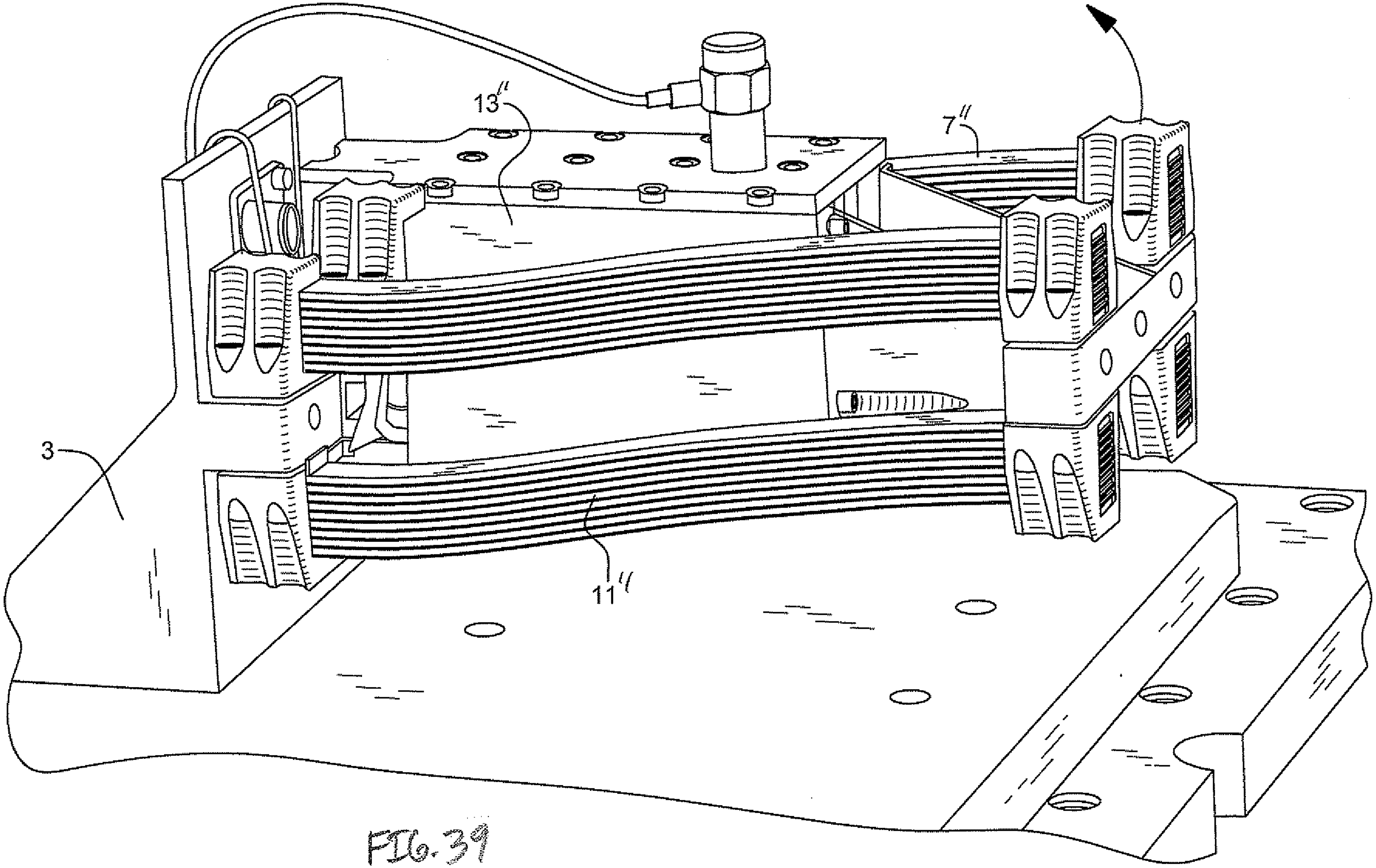


FIG. 39

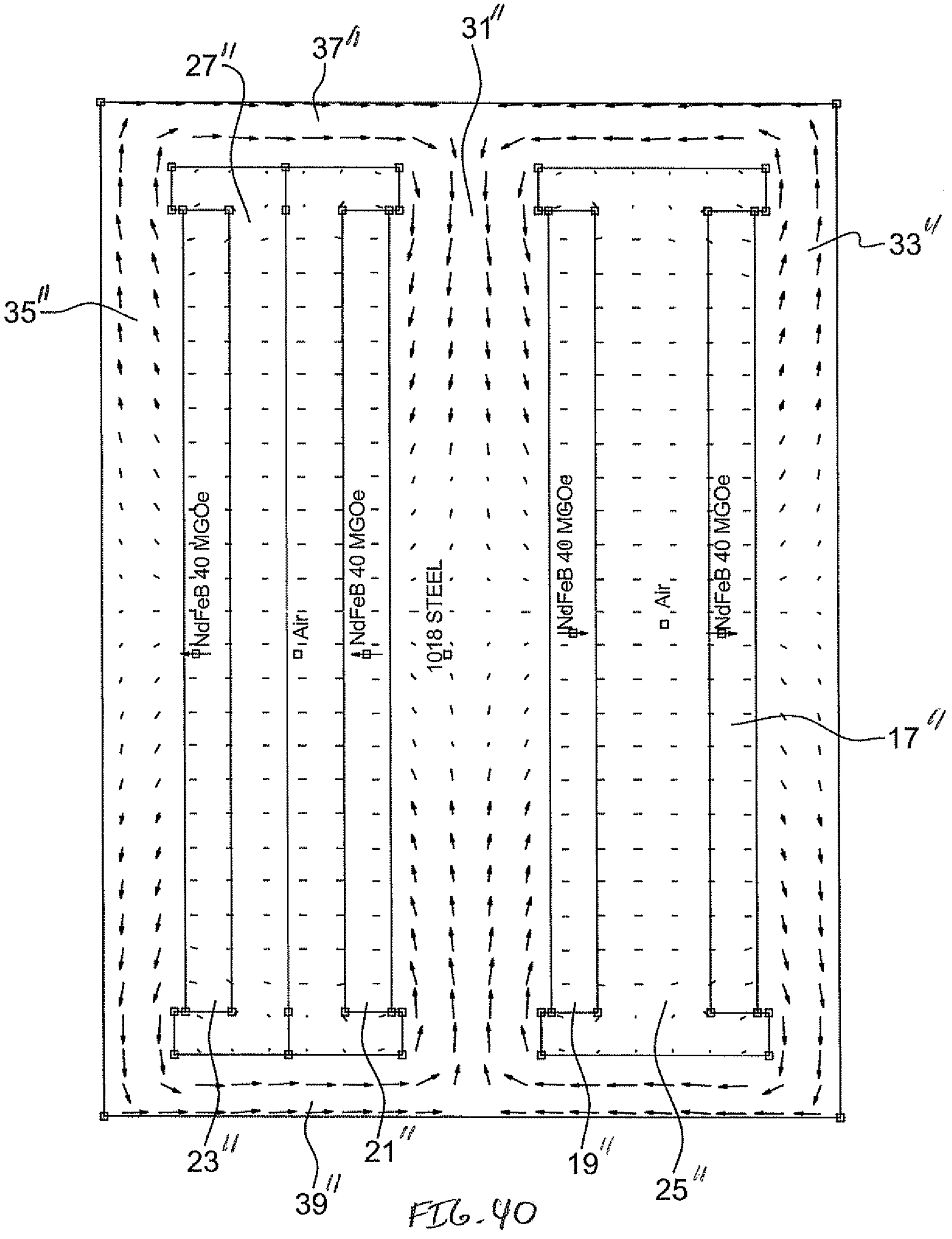

27''
37''
31''
33''
35''
NdFeB 40 MGOe
Air
NdFeB 40 MGOe
1018 STEEL
NdFeB 40 MGOe
Air
NdFeB 40 MGOe
17''
23''
21''
19''
25''
39''

FIG. 40

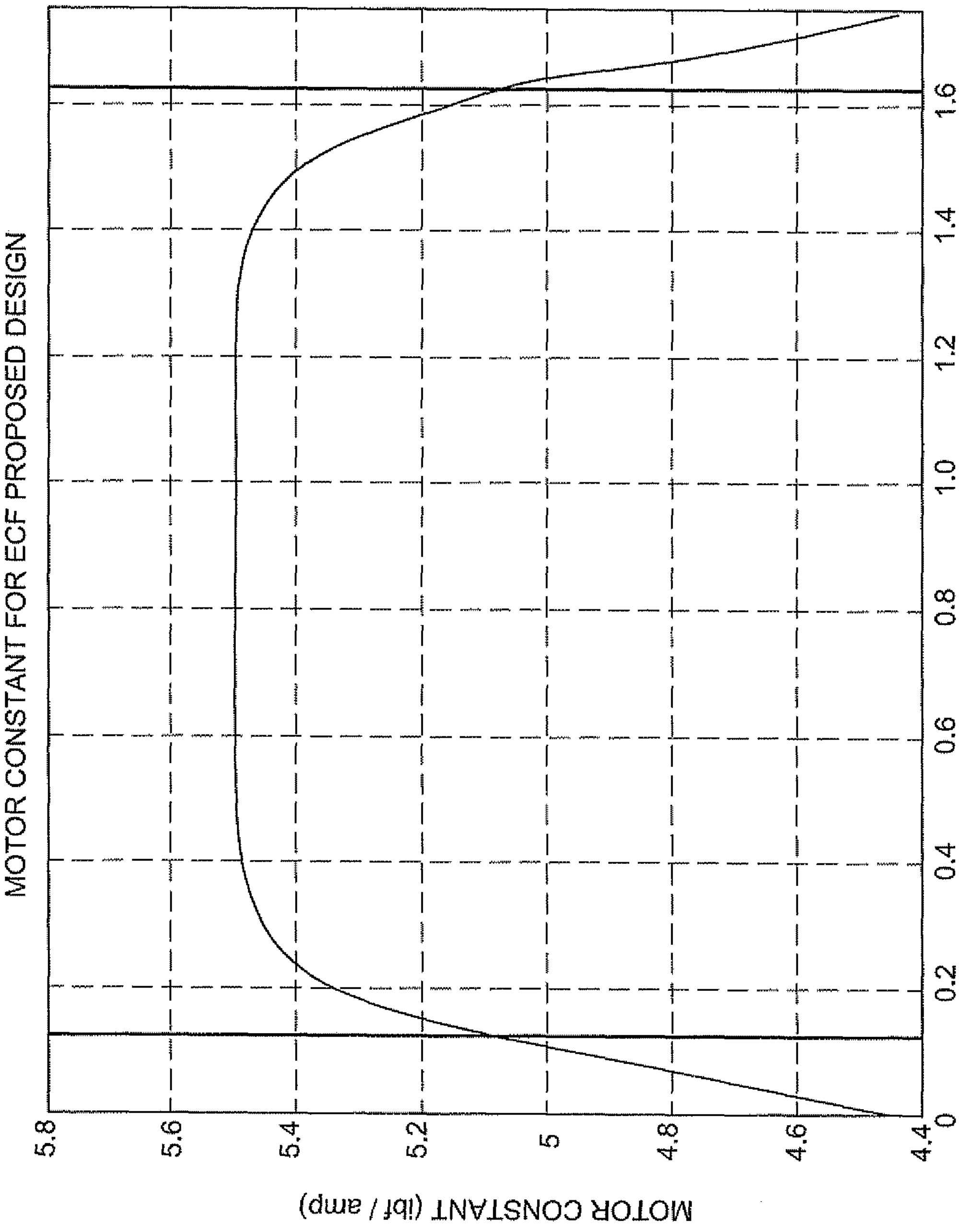

MOTOR CONSTANT FOR ECF PROPOSED DESIGN
MOTOR CONSTANT (lbf / amp)
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
MOTOR STROKE (inch)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

FIG. 41

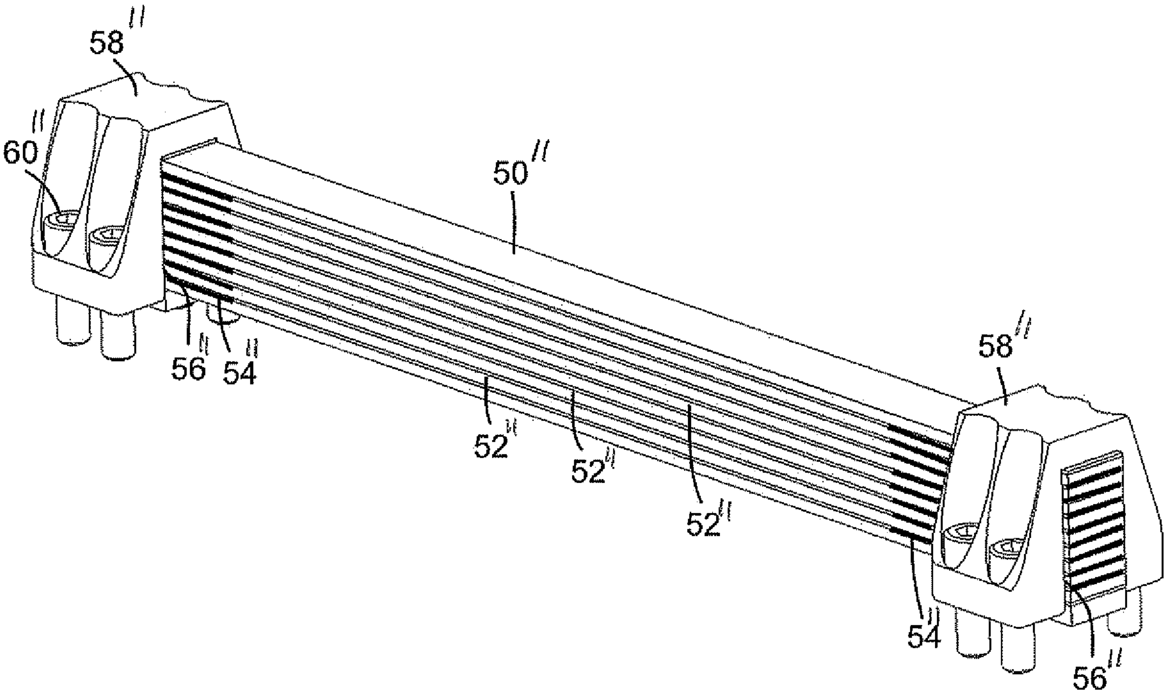


FIG. 42

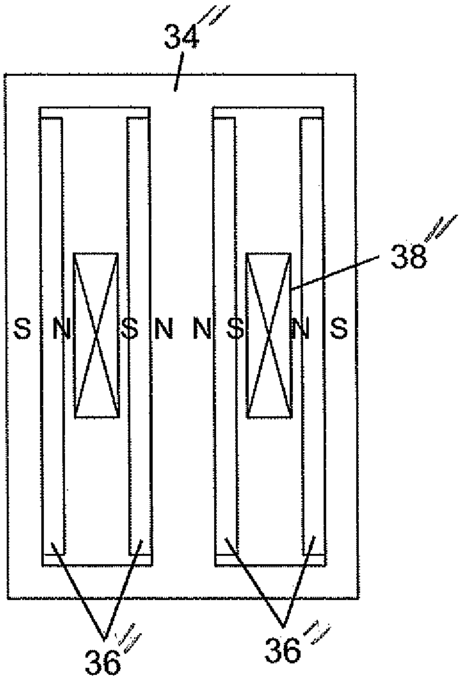


FIG. 43A

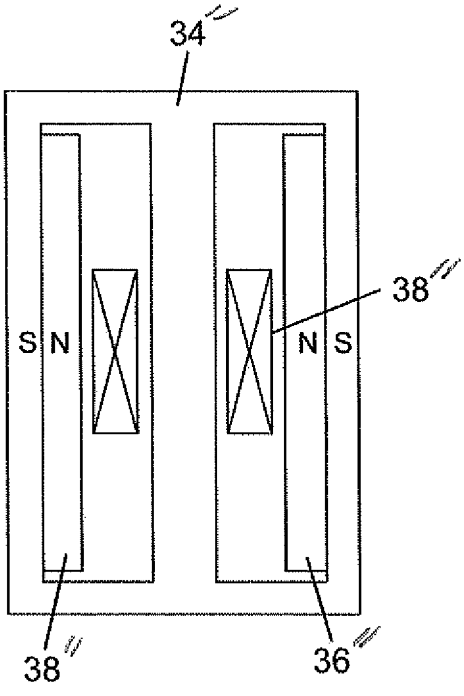


FIG. 43B

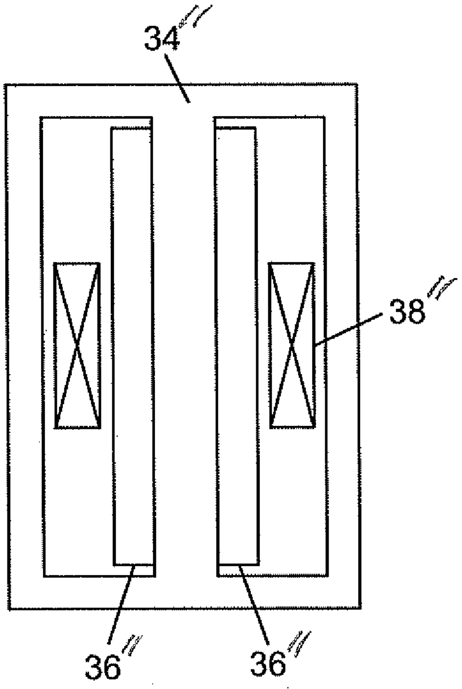


FIG. 43C

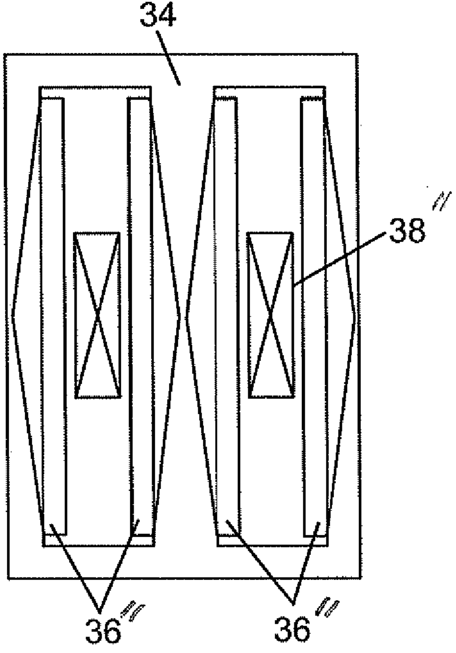


FIG. 43D

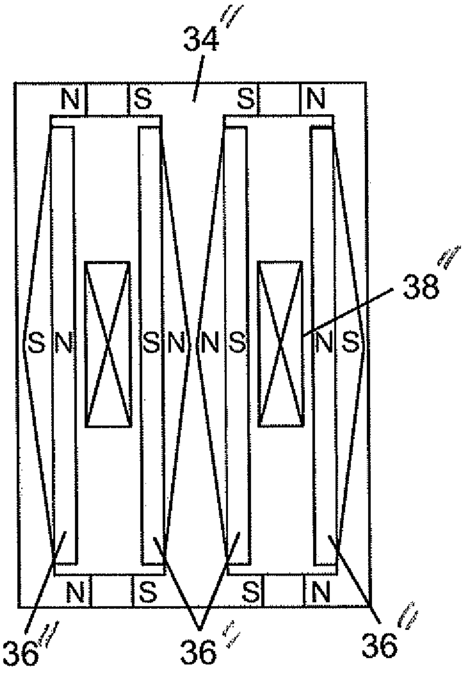


FIG. 43E

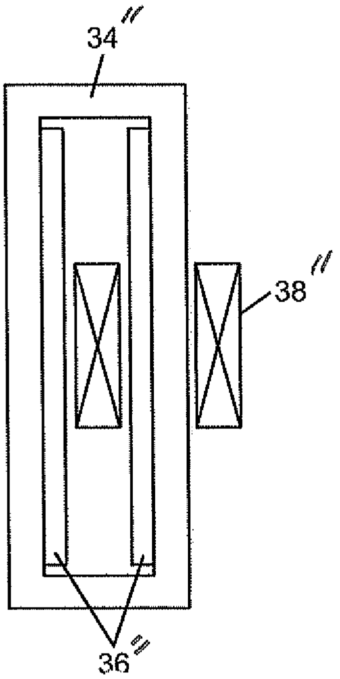


FIG. 43F

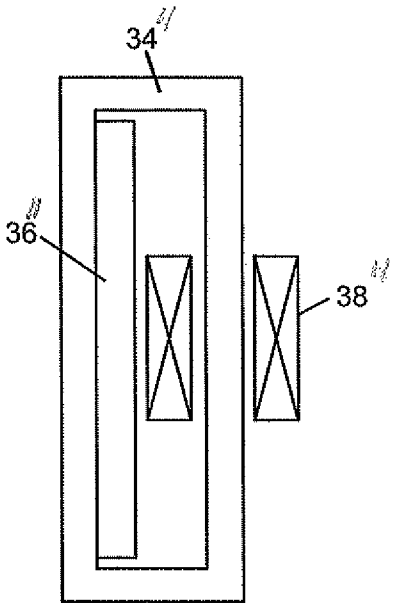


FIG. 43G

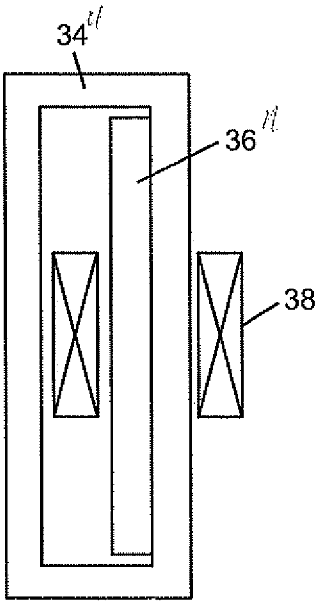


FIG 43 H

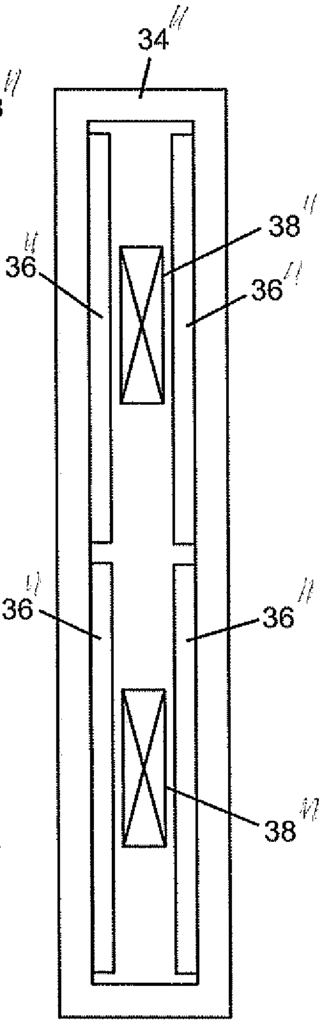


FIG. 43 K

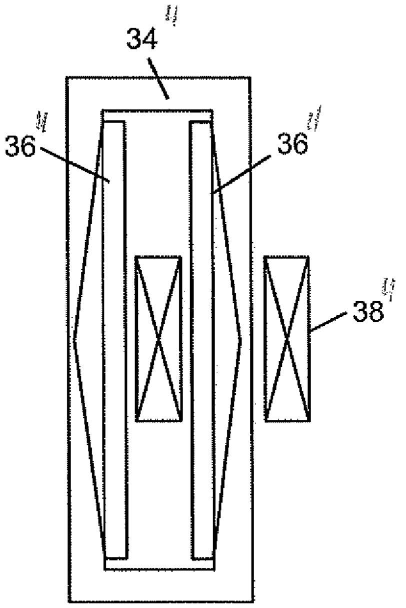


FIG. 43 I

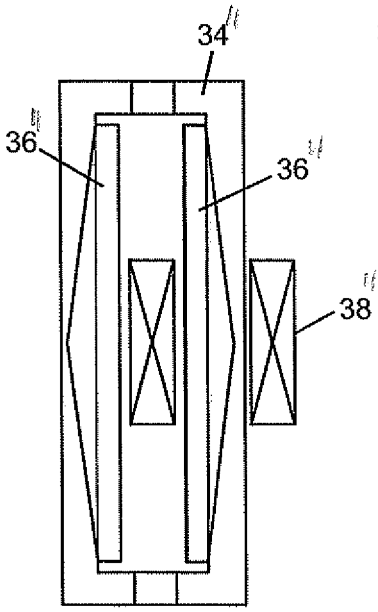


FIG. 43 J

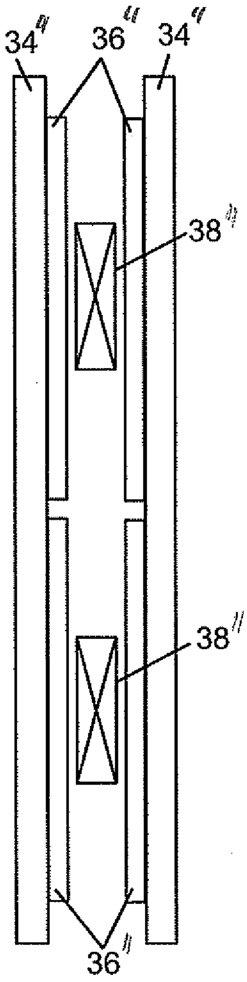


FIG. 43L

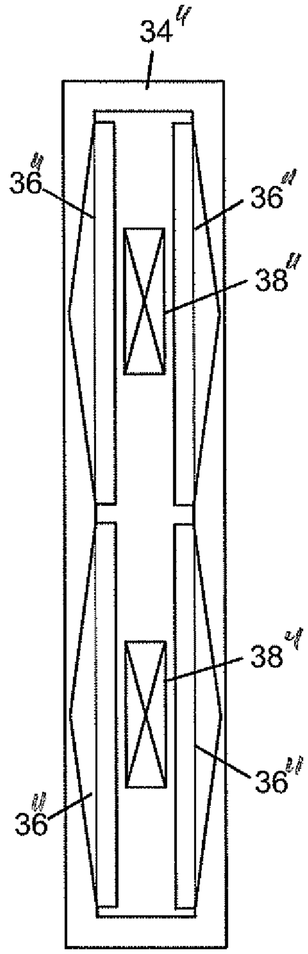


FIG. 43M

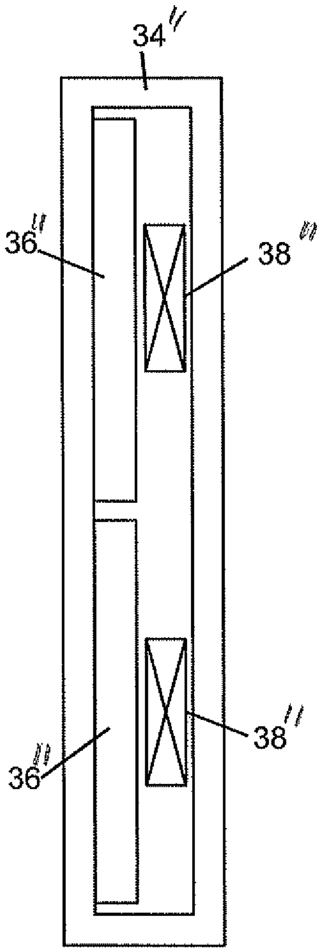


FIG. 43N

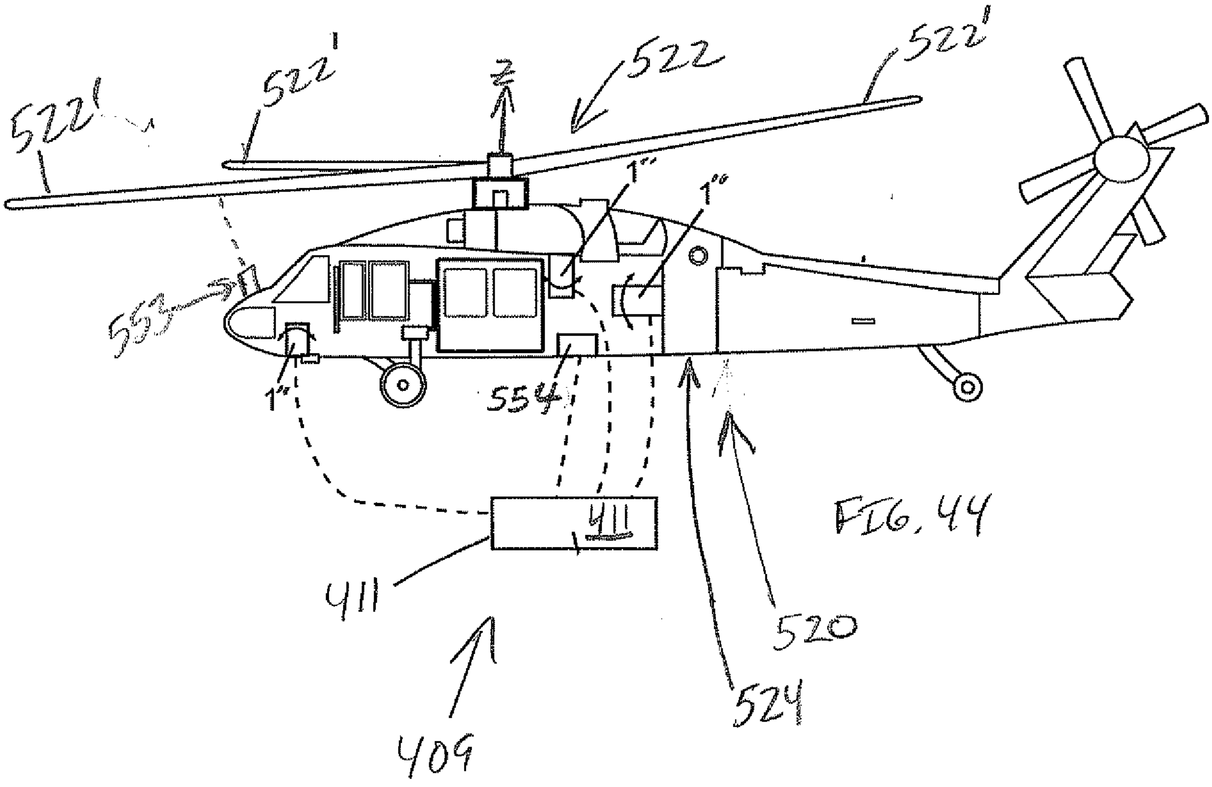


FIG. 44

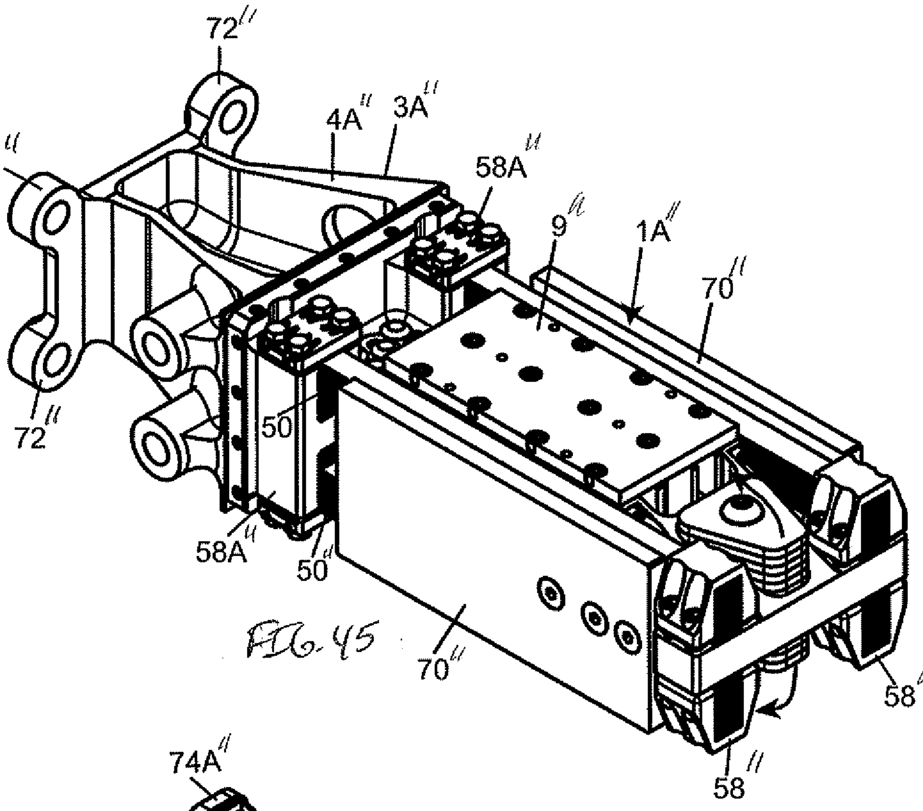

72''
72''
4A''
3A''
58A''
9''
1A''
70''
50
72''
58A''
50''
70''
58''
58''

FIG. 45

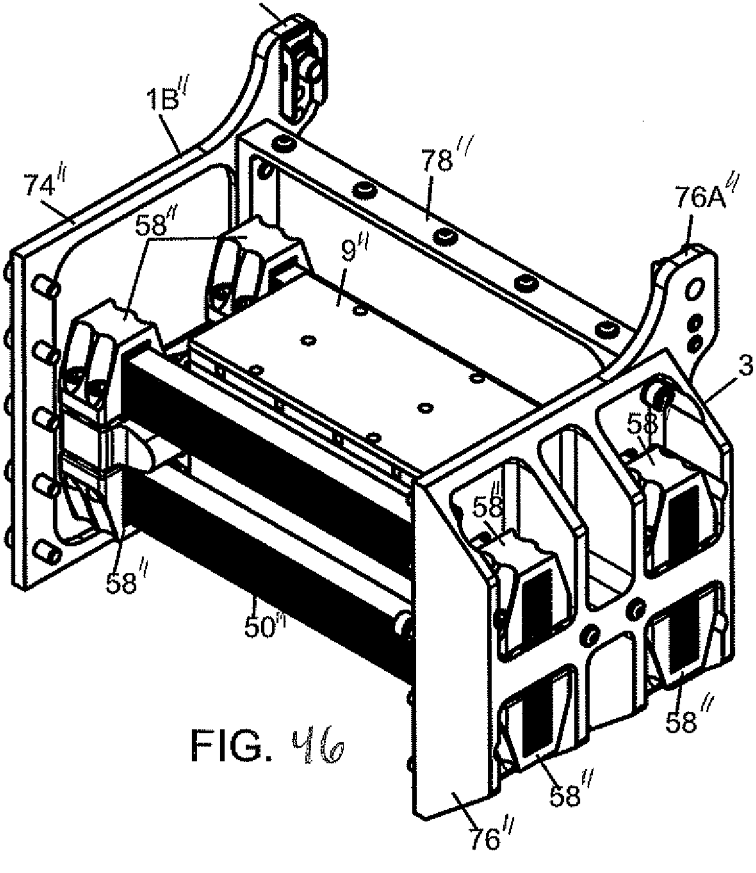

74A''
1B''
78''
74''
58''
9''
76A''
3B''
58''
58''
58''
50''
58''
58''
76''

FIG. 46

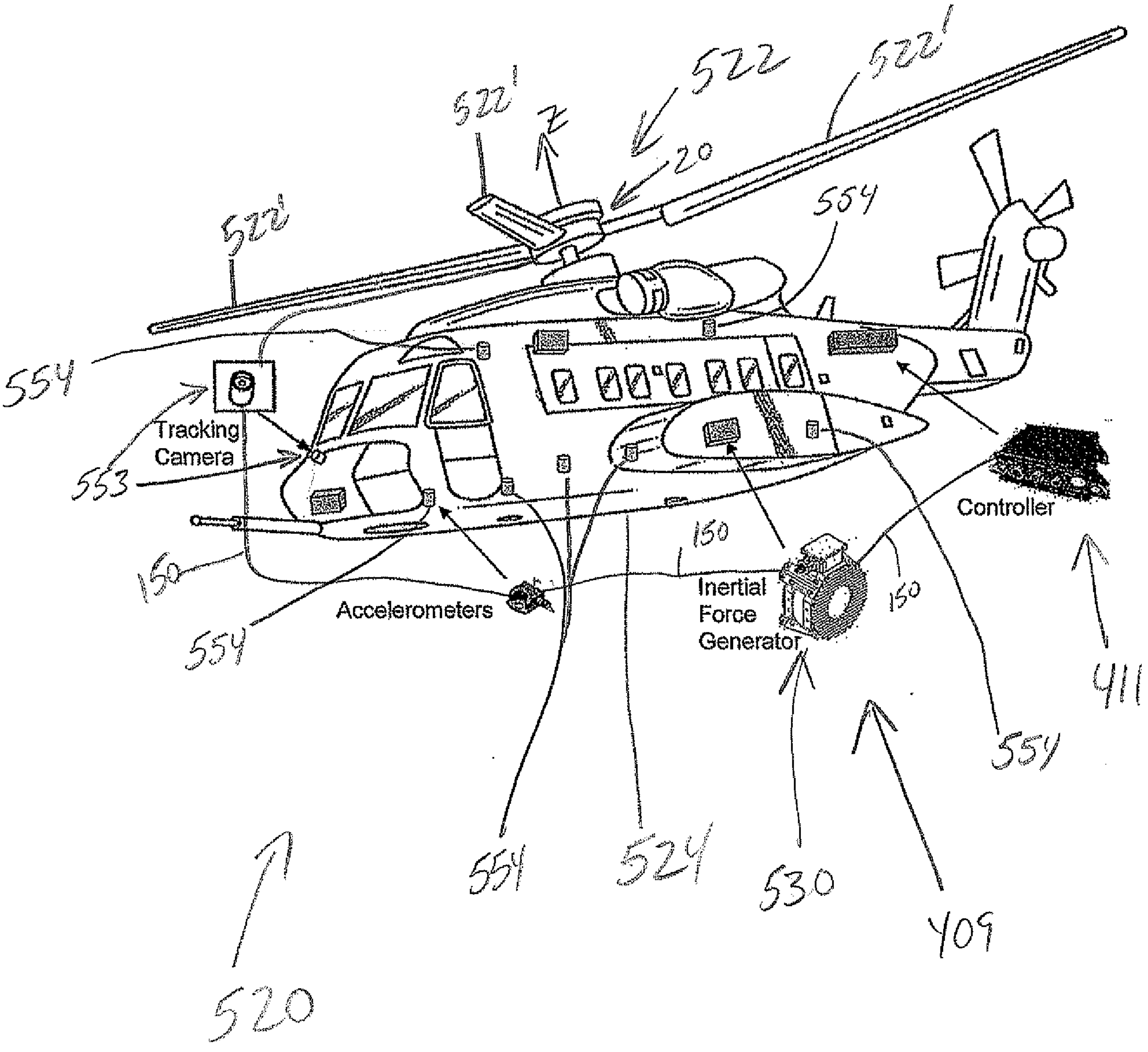
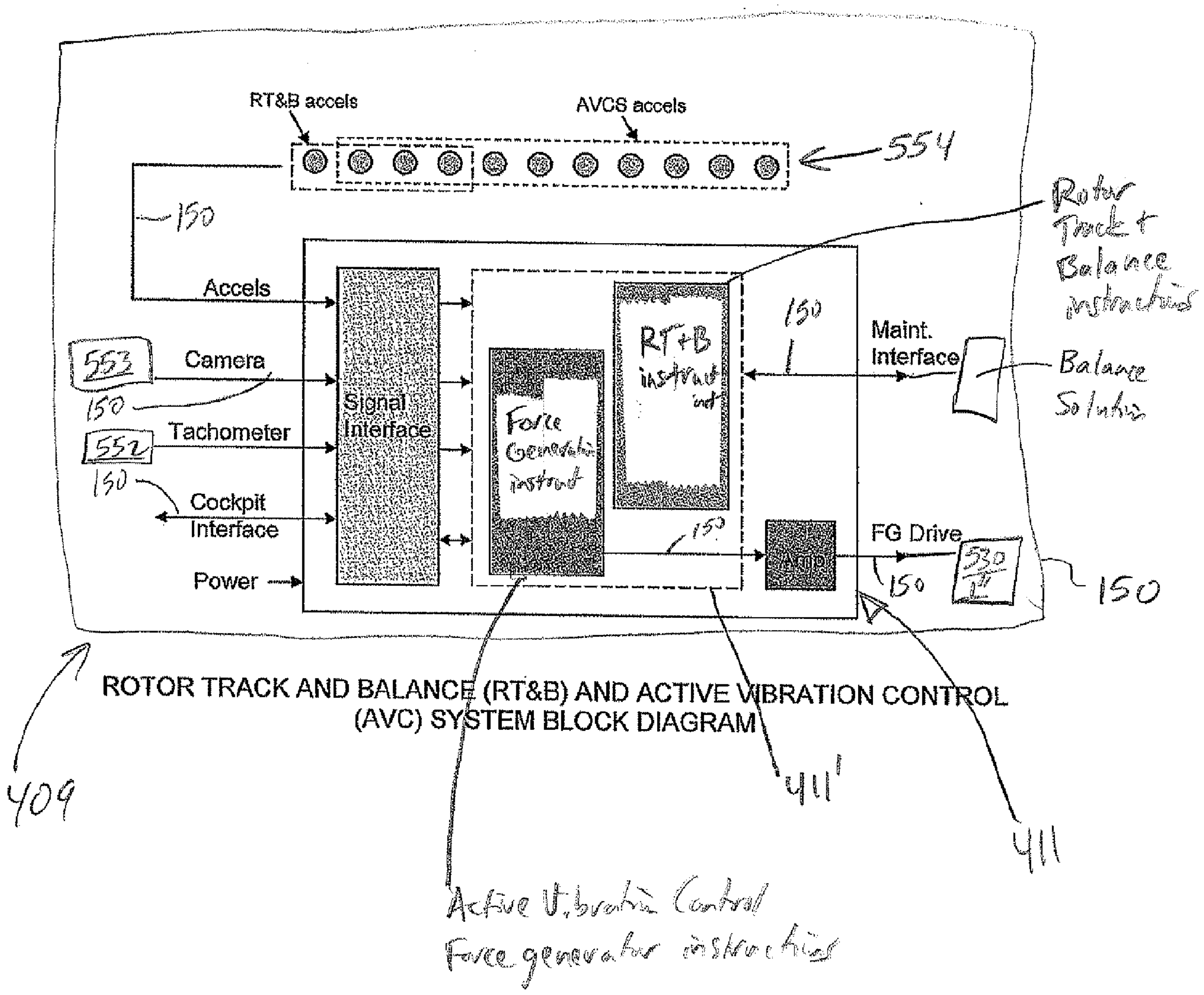

522'
522
522'
522'
Z
20
554
554
Tracking Camera
553
553
150
Accelerometers
554
150
Inertial Force Generator
150
Controller
554
411
554
524
530
409
520

FIG. 47



ROTOR TRACK AND BALANCE (RT&B) AND ACTIVE VIBRATION CONTROL (AVC) SYSTEM BLOCK DIAGRAM

FIG. 48