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(72) Inventeurs/Inventors:
KARNOFSKI, KENT E., US;
JASKLOWSKI, CHRIS T., US;
JACKOWSKI, JASON J., US

(73) Propriétaire/Owner:
THE BOEING COMPANY, US

(74) Agent: SMART & BIGGAR LLP

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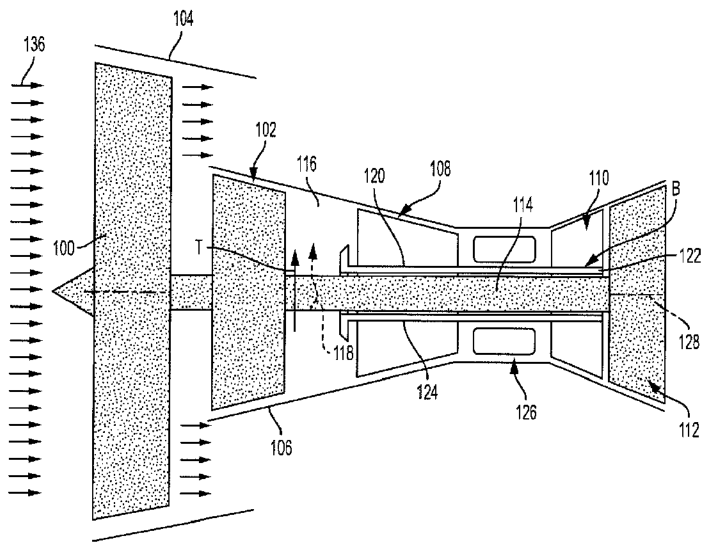

(57) Abrégé/Abstract:
Pressurized fluid is stored while a jet engine is running. After engine shutdown, the fluid is used to drive a pneumatic or hydraulic turning motor that rotates the engine's High Pressure (HP) rotor. The rotation encourages even heat distribution across the HP rotor and thus prevents bowing of the HP rotor.

ABSTRACT

Pressurized fluid is stored while a jet engine is running. After engine shutdown, the fluid is used to drive a pneumatic or hydraulic turning motor that rotates the engine's High Pressure (HP) rotor. The rotation encourages even heat distribution across the HP rotor and thus prevents bowing of the HP rotor.

ENGINE TURNING MOTOR VIA PNEUMATIC OR HYDRAULIC MOTOR

BACKGROUND

1. Field

The present disclosure relates to a system for rotating a rotor in a gas turbine engine.

2. Description of the Related Art

FIG. **1**A illustrates an aircraft engine comprising a fan **100**, a low pressure (LP) compressor **102**, a fan case **104**, an engine casing **106**, a High Pressure (HP) compressor **108**, a HP turbine **110**, a LP turbine **112**, and a LP shaft **114** connecting the LP compressor **102** and the LP turbine **112**. After engine shutdown on the ground, residual hot air **116** in the engine core rises **118** and is trapped by the engine casing **106**. As the hot air rises **118**, the upper portion **120** of the HP compressor's (engine's rotor) **108** rotor shaft **122** becomes hotter than the lower portion **124** of the rotor shaft **122** and causes uneven cooling and thermal deformation of the engine rotor shaft **122** (i.e., rotor bowing B, where the upper portion **120** of the rotor shaft **122** becomes longer than the lower portion **124**). Upon engine restart (e.g., prior to fuel ignition in the combustor **126**), even tiny fractions of rotor shaft **122** bowing can cause the HP compressor (engine's rotor) **108** to rub against the engine's casing **106**. The rub causes vibrations (manifested as disconcerting noise in the aircraft cabin) or even damage to the aircraft (e.g., engine damage, damage to the engine case lining, or damage to other accessories). FIG. **1**B illustrates that on an aircraft **130**, the engine **132** is housed in a nacelle **134**. The nacelle **134** may also trap rising **118** hot air **116** that causes a temperature gradient T. Also shown in FIG. **1**A is flow **136** of air into the engine **132**.

One method to mitigate these problems is to build the engine with wider cold build clearances ("opened up" clearances), so that the compressor rotor shaft **122** can bow without causing blades to rub on the engine casing **106**. However, more advanced engine designs prefer less "gap" between the engine casing and the compressor rotors

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(tighter "cold build clearances") to reduce air leakage and improve thrust specific fuel consumption (TSFC). Thus, the overriding need to reduce fuel consumption renders wider cold build clearances less desirable. Indeed, as ever tighter cold build clearances are implemented, the problems caused by engine rub will become more severe.

Conceivably, an engine architecture could add rotor stiffening or bearing arrangements to
reduce the amount of rotor shaft bow that is physically possible. However, these architecture changes would add weight and manufacturing cost to the engine.

Other methods of mitigating rotor shaft bow comprise rotating the shaft (**1**) so that the shaft cools uniformly, returns to thermal equilibrium, and straightens, and/or (**2**) so that centrifugal forces straighten the bow. The shaft rotation is achieved (**1**) by motoring the engine at relatively low revolutions per minute (RPM) after starting the engine (but before running the engine at high RPM) and/or (**2**) using an Engine Turning Motor (ETM) to turn the rotor shaft when the engine is off.
However, conventional methods for providing power to the ETM or the engine so as to straighten the bow can be problematic. Some smaller aircraft, such as the Boeing **737** airplane, fly into remote airports where facility power is not available to power the ETM or engine. Furthermore, auxiliary power unit (APU) power on the aircraft is not always available to power the engine or ETM because some airports limit APU use at gates due to emissions and noise concerns and aircraft are not powered when they are towed between gates. In addition , airplanes may operate with a nonfunctional APU or the powering of the ETM or engine may cause undesirable APU wear (extended motoring prolongs the APU's exposure to main engine start (MES) mode, reducing APU life). Finally, the use of lithium-ion and nickel-cadmium batteries for powering the ETM is problematic due to high failure rates and flammability concerns associated with the engine environment (extreme heat, extreme cold, and high vibration).
Moreover, rotating the shaft shortly before departure causes departure delays, especially if reduced engine clearances require turning the rotor at low speeds. These delays not only inconvenience the passengers but also increase costs associated with increased waiting times and parking fees.

What is needed then, is a more efficient method for mitigating rotor shaft bowing that simplifies ground logistics. The present disclosure satisfies this need.

SUMMARY

The present disclosure describes an aircraft engine assembly comprising a rotor and means for rotating the rotor using a hydraulic or pneumatic system so that the rotating reduces or prevents thermal bowing of the rotor shaft in an environment exposing the rotor shaft to a temperature/thermal gradient.

In one embodiment, the means comprises a pressure vessel for containing compressed air; an air supply valve connected to the pressure vessel; a pneumatic motor connected to the valve; and ducting connected to the valve, the pressure vessel, and the pneumatic motor. The pneumatic motor rotates the rotor shaft when the rotor shaft is coupled to the pneumatic motor and compressed air is supplied from the pressure vessel to the pneumatic motor through the ducting and the valve.

In one embodiment, the pneumatic motor is connected to a transmission connected to the rotor shaft. The pneumatic motor converts pressure exerted by the compressed air into torque and the transmission applies the torque to the rotor shaft so as to rotate the rotor.

In another embodiment, the pneumatic motor comprises an accessory turbine mounted on the rotor. The pneumatic motor converts pressure exerted by the compressed air into torque and the accessory turbine applies torque directly to the rotor shaft.

In yet another embodiment, the pneumatic motor comprises an air stepper motor. In one example, a pneumatic timer is connected to the valve and the pneumatic motor rotates the rotor shaft when the pneumatic timer pulses the compressed air so as to deliver pulses of the compressed air to the pneumatic motor.

In yet a further embodiment, the means comprises a pressure vessel for containing oil; a valve connected to the pressure vessel; an oil timer connected to the valve; a hydraulic motor connected to the oil timer; and ducting connected to the valve, the pressure vessel, and the hydraulic motor. The hydraulic motor rotates the rotor shaft when the hydraulic motor is coupled to the rotor shaft and the oil is supplied to the

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hydraulic motor from the pressure vessel through the ducting, the oil timer, and the valve.

The pneumatic/oil timer and pressure vessel are mounted on the aircraft engine, e.g., on a nacelle, housing, or engine casing. Exemplary locations for the pressure vessel include, but are not limited to, in a thrust link, a brace, or a strut link attached to the gas turbine engine.

The present disclosure further describes a method of rotating a rotor shaft in an aircraft engine, comprising storing pressurized fluid on an aircraft comprising a nacelle housing a gas turbine engine; and driving the rotor shaft using the pressurized fluid, when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient.

In one embodiment, the storing comprises charging the pressure vessel with high pressure air or oil during engine operation. In one embodiment, after engine shut down, a valve connected to the pressure vessel opens automatically upon receiving signal from an engine shut off switch, thereby activating the pneumatic or hydraulic motor.

In another embodiment, there is provided an aircraft engine assembly. The aircraft engine assembly includes a gas turbine engine including a rotor having a rotor shaft, wherein the rotor shaft has a longitudinal axis, and a nacelle housing the rotor and comprising trapped air creating a temperature gradient perpendicular to the longitudinal axis when the gas turbine engine is cooling down. The aircraft engine assembly further includes means for rotating the rotor shaft using pressurized fluid, the rotating reducing or preventing thermal bowing of the rotor shaft in the temperature gradient.

The means may include a pressure vessel for containing the pressurized fluid, a valve connected to the pressure vessel, and a stepper motor rotating the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel and the air stepper motor is coupled to the rotor shaft.

The aircraft engine assembly may further include a thrust link attached to the gas turbine engine and doubling as the pressure vessel.

The means may include a pressure vessel for containing the fluid comprising compressed air, a valve connected to the pressure vessel, a pneumatic timer connected

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to the valve, and an accessory turbine mounted on the rotor shaft, the accessory turbine rotating the rotor shaft when the pneumatic timer applies the compressed air onto the accessory turbine.

The pneumatic timer may be mounted on the nacelle.

The aircraft engine assembly may include a thrust link attached to the gas turbine engine and comprising the pressure vessel.

The means may include a pressure vessel for containing the pressurized fluid comprising oil, a valve connected to the pressure vessel, an oil timer connected to the pressure vessel, and a hydraulic motor rotating the rotor when the oil is supplied to the hydraulic motor from the oil timer and the hydraulic motor is coupled to the rotor shaft.

The aircraft engine assembly may include a brace or strut link attached to the gas turbine engine and comprising the pressure vessel.

In another embodiment, there is provided an aircraft engine. The aircraft engine includes a gas turbine engine including a rotor shaft, a hydraulic or pneumatic motor mounted on the rotor or connected to a transmission connected to the rotor shaft, and a pressure vessel. The aircraft engine further includes a valve, and ducting connected to the valve, the pressure vessel, and the motor.

The motor may convert pressure exerted by a fluid into torque, when the fluid is delivered to the motor through the ducting and the valve, and the transmission applies the torque to the rotor shaft so as to rotate the rotor shaft.

The engine may include a pneumatic timer or hydraulic timer connected to the ducting, wherein the pneumatic timer or the hydraulic timer pulses the fluid so as to deliver pulses of the fluid to the motor.

The timer may be a hydraulic timer, the motor may be a hydraulic motor, and the fluid may include oil.

The timer may be a pneumatic timer, the motor may be a pneumatic motor, and the fluid may include compressed air.

The engine may include a casing housing the gas turbine engine, and a pneumatic timer connected to the ducting and mounted on the casing. The fluid may include compressed air, the pneumatic timer pulses the compressed air delivered from the pressure vessel so as to deliver pulses of the compressed air to the motor, and the pneumatic motor, comprising an accessory turbine mounted on the rotor shaft, applies torque to the rotor shaft when the pulses drive the accessory turbine.

The aircraft engine may include a thrust link, a brace, or a strut attached to the gas turbine engine and comprising the pressure vessel.

The gas turbine engine may include a high pressure compressor including the rotor shaft.

In another embodiment, there is provided a method of rotating a rotor shaft in an aircraft engine. The method may involve storing pressurized fluid on an aircraft comprising a nacelle housing a gas turbine engine, and driving a rotor shaft using the pressurized fluid, when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient.

The driving may involve connecting a pneumatic or hydraulic motor to the rotor shaft, driving the pneumatic or hydraulic motor with the pressurized fluid, wherein the pneumatic or hydraulic motor converts pressure exerted by the pressurized fluid into torque, and applying the torque to the rotor shaft, wherein the torque rotates the rotor shaft.

The method may involve a thrust link storing the pressurized gas and attached to the gas turbine engine.

The pressurized fluid may be stored in a pressure vessel attached to the engine, and the driving may include inputting the fluid into a timer, wherein the timer outputs pulses of the fluid, connecting a paddle turbine, comprising paddles, to the rotor shaft, applying the pulses of fluid onto the paddles, wherein the pulses of fluid drive the paddle turbine and the paddle turbine outputs torque, connecting the paddle turbine to the rotor shaft, and using the torque to rotate the rotor shaft.

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In one embodiment, there is provided an aircraft engine assembly including a gas turbine engine including a rotor having a rotor shaft. The rotor shaft has a longitudinal axis. The aircraft engine assembly further includes a nacelle housing the rotor and means for rotating the rotor shaft using intermittent rotational motion driven by a pressurized fluid outputted by at least one of a timer and a stepper motor. The intermittent rotational motion reduces or prevents thermal bowing of the rotor shaft in a temperature gradient perpendicular to the longitudinal axis when the gas turbine engine is cooling down.

In another embodiment, there is provided an aircraft engine including: a gas turbine engine including a rotor shaft; a motor including a hydraulic motor or a pneumatic motor, the motor mounted on the rotor shaft or connected to a transmission connected to the rotor shaft; a pressure vessel storing a fluid; a valve; and ducting connected to the valve, the pressure vessel, and the motor. The motor converts pressure exerted by the fluid into torque driving the rotor shaft when the fluid is delivered to the motor through the ducting and the valve. The motor includes at least one of a stepper motor and a timer, the timer applying pulses of the fluid onto the motor so as to drive the motor.

In another embodiment, there is provided a method of rotating a rotor shaft in an aircraft engine. The method involves storing a pressurized fluid in a pressure vessel on an aircraft including the aircraft engine, the aircraft engine including a nacelle housing and a gas turbine engine. The method further involves driving a rotor shaft of the gas turbine engine with intermittent rotational motion using the pressurized fluid outputted by at least one of a timer and a stepper motor when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient.

In another embodiment, there is provided an aircraft engine assembly including a gas turbine engine including a rotor having a rotor shaft. The rotor shaft has a longitudinal axis. The aircraft engine assembly further includes: a nacelle housing the rotor; means for rotating the rotor shaft using pressurized fluid, the rotating reducing or preventing thermal bowing of the rotor shaft in a temperature gradient perpendicular to the longitudinal axis when the gas turbine engine is cooling down; and means adapted to store energy by compressing a fluid into a pressure vessel to generate the pressurized

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fluid by using power generated while the gas turbine engine is running in combustion mode with intake of air. The means for rotating the rotor shaft includes the pressure vessel for containing the pressurized fluid, a valve connected to the pressure vessel, and a stepper motor coupled to the rotor shaft. The stepper motor includes a combination of a timer and a motor. The stepper motor is configured to rotate the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel.

In another embodiment, there is provided a method of rotating a rotor shaft in an aircraft engine. The method involves storing energy by compressing a fluid into a pressure vessel to generate pressurized fluid using power generated while the aircraft engine is running in combustion mode with intake of air, the aircraft engine including a nacelle housing and a gas turbine engine. The method further involves driving a rotor shaft of the gas turbine engine by supplying the pressurized fluid through a valve connected to the pressure vessel to a stepper motor coupled to the rotor shaft when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient. The stepper motor includes a combination of a timer and a motor and rotates the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1**A is a schematic illustration of a gas turbine engine.

FIG. **1**B illustrates the gas turbine engine mounted in a nacelle on an aircraft.

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FIG. **2**A is a cross sectional schematic of a system providing pressurized gas to an accessory turbine mounted on a rotor shaft, according to one or more embodiments.

FIG. **2**B illustrates an engine rotor mounted air paddle-turbine, according to one or more embodiments.

FIG. **2**C is a close up view of the engine rotor mounted air paddle turbine in FIG. **2**B.

FIG. **3**A illustrates an accessory gearbox mounted air turbine, according to one or more embodiments.

FIG. **3**B illustrates an engine connected to a thrust link comprising the pressure vessel, according to one or more embodiments.

FIG. **4**A illustrates an accessory gearbox mounted hydraulic motor, according to one or more embodiments.

FIG. **4**B illustrates an engine comprising thrust link comprising a hydro-accumulator, according to one or more embodiments.

FIG. **5** is a flowchart illustrating a method of fabricating a system for rotating a rotor shaft, according to various embodiments.

FIG. **6** is a flowchart illustrating a method of mitigating rotor shaft bow, according to various embodiments.

FIG. **7** illustrates a hardware environment for operating the pneumatic or hydraulic motor, according to one or more embodiments.

DESCRIPTION

In the following description, reference is made to the accompanying drawings which form a part hereof, and which is shown, by way of illustration, several embodiments. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present disclosure.

The present disclosure describes an aircraft engine assembly comprising a gas turbine engine including a rotor **108** having a rotor shaft **122**, wherein the rotor shaft has a longitudinal axis **128**, AA'; a casing **106** and/or nacelle **134** comprising trapped air **116** creating a temperature gradient increasing along vector T perpendicular to the longitudinal axis **128**, AA when the gas turbine engine is cooling down in the temperature gradient; and means for rotating the rotor using pressurized fluid. The rotor **108** comprising a rotor shaft **122** is housed in the casing **106** and nacelle **134** and the rotating reduces or prevents thermal bowing of the rotor shaft **122** in the temperature gradient T.

Several examples of the means for rotating the rotor are further described below.

<u>First Example</u>

FIG. **2**A, **2**B, and **2**C illustrate a gas turbine engine **200** including a rotor shaft **202** having a longitudinal axis AA'; a pneumatic motor **204** mounted on the rotor shaft **202**; and a pressure vessel (air cylinder **206**) connected **208** to the pneumatic motor **204**. An auxiliary compressor **210** pressurizes the pressure vessel **206** with air through a check valve **212**.

One or more ducts **214**, an air supply valve/remote air valve **216**, and a pneumatic timer **218** connect the pressure vessel **206** (containing compressed air **206**a) to the motor **204**. The remote air valve **216** connected to the ducting **214** regulates flow **220** of the compressed air **206**a from the pressure vessel **206** to the pneumatic timer **218**. The pneumatic timer **218** connected to the ducting **214** portions the flow of compressed air **206**a into air pulses **222**.

The pneumatic motor **204** comprises an accessory turbine **204**a comprising paddles **224**, an input **226** connected to the ducting **214** receiving the air pulses **222**, and an output **228** to atmosphere **230**. The air pulses **222** delivered onto the paddles **224** drive the accessory turbine **204**a housed in turbine housing **232**.

The accessory turbine **204**a is mounted on the rotor shaft **202** such that the accessory turbine **204**a converts pressure exerted by the air pulses **222** into torque **234**a that drives the rotor shaft **202** so as to rotate **236** the rotor shaft **122** about axis AA'. The pneumatic timer **218** is mounted on the turbine housing. In another embodiment, the pneumatic timer **218** is mounted on the engine casing **106** or **104** or other engine housing.

This first example does not require a dedicated pad on an accessory gearbox and thus provides enhanced spatial integration and technology packaging.

Second Example

FIG. **3**A illustrates another system **300** or apparatus for rotating a rotor shaft **122**. The system comprises a pneumatic motor **302**, a transmission **304** connecting the pneumatic motor **302** to the rotor shaft **122**, and a pressure vessel **306** connected to the pneumatic motor **302**. An auxiliary compressor **308** pressurizes the pressure vessel **306** with air **306**a through a check valve **310**.

A duct **312** or system of ducts **312**, an air supply valve or remote air valve **314**, and a pneumatic timer **316** connect the pressure vessel **306** (containing compressed air **306**a) to the motor **302**. The remote air valve **314** connected to the duct **312** regulates flow **318** of the compressed air **306**a from the pressure vessel **306** to the pneumatic timer **316**. The pneumatic timer **316** connected to the duct **312** portions the flow **318** of compressed air **306**a into air pulses **320**.

The pneumatic motor **302** comprises an accessory or air turbine **302**a comprising paddles **322**, an input **324** connected to the duct **312** and receiving the air pulses, and an output **326** to atmosphere **328**. The air pulses **320** delivered onto the paddles **322** drive the accessory turbine **302**a. Thus, the accessory turbine **302**a converts pressure exerted by the air pulses **320** into torque **330**a or rotation **330**b, **330**c used to drive rotation **340** of the rotor shaft **122** about axis AA', **128** when the air pulses **320** are supplied to the accessory turbine **302**a through the ducts or conduit **312**. In one embodiment, the paddles **322** are intermittently driven by the air pulses. In another embodiment, the paddles **332** are driven by measured timed air pulses from the pneumatic timer **316**.

The transmission **304** (comprising drive shafts **332**, gearing (beveled gears **334**), an accessory gearbox **336**; and a tower shaft **338**) applies the torque **330**a to the rotor shaft **122** so as to rotate **340** the rotor shaft **122**. Specifically, when the pneumatic motor **302** is activated and operatively coupled to the rotor shaft **122** via the transmission **304**, the pneumatic motor **302** drives the engine accessory gearbox **336** via the drive shafts **332** and the engine accessory gearbox **336** back-drives the rotor shaft **122** by driving the tower shaft **338**.

While the second example illustrates the pneumatic motor **302** driving the accessory gearbox **336**, in another embodiment, the pneumatic motor drives the compressor rotor shaft **122** directly via the tower shaft **338** and drive shaft **332** without connecting to the gearbox **336**.

FIG. **3**B illustrates an aircraft engine assembly **340** comprising a gas turbine engine **342** comprising the rotor **108**, wherein the gas turbine engine **342** is connected to a thrust link **344**, and the thrust link **344** comprises or embeds the pressure vessel **306**. Thus, the aircraft engine assembly **340** comprises the pneumatic motor **302** connected to a transmission (including gearbox **336**) connected to the rotor **108** comprising rotor shaft **122**; the pressure vessel **306**; a valve **314**; and ducting **312** connected to the valve **314**, the pressure vessel **306**, and the motor **302**.

In another variation, a fluid other than air is used, such as, but not limited to, nitrogen.

Third Example

FIG. **4**A illustrates yet another system **400** or apparatus for rotating a rotor shaft **122**. The system comprises a hydraulic motor **402**, a transmission **404** connecting the hydraulic motor **402** to the rotor shaft **122**, and a pressure vessel comprising a hydro-accumulator **406** connected to the hydraulic motor **402**. Oil **408** from an accessory oil pump mounted on the engine accessory gearbox **410** supplies oil to the hydro-accumulator via check valve **412**.

A duct or conduit **414** or system of ducts or conduits **414**, a remote oil valve **416**, and an oil timer **418** connect the hydro-accumulator **406** (containing pressurized oil **408** and air **420**) to the motor **402**. The remote oil valve **416** connected to the duct **414** regulates flow **422** of the oil from the hydro-accumulator to the oil timer **418**. The oil timer **418** connected to the duct **414** portions the flow **422** of compressed oil into oil pulses.

The hydraulic motor **402** comprises paddles **424**, an input **426** connected to the duct **414** and receiving the oil pulses, and an output to the engine accessory gearbox **410** via duct **428**. The oil pulses delivered onto the paddles **424** drive the motor **402**. Thus, the motor **402** converts pressure exerted by the oil pulses into torque **430**a or rotation **430**b, **430**c used to drive the rotor shaft **122**, when the oil pulses are supplied to the motor **402** through the ducts or conduit **414**. In one embodiment, the paddles **422** are intermittently driven by the oil pulses. In another embodiment, the paddles **422** are driven by measured, timed oil pulses from the oil timer **418**.

The transmission **404** (comprising drive shafts **432**, gearing (beveled gears **434**), an accessory gearbox **410**; and a tower shaft **338**) applies the torque **430**a to the rotor shaft **122** so as to rotate **340** the rotor shaft **122** about axis **122**. Specifically, when the hydraulic motor **402** is activated and operatively coupled to the rotor shaft **122** via the transmission **404**, the hydraulic motor **402** drives the engine accessory gearbox **410** via the drive shafts **432** and the engine accessory gearbox **410** back-drives the rotor shaft **122** by driving the tower shaft **338**.

While the second example illustrates the hydraulic motor **402** driving the accessory gearbox **410**, in another embodiment, the pneumatic motor drives the rotor shaft **122** directly via the tower shaft **338** and drive shaft **432** without connecting to the gearbox **410**.

FIG. 4B illustrate an aircraft engine assembly **434** comprises engine **436** comprising rotor **108**, wherein the aircraft engine assembly **434** comprises the hydraulic motor **402** connected to a transmission (including gearbox **410**) connected to the rotor shaft **122**; strut links **344** comprising or embedding the pressure vessel **406**; a valve **416**; and ducting **414** connected to the valve **416**, the pressure vessel **406**, and the motor **402**.

In another variation, a fluid other than oil **408** is used.

Process Steps

Fabrication

FIG. **5** is a flowchart illustrating a method of fabricating means for rotating a rotor shaft using pressurized fluid. Examples of the rotor shaft **202**, **122** include a low-pressure or a high-pressure shaft **122** in a **2**-spool engine **200**, **346**, or a low-pressure or intermediate-pressure shaft in a **3** spool engine.

Block **500** represents attaching a pressure vessel **306**, **408** to an aircraft, e.g. to a thrust link **346**, brace, strut link, engine strut **344** attached to the gas turbine engine **342**. In one embodiment the thrust link **346**, brace, strut link, or engine strut **344** comprises or doubles as the pressure vessel **306**, **406**.

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Block **502** represents mounting a pneumatic motor **204**, **302**, or hydraulic motor **402**.

Block **504** represents connecting a valve **216**, **314**, **416** to the pressure vessel **306**, **406** using a duct **214**, **312**, **414**.

Block **506** represents connecting a timer **418**, **316**, **218** to the valve **216**, **314**, **416** using a duct **214**, **312**, **414**.

Block **506** further represents connecting the timer **418**, **316**, **218** to the pneumatic motor **204**, **302** or hydraulic motor **402** using a duct **214**, **312**, **414**.

Block **508** represents the end result, a pneumatic or hydraulic system or means for rotating **236**, **340** the shaft **122**, **202** using pressurized fluid **408**, **320**.

In one embodiment, the means comprises a pressure vessel **406** for containing oil **408**; the valve **416** connected to the pressure vessel **406**; the oil timer **418** comprising oil **408** connected to the valve **416**; and a hydraulic motor **402** rotating **340** the rotor shaft **122** about axis **128** when the oil **408** is supplied to the hydraulic motor **402** from the oil timer **418** and the hydraulic motor **402** is coupled to the rotor shaft **122**, as illustrated in FIG. **4**A.

In another embodiment, means for rotating the rotor shaft **122** comprises the pressure vessel **306**, **206** for containing the pressurized fluid **206**c (e.g., compressed air **306**a or oil **408**); a valve **216**, **314**, **416** connected to the pressure vessel **306**, **408**, **206**; and a stepper motor **350** connected or coupled to the rotor shaft **122**. In one embodiment, the stepper motor **350** comprises a combination of the timer **218** and motor **204**, **302**, **402** as illustrated in FIGs. **2**A, **3**A, **4**A.

In yet another embodiment, the means for rotating the rotor comprises an accessory turbine **204**a directly mounted on the rotor shaft **202**, as illustrated in FIG. **2**A. The pneumatic timer **218** applies/delivers/supplies the compressed air **222** that enters the accessory turbine **204**a. The compressed air **222** rotates **234**a the accessory turbine **204**a and the gas turbine rotor shaft **202** connected to the accessory turbine **204**a. FIG. **2**A illustrates a casing **106** housing the gas turbine engine **200**; and a pneumatic timer **218** connected to the ducting **214** and mounted on the casing **106**, wherein the fluid comprises compressed air **206**a; the pneumatic timer **218** pulses the compressed air **206**a delivered from the pressure vessel **206** so as to deliver pulses

222 of the compressed air **206**a to the motor **204**; the pneumatic motor **204**, comprising an accessory turbine **204**a mounted on the rotor shaft **202**, applies torque **234**a that rotates **236** the rotor shaft **202** when the pulses **222** drive **234**a the accessory turbine **204**a.

Operation

FIG. **6** is a flowchart illustrating a method for rotating a rotor shaft **122**, **202** in a gas turbine engine **342**. The gas turbine engine **200**, **342** is typically housed in a nacelle **134** attached to the aircraft.

Block **600** represents storing pressurized fluid **206**a, **408** on the aircraft. In one embodiment, pneumatic energy is stored by compressing the fluid (e.g., air **206**a or oil **408**) into a pressure vessel **306**, **206**, **406** using power generated while the engine **200**, **342** is running in combustion mode with intake of air **136**.

Blocks **602-606** represent driving **236** the rotor shaft **122** using the pressurized fluid **222**, **408**, when the rotor shaft is cooling down in a temperature gradient T perpendicular to the longitudinal axis AA', **128** of the rotor shaft **122**, **202**, thereby reducing or preventing any thermal bowing of the rotor shaft **122**, **202** in the temperature differential/gradient T.

The driving comprises connecting the pneumatic motor **204**, **302**, hydraulic motor **402**, or stepper motor **350** to the rotor shaft (Block **602**); driving **234**a, **330**a, **430**a the pneumatic motor **204**, **304** or hydraulic motor **402** with the pressurized fluid **408**, **222**, **320** (Block **604**) so that the pneumatic motor **204**, **302** or hydraulic motor **402** converts pressure exerted by the pressurized fluid **222**, **320**, into torque **234**a, **330**a, **430**a; and applying the torque **234**a, **330**a, **430**a to the rotor shaft **122** so that the torque **234**a, **330**a, **430**a rotates **340**, **236** the rotor shaft **122** (Block **606**). In one embodiment, the driving **234**a, **330**a, **430**a comprises inputting fluid **220**, **318**, **422** from the pressure vessel **206** into a timer **218**, **316**, **418** wherein the timer **218**, **316**, **418** outputs pulses of the fluid **222**, **320**; applying the pulses of fluid **222**, **320** onto paddles **322**, **424**, **224** of the accessory turbine **302**a, **204**a, **402**, wherein the pulses of fluid drive the paddle turbine **204**a, **302**a so that the paddle turbine **302**a, **204**a, **402** outputs torque **330**a,

430a; and connecting the accessory/paddle turbine **302**, **204**, **402** to the rotor shaft **122** so that the torque **330**a, **330**b is used to rotate **236**, **340** the rotor shaft **122**, **202**.

In one embodiment, the accessory turbine **204**a mounted on the rotor shaft **202** and the accessory turbine **204**a rotates **236** the rotor shaft **202** when the pneumatic timer **218** applies the compressed air **222** onto the accessory turbine **204**a.

The stepper motor embodiment rotates **340** the rotor **108** and shaft **122** when the pressurized fluid (e.g., air **206**a, **306**a) is supplied to the stepper motor from the pressure vessel, releasing the stored pneumatic/hydraulic energy in a series of bursts. The stepper motor operates similar to a winding clock, i.e., the stepper motor delivers intermittent or timed rotational motion using air or hydraulics instead of a spring. In one embodiment, the fluid supply lasts a sufficient time to enable slow rotation of the rotor **108** and subsequently gradual cooling of the rotor that prevents rotor bowing (while using the relatively low power provided by the clock-like pneumatic motor).

In one embodiment, the pneumatic motor **204**, **302** or hydraulic motor **402** is used to rotate **236**, **340** the rotor shaft **122**, **202** soon/immediately after engine **200**, **342** shut down so as to minimize departure delays. In another embodiment, the motor **204**, **304**, **402** is activated to rotate **236**, **340** the rotor shaft **122** prior to engine start (i.e., prior to motoring the engine **200**, **342**, and wherein motoring refers to rotating the shaft after engine start but prior to fuel on).

Rotation Speed and Duration

The pneumatic/hydraulic motor **204**, **302**, **402** rotates **340**, **236** the rotor shaft **122**, **202** at one or more speeds, using one or more torques, and/or for one or more durations, so as to reduce or prevent the thermal bowing of the rotor shaft in the temperature differential. Examples of rotation speeds include, but are not limited to, low speeds such as between **0.5**-**2.0** rpm.

Rotation of the rotor includes, but is not limited to, pulsed rotation, continuous rotation, a combination of both pulsed rotation and continuous rotation, clocked rotation, and/or sporadic rotation.

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In one periodic pulsing scheme, torque is applied after a plurality of minutes (e.g. every **5-15** minutes) so that the rotor rotates a partial turn or in increments. In one embodiment, partial turns are 'clocked,' e.g., for a one-half turn. In another example, the pulse provides random rotor movement. In one embodiment, pulse modulation is achieved by programming the pneumatic or hydraulic timer to emit carefully timed pulses. In one embodiment, the piezoelectric motor rotates the shaft by turning the shaft in one or more increments comprising a partial revolution of the shaft.

In one example, the rotation speed and duration are such that the probability of a compressor rub is less than e-**8** per flight-hour.

System Dimensions

In one or more embodiments, the pneumatic/hydraulic motor system described herein has weight and dimensions optimized for compactness to overcome weight and space constraints, e.g., so that the hydraulic/pneumatic motor system can be integrated into the engines of smaller aircraft such as a Boeing **737** Max. In one example, the pneumatic or hydraulic motor has a diameter of at most **6**", is at most **12**" long, and has a weight of at most **25** pounds. However, the hydraulic/pneumatic motor can be implemented in all aircraft, including, but not limited to, Boeing **787**, **777**, and **747** aircraft.

Example System Features

One or more embodiments of the ETM system comprise a pneumatic or hydraulic motor system installed in an aircraft using components such that:

- the aircraft is capable of being dispatched for at least **10** days after a failure of the ETM;
- failure of the ETM system does not require line maintenance to dispatch the aircraft;
- failure of the ETM does not interfere with engine operation, and in particular, does not interfere with engine start;
- failure rate of the ETM is e-**5** per flight hour or better;

- the ETM is sufficiently reliable that a backup scheme is not required (e.g., the ETM has a reliability of at least e-**6** per flight hour or at least e-**7** per flight hour);
- the ETM has a lock out feature, in case unforeseen issues arise and the system must be easily disabled;
- energy demands for rotating the rotor and reducing the thermal bowing are reduced as compared to systems using an electric motor to rotate the rotor; and/or
- the installation and certification is easier as compared to systems using an electric motor to rotate the rotor (e.g., the ETM system does not include a new ignition source or fuel source adding to engine fire protection designs).

Processing Environment

FIG. **7** illustrates an exemplary computer or system **700** that could be used to implement processing elements needed to control rotation of the hydraulic or pneumatic motor systems **714**, **300**, **400** described herein. The computer system is typically located on the aircraft e.g., but not limited to, in a box mounted on the engine fan case **104**, casing **106**, or inside the aircraft.

The computer **702** comprises a processor **704** (general purpose processor **704**A and special purpose processor **704**B) and a memory, such as random access memory (RAM) **706**. Generally, the computer **702** operates under control of an operating system **708** stored in the memory **706**, and interfaces with the user/other computers to accept inputs and commands (e.g., analog or digital signals) and to present results through an input/output (I/O) module **710**. The computer program application **712** accesses and manipulates data stored in the memory **706** of the computer **702**. The operating system **708** and the computer program **712** are comprised of instructions which, when read and executed by the computer **702**, cause the computer **702** to perform the operations herein described. In one embodiment, instructions implementing the operating system **708** and the computer program **710** are tangibly embodied in the memory **706**, thereby making a computer program product or article of manufacture. As such, the terms "article of manufacture," "program storage device" and "computer program product" as used herein are intended to encompass a computer program accessible from any computer readable device or media.

In one embodiment, computer **702** comprises one or more field programmable gate arrays (FPGAs).

In one embodiment, the computer **700** comprises a controller activating the pneumatic/hydraulic motor by regulating/activating the valve and/or the timer. In one embodiment, an Electronic Engine Control (EEC) unit sends a digital request to the controller, via I/O **710**, to reduce/increase the pneumatic/hydraulic pressure via the timer or air supply valve, thus controlling compressor rotor speeds. In yet another embodiment, the computer provides status to the EEC via I/O **710** so that the controller and/or the EEC monitor system monitor performance and/or control the rotation of the rotor.

In another embodiment, the computer activates the pneumatic/hydraulic motor **204**, **302**, **404** after receiving a signal from an engine shut off switch indicating the engine **200**, **342** has been shut off., thereby activating the pneumatic or hydraulic motor. In one example, the pneumatic or hydraulic motor rotates the rotor soon/immediately after engine shut down so as to minimize aircraft departure delays caused by mitigating rotor shaft bow. In another embodiment, the computer **702** activates the pneumatic or hydraulic motor prior to engine start (i.e., prior to motoring the engine).

In another embodiment, the duration of rotation is optimized by having the computer estimate the amount of bow (based on time since last engine shutdown) and calculate the required rotation duration to be implemented. Various instrumentation to monitor the bowing can include accelerometers already used for vibration monitoring or microwave-based gap measuring sensors.

FIG. **7** further illustrates a power source **716** for providing power to the system **700**.

Those skilled in the art will recognize many modifications may be made to this configuration without departing from the scope of the present disclosure. For example, those skilled in the art will recognize that any combination of the above components, or any number of different components, peripherals, and other devices, may be used.

<u>Conclusion</u>

This concludes the description of certain embodiments of the present disclosure. The foregoing description has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of rights be limited not by this detailed description, but rather by the claims appended hereto.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An aircraft engine assembly comprising:

a gas turbine engine including a rotor having a rotor shaft, wherein the rotor shaft has a longitudinal axis;

a nacelle housing the rotor; and

means for rotating the rotor shaft using intermittent rotational motion driven by a pressurized fluid outputted by at least one of a timer and a stepper motor, wherein the intermittent rotational motion reduces or prevents thermal bowing of the rotor shaft in a temperature gradient perpendicular to the longitudinal axis when the gas turbine engine is cooling down.

2. The aircraft engine assembly of claim **1**, wherein the means for rotating comprises:

a pressure vessel for containing the pressurized fluid;

a valve connected to the pressure vessel; and

the stepper motor coupled to the rotor shaft, the stepper motor rotating the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel.

3. The aircraft engine assembly of claim **2**, further comprising a thrust link attached to the gas turbine engine and doubling as the pressure vessel .

4. The aircraft engine assembly of claim **1**, wherein the means for rotating comprises:

a pressure vessel for containing the pressurized fluid comprising compressed air;

a valve connected to the pressure vessel;

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the timer comprising a pneumatic timer connected to the valve; and

an accessory turbine mounted on the rotor shaft, the accessory turbine rotating the rotor shaft when the pneumatic timer applies the compressed air onto the accessory turbine.

5. The aircraft engine assembly of claim **4**, wherein the pneumatic timer is mounted on the nacelle.

6. The aircraft engine assembly of claim **4** or **5**, further comprising a thrust link attached to the gas turbine engine and comprising the pressure vessel.

7. The aircraft engine assembly of claim **1**, wherein the means for rotating comprises:

a pressure vessel for containing the pressurized fluid comprising oil;

a valve connected to the pressure vessel;

the timer comprising an oil timer connected to the pressure vessel; and

a hydraulic motor coupled to the rotor shaft, the hydraulic motor rotating the rotor shaft when the oil is supplied to the hydraulic motor from the oil timer.

8. The aircraft engine assembly of claim **7**, further comprising a brace or strut link attached to the gas turbine engine and comprising the pressure vessel.

9. An aircraft engine comprising:

a gas turbine engine including a rotor shaft;

a motor comprising a hydraulic motor or a pneumatic motor, the motor mounted on the rotor shaft or connected to a transmission connected to the rotor shaft;

a pressure vessel storing a fluid;

a valve; and

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ducting connected to the valve, the pressure vessel, and the motor,

wherein the motor converts pressure exerted by the fluid into torque driving the rotor shaft when the fluid is delivered to the motor through the ducting and the valve, and

wherein the motor comprises at least one of a stepper motor and a timer, the timer applying pulses of the fluid onto the motor so as to drive the motor.

10. The aircraft engine of claim **9**, wherein the transmission applies the torque to the rotor shaft so as to rotate the rotor shaft.

11. The engine of claim **9** or **10**, wherein the timer comprises a pneumatic timer or hydraulic timer connected to the ducting, wherein the pneumatic timer or the hydraulic timer pulses the fluid so as to deliver pulses of the fluid to the motor.

12. The engine of claim **11**, wherein the timer is the hydraulic timer, the motor is the hydraulic motor, and the fluid comprises oil.

13. The engine of claim **11**, wherein the timer is the pneumatic timer, the motor is the pneumatic motor, and the fluid comprises compressed air.

14. The engine of claims **9** or **10**, further comprising a casing housing the gas turbine engine and wherein:

the timer comprises a pneumatic timer connected to the ducting and mounted on the casing,

the fluid comprises compressed air,

the pneumatic timer pulses the compressed air delivered from the pressure vessel so as to deliver pulses of the compressed air to the motor, and the motor comprises a pneumatic motor comprising an accessory turbine mounted on the rotor shaft, the pneumatic motor applying torque to the rotor shaft when the pulses of the compressed air drive the accessory turbine.

15. The aircraft engine of any one of claims **9**-**14**, further comprising a thrust link, a brace, or a strut attached to the gas turbine engine and comprising the pressure vessel.

16. The engine of any one of claims **9**-**15**, wherein the gas turbine engine comprises a high pressure compressor including the rotor shaft.

17. The engine of claim **9** or **10**, wherein:

the motor further comprises a turbine connected to the timer, and

the timer applying the pulses of the fluid onto the turbine so as to drive the turbine.

18. A method of rotating a rotor shaft in an aircraft engine, the method comprising:

storing a pressurized fluid in a pressure vessel on an aircraft comprising the aircraft engine, the aircraft engine comprising a nacelle housing and a gas turbine engine; and

driving a rotor shaft of the gas turbine engine with intermittent rotational motion using the pressurized fluid outputted by at least one of a timer and a stepper motor when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient.

19. The method of claim **18**, wherein the stepper motor comprises a pneumatic motor or a hydraulic motor, the driving further comprises:

connecting the pneumatic motor or the hydraulic motor to the rotor shaft;

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driving the pneumatic motor or the hydraulic motor with the pressurized fluid, wherein the pneumatic motor or the hydraulic motor converts pressure exerted by the pressurized fluid into torque; and

applying the torque to the rotor shaft, wherein the torque rotates the rotor shaft.

20. The method of claim **18**, wherein the driving further comprises:

inputting the pressurized fluid into the timer, wherein the timer outputs pulses of the pressurized fluid;

connecting a paddle turbine, comprising paddles, to the rotor shaft;

applying the pulses of the pressurized fluid onto the paddles, wherein the pulses of the pressurized fluid drive the paddle turbine and the paddle turbine outputs a torque; and

using the torque to rotate the rotor shaft.

21. The method of any one of claims **18**-**20**, wherein a trust link comprises the pressure vessel and the method further comprises storing the pressurized fluid in the thrust link, wherein the trust link is attached to the gas turbine engine.

22. The method of any one of claims **18**-**20**, wherein the pressure vessel is attached to the aircraft engine.

23. An aircraft engine assembly comprising:

a gas turbine engine including a rotor having a rotor shaft, wherein the rotor shaft has a longitudinal axis;

a nacelle housing the rotor;

means for rotating the rotor shaft using pressurized fluid, the rotating reducing or preventing thermal bowing of the rotor shaft in a temperature gradient

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perpendicular to the longitudinal axis when the gas turbine engine is cooling down; and

means adapted to store energy by compressing a fluid into a pressure vessel to generate the pressurized fluid by using power generated while the gas turbine engine is running in combustion mode with intake of air,

wherein the means for rotating the rotor shaft comprises:

the pressure vessel for containing the pressurized fluid;

a valve connected to the pressure vessel; and

a stepper motor coupled to the rotor shaft, the stepper motor comprising a combination of a timer and a motor, wherein the stepper motor is configured to rotate the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel.

24. The aircraft engine assembly of claim **23**, further comprising a thrust link doubling as the pressure vessel, wherein the thrust link is attached to the gas turbine engine.

25. The aircraft engine assembly of claim **23**, further comprising a thrust link comprising the pressure vessel, wherein the thrust link is attached to the gas turbine engine.

26. The aircraft engine assembly of claim **23**, further comprising a brace or strut link comprising the pressure vessel, wherein the brace or the strut link is attached to the gas turbine engine.

27. The aircraft engine assembly of any one of claims **23**-**26**, wherein:

the pressurized fluid comprises compressed air,

the timer comprises a pneumatic timer connected to the valve, and

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the means for rotating the rotor shaft further comprises an accessory turbine mounted on the rotor shaft, the accessory turbine rotating the rotor shaft when the pneumatic timer applies the compressed air onto the accessory turbine.

28. The aircraft engine assembly of claim **27**, wherein the pneumatic timer is mounted on the nacelle.

29. The aircraft engine assembly of any one of claims **23**-**26**, wherein:

the pressurized fluid comprises oil,

the timer comprises an oil timer connected to the pressure vessel, and

the stepper motor comprises a hydraulic motor coupled to the rotor shaft and configured to rotate the rotor shaft when the oil is supplied to the hydraulic motor from the oil timer.

30. A method of rotating a rotor shaft in an aircraft engine, the method comprising:

storing energy by compressing a fluid into a pressure vessel to generate pressurized fluid using power generated while the aircraft engine is running in combustion mode with intake of air, the aircraft engine comprising a nacelle housing and a gas turbine engine; and

driving a rotor shaft of the gas turbine engine by supplying the pressurized fluid through a valve connected to the pressure vessel to a stepper motor coupled to the rotor shaft when the rotor shaft is cooling down in a temperature gradient perpendicular to a longitudinal axis of the rotor shaft, thereby reducing or preventing any thermal bowing of the rotor shaft in the temperature gradient, wherein the stepper motor comprises a combination of a timer and a motor and rotates the rotor shaft when the pressurized fluid is supplied to the stepper motor from the pressure vessel.

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31. The method of claim **30**, wherein the motor comprise a pneumatic motor or a hydraulic motor and the driving comprises:

connecting the pneumatic motor or the hydraulic motor to the rotor shaft;

driving the pneumatic motor or the hydraulic motor with the pressurized fluid, wherein the pneumatic motor or the hydraulic motor converts pressure exerted by the pressurized fluid into torque; and

applying the torque to the rotor shaft, wherein the torque rotates the rotor shaft.

32. The method of claims **30** or **31**, wherein a thrust link attached to the gas turbine engine comprises the pressure vessel and the storing comprises storing the pressurized fluid in the thrust link.

33. The method of claim **30**, wherein the pressure vessel is attached to the gas turbine engine, and the motor comprises a paddle turbine comprising paddles, the driving comprises:

inputting the pressurized fluid into the timer, wherein the timer outputs pulses of the pressurized fluid;

connecting the paddle turbine to the rotor shaft;

applying the pulses of the pressurized fluid onto the paddles, wherein the pulses of the pressurized fluid drive the paddle turbine and the paddle turbine outputs torque; and

using the torque to rotate the rotor shaft.

34. The method of claim **33**, wherein the pluses of the pressurized fluid provide random rotor shaft movement.

35. The method of any one of claims **30**-**34**, wherein the stepper motor is used to rotate the rotor shaft immediately after the gas turbine engine shuts down.

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36. The method of any one of claims **30**-**35**, wherein stepper motor outputs torque after a plurality of minutes so that the rotor shaft rotates a partial turn or in increments.

37. The method of claim **36**, wherein the plurality of minutes are between **5** minutes and **15** minutes.

38. The method of any one of claims **30**-**37**, wherein a rotation speed of the rotor shaft is between **0**.**5** rpm and **2**.**0** rpm.

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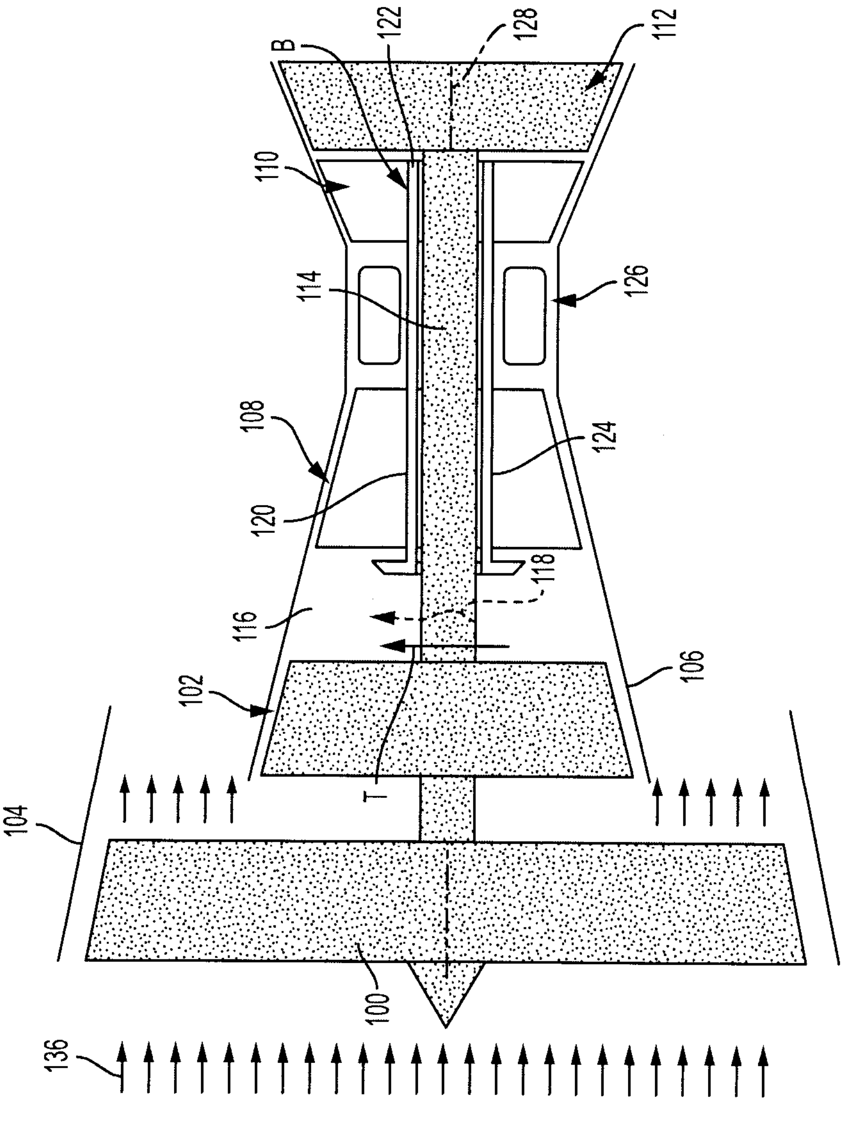


B
122
128
112
110
114
126
108
120
124
118
116
102
106
T
104
100
136

FIG. 1A

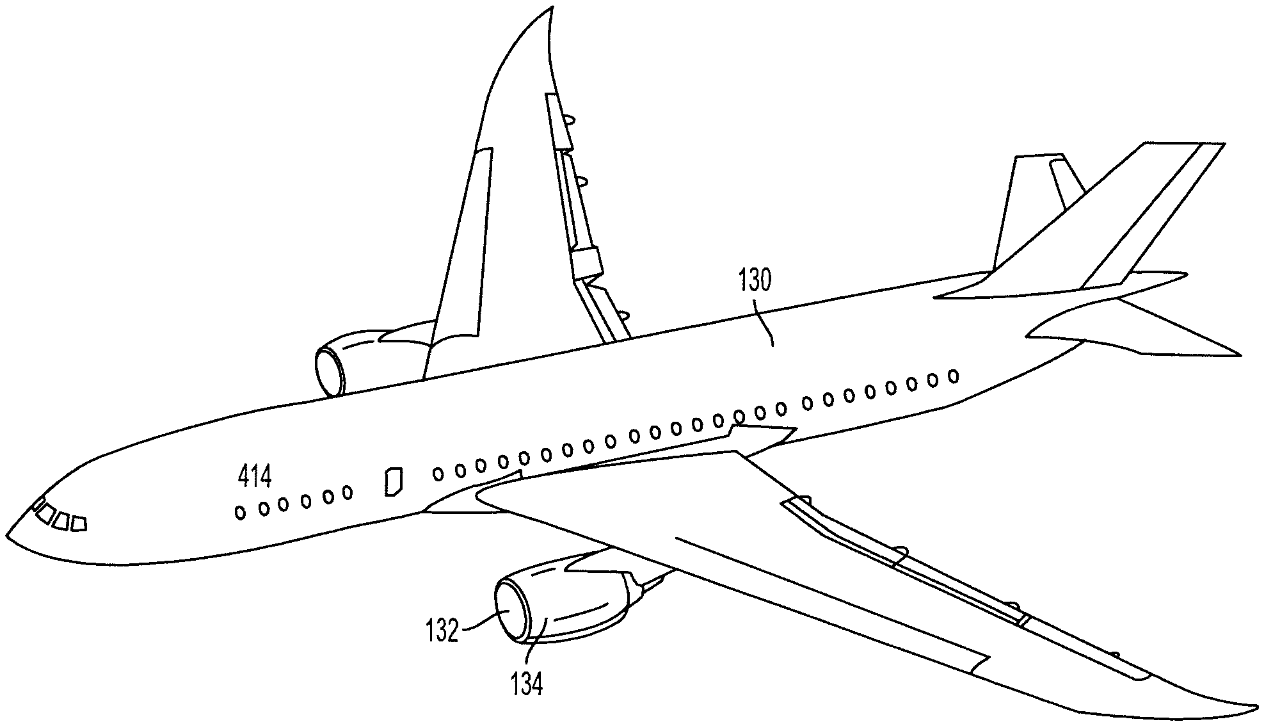


FIG. 1B

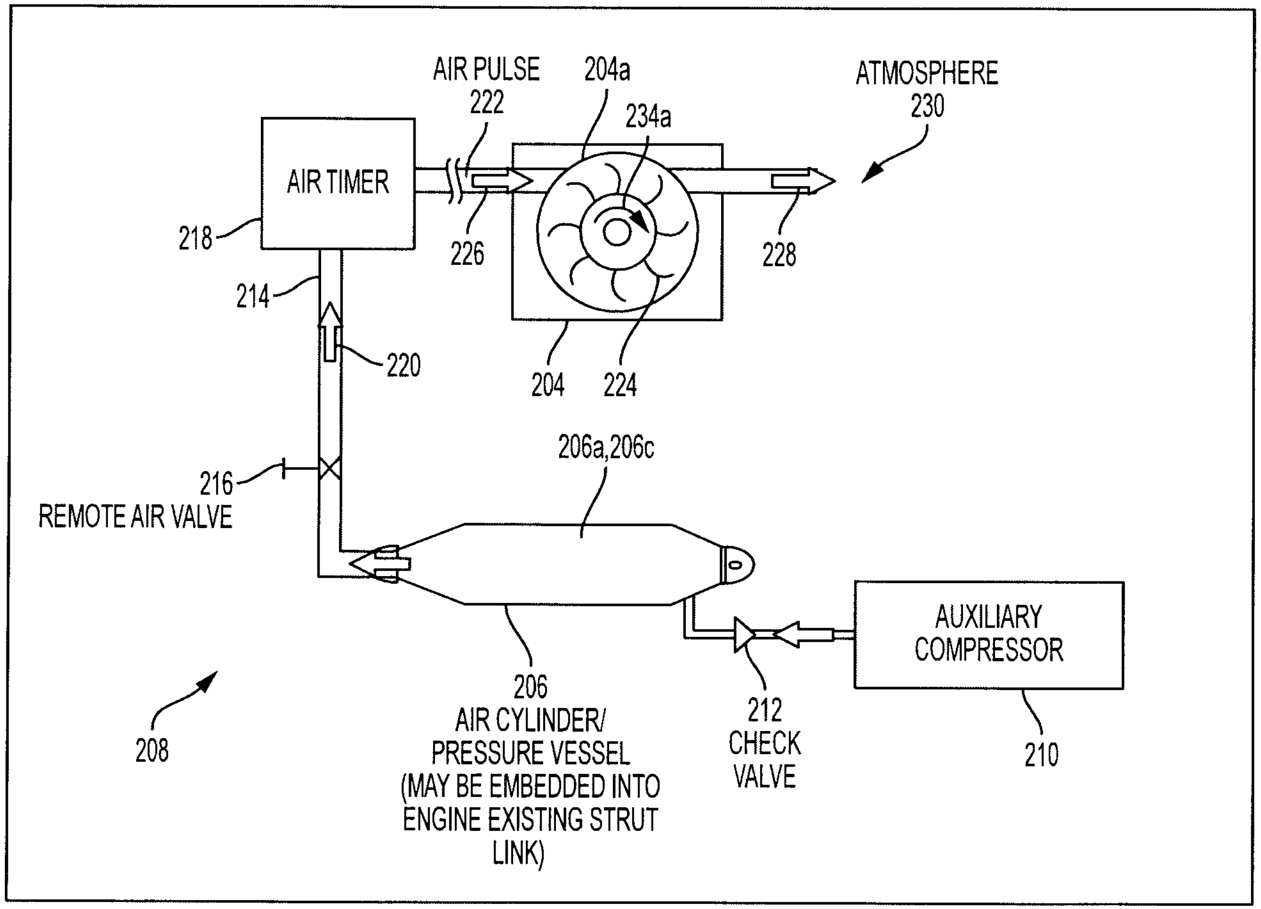

AIR PULSE
222
204a
234a
ATMOSPHERE
230
AIR TIMER
218
226
228
214
220
204
224
216
REMOTE AIR VALVE
206a,206c
AUXILIARY
COMPRESSOR
206
AIR CYLINDER/
PRESSURE VESSEL
(MAY BE EMBEDDED INTO
ENGINE EXISTING STRUT
LINK)
212
CHECK
VALVE
210
208

FIG. 2A

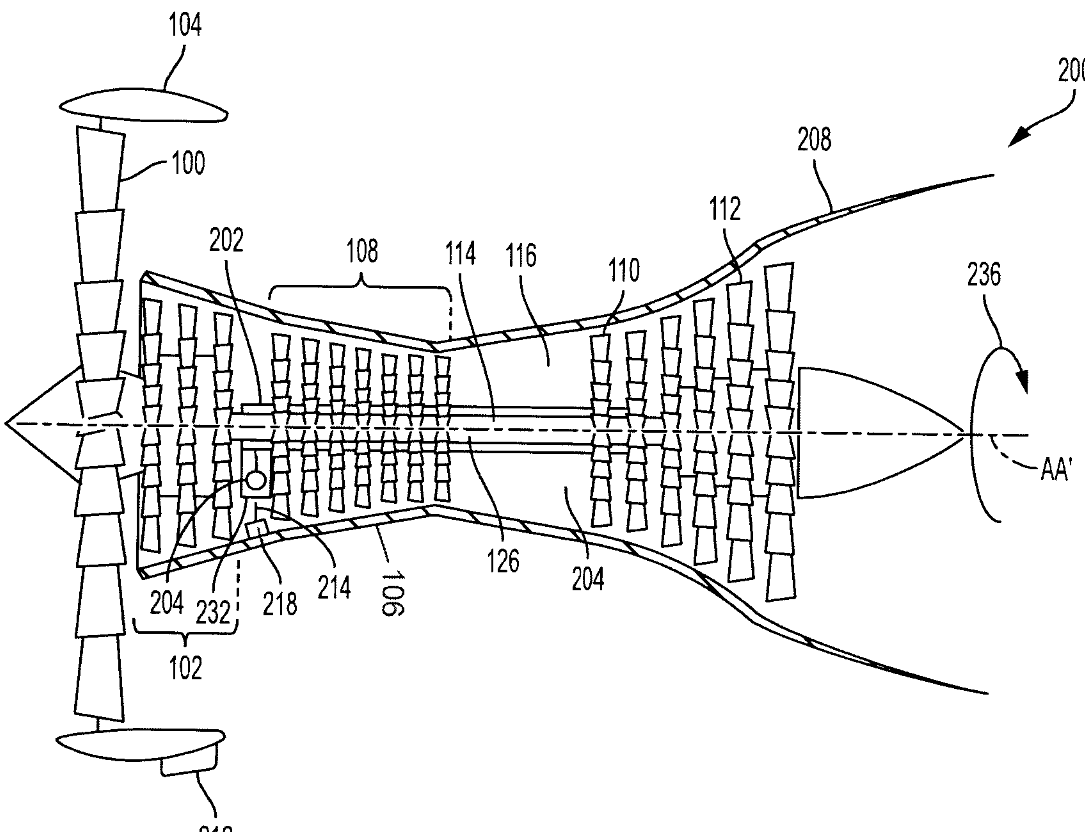

104
100
212
202
108
114
116
110
112
208
200
236
AA'
204
232
102
218
214
106
126
204

FIG. 2B

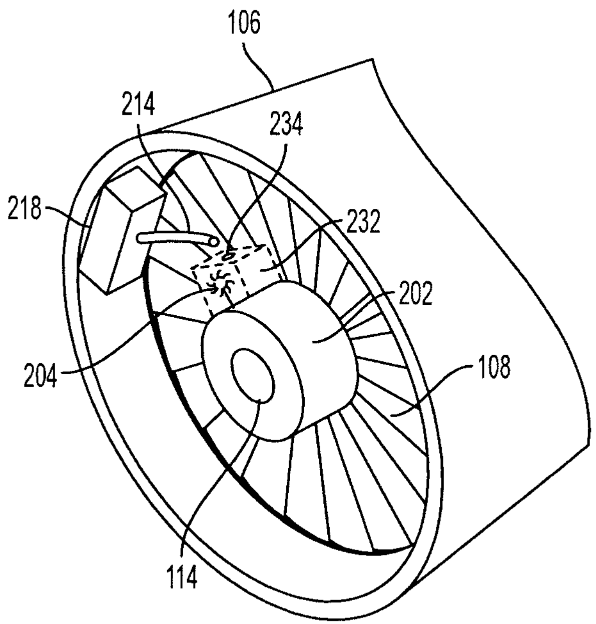

106
214
234
218
232
202
204
108
114

FIG. 2C

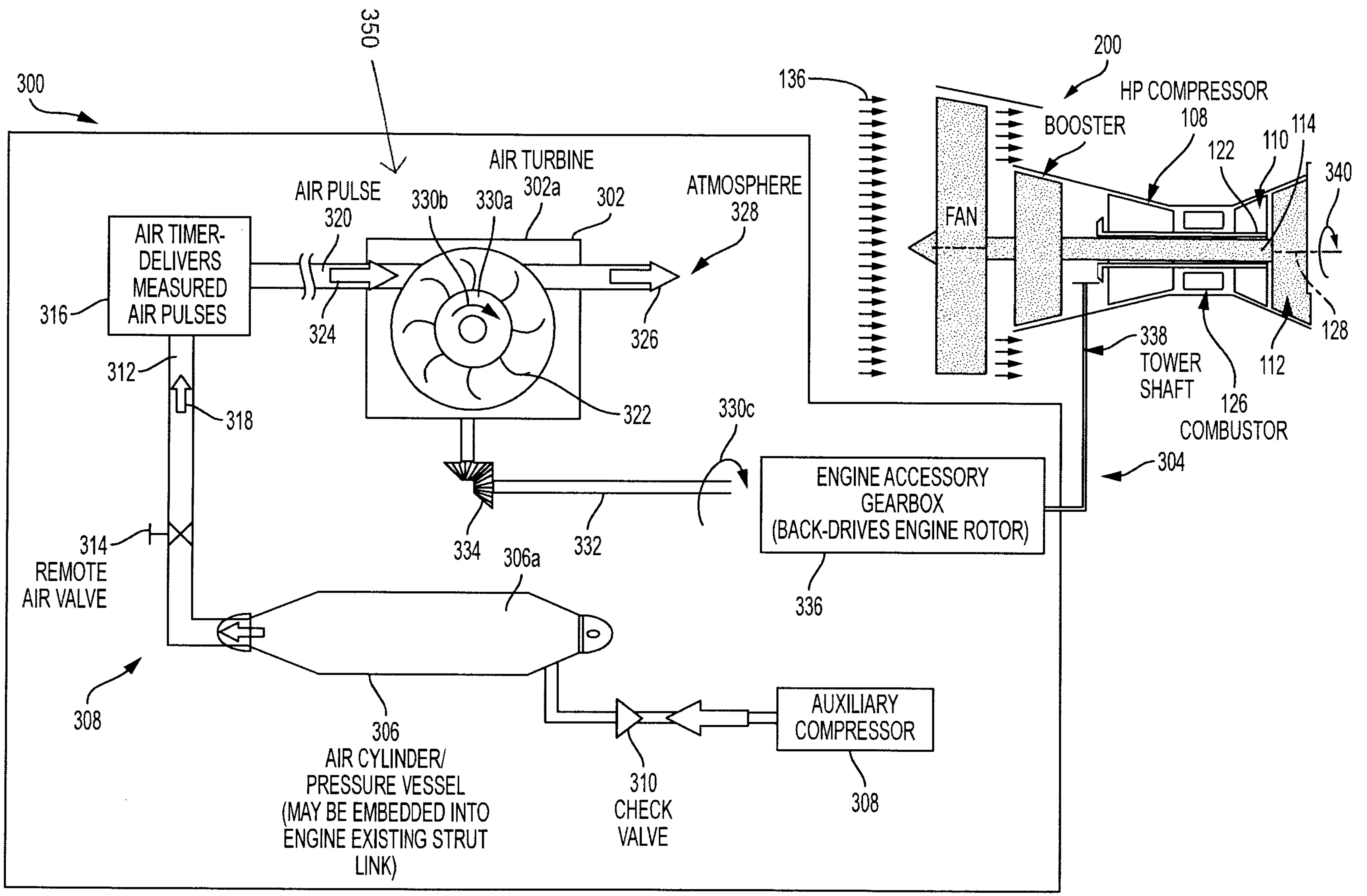

300
350
AIR TURBINE
AIR PULSE
320
330b
330a
302a
302
ATMOSPHERE
328
AIR TIMER-
DELIVERS
MEASURED
AIR PULSES
316
324
326
312
322
318
330c
314
REMOTE
AIR VALVE
334
332
306a
ENGINE ACCESSORY
GEARBOX
(BACK-DRIVES ENGINE ROTOR)
336
308
306
AIR CYLINDER/
PRESSURE VESSEL
(MAY BE EMBEDDED INTO
ENGINE EXISTING STRUT
LINK)
310
CHECK
VALVE
AUXILIARY
COMPRESSOR
308
136
200
HP COMPRESSOR
108
BOOSTER
FAN
122
110
114
340
128
112
338
TOWER
SHAFT
126
COMBUSTOR
304

FIG. 3A

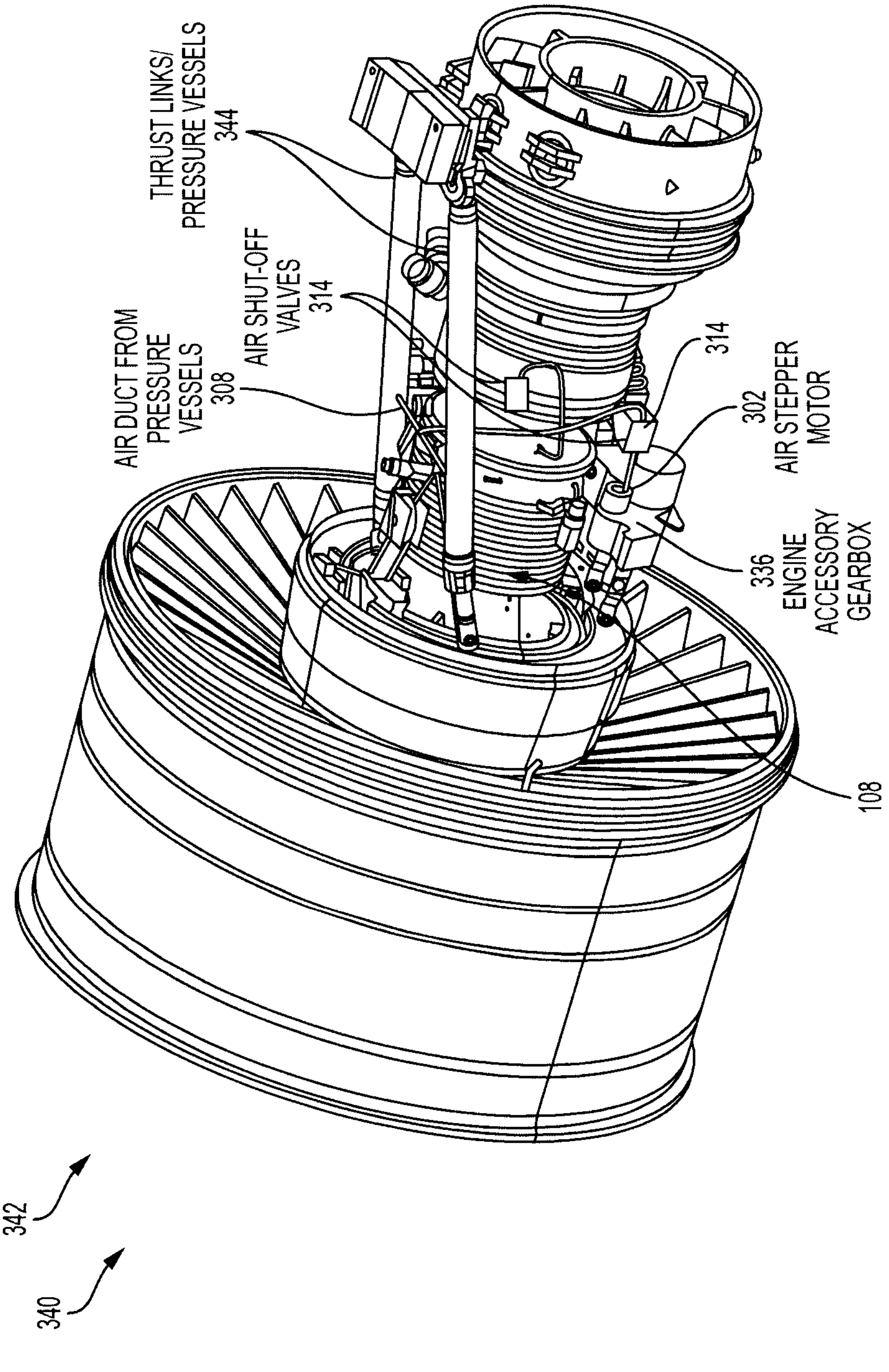

THRUST LINKS/
PRESSURE VESSELS
344
AIR SHUT-OFF
VALVES
314
AIR DUCT FROM
PRESSURE
VESSELS
308
314
302
AIR STEPPER
MOTOR
336
ENGINE
ACCESSORY
GEARBOX
108
342
340

FIG. 3B

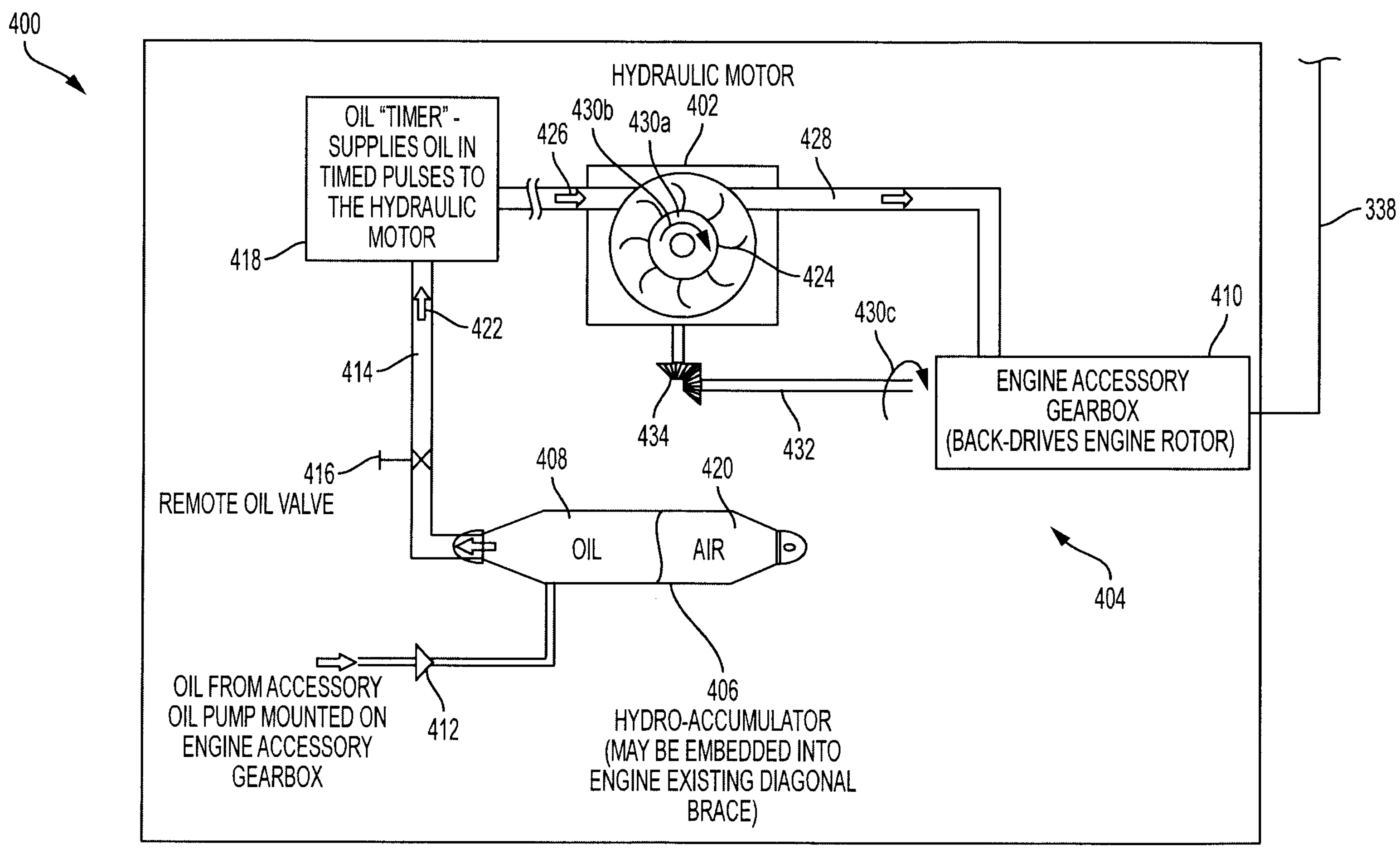

400
HYDRAULIC MOTOR
OIL "TIMER" - SUPPLIES OIL IN TIMED PULSES TO THE HYDRAULIC MOTOR
426
430b
430a
402
428
418
424
422
414
430c
410
338
ENGINE ACCESSORY GEARBOX (BACK-DRIVES ENGINE ROTOR)
434
432
416
REMOTE OIL VALVE
408
420
OIL
AIR
404
OIL FROM ACCESSORY OIL PUMP MOUNTED ON ENGINE ACCESSORY GEARBOX
412
406
HYDRO-ACCUMULATOR (MAY BE EMBEDDED INTO ENGINE EXISTING DIAGONAL BRACE)

FIG. 4A

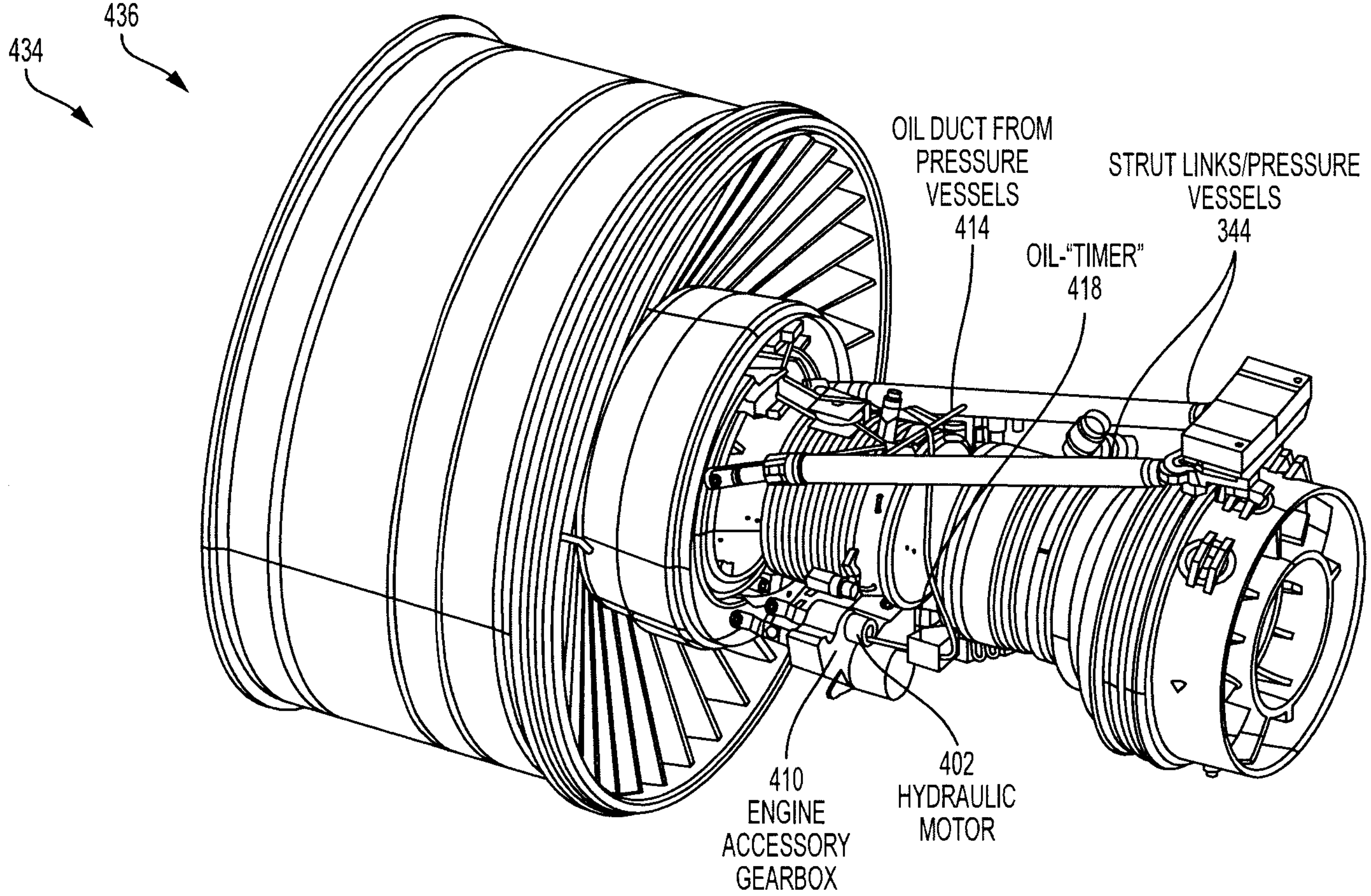

436
434
OIL DUCT FROM PRESSURE VESSELS 414
OIL-"TIMER" 418
STRUT LINKS/PRESSURE VESSELS 344
410 ENGINE ACCESSORY GEARBOX
402 HYDRAULIC MOTOR

FIG. 4B

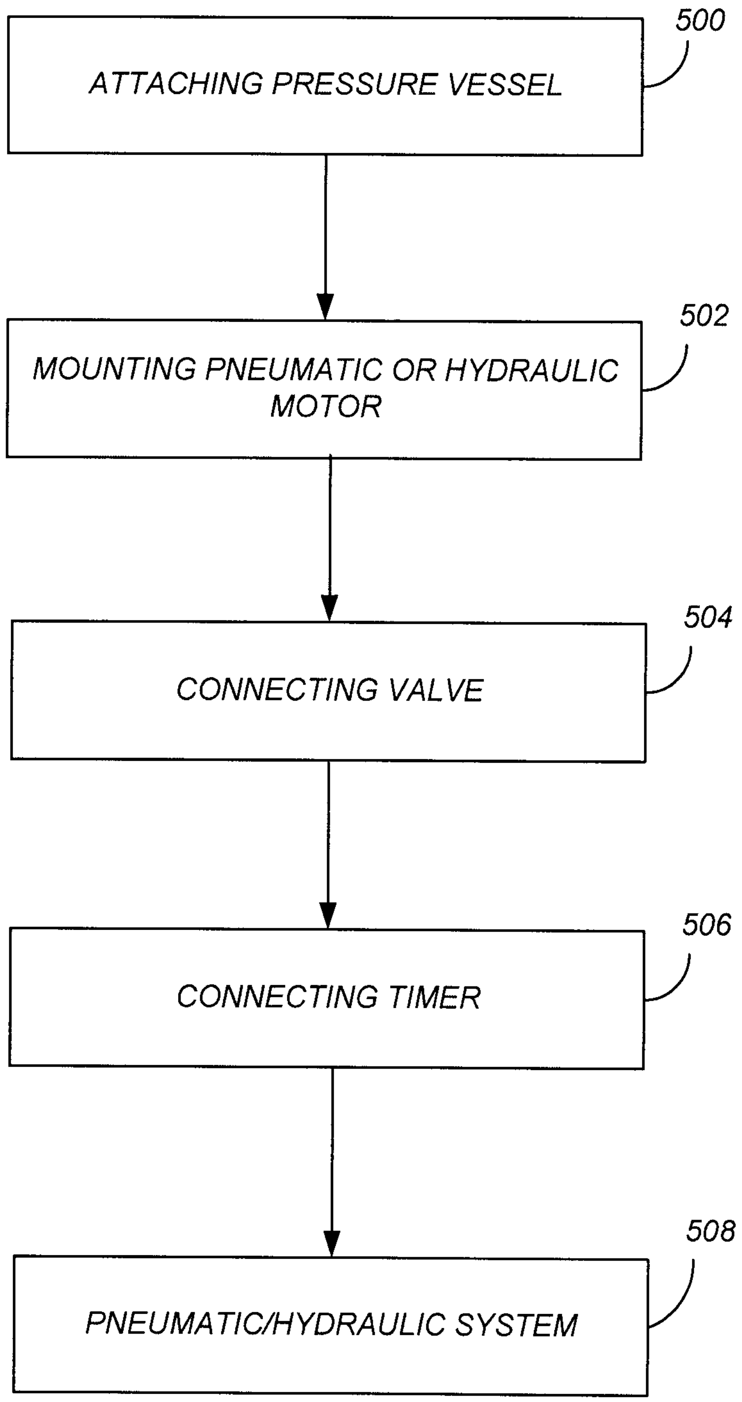

ATTACHING PRESSURE VESSEL
500
MOUNTING PNEUMATIC OR HYDRAULIC MOTOR
502
CONNECTING VALVE
504
CONNECTING TIMER
506
PNEUMATIC/HYDRAULIC SYSTEM
508

FIG. 5

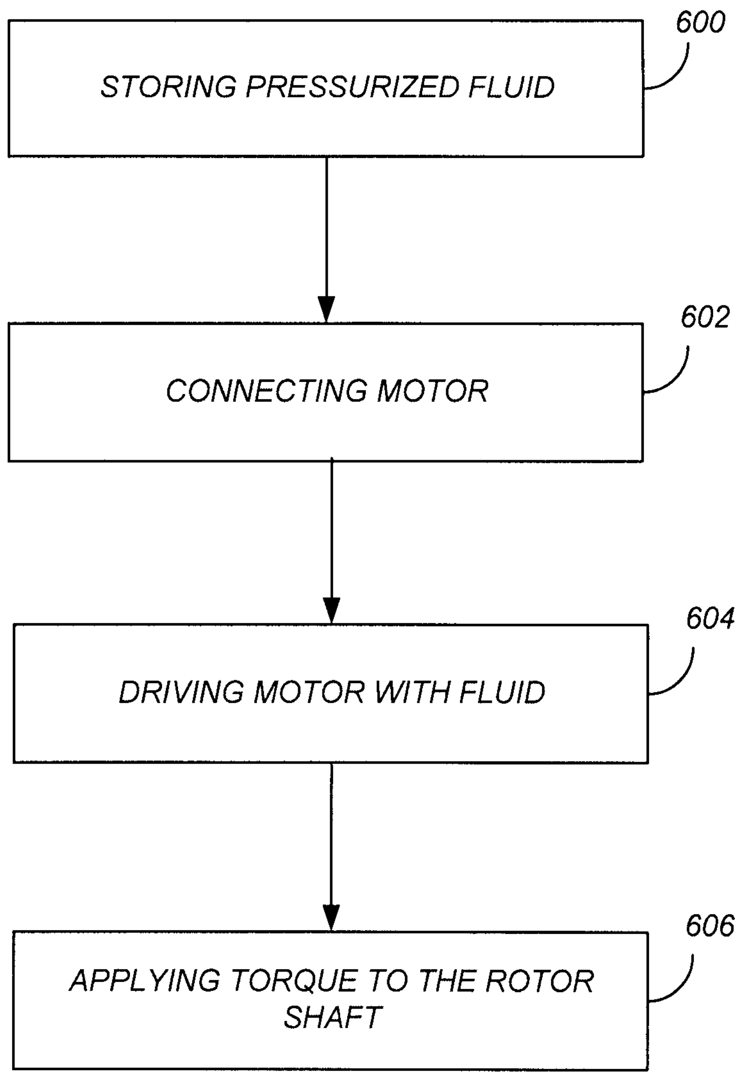

600
STORING PRESSURIZED FLUID
602
CONNECTING MOTOR
604
DRIVING MOTOR WITH FLUID
606
APPLYING TORQUE TO THE ROTOR SHAFT

FIG. 6

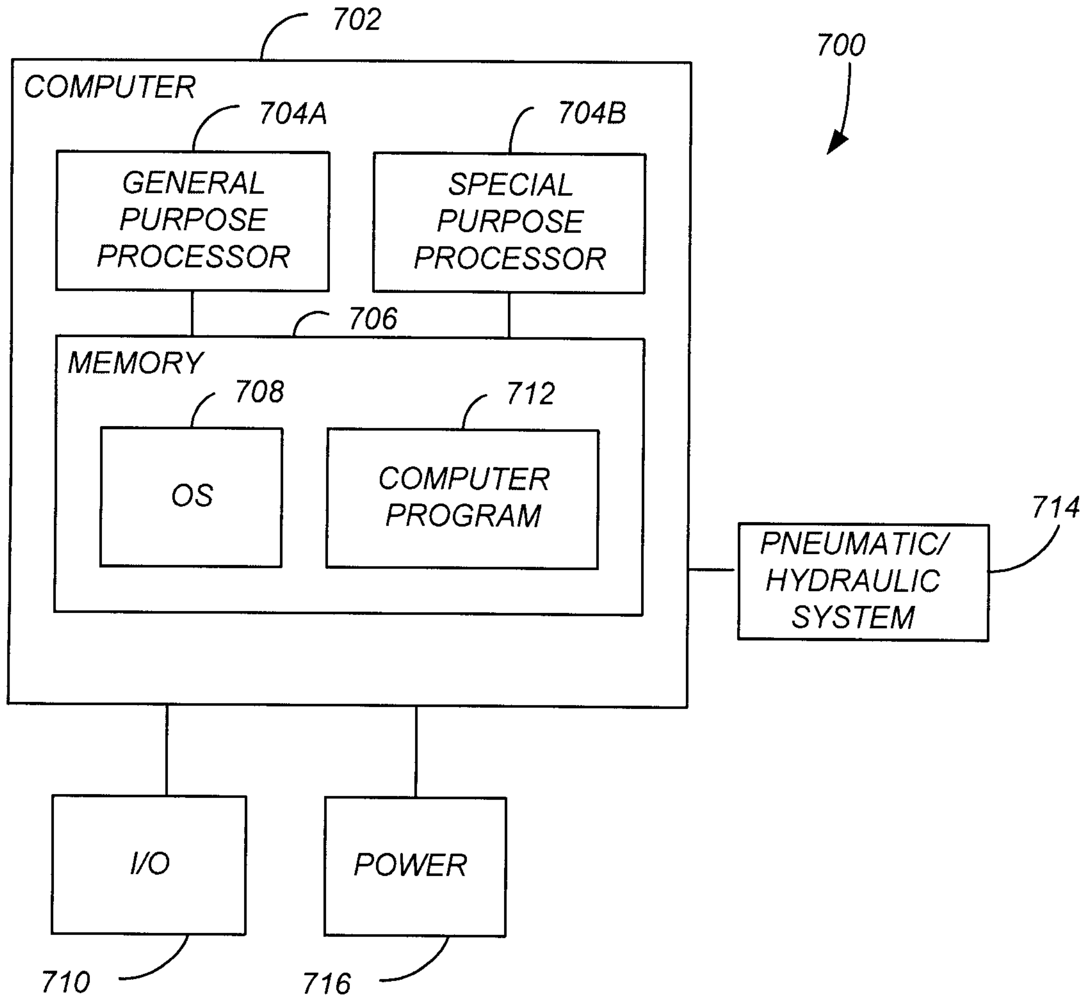
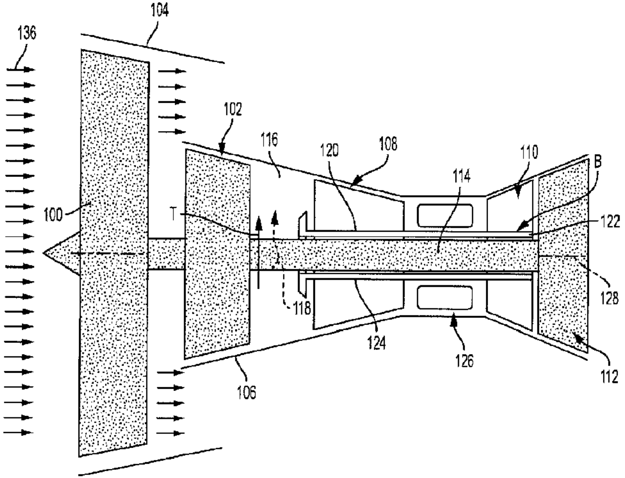

702
700
COMPUTER
704A
704B
GENERAL PURPOSE PROCESSOR
SPECIAL PURPOSE PROCESSOR
706
MEMORY
708
712
OS
COMPUTER PROGRAM
714
PNEUMATIC/ HYDRAULIC SYSTEM
I/O
POWER
710
716

FIG. 7


104
136
102
116
120
108
110
B
114
100
T
122
128
118
124
126
112
106