OPIC
Office de la propriété intellectuelle du Canada

CIPO
Canadian Intellectual Property Office

(12) (19) (CA) **Demande-Application**

(21) (A1) **2,336,281**

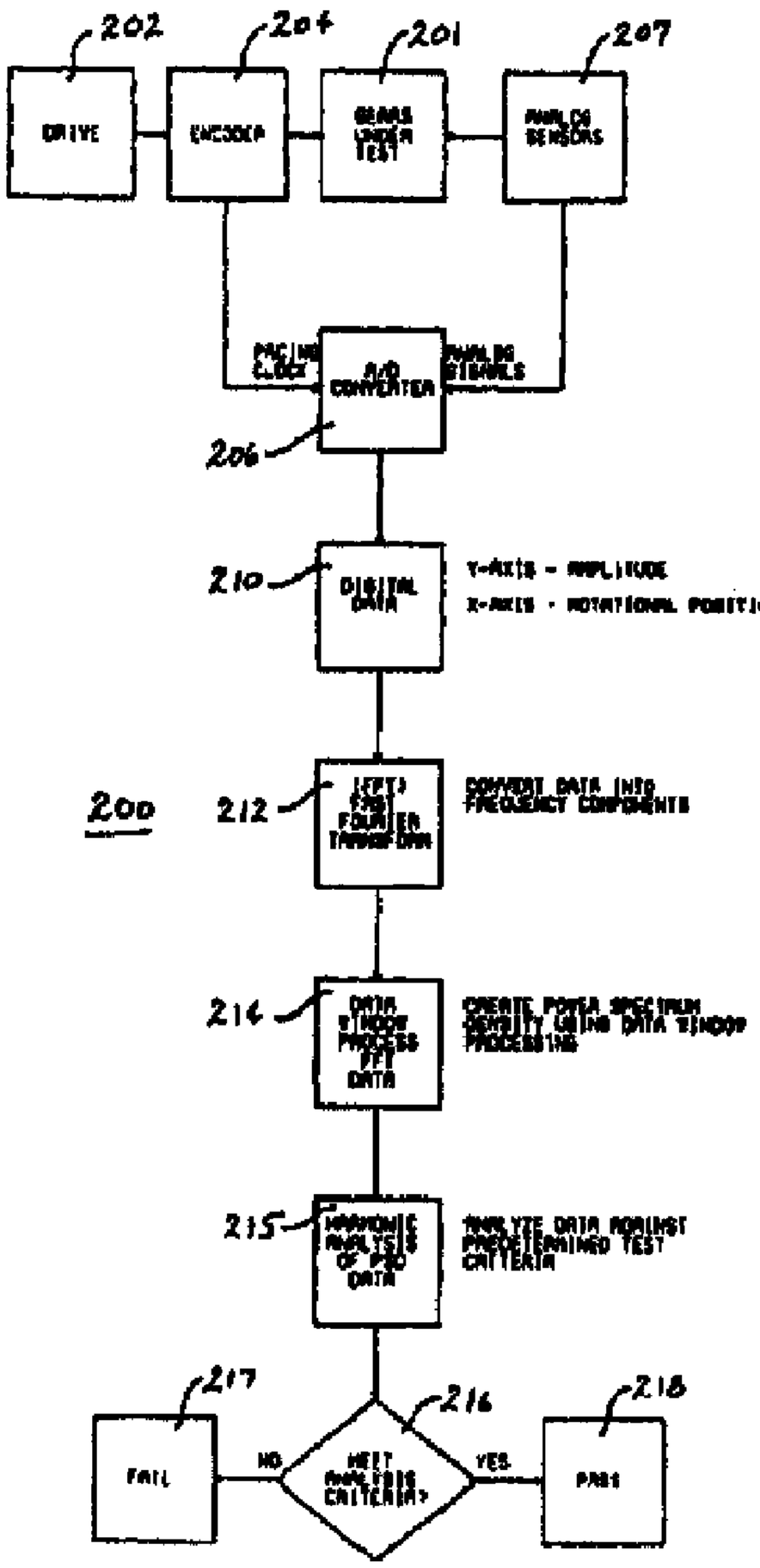
(86) 1999/06/29
(87) 2000/01/06

(72) JURANITCH, JAMES C., US
(72) LEWIS, ERIC J., US
(72) THEISZ, LAWRENCE C., US
(71) VERI-TEK, INC., US

(51) Int.Cl.[6] G01M 13/02
(30) 1998/06/29 (09/107,096) US

(54) SYSTEME DE TRAITEMENT DU SIGNAL DESTINE A UN DISPOSITIF DE TRANSFERT D'ENERGIE SOUMIS A UN TEST

(54) SIGNAL PROCESSING SYSTEM FOR ENERGY TRANSFER ARRANGEMENT UNDER TEST



OPIC
Office de la propriété intellectuelle du Canada

CIPO
Canadian Intellectual Property Office

(21) (A1) 2,336,281
(86) 1999/06/29
(87) 2000/01/06

(57) Des procédés et un appareil utilisés pour l'analyse du signal permettent de déterminer si un système mécanique soumis à un test est classé comme correct ou incorrect au niveau de la bruyance, particulièrement du fait de la présence de bosses et d'indentations dans des systèmes de train d'engrenages soumis à un test. Dans un aspect du processus, destiné à un système d'engrenages, une entrée de couple est appliquée. Un premier signal de réaction au bruit du système d'engrenage soumis au test est produit, puis converti en données numériques suite à une première corrélation effectuée entre le premier signal et le temps. Des pointes dans les données numériques sont mesurées pour déterminer si elles dépassent une valeur maximale de seuil prédéterminée. Les pointes qui dépassent la valeur maximale de seuil prédéterminée sont soumises à une analyse des harmoniques, dont les résultats sont comparés aux harmoniques des dents d'engrenage pour déterminer si les pointes constituent une anomalie. Une charge est appliquée sur le système d'engrenages soumis au test, cette charge pouvant être modifiée en réponse aux signaux de bruit.

(57) Processes and apparatus for signal analysis enable "pass/fail" determinations to be made with respect to noisiness of a mechanical system under test, particularly the presence of bumps and nicks in gear train systems under test. In a process aspect, for a gear system, a torque input is applied. A first signal responsive to the noise of the gear system under test is produced, which is converted to digital data responsive to a first correlation between the first signal and time. Peaks in the digital data are measured to determine whether they exceed a predetermined threshold magnitude. The peaks that exceed the predetermined threshold magnitude are subjected to harmonic analysis, the results being compared to gear tooth harmonics to determine whether the peaks constitute an anomaly. A load is applied to the gear system under test, the load being controllable in response to the noise signals.

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01M 13/02	A2	(11) International Publication Number: WO 00/00805
		(43) International Publication Date: 6 January 2000 (06.01.00)

(21) International Application Number: PCT/US99/14896

(22) International Filing Date: 29 June 1999 (29.06.99)

(30) Priority Data:
09/107,096 29 June 1998 (29.06.98) US

(63) Related by Continuation (CON) or Continuation-in-Part (CIP) to Earlier Application
US 09/107,096 (CON)
Filed on 29 June 1998 (29.06.98)

(71) Applicant *(for all designated States except US)*: VERI–TEK, INC. [US/US]; 24395 Indoplex Circle, Farmington Hills, MI 48395 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: JURANITCH, James, C. [US/US]; 2251 Shankin, Walled Lake, MI 48390 (US). LEWIS, Eric, J. [US/US]; 11767 Burgoyne, Brighton, MI 48114 (US). THEISZ, Lawrence, C. [US/US]; 16268 Houghton, Livonia, MI 48154 (US).

(74) Agents: ROHM, Benita, J. et al.; Rohm & Monsanto, P.L.C., Suite 1525, 660 Woodward Avenue, Detroit, MI 48226 (US).

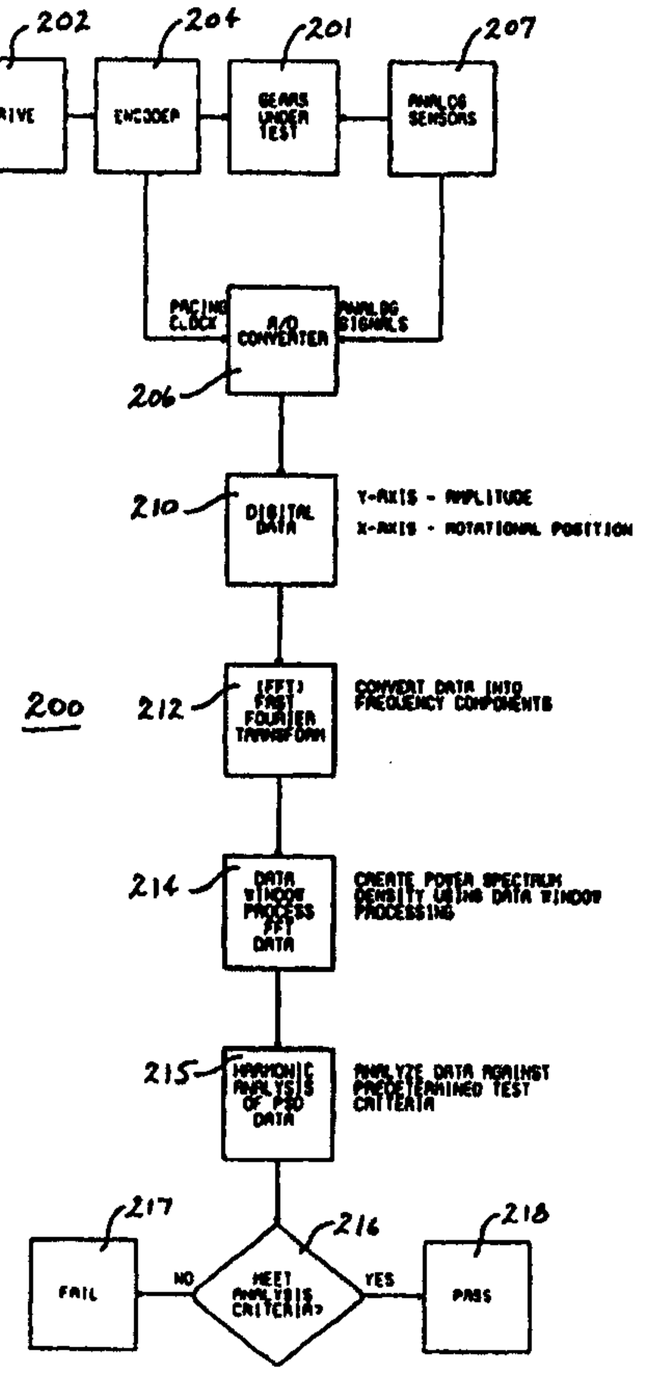
(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: SIGNAL PROCESSING SYSTEM FOR ENERGY TRANSFER ARRANGEMENT UNDER TEST

(57) Abstract

Processes and apparatus for signal analysis enable "pass/fail" determinations to be made with respect to noisiness of a mechanical system under test, particularly the presence of bumps and nicks in gear train systems under test. In a process aspect, for a gear system, a torque input is applied. A first signal responsive to the noise of the gear system under test is produced, which is converted to digital data responsive to a first correlation between the first signal and time. Peaks in the digital data are measured to determine whether they exceed a predetermined threshold magnitude. The peaks that exceed the predetermined threshold magnitude are subjected to harmonic analysis, the results being compared to gear tooth harmonics to determine whether the peaks constitute an anomaly. A load is applied to the gear system under test, the load being controllable in response to the noise signals.



WO 00/00805 PCT/US99/14896

Signal Processing System for Energy Transfer Arrangement Under Test

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates generally to systems for testing electrical and mechanical energy transfer systems that exhibit vibratory and other responses to electrical or mechanical input energy, and more particularly, to an arrangement that isolates a mechanical or electrical system under test and produces signals and data corresponding to a plurality of operating characteristics of the system under test in response to the input energy.

DESCRIPTION OF THE RELATED ART

Noise testing of gears to date has been attempted by methods that rigidly mount the gear or axle assemblies in one or more planes. Some other previous attempts chose to have one of the rigidly mounted planes resonate at a frequency sympathetic to gear noise. None of these methods, or any other rigidly mounted test system has been successful. This is due to the lack of repeatability of the previous systems, largely as a result of interacting resonances, and external background noise that is transferred through the rigid mounting system. This is especially true in a production test environment.

These deficiencies in the prior art are most evident in the axle industry. At this time, the only widely accepted way of measuring gear noise is to acquire an assembled axle and install it in a test car. A specially trained individual then drives the car over its typical operating range while carefully listening for axle gear noise. The individual rates the quality of axle gear noise on a scale that is typically 0 to 10. Ten is usually a perfect axle, *i.e.* one that has no gear noise. This method is made difficult by:

1. The lack of available trained noise rating individuals
2. The cost of test cars.
3. The lack of quality roads or test tracks on which to perform a repeatable and accurate test.
4. The time required for each test.
5. The subjectivity that humans bring into the rating system

Typically less than a dozen axles can be tested by a major manufacturer in one shift due to all of the above complications. This low number is not statistically valid when it is considered that most manufacturers make thousands of axles each day. Even with all of the above problems, human testers in cars are the only widely accepted method of axle testing in the industry due to the lack of a better more reliable testing method. This lack of a scientific basis for rating axles and gear systems is made worse when the reader considers that modern cars are extremely quiet, and are evolving to become more quite. This market direction increases the pressure on axle and other gear manufacturers to make their products quieter. There is a need for a system that offers gear and axle manufacturers a repeatable, reliable, accurate and practical way of measuring gear noise in production or laboratory environments.

It is, therefore, an object of this invention to provide a system for testing an energy transfer system, such as a vehicle axle, quickly and inexpensively, and achieving repeatable results.

SUMMARY OF THE INVENTION

The foregoing and other objects are achieved by this invention which provides, in a first method aspect thereof, a method of signal analysis for processing information from a gear system under test. This further method aspect includes the steps of:

driving the gear system under test by application of a rotatory input;

producing a first signal responsive to the torque applied to the gear system under test;

producing first digital data responsive to a first correlation between the first signal and time;

measuring peaks in said first digital data to determine whether the peaks exceeds a predetermined threshold magnitude; and

first subjecting those of the peaks that exceed the predetermined threshold magnitude to harmonic analysis.

In a specific illustrative embodiment of the invention of this further method aspect, there is provided the further step of comparing the result of the harmonic analysis of the step of first subjecting against gear tooth harmonics to determine whether the peaks constitute an anomaly. Such an anomaly is a bump or a nick on a tooth of the gear system under test.

In a highly advantageous embodiment of the invention wherein improved results are obtained, there are provided the further steps of:

producing a second signal responsive to a noise produced by the gear system under test in response to the step of driving;

producing a second digital data responsive to a second correlation between the second signal and time;

identifying peaks in the second digital data that are simultaneous with peaks in said first digital data;

measuring the simultaneous peaks in the second digital data to determine whether they exceed a second predetermined threshold magnitude; and

second subjecting those of the simultaneous peaks in the second digital data that exceed the second predetermined threshold magnitude to harmonic analysis.

In a further embodiment of the invention, there is provided the step of applying a load to the gear system under test. Preferably, there is provided the further step of controlling the loading applied to the gear system under test, and such control can be responsive to the second signal.

As is the case in the embodiment where only the torque signal is subjected to harmonic analysis, there is additionally provided in this embodiment the further step of comparing the result of the harmonic analysis of the steps of first subjecting and second subjecting against gear tooth harmonics to determine whether the simultaneous peaks constitute an anomaly. Thus, in this embodiment, the torque and the noise signals are subjected to harmonic analysis. It is desired in an embodiment of the invention that is used to test gear systems, to determine whether the anomaly is a bump or a nick on a tooth of the gear system under test. In a further step of calculating, the severity of the anomaly determined in the step of comparing is determined.

In a still further embodiment of this method aspect, there are provided the further steps of:

establishing predetermined harmonic criteria; and

determining whether the results of the analysis in the step of subjecting conforms to the predetermined harmonic criterial of the step of establishing.

In accordance with a still further method aspect of the invention, there is provided a method of signal analysis for processing information from a gear system under test for determining the presence of bumps or nicks therein. In this still further method aspect, there are provided the steps of:

driving the gear system under test by application of a rotatory input;

producing a first signal responsive to the torque applied the gear system under test;

producing a second signal responsive to a noise produced by the gear system under test in response to the step of driving;

producing first digital data responsive to a first correlation between the first signal and time;

producing a second digital data responsive to a second correlation between the second signal and time;

identifying simultaneous peaks in the first and second digital data;

measuring the simultaneous peaks in the first and second digital data to determine whether they exceed a predetermined threshold magnitude; and

subjecting those of the simultaneous peaks that exceed the predetermined threshold magnitude to harmonic analysis.

The further method aspect of the invention can be performed exclusively with the torque signal, in certain embodiments of the invention.

In one embodiment of this method aspect, there is provided the further step of comparing the result of the harmonic analysis of the step of subjecting against gear tooth harmonics to determine whether the simultaneous peaks constitute an anomaly. In a further embodiment, there is provided the further step of calculating the severity of the anomaly of the step of comparing.

In accordance with a yet further method aspect of the invention, there is provided a method of testing a gear assembly of the type having an input and an output, the method having the steps of:

installing the gear assembly on a mounting arrangement that resiliently permits motion of the gear assembly in a plurality of directions, and that has a resilient frequency characteristic that excludes all natural frequencies of the gear assembly;

applying a torque at the input of the gear assembly, whereby the gear assembly is rotatably operated;

applying a load at the output of the gear assembly;

sensing a predetermined operating characteristic of the gear assembly;

producing a first signal responsive to the predetermined operating characteristic of the gear assembly;

producing a second signal responsive to a noise produced by the gear assembly in response to said step of applying a torque;

producing digital data responsive to a correlation between the first and second signals;

converting the digital data into corresponding frequency components;

subjecting the frequency components to analysis to determine a power spectrum density of the frequency components; and

subjecting the power spectrum density to harmonic analysis.

In one embodiment of this method aspect of the invention, the step of sensing is provided with the step of detecting acoustic energy issued by the gear assembly. Also, the step of detecting acoustic energy issued by the gear assembly is provided with the step of placing a microphone n the vicinity of the gear assembly.

In a further embodiment, the step of sensing is provided with the step of detecting vibratory displacement energy issued by the gear assembly. The step of detecting vibratory displacement energy issued by the gear assembly is provided with the further step of effecting communication between an accelerometer and the gear assembly, and the step of detecting vibratory displacement energy issued by the gear assembly is

provided with the further step of effecting communication between a velocity sensor and the gear assembly.

Sensing is effected by monitoring a first sensor that receives acoustic energy that is responsive to a qualitative condition of the gear assembly in a drive mode of operation. When the drive mode of operation is in a first direction of operation, the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a first surface of the teeth of the gear assembly. Also when drive mode of operation is in a first direction of operation, the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a profile of a gear of the gear assembly, and a qualitative condition of the eccentricity of a gear of the gear assembly. Additionally, the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of the angular orientation of the gears of the gear assembly. In still further embodiments of the method aspect of the invention, wherein the drive mode of operation is in a first direction of operation, the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a plurality of moving components of the gear assembly.

In a further embodiment of the invention, the step of sensing is provided with the further step of monitoring a second sensor that receives acoustic energy that is responsive to a qualitative condition of the gear assembly in a coast mode of operation. The coast mode of operation includes a qualitative condition of a second surface of the teeth of the gear assembly. When the coast mode of operation is in a first direction of operation, the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of a profile of a gear of the gear assembly. Additionally, the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of the eccentricity of a gear of the gear assembly, as well as the angular\ orientation of the gears of the gear assembly. In further embodiments, the coast mode of operation includes a qualitative condition of a plurality of moving components of the gear assembly.

In accordance with a further embodiment of this method aspect of the invention, the drive and coast modes of operation are cyclical over a period that is shorter than a

cycle period of the input of the gear assembly. Conversely, the period can be longer than a cycle period of the input of the gear assembly. This will depend, to an extent, upon the operating ratios within the system under test. In situations where the system under test is an electrical system, harmonics and signal distortions may affect the apparent cycle period in relation to the cycle period of the input energy.

In an advantageous embodiment, the first and second sensors are disposed at respective locations that are distal from each other, with the gear assembly interposed therebetween. This enables distinguishing between operating modalities of the system under test, as well as facilitating analysis of operating characteristics of the system under test that have directional components.

In accordance with an apparatus aspect of the invention, an arrangement is provided for isolating an energy transfer system while it is subjected to a test process for noise, the energy transfer system being of the type having an energy input and at least one energy output. In accordance with the invention, the arrangement is provided with a base for supporting the arrangement and the energy transfer system. An isolation support supports the energy transfer system whereby the energy transfer system is translatable in at least one plane of freedom with respect to the base. Additionally, an engagement arrangement is provided for securing the energy transfer system to the isolation support. There is additionally provided a first acoustic sensor arranged at a first location in the vicinity of the energy transfer system for producing an electrical signal responsive to a noise produced by the energy transfer system under test. A first converter produces digital data responsive to the electrical signal, and a second converter converts the digital data into corresponding frequency components. A processor subjects the frequency components to analysis to determine a power spectrum density of the frequency components, and subjects the power spectrum density to harmonic analysis

In one embodiment, there is further provided an energy supply coupled to the energy transfer system for supplying energy thereto. The energy transfer system is, in one embodiment of the arrangement of the present invention, a mechanical energy transfer system, and in such an embodiment, the energy supply, which is a part of the arrangement of the invention, is in the form of a source of rotatory mechanical energy.

A rotatory coupler couples the source of rotatory mechanical energy to the energy transfer system.

In a highly advantageous embodiment of the invention, the mechanical energy transfer system test has forward and reverse directions of operation, and drive and coast modes of operation for each of the forward and reverse directions of operation. The mechanical energy transfer system contains at least a pair of meshed elements, at least one of the pair of meshed elements being a gear having a plurality of gear teeth thereon, the gear teeth each having first and second gear tooth surfaces for communicating with the other element of the pair of meshed elements. A mechanical energy transfer communication between the pair of meshed elements is effected primarily via the respective first gear tooth surfaces during forward-drive and reverse-coast modes of operation, and primarily via the respective second gear tooth surfaces during forward-coast and reverse-drive modes of operation. With such a system under test, the arrangement of the present invention is provided with a first acoustic sensor arranged at a first location in the vicinity of the mechanical energy transfer system for producing a first signal that is responsive substantially to a qualitative condition of the first gear tooth surfaces. A second acoustic sensor is arranged at a second location in the vicinity of the mechanical energy transfer system, and produces a second signal that is responsive substantially to a qualitative condition of the second gear tooth surfaces. The first and second locations are distal from each other on opposite sides of the pair of meshed elements.

A torque sensor advantageously is interposed, in a highly advantageous embodiment, between the source of rotatory mechanical energy and the energy transfer system. The torque sensor produces a signal that is responsive to a torque applied by the source of rotatory mechanical energy to the energy transfer system. The torque sensor is provided with a torque-transmitting element that has a predetermined deformation characteristic. Thus, the torque-transmitting element becomes deformed in response to the torque that is applied by the source of rotatory mechanical energy to the energy transfer system. In this embodiment of the invention, the torque sensor further is provided with a strain sensor that is coupled to the torque-transmitting element for

producing a strain signal responsive to the predetermined deformation characteristic of the torque-transmitting element. The strain signal, therefore, is proportional to the torque.

It is very advantageous to determine the residual torque required to initiate motion of the system under test. The torque sensor is therefore arranged to produce a static torque signal that is responsive to the magnitude of the torque required to initiate rotatory motion in the mechanical energy transfer system. In addition, it is advantageous that the torque sensor be arranged to produce a dynamic torque signal that is responsive to the magnitude of torque required to maintain rotatory motion in the mechanical energy transfer system.

In a further embodiment of the invention, the energy transfer system under test is an electrical energy transfer system, and the energy supply is provided with a source of electrical energy. In such an embodiment, there is provided an electrical load for receiving an output electrical energy from the energy transfer system. A first sensor is arranged to communicate with the energy transfer system for producing an information signal that is responsive to an operating characteristic of the energy transfer system in response to the energy supplied by the energy supply. The first sensor is arranged to contact the energy transfer system to produce the signal. Alternatively, the first sensor is arranged to contact the isolation support for producing the information signal.

When it is desired to monitor an acoustic energy emitted by the system under test, a microphone is provided for producing a signal that is responsive to an acoustic energy issued by the energy transfer system in response to the energy supplied by the energy supply. A laser sensor may additionally be provided for producing a signal that is responsive to a displacement of the energy transfer system in response to the energy supplied by the energy supply. In still further embodiments, an accelerometer or a velocity sensor is employed.

The resilient support element that supports the energy transfer system, in a preferred embodiment of the invention, is configured to exclude a natural frequency of any combination of the base, the engagement arrangement, and the energy transfer system. Thus, the vibratory or acoustic energy provided by the system under test

constitutes all of the energy that would be measured and analyzed, without contribution or modification thereof by the structure of the support system.

In a further embodiment, there is provided a thermal sensor for producing a thermal signal that is responsive to a temperature of the energy transfer system. The thermal sensor may be in the form of an infrared sensor that communicates optically with the energy transfer system. In one specific illustrative embodiment of the invention, the thermal sensor means has a directional characteristic and is directed to a predetermined region of the energy transfer system for determining a rate of change of temperature of the predetermined region with respect to time. In this embodiment, there is provided an acoustic sensor sensitivity control arrangement that is responsive to the thermal sensor for varying the amplitude of a noise signal in response to temperature. The variation of the amplitude of the noise signal with respect to temperature is performed in accordance with a non-linear amplitude-temperature relationship.

BRIEF DESCRIPTION OF THE DRAWING

Comprehension of the invention is facilitated by reading the following detailed description, in conjunction with the annexed drawing, in which:

Fig. 1 is a front plan representation of an arrangement for isolating a system under test, constructed in accordance with the principles of the invention;

Fig. 2 is a side plan view of the embodiment of Fig. 1;

Fig. 3 is an exploded plan representation of the embodiment of Fig. 1 showing certain drive components;

Fig. 4 is a top plan view of the embodiment of Fig. 1;

Fig. 5 is a partially phantom front plan view of a drive arrangement that supplied rotatory mechanical energy to an isolate mechanical energy transfer system under test;

Fig. 6 is side plan view of the drive system of Fig. 5;

Fig. 7 is a side plan representation of the drive system as shown in Fig. 6, enlarged to show greater detail;

Fig. 8 is a side plan view of a coupler that couples the drive system to the mechanical system under test;

Fig. 9 is a top plan view of the coupler of Fig. 8 showing therein three engagement surfaces for coupling with the flanks of an hexagonal nut (not shown in this figure) at the rotatory input of the mechanical system under test;

Fig. 10 is a plan representation of a clamping arrangement constructed in accordance with the principles of the invention, the clamping arrangement being shown in two positions;

Fig. 11 is a compact drive arrangement constructed in accordance with the invention for coupling the rotatory output of a mechanical energy transfer system under test to a rotatory load;

Fig. 12 is a partially cross-sectional side plan view of the compact drive arrangement of Fig. 11 further showing a resilient coupling element;

Fig. 13 is a partially phantom enlarged representation of the resilient coupling element shown in Fig. 12;

Fig. 14 is an isometric representation of an arrangement for isolating a system under test, constructed in accordance with the principles of the invention, the system under test being an electrical energy transfer device;

Fig. 15 is a process diagram of a typical process for conducting an energy analysis;

Fig. 16 is a process diagram of a process for conducting an energy analysis in accordance with the principles of the present invention; and

Fig. 17 is a process diagram of a process for conducting an energy analysis in accordance with the principles of the present invention for determining bumps and nicks in a mechanical energy transfer system.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 is a front plan representation of an arrangement for isolating a system under test, constructed in accordance with the principles of the invention. As shown in this

figure, an isolating arrangement 10 is arranged to support in relative isolation a mechanical drive system in the form of a differential 11. Differential 11 is of the type that is conventionally employed in a motor vehicle (not shown) and is intended to be tested for a variety of operating conditions, using isolating arrangement 10. The differential is of the type having a rotatory input 13 that receives rotatory mechanical energy from a drive arrangement (not shown in this figure) that will be described below. In addition, differential 11 has rotatory outputs 14 and 15, respectively, that produce rotatory mechanical energy in response to the rotatory input energy received at rotatory input 13. When employed in a motor vehicle (not shown), differential 11 is coupled to the drive shaft (not shown) of the vehicle at rotatory input 13, and rotatory outputs 14 and 15 are coupled to the vehicle's drive wheels (not shown).

Differential 11 is shown to be supported on a pair of supports 18 and 19 that are installed on a base 20. Each of supports 18 and 19 has installed thereon a respectively associated one of resilient isolating elements 22 and 23. A respective one of engagement arrangements 24 and 25 are installed on resilient isolating elements 22 and 23. The engagement arrangements will be described in detail hereinbelow and serve to couple differential 11 at its rotatory outputs 14 and 15 whereby it is secured with respect to base 20, yet limited motion of differential 11 is permitted relative to base 20.

Fig. 1 further shows a pair of load arrangements 28 and 29 that apply a controllable load to respectively associated ones of rotatory outputs 14 and 15. The rotatory outputs are coupled mechanically (coupling not shown in this figure) to load arrangements 28 and 29 in a manner that facilitates limited motion of the rotatory outputs with respect to base 20. The permissible displacement of differential 11 in accordance with the present invention is along multiple planes of freedom, and, as will be described hereinbelow, the coupling arrangements (not shown in this figure, between rotatory outputs 14 and 15 and their respective associated load arrangements 28 and 29 permit axial and rotative degrees of freedom of motion. Such couplings will be described with respect to Figs. 9-12.

Fig. 2 is a side plan view of the embodiment of Fig. 1. This figure is taken along line 2-2 of Fig. 1. In addition to some of the structure shown in Fig. 1, Fig. 2 shows a

safety cover 30 that protects the user (not shown) of the isolating arrangement in accordance with established safety standards. Elements of structure that correspond to those discussed hereinabove with respect to Fig. 1 are similarly designated.

Fig. 2 shows engagement arrangement 24 having engagement arms 32 and 33 that are shown in an engaged position around rotatory output 14. As will be described hereinbelow, engagement arms 32 and 33 have engaged and disengaged (not shown) positions in response to actuation of an engagement driver which is shown in this figure in the form of a linear actuator 35.

A safety cover 30 is shown to be coupled to a cover hinge 31, whereby the safety cover is rotatable thereabout in response to actuation of a cover actuator 34. In operation, the safety cover is arranged in the position shown in the figure during performance of the testing procedure, and it is raised to a position that is not shown in order to facilitate installation and removal of the system under test, *i.e.*, differential 11.

Fig. 2 additionally shows a drive motor 40, which in this embodiment, is coupled to a belt pulley 42, shown in Fig. 1.

Fig. 3 is an exploded plan representation of the embodiment of Fig. 1 showing certain drive components. Elements of structure that have previously been discussed are similarly designated. The drive arrangement, and the manner by which it is coupled to differential 11, will be discussed in detail hereinbelow with respect to Figs. 5-8.

Fig. 4 is a top plan view of the embodiment of Fig. 1. Elements of structure that have previously been discussed are similarly designated. Moreover, differential 11 has been removed, and therefore, is not visible in this figure.

In Fig. 4, each of load arrangements 28 and 29 has associated therewith a respective one of load coupler arrangements 44 and 45, each of which is coupled by a respective load belt 46 and 47 to a respective one of load units 48 and 49. Load arrangement 28 will be described in detail hereinbelow with respect to Fig. 11, and the load coupler arrangements, 44 and 45, will be described in detail with respect to Fig. 12. Referring to Fig. 4, rotatory outputs 14 and 15 (not shown in this figure) are coupled (coupling not shown in this figure) to respectively associated ones of load coupler arrangements 44 and 45 which, as previously noted, provide multiple degrees of freedom

of movement. Load units 48 and 49, in this specific illustrative embodiment of the invention, are in the form of electric brakes or electric motors. Of course, other forms of loads can be employed in the practice of the invention. In embodiments of the invention where the load units are in the form of electric motors, such motors can provide simulated braking and driving operations. Thus, in the present embodiment where the isolating arrangement is directed to the testing of a drive component for a vehicle, such as a differential, the load units can be operated in a drag, or generator mode, wherein the differential would be operated in a simulated drive mode. That is, the load is driven by the differential. Alternatively, the load units can be operated in a motor drive mode, wherein the differential is itself driven by the load, *i.e.*, operated in a simulated coast mode. In a highly advantageous embodiment of the invention, the differential can be operated and thereby tested in drive and coast modes of operation in forward and reverse directions. It is to be remembered that during drive and coast modes of operation different gear tooth surfaces (not shown) within the differential are caused to communicate with one another, thereby affording enhanced testing capability.

Fig. 5 is a partially phantom front plan view of a drive arrangement that supplies rotatory mechanical energy to an isolated mechanical energy transfer system under test. Elements of structure that have previously been discussed are similarly designated. As shown in this figure, output shafts 52 and 53 are shown protruding from the fragmented representation of rotatory outputs 14 and 15, respectively. The output shafts rotate in response to the application of a rotatory drive at rotatory input 13.

Fig. 6 is side plan view of the drive system of Fig. 5. The operation of the drive arrangement that will supply a rotatory drive to rotatory input 13 of differential 11 is described herein with reference to Figs. 5-9. As stated, drive motor 40 is coupled via a drive belt 41 to belt pulley 42 which is installed on a drive shaft 55 that is shown in the figures to extend axially vertically. Belt pulley 42 contains a torque sensing arrangement (not shown) that provides an electrical signal responsive to torque differential between the belt pulley and drive shaft 55. The electrical signal responsive to torque (not shown) is available at signal output connector 56.

In this specific illustrative embodiment of the invention, the torque sensing arrangement contained within belt pulley 42 and its associated signal output connector 56 is in the form of a strain gauge (not shown) installed to respond to the displacement of a web (not shown). That is, in the practice of this aspect of the invention, torque is transmitted across a web whereby, for example the torque is applied across the periphery of the web, and an output shaft is coupled nearer to the center of the web. Of course, these may be reversed. As torque is applied, the web is correspondingly deformed, and a strain gauge installed on the web measures the deformity in the web in response to the applied torque. Over a predetermined range of torque, the deformation of the web, as determined by the strain gauge, can be correlated to the magnitude of the applied torque. Signal output connector 56, in this specific illustrative embodiment of the invention, additionally contains circuitry (not shown) that is AC coupled to the torque sensing arrangement, and that modulates and demodulates the resulting torque signal.

Shaft 55 is shown in Fig. 6 to be supported against axially transverse motion by a pair of journal bearings 58. Drive shaft 55, therefore, rotates about its axis in response to a rotatory drive energy supplied by drive motor 40 and delivered thereto by drive belt 41.

A coupling arrangement 60 that is fixed axially onto drive shaft 55 permits resilient axial displacement of a coupling shaft 62 with respect to the axis of drive shaft 55. Coupling arrangement 60 is formed of a flanged member 61 that is coupled to rotate with drive shaft 55. A further flanged member 63 is shown to be engaged with coupling shaft 62. Flanged members 61 and 63 are each provided with respective resilient elements 65 that facilitate the permissible axial displacement of coupling shaft 62 with respect to the central axis defined by drive shaft 55. The rotatory energy is transmitted across intermediate element 67, with which resilient elements 65 communicate.

Fig. 7 is a side plan representation of the drive system as shown in Fig. 6, enlarged to show greater detail. As shown in Figs. 6 and 7, the uppermost end of coupling shaft 62 is arranged to be connected to rotatory input 13 of differential 11 (shown in fragmented form in these figures). Differential 11 is of the conventional type having an hexagonal nut 69 (Fig. 7) installed at rotatory input 13. Rotatory input 13 is

formed as a pinion shaft, and hexagonal nut 13 is threadedly engaged therewith. The application of a high tightening torque to hexagonal nut 13 during assembly of the differential prevents same from loosening during application of the rotatory energy via coupling shaft 62.

Fig. 7 shows differential 11 in the process of being installed onto coupling shaft 62, and therefore hexagonal nut 69 is shown in two positions, where it is designated 69 and 69', respectively. Upon completion of the installation of differential 11, hexagonal nut 69 becomes engaged with a nut driver 70. Nut driver 70 is axially translatable, and therefore is shown in two positions, where it is designated 70 and 70'.

Fig. 8 is a side plan view of nut driver 70 that couples the drive system to the mechanical system under test. Fig. 9 is a top plan view of nut driver 70 of Fig. 8 showing therein three engagement surfaces for coupling with the flanks of an hexagonal nut (not shown in this figure) at the rotatory input of the mechanical system under test. As shown in Fig. 8 and Fig. 9, nut driver 70 has a tapered outward appearance when viewed from the side (Fig. 8). Internally, nut driver 70 is provided with three engagement surfaces 71. The engagement surfaces engage with the flank surfaces of the nut (not shown) at rotatory input 13 of differential 11. The nut driver is, as previously noted, axially displaceable along the axis of coupling shaft 62, and is urged upward toward the nut at the rotatory input of the differential by operation of a resilient spring member 72 (Fig. 6). Thus, the nut driver is urged into communication with the nut by operation of the light resilient bias supplied by spring 72, thereby ensuring engagement between nut driver 70 and the hexagonal nut (not shown in Figs. 8 and 9) at the rotatory input of differential 11. It is to be noted that the light axial bias applied by the engagement spring is negligible and affords the differential a degree of freedom of movement in the axial direction.

Referring once again to Fig. 7, sensors 73-76 are shown for monitoring various aspects of the operation of the differential in response to the application of the rotatory input. For example, in one embodiment of the invention, the various sensors are configured to monitor angular position of the rotatory input, transaxial displacement of the drive shaft, transaxial displacement of the differential in response to the application

of the rotatory input energy, temperature in the region of the input bearing (not shown) of the differential, acoustic noise, *etc.*

Fig. 10 is a plan representation of a clamping arrangement constructed in accordance with the principles of the invention, the clamping arrangement being shown in two positions. Elements of structure that correspond to those previously described are similarly designated. As shown, support 18 is coupled to base 20, illustratively via one or more fasteners 140. In this embodiment, a pair of resilient support elements 141 are disposed on support element 18 and there is supported thereon an isolation support 142. The isolation support has a central V-shaped region 144 in the vicinity of which are installed support bearings 146 and 147. Rotatory output 14 of differential 11 (not shown in this figure) rests on the support bearings.

Engagement arms 32 and 33, as previously noted, have first and second positions corresponding to open and closed conditions. Engagement arms 32 and 33 are shown in the closed condition, wherein rotatory output 14 is clamped to support bearings 146 and 147. When the support arms are in the open position, identified as 32' and 33' (shown in phantom), the differential can be removed or installed onto isolation support 142. Actuation of the engagement arms between the open and closed conditions is effected by operation of linear actuator 35 which is coupled to the engagement arms by respectively associated ones of engagement coupler links 148 and 149. Engagement coupler links 148 and 149 are each coupled at a respective first ends thereof to a respectively associated one of engagement arms 32 and 33, and they each are coupled to one another at a central pivot coupling 150. An armature 151 of linear actuator 35 travels vertically to effect clamping and release of rotatory output 14.

When armature 151 is extended upward, engagement arms 32 and 33 are urged toward rotatory output 14, whereby spring-loaded contacts 152 and 153 communicate with rotatory output 14. In this embodiment, the spring-loaded contacts exert a resilient biased force against rotatory output 14 facilitating the latching of the engagement arms by operation of armature 151. As shown, when the armature is extended fully upward, engagement coupler links 148 and 149 are urged beyond the point where their respective axes are parallel, and therefore, the engagement coupler links are biased against the

underside of isolation support 142. It should be noted that the pivot pin (not specifically shown) coupled to armature 151 at pivot coupling 150 has a smaller diameter than the apertures in the engagement coupler links. Thus, during testing of the vibration and noise of the differential, armature 151 of linear actuator 35 is essentially decoupled from engagement coupler links 148 and 149 and isolation support 142.

When it is desired to remove differential 11 from isolating arrangement 10, armature 151 is withdrawn, whereupon pivot coupling 150 is translated to the location identified as 150'. In this position, the engagement arms are translated to the location shown in phantom as 32' and 33'.

In a further embodiment of the invention, one or both of spring-loaded contacts 152 and 153 is provided with a displacements sensor 154 that produces an electrical signal, or other indication, responsive to the extent of inward translation of the spring-loaded contact. Such an indication would be responsive to the outside dimension of the rotatory output of differential 11, thereby providing a means for determining dimensional variations of the differential housing (not specifically identified in this figure) during a production run.

Fig. 11 is a compact drive arrangement constructed in accordance with the invention for coupling the rotatory output of a mechanical energy transfer system under test (not shown in this figure) to a rotatory load, which will be described hereinbelow in the form of an electric rotatory device that is operable in drive and generator modes. As shown in this figure, a load arrangement 80 is provided with a load motor 81 having a belt pulley 82 arranged to rotate with a load motor shaft 83.

In this specific embodiment, pulley 82 is coupled to a further belt pulley 85 via a load belt 86. Pulley 85 is coupled to a tubular shaft 89 having a flanged portion 90 that is arranged in axial communication with tubular shaft 89. In a manner similar to that of pulley 46 in Fig. 6, belt pulley 82 in Fig. 11 contains a torque sensing arrangement 87 that provides an electrical signal (not shown) responsive to a torque differential between the belt pulley and load motor shaft 83. The electrical signal responsive to torque is available at signal output connector 84, as described below.

In this specific illustrative embodiment of the invention, torque sensing arrangement 87 contained within belt pulley 82 and its associated signal output connector 84 include a strain gauge 88 installed to respond to the displacement of a web 92. That is, in the practice of this aspect of the invention, torque is transmitted across web 92 wherein, for example, the torque is applied across the periphery of the web, and an output shaft 98 is coupled nearer to the center of the web. Of course, the application of the torque may be rotationally reversed. As the torque is applied, web 92 is correspondingly deformed, and strain gauge 88 installed on the web measures the deformity in the web in response to the applied torque. Over a predetermined range of torque, the deformation of web 92, as determined by measurement of the electrical response of strain gauge 88 at signal output connector 84, can be correlated to the magnitude of the applied torque.

As described hereinabove with respect to signal output connector 56 in Fig. 6, in this specific illustrative embodiment of the invention, signal output connector 84 in Fig. 11 additionally contains circuitry (not shown) that is AC coupled to the torque sensing arrangement, and that modulates and demodulates the resulting torque signal. The torque signal will be to a significant extent responsive to the load or drive characteristic of load motor 81, which is controllable by the application of appropriate electrical signals (not shown) or connection of electrical loads (not shown) at electrical terminals 99 thereof.

Tubular shaft 89 is supported rotatably by ball bearings 91. On the other side of pulley 85 is arranged a resilient element 93 that is secured to remain in communication with pulley 85 by operation of an end cap 94. End cap 94 has internally affixed thereto a load shaft 95 that is arranged to extend along the interior length of tubular shaft 89. Thus, notwithstanding that tubular shaft 89 is axially fixed in a support 96, load shaft 95 will rotate with the tubular shaft but can experience displacement transverse to axis of rotation 98. Thus, any rotatory element (not shown in this figure) that would be coupled to load shaft 95 at its associated coupler 97 would be provided with freedom of motion in any direction transverse to the axis of rotation of the load shaft, and therefore would not be constrained in the axially transverse direction.

Fig. 12 is a partially cross-sectional side plan view of a compact drive arrangement similar in some respects to that of Fig. 11. This figure shows a shaft support system 100 that provides the degree of freedom of motion discussed hereinabove with respect to the embodiment of Fig. 11, and additionally provides axial thrust support. Shaft support system 100 is provided with a pulley 101 that can be coupled to another rotatory element (not shown) via a belt 102. The pulley is fixed to a tubular shaft 104 that is axially fixed in a support 105 by ball bearings 106. At the other end of tubular shaft 104, the tubular shaft is expanded radially to form a shaft portion 108 having a large diameter than the central portion of the tubular shaft. A resilient coupling arrangement that is generally designated as 110 is resiliently coupled to shaft portion 108. Resilient coupling arrangement 110 is provided with an intermediate plate 111 and an end plate 112 that are resiliently coupled to one another whereby they rotate with tubular shaft 104. A central shaft 114 is coupled at its right-most end to end plate 112 so as to be rotatable therewith. The central shaft, however, experiences freedom of movement in all directions transverse to its axis of rotation. Any travel of central shaft 114 toward the right hand side is limited by an end stop 115, which is arranged, in this embodiment, to provide a measure of axial adjustment. The other end of central shaft 114 is coupled to a resilient coupling arrangement which is generally designated as 117.

Fig. 13 is a partially phantom enlarged representation of the resilient coupling element shown in Fig. 12. Resilient coupling element 117 is shown in this figure in an expanded form to facilitate this detailed description. Central shaft 114 (Fig. 12) has a reduced diameter end portion 120 on which is installed a flanged washer 121 having a reduced diameter portion 122 and a flange 123 formed therearound. A further flanged element 125 is installed on reduced diameter end portion 120 of central shaft 114, a shear pin 127 being disposed between flanged washer 121 and further flanged element 125. In addition, an annular portion 128 is arranged to surround the flanged washer and the further flanged element, and to overlie circumferentially the axial region where resilient element 127 is disposed. All of these elements are secured to reduced diameter end portion 120 of central shaft 114 by a fastener 129 and a washer 130. As shown, fastener 129 is threadedly engaged axially onto the end of central shaft 114.

A support portion 132 is fixed onto further flanged element 125 by fasteners 133. Support portion 132 is resiliently coupled to a flanged shaft 135 by means of studs 136. Thus, even though central shaft 114 enjoys freedom of movement transverse to its axis of rotation, resilient coupling arrangement 117 provides yet further freedom of movement in all directions transverse to the axis of rotation for flanged shaft 135. Flanged shaft 135, in one embodiment of the invention, is ultimately coupled to a rotatory output, such as rotatory output 15 of Fig. 1. Alternatively, shaft support system 100 can be used in the drive arrangement of Fig. 6 to provide significant degree of motion lateral to the axis of rotation to the drive shaft.

Fig. 14 is an isometric representation of an arrangement for isolating a system under test, the isolation system being constructed in accordance with the principles of the invention. In this embodiment, the system under test is an electrical energy transfer device. As shown in this figure, an isolation support 160 isolates an electrical energy transfer device, illustratively in the form of an electrical transformer 162. The electrical transformer is secured to an isolation base 164 by operation of a toggle locking device 165. Isolation base 164 is mechanically isolated from a ground surface 166 by a plurality of resilient isolation elements 170. That is, the isolation base is permitted freedom of movement in at least one plane of motion, and preferably a plurality of planes of motion, by operation of the resilient isolation elements.

In the practice of this specific illustrative embodiment of the invention, the resilient isolation elements have a resilience characteristic that, as previously noted in regard of other embodiments of the invention, exclude a natural frequency of isolation support 160 and transformer 162. The motion of the transformer and the isolation support is therefore responsive substantially entirely to the electrical energy that is transferred to or from transformer 162 via its electrical terminals 172.

Fig. 15 is a process diagram of a typical process for conducting an energy analysis of a gear system. In this known system, gears under test 180 are driven by a drive 181, the speed of which is controlled by a speed control 183. Information relating to the drive speed is conducted to a digital data storage system 185.

Analog sensors 187 obtain analog data from gears under test 180, the analog signals from the sensors being conducted to an A/D converter 188. The A/D converter performs the conversion of the analog signals in response to a clock 190, and the resulting digital data is conducted to digital data storage system 185. Thus, digital data storage system 185 contains the digitized analog signals obtained from sensors 187, which data is correlated to the speed at which gears under test 180 are driven.

The digital data of digital data storage system 185 is converted to the frequency domain by subjecting same to a fast Fourier transform at step 193. The resulting frequency components are then ordered at step 194 and analyzed manually at step 195. At this step, the collected data, in the frequency domain, is analyzed in the context of predetermined test criteria. The pass/fail decision is then made at step 197, and if the predetermined criteria is not met, a "fail" indication is produced at step 198. Otherwise, a "pass" indication is issued at step 199.

Fig. 16 is a process diagram of a process for conducting an energy analysis in accordance with the principles of the present invention. As show in this figure, gears under test 201 are driven into rotation by a drive system 202, which also drives an encoder 204. Encoder 204 delivers signals responsive to the rotation of gears under test 201 to an A/D converter 206. In this embodiment, the signal from encoder 204 serves as a pacing clock for the A/D converter. Information relating to noise and displacement issued by the gears under test is collected by analog sensors 207. The resulting analog signals are conducted to A/D converter 206 where they are converted to digital signals correlated to the rotation of drive system 202.

The digital signals from A/D converter 206 are conducted to a digital data store 210 where they are maintained in correlation to the drive information obtained from encoder 204. In this specific illustrative embodiment of the invention, the digital data is stored two-dimensionally, wherein sensor signal amplitude is identified with the y-axis, and rotational position is identified with the x-axis. The correlated digital data is subjected to a fast Fourier transform at step 212 wherein the data is converted into its frequency components.

Data in the frequency domain is subjected to processing at step 214, where a power spectrum density is created using a data window. The power spectrum density data is then analyzed harmonically at step 215 to determine its relationship with predetermined test criteria. The decision whether the power spectrum density data passes or fails with respect to predetermined test criteria is made at step 216, and the predetermined criteria is not met, a "fail" indication is produced at step 217. Otherwise, a "pass" indication is issued at step 218.

Fig. 17 is a diagram of a process for conducting an analysis 230 in accordance with the principles of the present invention for determining bumps and nicks in a mechanical energy transfer system. As show in this figure, gears under test 231 are driven into rotation by a drive system 232, via a torque sensor 234. Torque sensor 234 delivers signals responsive to the rotatory force supplied to gears under test 231 to an A/D converter 236. Information relating to noise and displacement issued by the gears under test is collected by noise sensors 237, which may include velocity sensors (not shown in this figure), accelerometers (not shown in this figure), microphones (not shown in this figure), *etc.* The resulting noise signals are conducted to A/D converter 236 where they are converted to digital signals correlated to the torque applied by drive system 232 to gears under test 231.

The digital signals from A/D converter 236 are conducted to a digital data store 240 where they are maintained in correlation to the drive information obtained from torque sensor 234. In this specific illustrative embodiment of the invention, the digital data is stored as two two-dimensional data sets, wherein noise sensor signal amplitude is identified with a first y-axis, and time is identified with the x-axis. The amplitude of the torque signal is identified with a second y-axis, and time is again identified with the x-axis.

Correlated data from digital data store 240 is subjected to analysis at step 242, wherein peaks that occur simultaneously in the torque and noise signal waveforms are identified. These peaks are then measured at step 244 to determine whether they exceed predetermined thresholds. Those peaks that exceed the predetermined thresholds are

then tested at step 245 against the harmonics of each gear tooth frequency, to determine whether the peaks correspond to anomalous conditions.

The decision whether the gears under test pass or fail with respect to predetermined test criteria is made at step 246, and if the predetermined criteria is not met, a "fail" indication is produced at step 247. Otherwise, a "pass" indication is issued at step 248. In some embodiments of the invention, a calculation of the severity of the bumps or nicks that caused the anomalous conditions is calculated at step 249.

In one embodiment of the process of Fig. 17, analysis is performed using only the torque data derived from torque sensor 234, without correlation to the noise data obtained from noise sensor 237. In this embodiment, therefore, noise sensor 237 need not be provided, as the noise signal therefrom is not used. Thus, torque sensor 234 delivers signals responsive to the rotatory force supplied to gears under test 231 to A/D converter 236, and the digital data is stored as a single two-dimensional data set, wherein the amplitude of the torque signal is identified with the y-axis, and time is identified with the x-axis.

Peaks in the torque signal are then measured at step 244 to determine whether they exceed a predetermined threshold. Those peaks that exceed the predetermined thresholds are then tested at step 245 against the harmonics of each gear tooth frequency, to determine whether the peaks correspond to anomalous conditions.

The decision whether the gears under test pass or fail with respect to predetermined test criteria is made at step 246, and if the predetermined criteria is not met, a "fail" indication is produced at step 247. Otherwise, a "pass" indication is issued at step 248. As previously noted, a calculation of the severity of the bumps or nicks that caused the anomalous condition is calculated at step 249.

Although the invention has been described in terms of specific embodiments and applications, persons skilled in the art can, in light of this teaching, generate additional embodiments without exceeding the scope or departing from the spirit of the claimed invention. Accordingly, it is to be understood that the drawing and description in this disclosure are proffered to facilitate comprehension of the invention and should not be construed to limit the scope thereof.

WHAT IS CLAIMED IS:

1. A method of signal analysis for processing information from a gear system under test, the method comprising the steps of:

driving the gear system under test by application of a rotatory input;

producing a first signal responsive to the rotation of the gear system under test;

producing a second signal responsive to a noise produced by the gear system under test in response to said step of driving;

producing digital data responsive to a correlation between the first and second signals;

converting the digital data into corresponding frequency components;

subjecting the frequency components to analysis to determine a power spectrum density of the frequency components; and

subjecting the power spectrum density to harmonic analysis.

2. The method of claim 1, wherein there are provided the further steps of:

establishing predetermined harmonic criteria; and

determining whether the results of the analysis in said step of subjecting conforms to the predetermined harmonic criterial of said step of establishing.

3. The method of claim 1, wherein the first signal responsive to the rotation of the gear system under test is responsive to the angular position of the gear system under test.

4. The method of claim 1, wherein there is further provided the step of applying a load to the gear system under test.

5. The method of claim 4, wherein there is further provided the step of controlling the loading applied to the gear system under test.

6. The method of claim 5, wherein said step of controlling the loading applied to the gear system under test is responsive to the second signal.

7. A method of signal analysis for processing information from a gear system under test for determining the presence of an anomaly therein, the method comprising the steps of:

driving the gear system under test by application of a rotatory input;

producing a first signal responsive to the torque applied to the gear system under test;

producing first digital data responsive to a first correlation between the first signal and time;

measuring peaks in said first digital data to determine whether the peaks exceeds a predetermined threshold magnitude; and

first subjecting those of the peaks that exceed the predetermined threshold magnitude to harmonic analysis.

8. The method of claim 7, wherein there is provided the further step of comparing the result of the harmonic analysis of said step of first subjecting against gear tooth harmonics to determine whether the peaks constitute an anomaly.

9. The method of claim 7, wherein there is provided the step of applying a load to the gear system under test.

10. The method of claim 9, wherein there is further provided the step of controlling the loading applied to the gear system under test.

11. The method of claim 10, wherein said step of controlling the loading applied to the gear system under test is responsive to the first signal.

12. The method of claim 8, wherein the anomaly is a bump or a nick on a tooth of the gear system under test.

13. The method of claim 7, wherein there are provided the further steps of:

producing a second signal responsive to a noise produced by the gear system under test in response to said step of driving;

producing a second digital data responsive to a second correlation between the second signal and time;

identifying peaks in said second digital data that are simultaneous with peaks in said first digital data;

measuring said simultaneous peaks in said second digital data to determine whether they exceed a second predetermined threshold magnitude; and

second subjecting those of the simultaneous peaks in said second digital data that exceed the second predetermined threshold magnitude to harmonic analysis.

14. The method of claim 13, wherein there is provided the further step of comparing the result of the harmonic analysis of said steps of first subjecting and second subjecting against gear tooth harmonics to determine whether the simultaneous peaks constitute an anomaly.

15. The method of claim 14, wherein the anomaly is a bump or a nick on a tooth of the gear system under test.

16. The method of claim 14, wherein there is provided the further step of calculating the severity of the anomaly of said step of comparing.

17. A method of testing a gear assembly of the type having an input and an output, the method comprising the steps of:

installing the gear assembly on a mounting arrangement that resiliently permits motion of the gear assembly in a plurality of directions, and that has a resilient frequency characteristic that excludes all natural frequencies of the gear assembly;

applying a torque at the input of the gear assembly, whereby the gear assembly is rotatably operated;

applying a load at the output of the gear assembly;

sensing a predetermined operating characteristic of the gear assembly;

producing a first signal responsive to the predetermined operating characteristic of the gear assembly;

producing a second signal responsive to a noise produced by the gear assembly in response to said step of applying a torque;

producing digital data responsive to a correlation between the first and second signals;

converting the digital data into corresponding frequency components;

subjecting the frequency components to analysis to determine a power spectrum density of the frequency components; and

subjecting the power spectrum density to harmonic analysis.

18. The method of claim 17, wherein said step of sensing comprises the step of detecting acoustic energy issued by the gear assembly.

19. The method of claim 18, wherein there is further provided the step of detecting electromagnetic energy issued by the gear assembly.

20. The method of claim 19, wherein said step of detecting electromagnetic energy comprises the further step of directing a thermal energy sensor to monitor the temperature of a predetermined region of the gear assembly.

21. The method of claim 20, wherein said predetermined region is a region of a bearing of the gear assembly.

22. The method of claim 21, wherein there is provided the further step of monitoring a variation in temperature over time of the region of the bearing.

23. The method of claim 22, wherein there is provided the further step of determining a qualitative characteristic of the bearing in response to said step of monitoring a variation in temperature over time of the region of the bearing.

24. The method of claim 19, wherein there is provided the further step of determining a qualitative characteristic of a lubricant in the gear assembly.

25. The method of claim 20, wherein there is provided the further step of correlating a predetermined characteristic of the acoustic energy issued by the gear assembly to the thermal energy issued by the gear assembly.

26. The method of claim 19, wherein there is provided the further step of controlling a sensitivity characteristic of an acoustic sensor system in response to the thermal energy issued by the gear assembly.

27. The method of claim 18, wherein said step of detecting acoustic energy issued by the gear assembly comprises the step of placing a microphone in the vicinity of the gear assembly.

28. The method of claim 17, wherein said step of sensing comprises the step of detecting vibratory displacement energy issued by the gear assembly.

29. The method of claim 28, wherein said step of detecting vibratory displacement energy issued by the gear assembly comprises the further step of effecting communication between an accelerometer and the gear assembly.

30. The method of claim 28, wherein said step of detecting vibratory displacement energy issued by the gear assembly comprises the further step of effecting communication between a velocity sensor and the gear assembly.

31. The method of claim 17, wherein said step of sensing comprises the further step of monitoring a first sensor that receives acoustic energy responsive to a qualitative condition of the gear assembly in a drive mode of operation.

32. The method of claim 31, wherein said drive mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a first surface of the teeth of the gear assembly.

33. The method of claim 31, wherein said drive mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a profile of a gear of the gear assembly.

34. The method of claim 31, wherein said drive mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of the eccentricity of a gear of the gear assembly.

35. The method of claim 31, wherein said drive mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of the angular orientation of the gears of the gear assembly.

36. The method of claim 31, wherein said drive mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the drive mode of operation includes a qualitative condition of a plurality of moving components of the gear assembly.

37. The method of claim 31, wherein said step of sensing comprises the further step of monitoring a second sensor that receives acoustic energy responsive to a qualitative condition of the gear assembly in a coast mode of operation

38. The method of claim 37, wherein said coast mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of a second surface of the teeth of the gear assembly.

39. The method of claim 37, wherein said coast mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of a profile of a gear of the gear assembly.

40. The method of claim 37, wherein said coast mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of the eccentricity of a gear of the gear assembly.

41. The method of claim 37, wherein said coast mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of the angular orientation of the gears of the gear assembly.

42. The method of claim 37, wherein said coast mode of operation is in a first direction of operation, and the qualitative condition of the gear assembly in the coast mode of operation includes a qualitative condition of a plurality of moving components of the gear assembly.

43. The method of claim 37, wherein said drive and coast modes of operation are cyclical over a period that is shorter than a cycle period of the input of the gear assembly.

44. The method of claim 37, wherein said drive and coast modes of operation are cyclical over a period that is longer than a cycle period of the input of the gear assembly.

45. The method of claim 37, wherein the first and second sensors are disposed at respective locations that are distal from each other, with the gear assembly interposed therebetween.

46. An arrangement for determining a qualitative characteristic of an energy transfer system while it is subjected to a test process for noise, the energy transfer system being of the type having an energy input and at least one energy output, the arrangement comprising:

a base for supporting the arrangement and the energy transfer system;

isolation support means for supporting the energy transfer system whereby the energy transfer system is translatable in at least one plane of freedom with respect to said base;

engagement means for securing the energy transfer system to said isolation support means;

a first acoustic sensor arranged at a first location in the vicinity of the energy transfer system for producing an electrical signal responsive to a noise produced by the energy transfer system under test in response to said step of driving;

first converter for producing digital data responsive to the electrical signal;

second converter for converting the digital data into corresponding frequency components; and

a processor for:

subjecting the frequency components to analysis to determine a power spectrum density of the frequency components; and

subjecting the power spectrum density to harmonic analysis.

47. The arrangement of claim 46, wherein the energy transfer system is a mechanical energy transfer system, and said energy supply means comprises a source of rotatory mechanical energy.

48. The arrangement of claim 47, wherein said mechanical energy transfer system has forward and reverse directions of operation, and drive and coast modes of operation for each of the forward and reverse directions of operation.

49. The arrangement of claim 47, wherein there is further provided a second acoustic sensor arranged at a second location in the vicinity of the mechanical energy transfer system for producing a second signal responsive substantially to a qualitative condition of said second gear tooth surfaces.

50. The arrangement of claim 49, wherein the first and second locations are distal from each other on opposite sides of said pair of meshed elements.

51. The arrangement of claim 47, wherein there is further provided torque sensor means interposed between said source of rotatory mechanical energy and the energy transfer system for producing a torque signal responsive to a torque applied by said source of rotatory mechanical energy to the energy transfer system.

52. The arrangement of claim 51, wherein said torque sensor means is arranged to produce a static torque signal responsive to the magnitude of torque required to initiate rotatory motion in said mechanical energy transfer system.

53. The arrangement of claim 51, wherein said torque sensor means is arranged to produce a dynamic torque signal responsive to the magnitude of torque required to maintain rotatory motion in said mechanical energy transfer system.

54. The arrangement of claim 46, wherein the energy transfer system is an electrical energy transfer system, and said energy supply means comprises a source of electrical energy.

55. The arrangement of claim 54, wherein there is further provided electrical load means for receiving an output electrical energy from the energy transfer system.

56. The arrangement of claim 56, wherein said first acoustic sensor comprises a laser sensor for producing a signal responsive to a displacement of the energy transfer system in response to the energy supplied by said energy supply means.

57. The arrangement of claim 56, wherein said first acoustic sensor comprises an accelerometer.

58. The arrangement of claim 56, wherein said first acoustic sensor comprises a velocity sensor.

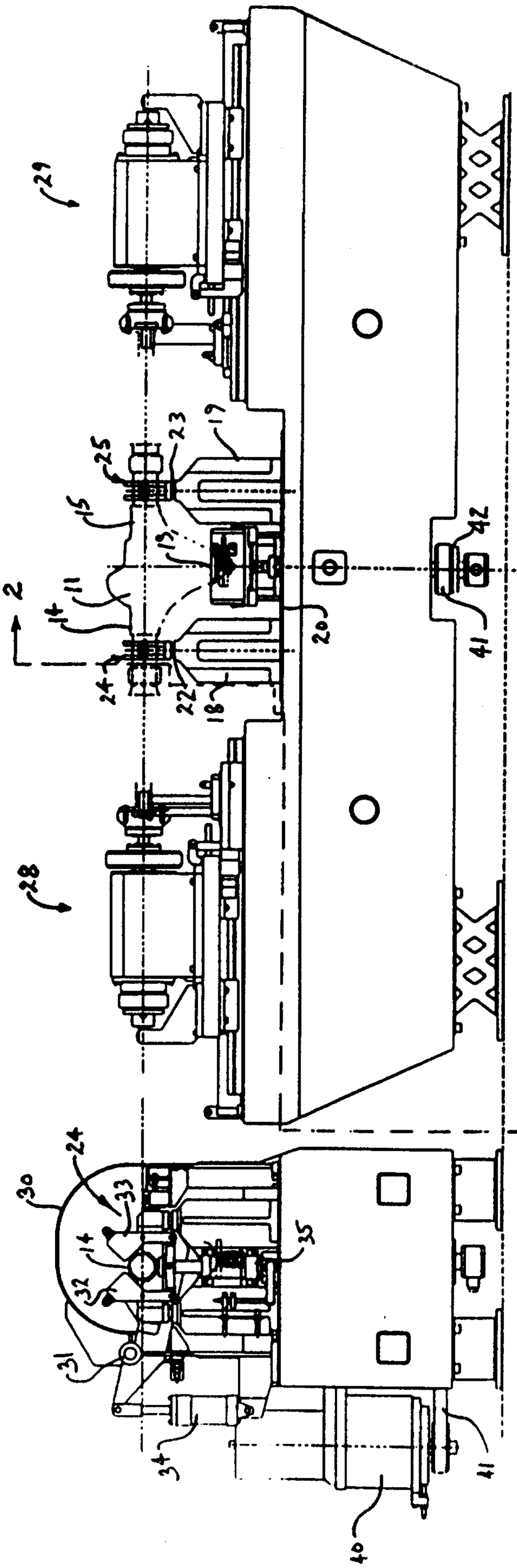

29
2
11
14
24
22
18
19
23
25
15
13
20
10
42
41
28
30
33
24
14
32
31
35
34
41
40
2

FIG. 1

FIG. 2

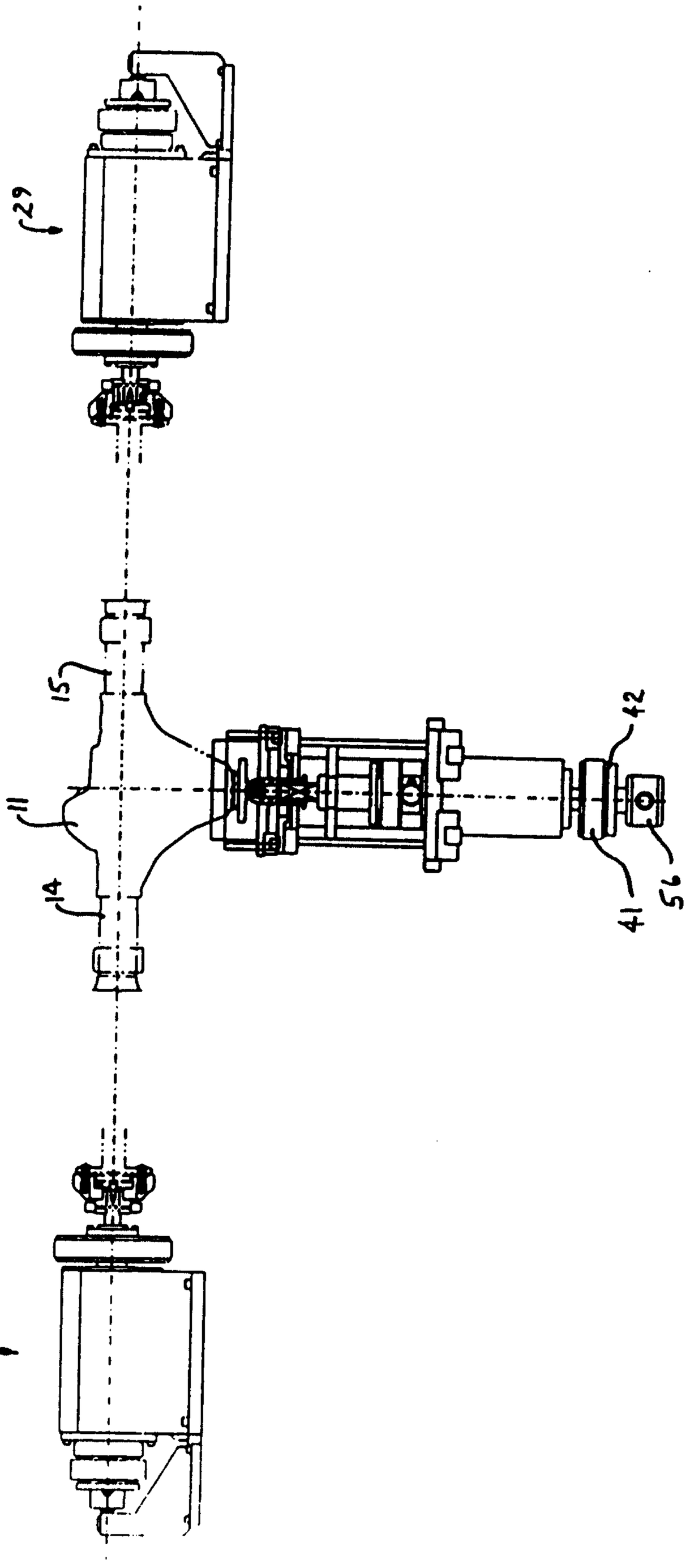


FIG. 3

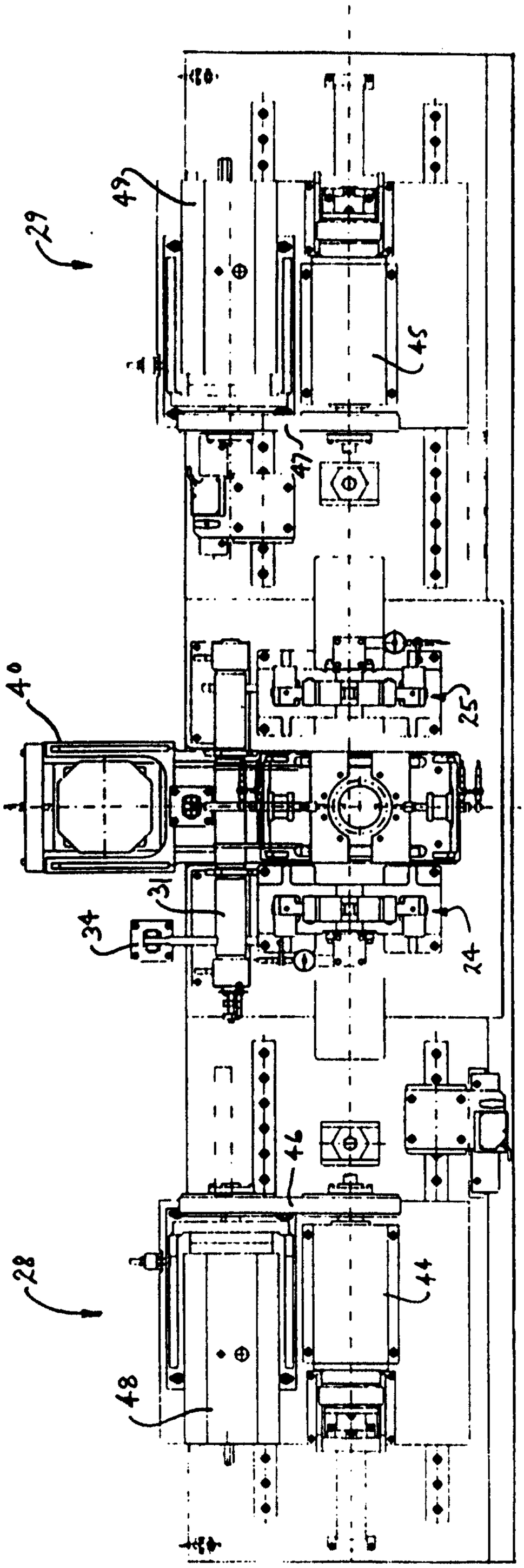


FIG. 4

FIG. 5

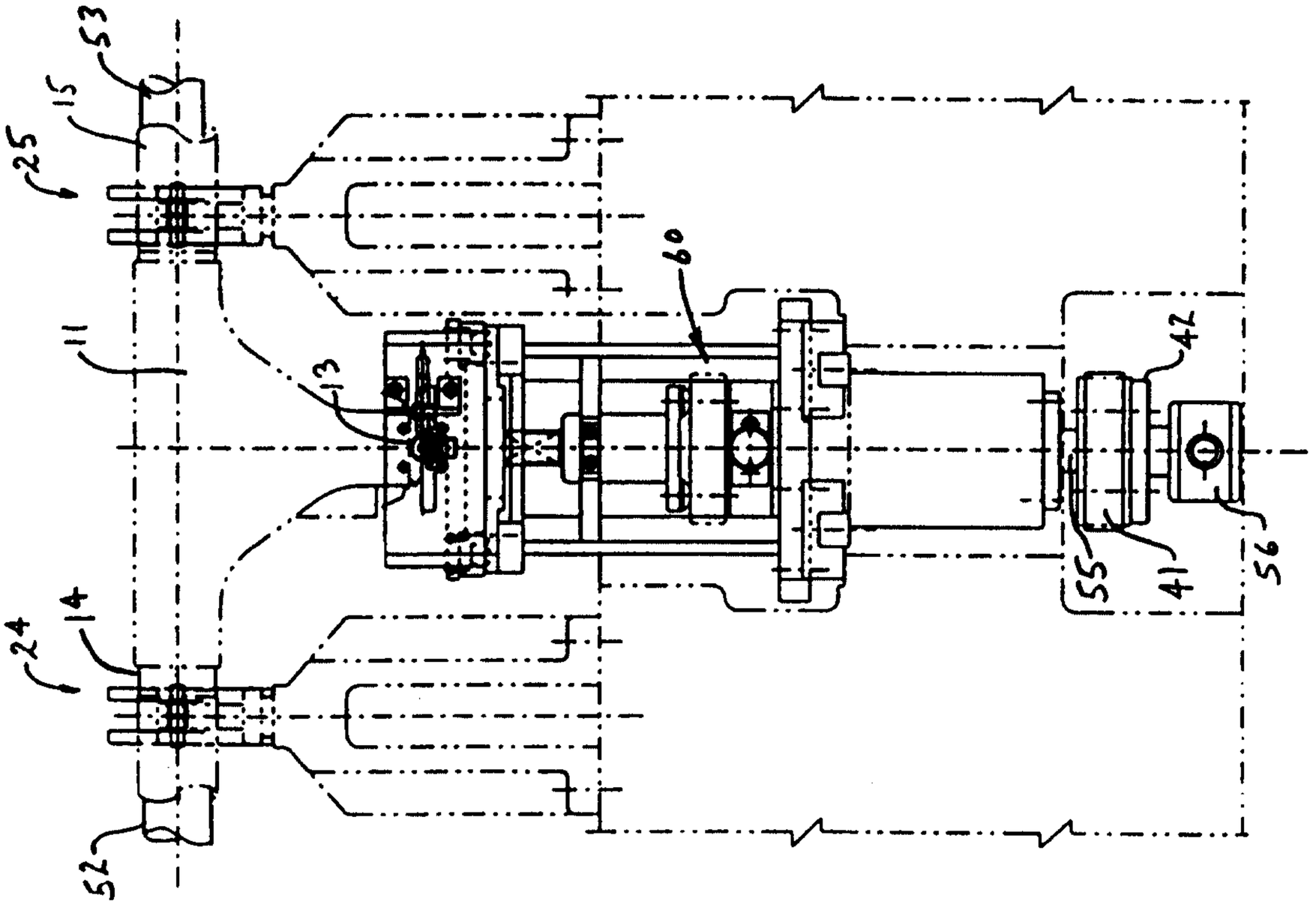
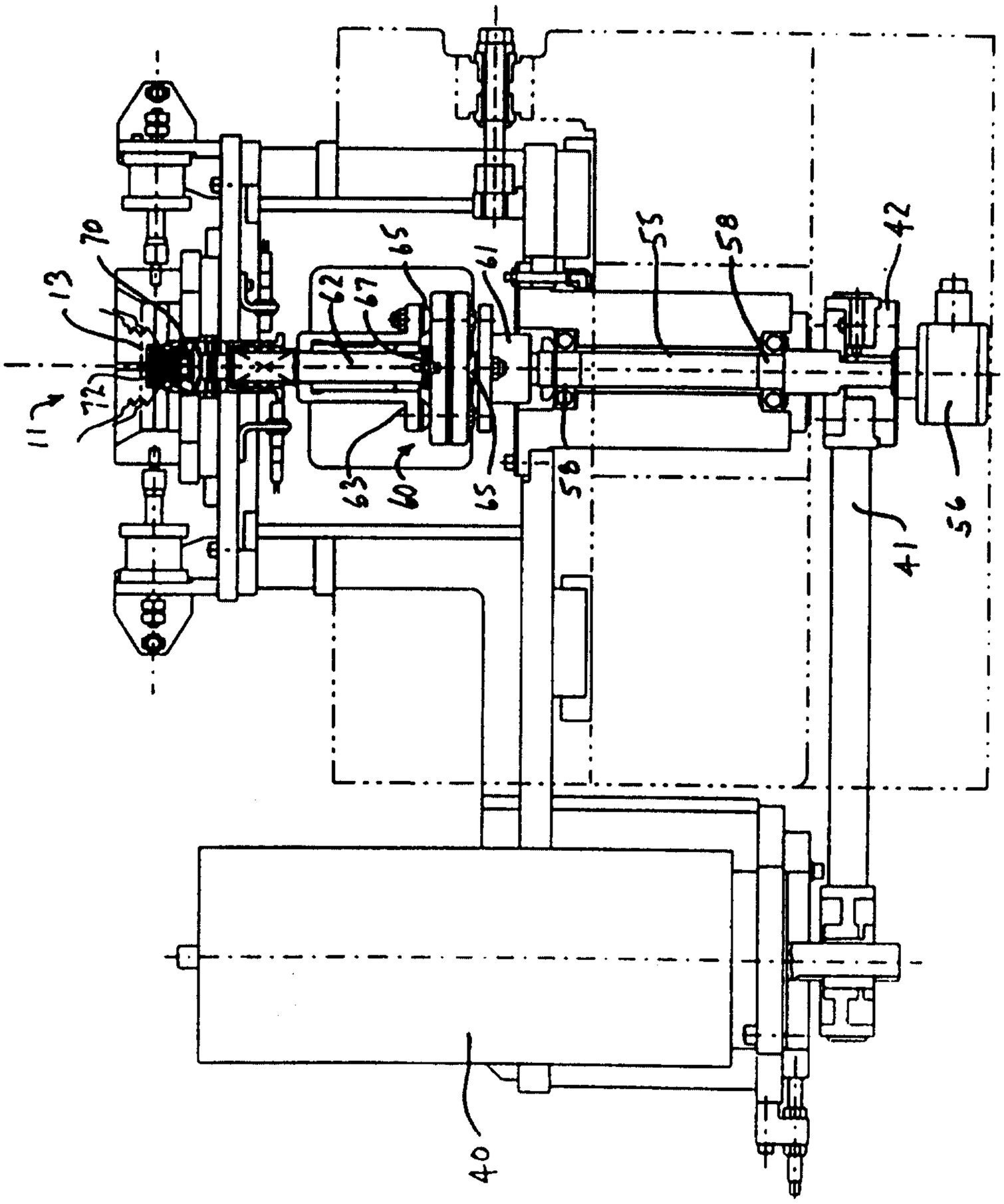


FIG.6



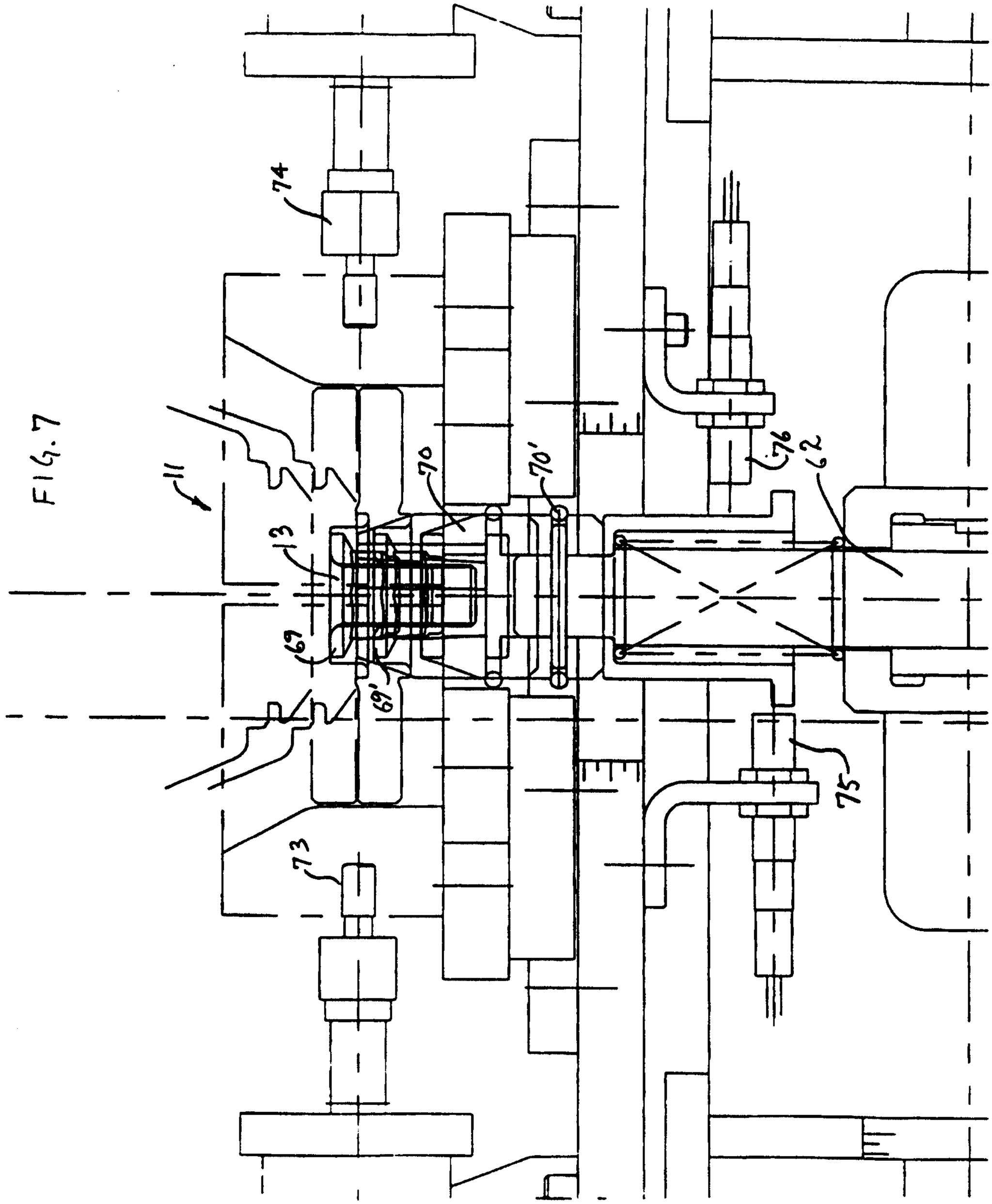


FIG. 7

FIG.9

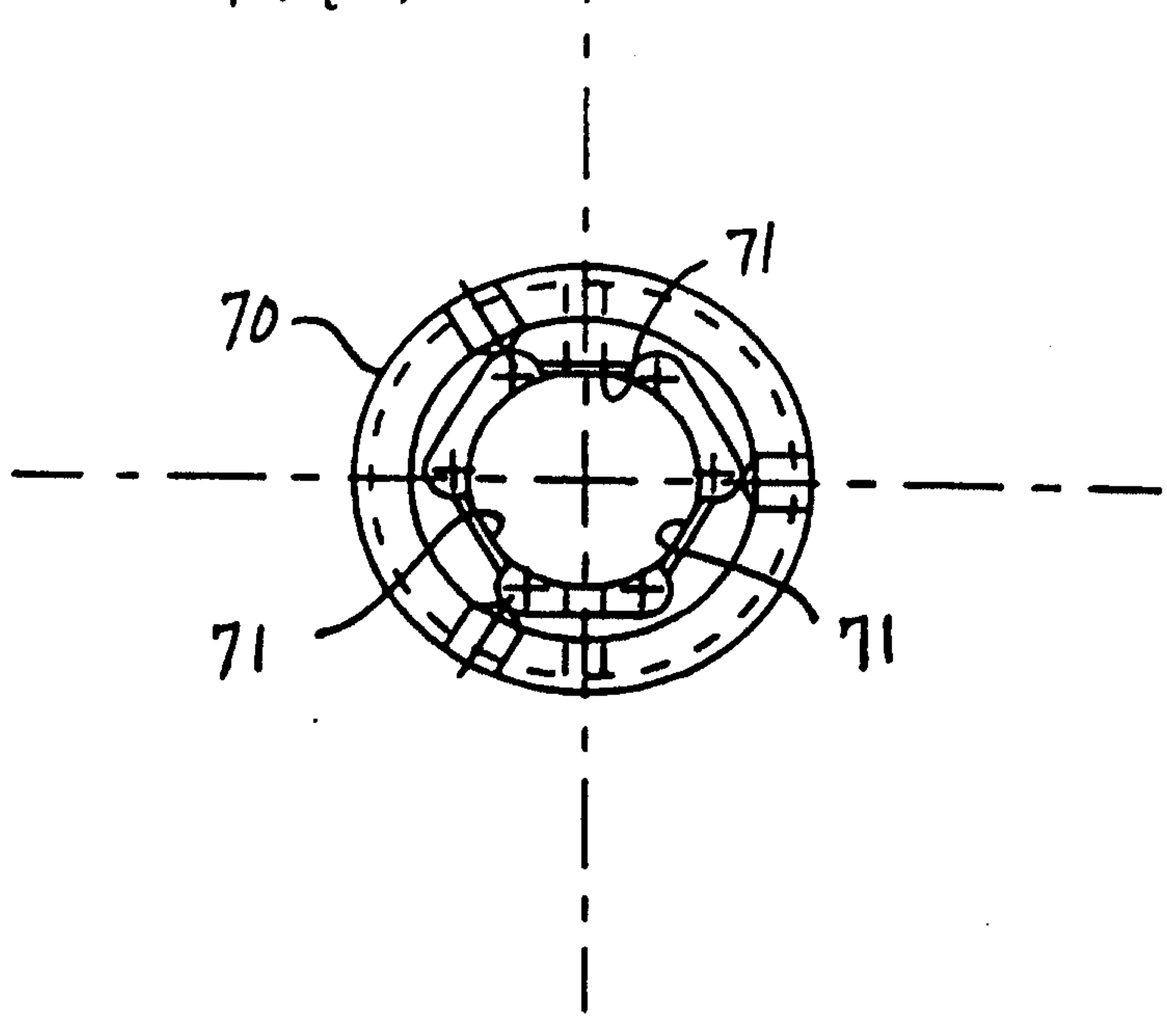


FIG.8

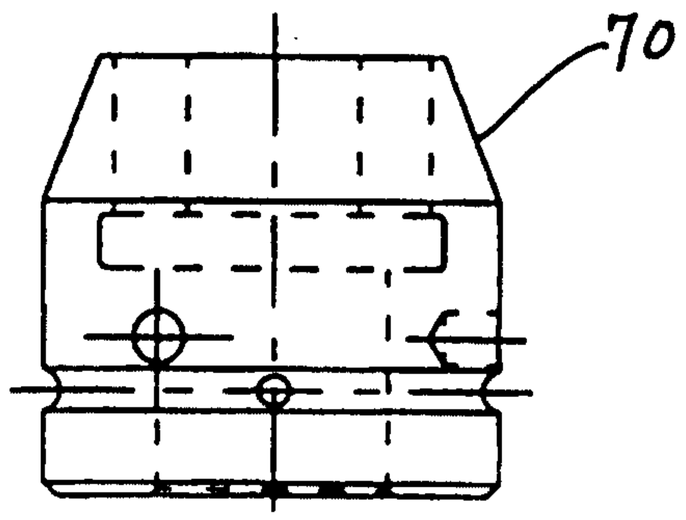
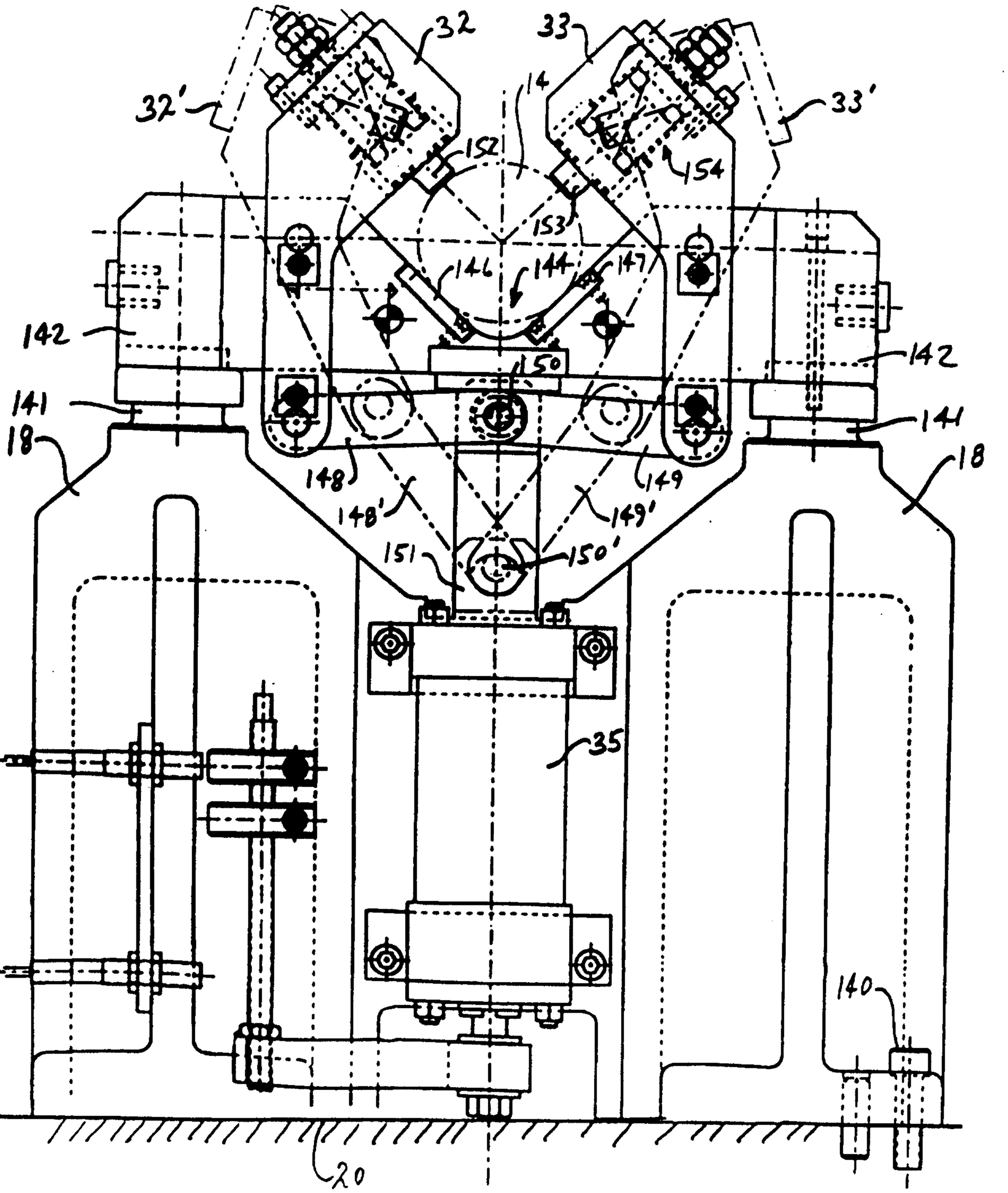


FIG. 10


32
32'
33
33'
14
152
154
153
146
144
147
142
150
141
18
148
148'
149
149'
151
150'
35
140
20

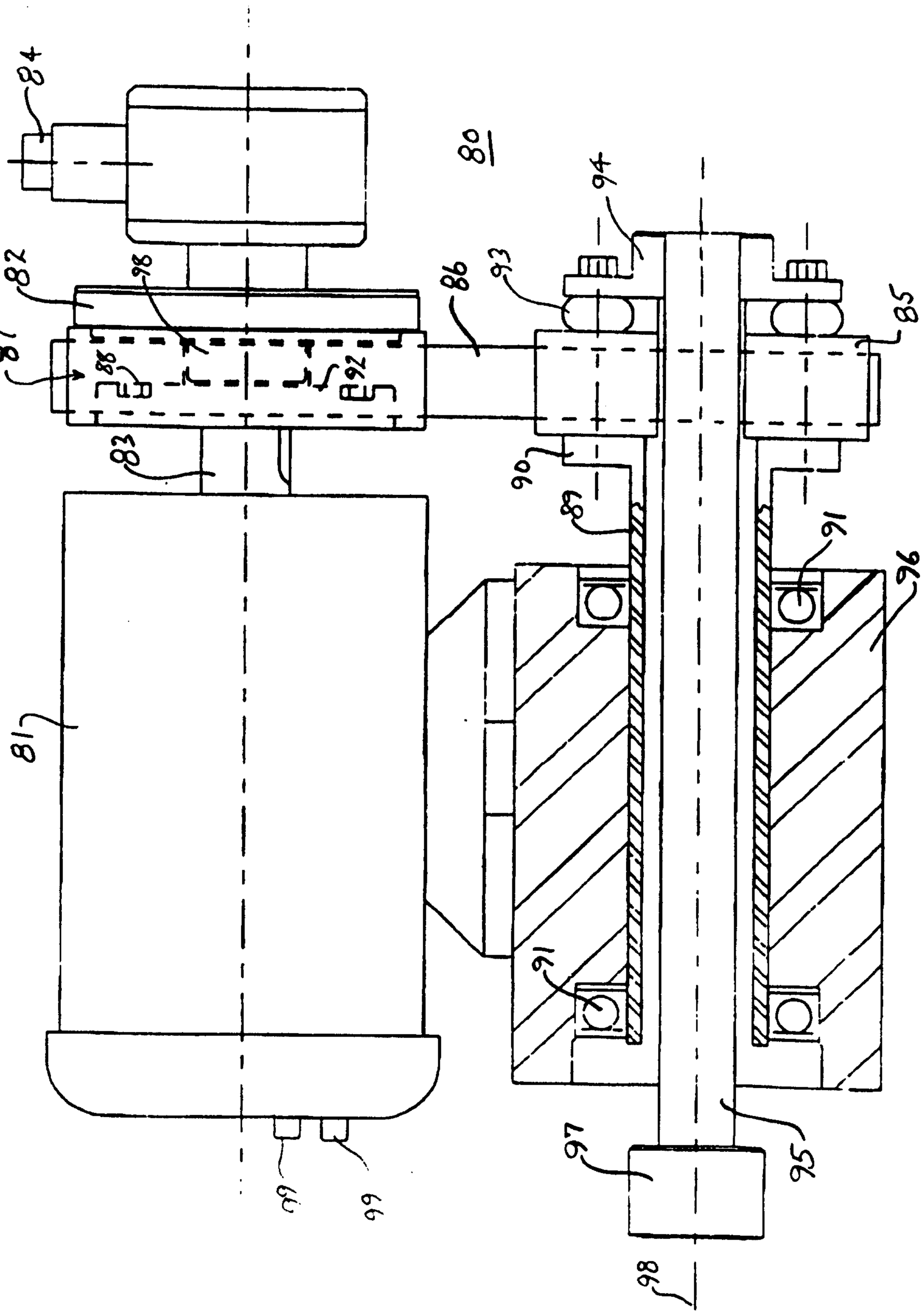


FIG. 11

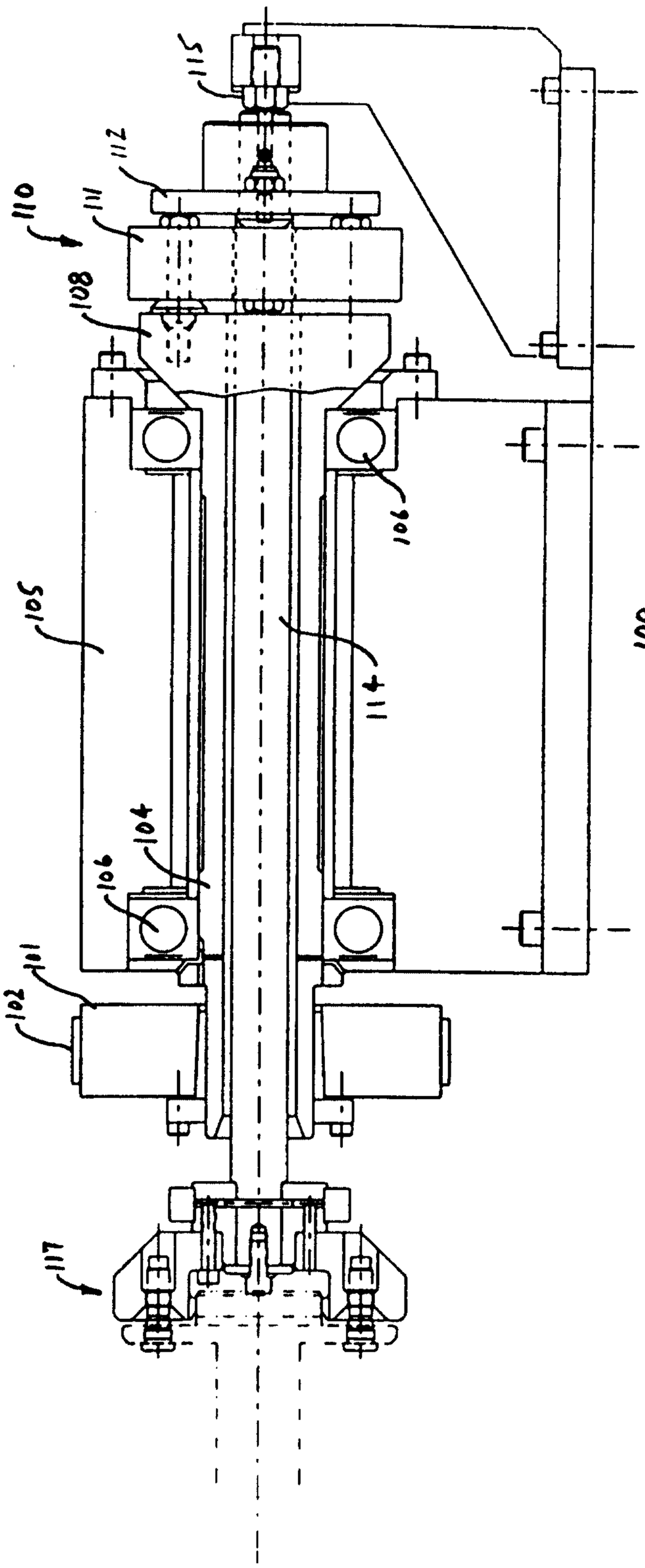


FIG. 12

FIG-13

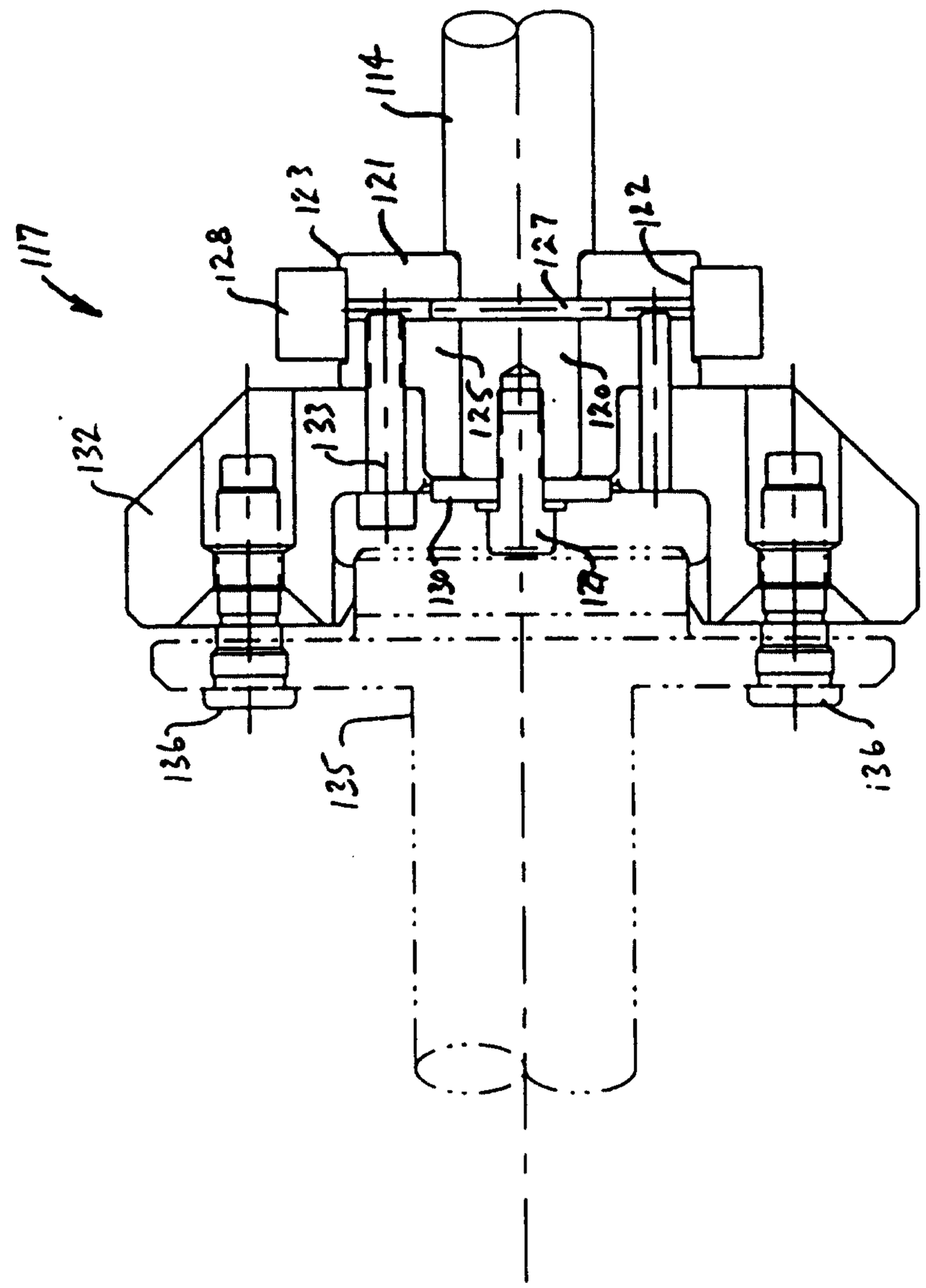


FIG. 14

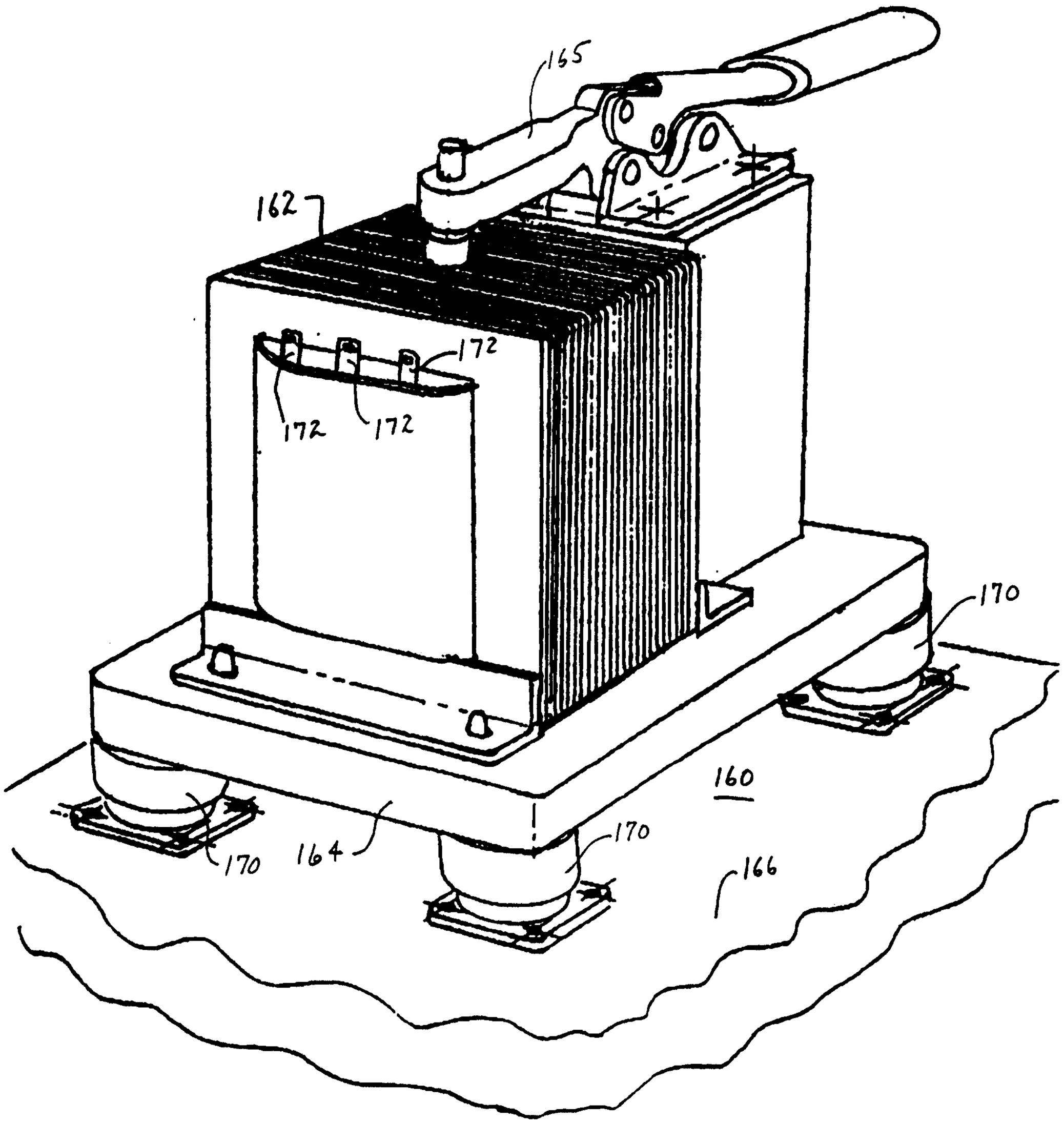


FIG. 15
(PRIOR ART)

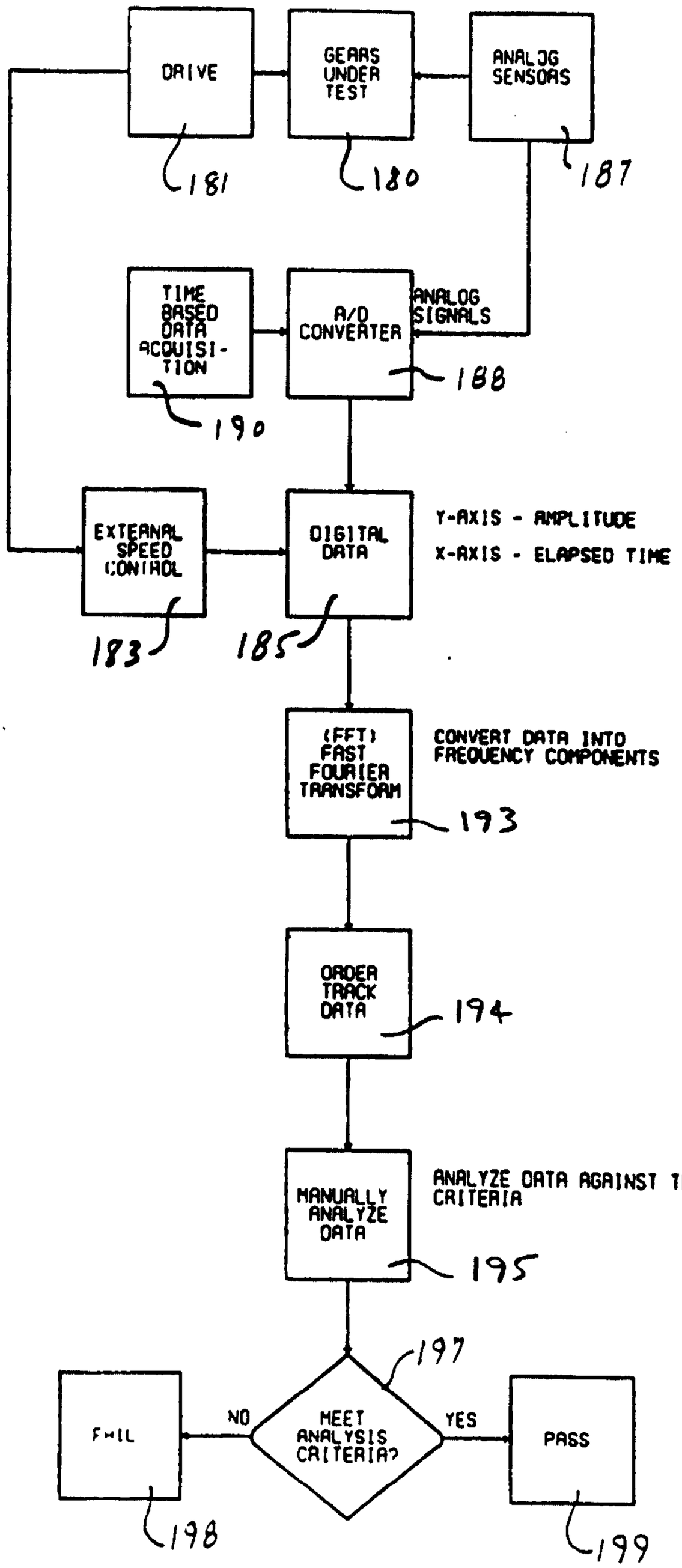


FIG. 16

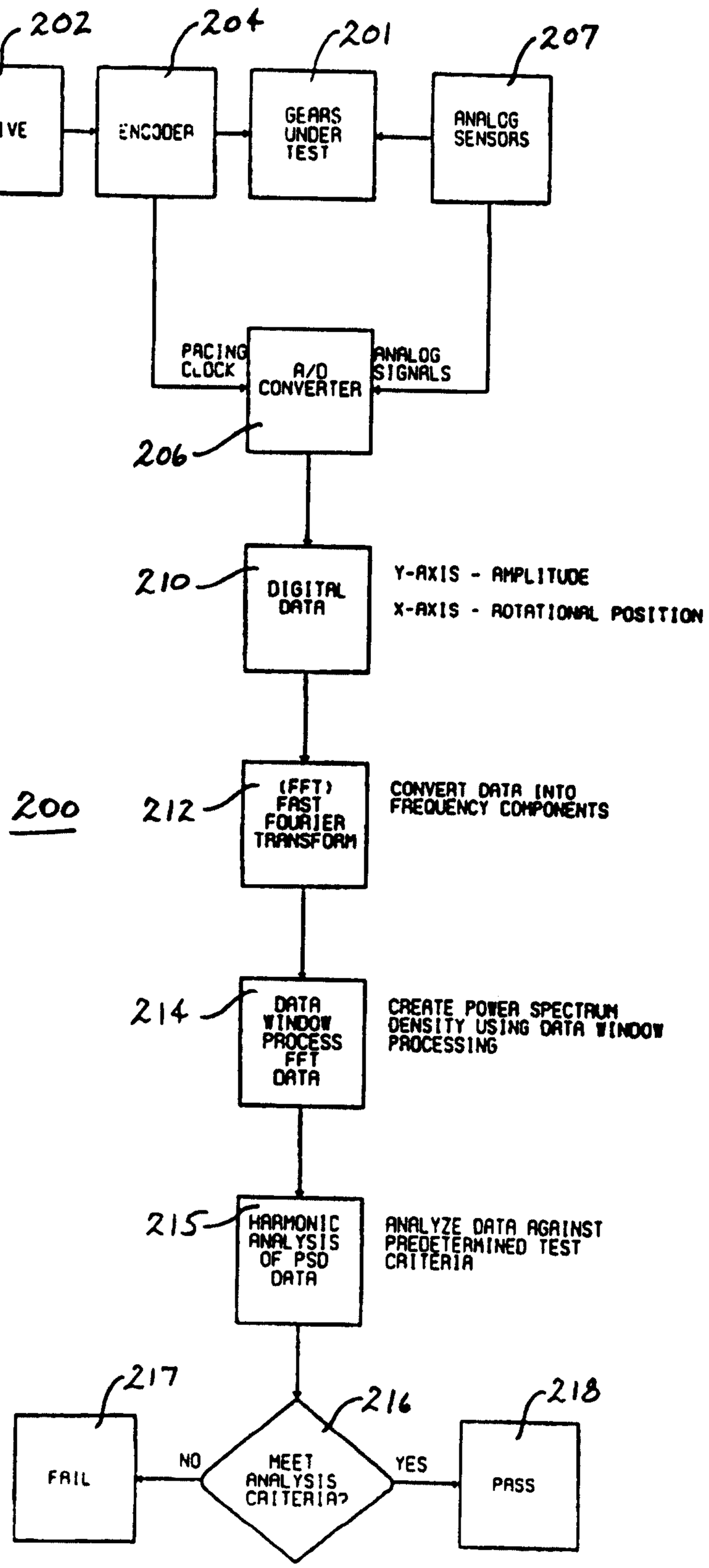
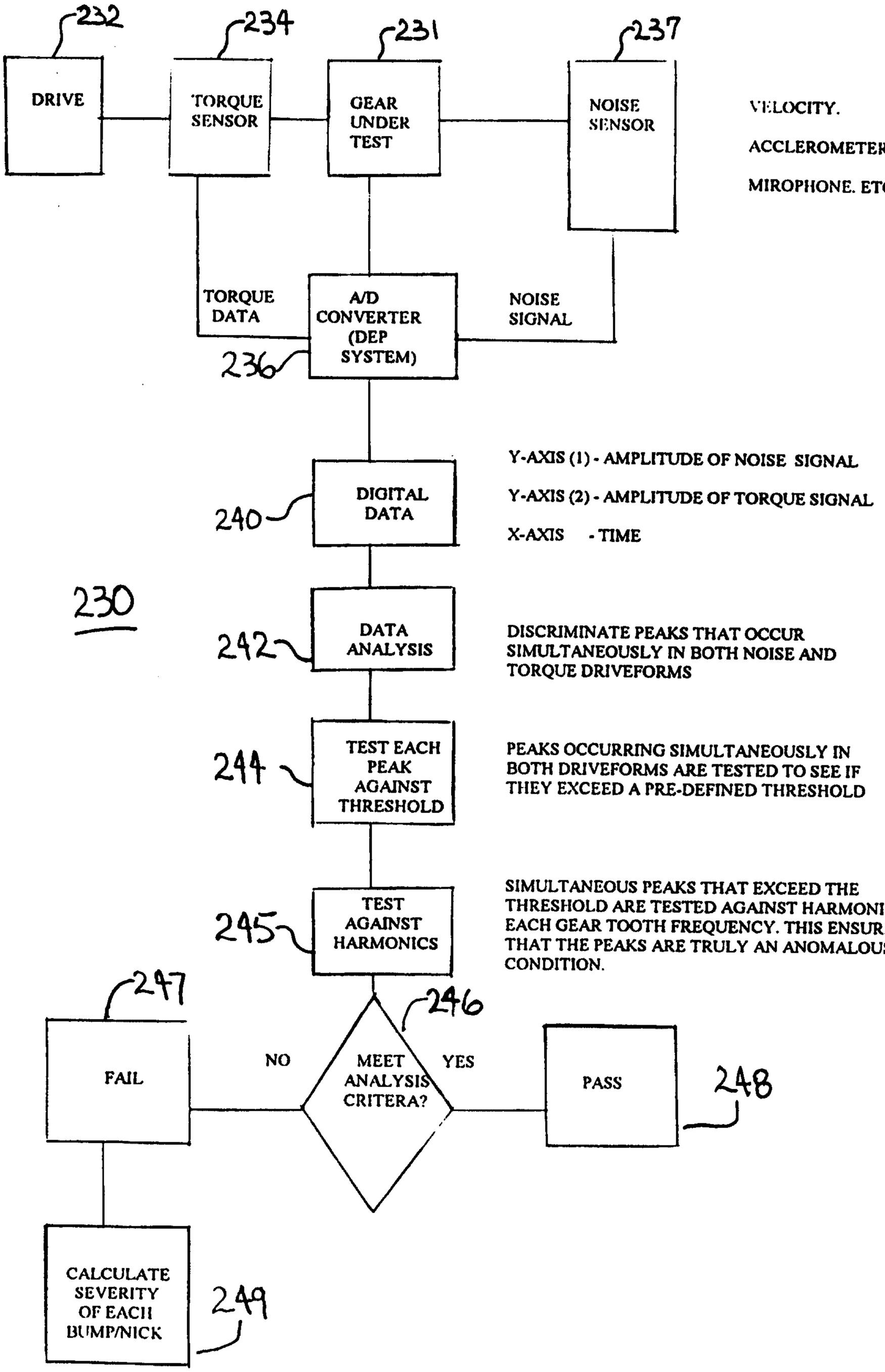
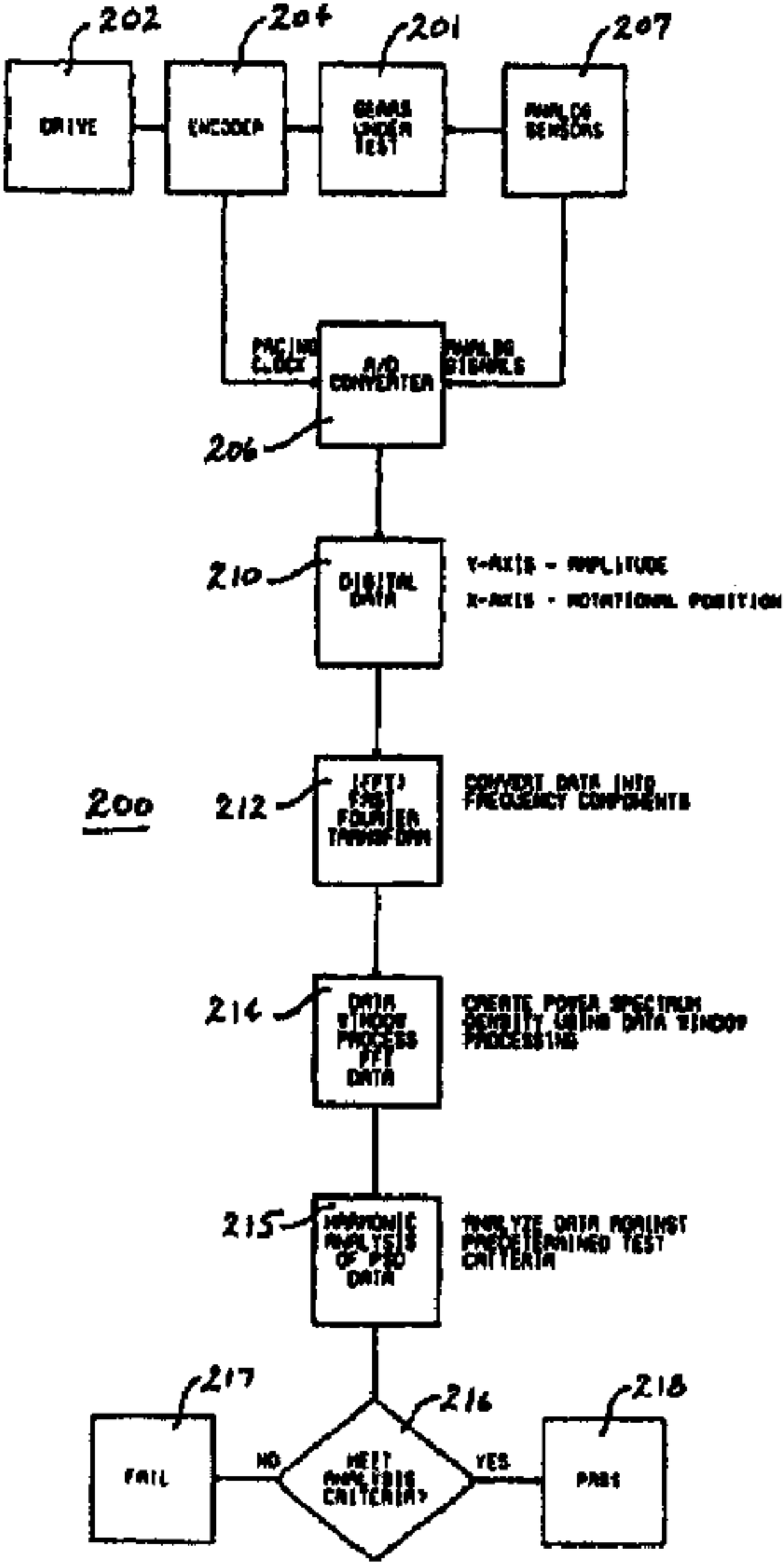

202
204
201
207
DRIVE
ENCODER
GEARS UNDER TEST
ANALOG SENSORS
PACING CLOCK
A/D CONVERTER
ANALOG SIGNALS
206
210
DIGITAL DATA
Y-AXIS - AMPLITUDE
X-AXIS - ROTATIONAL POSITION
200
212
(FFT) FAST FOURIER TRANSFORM
CONVERT DATA INTO FREQUENCY COMPONENTS
214
DATA WINDOW PROCESS FFT DATA
CREATE POWER SPECTRUM DENSITY USING DATA WINDOW PROCESSING
215
HARMONIC ANALYSIS OF PSD DATA
ANALYZE DATA AGAINST PREDETERMINED TEST CRITERIA
217
216
218
FAIL
NO
MEET ANALYSIS CRITERIA?
YES
PASS

FIG. 17


232
234
231
237
DRIVE
TORQUE SENSOR
GEAR UNDER TEST
NOISE SENSOR
VELOCITY.
ACCLEROMETER.
MIROPHONE. ETC.
TORQUE DATA
A/D CONVERTER (DEP SYSTEM)
NOISE SIGNAL
236
DIGITAL DATA
240
Y-AXIS (1) - AMPLITUDE OF NOISE SIGNAL
Y-AXIS (2) - AMPLITUDE OF TORQUE SIGNAL
X-AXIS - TIME
230
DATA ANALYSIS
242
DISCRIMINATE PEAKS THAT OCCUR SIMULTANEOUSLY IN BOTH NOISE AND TORQUE DRIVEFORMS
TEST EACH PEAK AGAINST THRESHOLD
244
PEAKS OCCURRING SIMULTANEOUSLY IN BOTH DRIVEFORMS ARE TESTED TO SEE IF THEY EXCEED A PRE-DEFINED THRESHOLD
TEST AGAINST HARMONICS
245
SIMULTANEOUS PEAKS THAT EXCEED THE THRESHOLD ARE TESTED AGAINST HARMONICS OF EACH GEAR TOOTH FREQUENCY. THIS ENSURES THAT THE PEAKS ARE TRULY AN ANOMALOUS CONDITION.
247
246
FAIL
NO
MEET ANALYSIS CRITERA?
YES
PASS
248
CALCULATE SEVERITY OF EACH BUMP/NICK
249


202
204
201
207
DRIVE
ENCODER
GEARS UNDER TEST
ANALOG SENSORS
A/D CONVERTER
206
210
DIGITAL DATA
Y-AXIS - AMPLITUDE
X-AXIS - ROTATIONAL POSITION
200
212
FFT
CONVERT DATA INTO FREQUENCY COMPONENTS
214
DATA WINDOW PROCESS FFT DATA
CREATE POWER SPECTRUM DENSITY USING DATA WINDOW PROCESSING
215
ANALYZE DATA AGAINST PREDETERMINED TEST CRITERIA
216
MEET ANALYSIS CRITERIA?
NO
YES
217
FAIL
218
PASS