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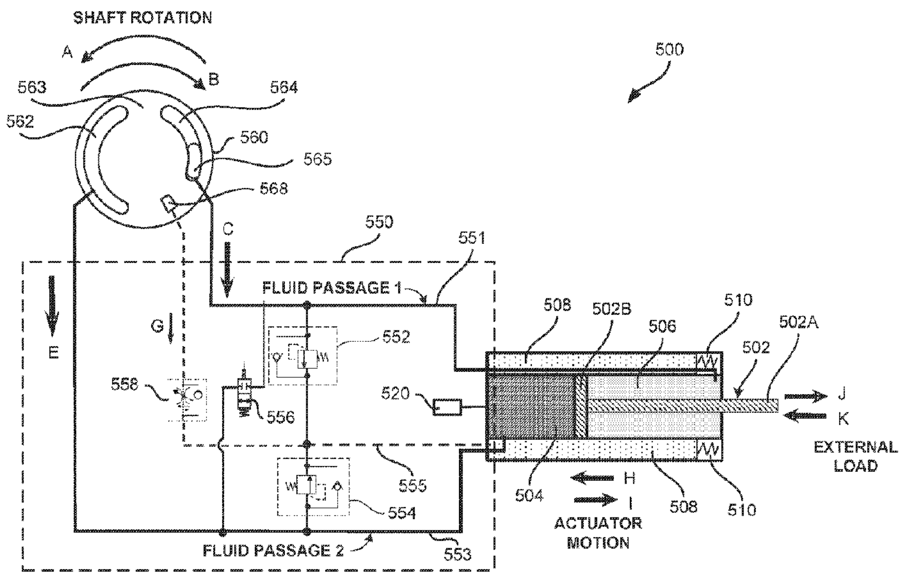

(57) Abrégé/Abstract:
In general, certain examples of the present disclosure provide an electro- hydrostatic actuator comprising a piston assembly and a hydraulic cylinder. The piston assembly, having a piston head and a piston rod extending from the piston head, is located and movable within the hydraulic cylinder. The hydraulic cylinder includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber, a reservoir for storing hydraulic fluid located within the hydraulic cylinder which is in fluid communication with the hydraulic fluid chamber region. The electro-hydrostatic actuator includes a hydraulic pump system for moving hydraulic fluid in the reservoir and the hydraulic fluid chamber region, the hydraulic pump system in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid within the hydraulic fluid chamber region, and an electric motor for driving the hydraulic pump system.

ABSTRACT

LOW PROFILE ELECTRO-HYDROSTATIC ACTUATOR

In general, certain examples of the present disclosure provide an electro-hydrostatic actuator comprising a piston assembly and a hydraulic cylinder. The piston assembly, having a piston head and a piston rod extending from the piston head, is located and movable within the hydraulic cylinder. The hydraulic cylinder includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber, a reservoir for storing hydraulic fluid located within the hydraulic cylinder which is in fluid communication with the hydraulic fluid chamber region. The electro-hydrostatic actuator includes a hydraulic pump system for moving hydraulic fluid in the reservoir and the hydraulic fluid chamber region, the hydraulic pump system in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid within the hydraulic fluid chamber region, and an electric motor for driving the hydraulic pump system.

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LOW PROFILE ELECTRO-HYDROSTATIC ACTUATOR

BACKGROUND

The present disclosure relates generally to fluid pressure actuators and, more specifically, to electro-hydrostatic actuators. Electro-Hydraulic actuators (EHAs) are known to power aircraft operations such as flight control surfaces, landing gear retraction or extension, steering or braking, as well as lifting mechanisms for various vehicles. A typical EHA system includes multiple components, for example, an electric motor that drives a hydraulic pump to move hydraulic fluid from a reservoir to a hydraulic cylinder for actuating the actuator. However, current component based EHA systems are bulky in size, heavy in weight, incurring higher cost at manufacturing and requiring assembly and plumbing at the installation.

Thus, there exists a need for a low profile EHA containing all the components in one integrated package and yet providing enhanced component durability for elongated hydraulic operation life.

SUMMARY

The following presents a simplified summary of the disclosure in order to provide a basic understanding of certain examples of the present disclosure. This summary is not an extensive overview of the disclosure and it does not identify key/critical elements of the present disclosure or delineate the scope of the present disclosure. Its sole purpose is to present some concepts disclosed herein in a simplified form as a prelude to the more detailed description that is presented later.

In general, certain examples of the present disclosure provide electro-hydrostatic actuators. According to various examples, an electro-hydrostatic actuator is provided comprising a piston assembly having a piston head and a piston rod extending from the piston head, and a hydraulic cylinder, with the piston assembly located and movable within the hydraulic cylinder. The hydraulic cylinder includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The

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electro-hydrostatic actuator further comprises a reservoir for storing hydraulic fluid located within the hydraulic cylinder which is in fluid communication with the hydraulic fluid chamber region. The electro-hydrostatic actuator further comprises a hydraulic pump system for moving hydraulic fluid in the reservoir and the hydraulic fluid chamber region. The hydraulic pump system may be in fluid communication with a flow control network for controlling a direction and flow magnitude of hydraulic fluid within the hydraulic fluid chamber region. The electro-hydrostatic actuator further comprises an electric motor located within the hydraulic cylinder for driving the hydraulic pump system.

In some examples, the electro-hydrostatic actuator further comprises an integrated control module located within the hydraulic cylinder for receiving a control signal and converting the control signal into a set-point value at which the electric motor drives the hydraulic pump system. In some examples, the electric motor rotates a fixed or variable angle swash plate to drive the hydraulic pump system. In some examples, the direction of hydraulic fluid flow is determined by a direction of movement of the fixed or variable angle swash plate and the flow magnitude of the hydraulic fluid into the hydraulic fluid chamber region is controlled by an angle through which the swash plate is tilted.

In some examples, the electro-hydrostatic actuator further comprises an integrated control module located within the hydraulic cylinder for receiving a control electric signal which controls the direction of movement of the fixed or variable angle swash plate and the angle of tilt of the fixed or variable angle swash plate. In some examples, the hydraulic pump system comprises a hydraulic pump cylinder block which is rotatable within the electro-hydrostatic actuator. The hydraulic pump cylinder block may comprise a plurality of pistons which are movable by rotation of the fixed or variable angle swash plate. In some examples, the plurality of pistons are coupled to the swash plate and slide within the rotating hydraulic pump cylinder block along a direction of a center axis (X) of the electro-hydrostatic actuator.

In some examples, the electro-hydrostatic actuator further comprises a separating member located within the hydraulic cylinder which separates the reservoir into a compressed gas chamber area and a hydraulic fluid chamber area. In some examples, the separating member is a membrane. In some examples, the separating member has a bellow shape. In some examples, the separating member is movably disposed within the hydraulic cylinder.

In some examples, the piston assembly is moved in a first direction from a retracted position to an extended position by pumping hydraulic fluid from at least one of the rod side chamber and from the reservoir into the piston side chamber and pushes fluid from the rod side chamber into the reservoir. The piston assembly may additionally be moved in a second direction opposite to the first direction by pumping hydraulic fluid from at least one of the piston side chamber and the reservoir into the rod side chamber and pushing hydraulic fluid from the piston side chamber into the reservoir.

In some examples, the hydraulic pump system includes a valve plate. In some examples, a direction of the hydraulic fluid flow supplied by or returned to the hydraulic pump system is controlled by the valve plate. In some examples, the valve plate is mechanically attached to or integral with the hydraulic cylinder boss. In some examples, the valve plate is rotatable within the hydraulic cylinder boss. In some examples, the flow control network is integrated into the hydraulic cylinder boss.

In some examples, the electric motor is a servo motor and the hydraulic pump system is a bi-directional, positive displacement pump. In some examples, a position of the piston assembly within the hydraulic cylinder and output force produced by the piston assembly are controlled by modulating one of: a speed of the electric servo motor, a speed of the positive displacement pump, or a combination thereof. In some examples, a position of the piston assembly and output force are controlled by changing a speed and direction of the servo motor.

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In some examples, the electro-hydrostatic actuator further comprises a thermal management system, the thermal management system disposed to surround thermal hot spots on an outer periphery of the actuator. In some examples, the electro-hydrostatic actuator further comprises a position sensor that monitors a position of the actuator, wherein at least one of a speed and a direction of the electric motor is controlled according to the position of the actuator.

In yet another example of the present disclosure, an integrated accumulator and manifold system of a hydrostatic actuator is provided. According to various examples, the integrated accumulator and manifold system of a hydrostatic actuator comprises an inner surface surrounding an outer periphery of a housing of a hydraulic cylinder including a piston assembly, which has a piston head and a piston rod extending from the piston head. The housing may include a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The integrated accumulator and manifold system further comprises an outer surface defining a reservoir between the inner surface and the outer surface, wherein the reservoir is in fluid communication with the hydraulic fluid chamber region; and a fluid flow control network in fluid communication with a hydraulic pump system of the actuator for controlling a direction and flow magnitude of hydraulic fluid within the hydraulic fluid chamber region, wherein the hydraulic pump system moves hydraulic fluid in the reservoir and the hydraulic fluid chamber region.

In some examples, the fluid flow control network comprises a valve plate disposed interfacing the hydraulic pump system, the hydraulic fluid chamber region, and the reservoir. In some examples, the valve plate is operated to control a direction of a fluid flow from or to the hydraulic pump system without changing a direction of a motor which drives the hydraulic pump system.

In some examples, the integrated accumulator and manifold system further comprises a separating member located within the inner surface and the outer surface, the separating member separates the reservoir into a compressed gas chamber area and a hydraulic fluid chamber area. In some examples, the integrated accumulator and manifold system is integrated within the hydrostatic actuator.

In still yet another example of the present disclosure, an aircraft is provided having an electro-hydrostatic actuator. According to various examples, the electro-hydrostatic actuator comprises a piston assembly having a piston head and a piston rod extending from the piston head. The electro-hydrostatic actuator may further comprise a hydraulic cylinder, with the piston assembly located and movable within the hydraulic cylinder. The hydraulic cylinder includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The electro-hydrostatic actuator further comprises a reservoir for storing hydraulic fluid located within the hydraulic cylinder which is in fluid communication with the hydraulic fluid chamber region. The electro-hydrostatic actuator may further comprise a hydraulic pump system for moving hydraulic fluid in the reservoir and the hydraulic fluid chamber region. The hydraulic pump system may be in fluid communication with a flow control network for controlling a direction and flow magnitude of hydraulic fluid within the hydraulic fluid chamber region. The electro-hydrostatic actuator may further comprise an electric motor located within the hydraulic cylinder for driving the hydraulic pump system. The electro-hydrostatic actuator may further comprise a valve plate rotatable within the hydraulic cylinder boss.

In one embodiment, there is provided an electro-hydrostatic actuator including a piston assembly having a piston head and a piston rod extending from the piston head and a hydraulic cylinder. The piston assembly is located and movable within the hydraulic cylinder, the hydraulic cylinder including a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The electro-hydrostatic actuator further includes a reservoir for storing hydraulic fluid located within the electro-hydrostatic actuator which is in fluid communication with the hydraulic fluid chamber region. The reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure chamber and a second pressure chamber

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by a bellow assembly. The first pressure chamber includes a first gas pressure chamber. The second pressure chamber includes a fluid pressure chamber. The bellow assembly includes a third pressure chamber different from the first and second pressure chambers and the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber. The electro-hydrostatic actuator further includes a hydraulic pump system for moving the hydraulic fluid in the reservoir and the hydraulic fluid chamber region. The hydraulic pump system is in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid flow within the hydraulic fluid chamber region. The electro-hydrostatic actuator further includes an electric motor located within the electro-hydrostatic actuator for driving the hydraulic pump system.

In another embodiment, there is provided an integrated accumulator and manifold system of a hydrostatic actuator. The integrated accumulator and manifold system has an inner surface surrounding an outer periphery of a housing of a hydraulic cylinder. The hydraulic cylinder includes a piston assembly having a piston head and a piston rod extending from the piston head. The housing includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The integrated accumulator and manifold system further has an outer surface defining a reservoir between the inner surface and the outer surface. The reservoir is in fluid communication with the hydraulic fluid chamber region. The reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure chamber and a second pressure chamber by a bellow assembly. The first pressure chamber includes a first gas pressure chamber. The second pressure chamber includes a fluid pressure chamber. The bellow assembly includes a third pressure chamber different from the first and second pressure chambers and the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber. The integrated accumulator and manifold system further includes a fluid flow control network in fluid communication with a hydraulic pump system of the hydrostatic actuator for controlling a direction and flow magnitude

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of hydraulic fluid flow within the hydraulic fluid chamber region. The hydraulic pump system moves hydraulic fluid in the reservoir and the hydraulic fluid chamber region.

In another embodiment, there is provided an aircraft having an electro-hydrostatic actuator. The electro-hydrostatic actuator includes a piston assembly having a piston head and a piston rod extending from the piston head and a hydraulic cylinder. The piston assembly is located and movable within the hydraulic cylinder. The hydraulic cylinder includes a hydraulic fluid chamber region including a piston side chamber and a rod side chamber. The electro-hydrostatic actuator further includes a reservoir for storing hydraulic fluid located within the electro-hydrostatic actuator which is in fluid communication with the hydraulic fluid chamber region. The reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure chamber and a second pressure chambers by a bellow assembly. The first pressure chamber includes a first gas pressure chamber. The second pressure chamber includes a fluid pressure chamber. The bellow assembly includes a third pressure chamber different from the first pressure chamber and the second pressure chamber, and the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber. The electro-hydrostatic actuator further includes a hydraulic pump system for moving the hydraulic fluid in the reservoir and the hydraulic fluid chamber region, the hydraulic pump system in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid flow within the hydraulic fluid chamber region. The electro-hydrostatic actuator further includes an electric motor located within the electro-hydrostatic actuator for driving the hydraulic pump system.

These and other examples are described further below with reference to the figures.

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BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure may best be understood by reference to the following description taken in conjunction with the accompanying drawings, which illustrate particular examples of the present disclosure.

FIG. **1** illustrates a cross section view of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure.

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FIG. **2** illustrates an exploded perspective view of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure.

FIG. **3** illustrates a fragmentary schematic view of a bellow assembly arranged within a reservoir of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure.

FIG. **4** illustrates a fragmentary cross section view of a pumping system disposed adjacent to a moveable valve plate and in fluid communication with a flow control network of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure.

FIG. **5** illustrates a schematic view of various operation fluid paths of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure.

FIG. **6** is a schematic illustration of an aircraft, in accordance with one or more examples of the present disclosure.

FIG. **7** is a block diagram of aircraft production and service methodology that may utilize methods and assemblies described herein.

DETAILED DESCRIPTION OF PARTICULAR EXAMPLES

Reference will now be made in detail to some specific examples of the present disclosure including the best modes contemplated by the inventors for carrying out the present disclosure. Examples of these specific embodiments are illustrated in the accompanying drawings. While the present disclosure is described in conjunction with these specific examples, it will be understood that it is not intended to limit the present disclosure to the described examples. On the contrary, it is intended to cover alternatives, modifications, and equivalents as may be included within the spirit and scope of the present disclosure as defined by the appended claims.

In the following description, numerous specific details are set forth in order to provide a thorough understanding of the present disclosure. Particular examples of the present disclosure may be implemented without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to unnecessarily obscure the present disclosure.

Various techniques and mechanisms of the present disclosure will sometimes be described in singular form for clarity. However, it should be noted that some examples include multiple iterations of a technique or multiple instantiations of a mechanism unless noted otherwise. For example, a system uses a processor in a variety of contexts. However, it will be appreciated that a system can use multiple processors while remaining within the scope of the present disclosure unless otherwise noted. Furthermore, the techniques and mechanisms of the present disclosure will sometimes describe a connection between two entities. It should be noted that a connection between two entities does not necessarily mean a direct, unimpeded connection, as a variety of other entities may reside between the two entities. For example, a processor may be connected to memory, but it will be appreciated that a variety of bridges and controllers may reside between the processor and memory. Consequently, a connection does not necessarily mean a direct, unimpeded connection unless otherwise noted.

Still furthermore, it should be noted that like reference numerals are intended to identify the same structural elements, portions or surfaces consistently throughout the figures, as such elements, portions or surfaces may be further described or explained by the entire written specification, of which this detailed description is an integral part. Unless otherwise indicated, the drawings are intended to be read (e.g., cross-hatching, arrangement of parts, proportion, degree, etc.) together with the specification, and are to be considered a portion of the entire written description of the embodiments described herein. As used in the following description, the terms "horizontal", "vertical", "left", "right", "up" and "down", as well as adjectival and adverbial derivatives thereof (e.g., "horizontally", "rightwardly", "upwardly", etc.), simply refer to the orientation of the illustrated structure as the particular drawing figure normally faces the reader. Similarly, the terms "inwardly" and "outwardly" generally refer to the orientation of a surface relative to its axis of elongation, or axis of rotation, as appropriate.

Overview

The present disclosure provides a low profile electro-hydrostatic actuator that self-contains a hydraulic actuator, a reservoir, an electric motor, and a hydraulic pump driven by the electric motor for moving hydraulic fluid from the reservoir to the hydraulic actuator for actuating the actuator.

In some examples, the electro-hydrostatic actuator is adapted with a bi-directional pump system to eliminate the stopping and direction reversing of the electric motor. In some examples, the electro-hydrostatic actuator is further adapted with a thermal management layer to maintain operating temperature.

Example Embodiments

FIG. **1** illustrates a cross section view of an example electro-hydrostatic actuator in accordance with one or more examples of the present disclosure. An electro-hydrostatic actuator **100** is shown herein to include a hydraulic cylinder **30** having a piston assembly **20** moveably located within a hydraulic fluid chamber housing **30**-A. The electro-hydrostatic actuator **100** is generally cylindrical in shape with a first end **11**A and an opposite second end **11**B along a center axis X at the A-A line. The piston assembly **20** is moveably arranged within a hydraulic fluid chamber region **28** of the hydraulic cylinder **30** on the end **11**A. In various examples, hydraulic cylinder **30**-A comprises a piston assembly **20** within hydraulic fluid chamber housing **30**-A surrounding a hydraulic fluid chamber region **28**. The piston assembly **20** comprises a piston head **26**, a piston rod **22** extending from the piston head **26**, and a rod end **24**, with the rod end **24** operably extending or retracting relatively to the end **11**A. The piston head **26** divides the hydraulic fluid chamber region **28** of the hydraulic

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cylinder **30** into a piston side chamber **32** and a rod side chamber **34**. The volume or size of piston side chamber **32** and rod side chamber **34** will vary based on the position of extension or retraction of piston assembly **20**.

The electro-hydrostatic actuator **100** further includes an integrated control module **60**, an electric motor **50**, a pumping system **40** having a valve plate **44**, a reservoir **36** in fluid communication with a flow control network **38** and the hydraulic fluid chamber region **28**. The reservoir **36** and the hydraulic fluid chamber **28** may both be sealed by an end cap **30**-C. End cap **30**-C may sealingly engages piston rod **22** allowing movement of the piston rod **22** along the X axis while preventing escape of fluid from the reservoir **36** or hydraulic fluid chamber **28**. At the outer periphery, the electro-hydrostatic actuator **100** includes a thermal management layer **70** to dissipate operating heat generated and maintain operating temperature.

The electric motor **50** is located adjacent to and operatively coupled to the pumping system **40** for driving the pumping system **40** in opposite first and second rotational directions. The pump system **40** includes a first inlet and outlet port **43**A, a second inlet and outlet port **43**B, a pump drive shaft **47**, and a swash plate **42** operating a plurality of pump pistons **46** for changing displacement of the pumping system **40**. In some examples, swash plate **42** may be a fixed swash plate. In other examples, swash plates may be a variable angle swash plate.

A first fluid passage **45**A connects the first inlet and outlet port **43**A and the piston side chamber **32**. A second fluid passage **45**B connects the second inlet and outlet port **43**B and the rod side chamber **34**. In various examples, second fluid passage **45**B is integrated within a portion of hydraulic fluid chamber housing **30**-A, as shown. A third fluid passage (not shown) returns the hydraulic fluid leaked from the pumping system **40** to the reservoir **36** for accumulation.

The reservoir **36** is in fluid communication with the pump system **40**, the flow control network **38**, and the hydraulic fluid chamber region **28**. As shown herein, the flow control network **38** is integrated in an integrated hydraulic cylinder boss **39**, such as

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hydraulic cylinder boss **211**, further described below with reference to FIG. **2**. A membrane **330** is adapted inside the reservoir **36**, between a surface **332** of an inner periphery of a reservoir wall and a surface **334** of an outer periphery of the hydraulic fluid chamber housing. The membrane **330** provides the reservoir **36** with boosted fluid pressure storage.

The hydraulic fluid reservoir **36** is connected via a first control valve **322** to the first fluid passage **45**A, and via a second control valve **324** to the second fluid passage **45**B. As the pump system **40** supplies hydraulic fluid to the piston side chamber **32**, the first control valve **322** closes the fluid passage into the reservoir **36**. On the other hand, as the piston rod **22** extends to discharge the hydraulic fluid from the rod side chamber **34**, the second control valve **324** opens the fluid passage to the reservoir **36**. Conversely, when the pump system **40** supplies hydraulic fluid to the rod side chamber **34** and discharges fluid from the piston side chamber **32**, the control valve **322** opens into the reservoir **36** while the control valve **324** closes the passage into the reservoir **36**.

The piston assembly **20** is operable for extending or retracting the piston rod **22** relative to the hydraulic cylinder **30** at the first end **11**A. The rod end **24** is typically in connection with an external load (not shown) to actuate the movement of the external load upon the movement of the piston rod **22**.

As used herein, pump system **40** may be referred to as a rotating group. In various examples, a rotating group may comprise one or more of the following: a hydraulic pump cylinder block **41**, one or more pump pistons **46**, swash plate **42**, and valve plate **44**. The multiple pump pistons **46** may be coupled to swash plate **42** which is configured at an angle about the X axis. As previously described, swash plate **42** may be a fixed swash plate and set at a fixed angle. Alternatively, swash plate **42** may be variable angle swash plate and the configuration of the angle may be determined by a motorized adjuster **43**, which may extend or retract based on a desired amount.

Each pump piston **46** is situated within a chamber of the hydraulic pump cylinder block **41**. Hydraulic pump cylinder block **41** may be hydraulic pump cylinder block **214** described below. Electric motor **50** may be mechanically coupled to one or more components of the rotating group via pump drive shaft **47**. As electric motor **50** is activated, it causes pump drive shaft **47** to rotate hydraulic pump cylinder block **41** and swash plate **42** with pump pistons **46** causing the each pump piston **46** to reciprocate in their respective chambers within hydraulic pump cylinder block **41**. This drives the hydraulic pump system and causes fluid to be flowed into and out of the hydraulic cylinder **30**.

In some examples, the direction of hydraulic flow is determined by a direction of movement of the electric motor. In some examples, the direction of the hydraulic flow is determined by a direction of movement of the fixed or variable angle swash plate. For example, the piston rod **22** may extend along the center axis X and towards the first end **11**A when the electric motor **50** is operated to drive the pump system **40** in a first direction causing the hydraulic fluid, e.g., oil or the like, supplied into the piston side chamber **32** and discharged from the rod side chamber **34**. Conversely, the piston rod **22** may retract along the center axis X and towards the second end **11**B, when the electric motor **50** is operated to drive the pump system **40** in a second direction causing the hydraulic fluid supplied into the rod side chamber **34** and discharged from the piston side chamber **32**.

Various sealing components and mechanisms may be used for closing the opening of the hydraulic fluid chamber region **28** located on the first end **11**A, as well as sealing about the piston rod **22** protruding on the first end **11**A. Various known sealing mechanisms for sealing the circumference of the piston head **26** may also be used to prevent hydraulic fluid flow between the piston side chamber **32** and the rod side chamber **34**.

In some other example, the electric motor **50** is an electric servo motor, and the pump system **40** is a bi-directional, positive displacement hydraulic pump. Control of actuator position, rate, and output force is provided by at least one of modulating motor/pump speed and changing direction of the motor/pump rotation. where the pump system **40** is a bi-directional pump and has a first and second inlet and outlet ports **43**A and **43**B respectively connected to the first fluid passage **45**A and the second fluid passage **45**B. The pump system **40** is operable in one direction for supplying pressurized fluid from the first inlet and outlet port **43**A to the piston side chamber **32** of the hydraulic fluid chamber region **28** while drawing fluid through the second fluid passage **45**B from the rod side chamber **34** of the hydraulic fluid chamber region **28** for extending the piston rod **22** in a first direction. The pumping system **40** is also operable in a second direction opposite the first direction for supplying pressurized fluid from a second inlet and outlet port **43**B through the second fluid passage **45**B to the rod side chamber **34** of the hydraulic fluid chamber region **28**, while drawing fluid through the first fluid passage **45**A from the piston side chamber **32** of the hydraulic fluid chamber region **28** for retracting the piston rod **22** in a second direction that is opposite the first direction.

Where pump system **40** is a bi-directional pump, pump system **40** can be any one of various types of pumps suitable to move hydraulic fluid in opposite directions through the ports to and from the piston side chamber **32** and the rod side chamber **34**. When a hydraulic servo pump such as swash plate piston pump is used, hydraulic power is provided by the combination of a unidirectional constant speed electric motor and the hydraulic servo pump. For example, a servo-pump can include a fixed swash plate or a variable angle swash plate for the control of flow magnitude and direction, with the direction of the flow being determined by direction of movement of the swash plate and the magnitude of the flow being controlled by the angle through which the swash plate is tilted. Thus, the reversal of the piston stroke can be accomplished without stopping and reversing direction of the motor/pump.

The flow of fluid from the pumping system **40** through the hydraulic cylinder boss **39** and into the hydraulic cylinder **30** may be managed by valve plate **44**. In various examples, valve plate **44** may have a series of kidney shaped passageways that are

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aligned with the chambers within pump cylinder block **41**. The structure and operation of valve plate **44** is further discussed below. In examples where the pump system **40** comprises a bi-directional pump, the swash plate **44** may be anchored and secured in a fixed position to the walls of the electro-hydrostatic apparatus **100**. In some examples, swash plate **44** may be anchored to hydraulic cylinder boss **39** in a fixed position.

However, a bi-directional pump system **40** may incur additional load on the rotating group and reversing rotation motions may add additional wear on the pump system **40** components, such as motor **50** and other bearings. Thus, in some examples, a unidirectional motor may be implemented for motor **50**. In such examples, motor **50** rotates pump drive shaft **47** and the rotating group in only one direction. This may be either clockwise or counterclockwise. Thus, to successfully control the movement of fluid into and out of hydraulic fluid chamber **28** and reservoir **36**, swash plate **44** may be configured to rotate relative to hydraulic cylinder boss **39** and the rotating group. In various examples, swash plate **44** may be rotated either clockwise or counterclockwise in order to align its passageways with particular chambers within pump cylinder block **41** such that fluid may be pumped into and out of the appropriate passageways of the flow control network **38**.

The integrated control module **60**, disposed at the second end **11**B opposite to the piston assembly, is adjacent to and operatively coupled to the pumping system **40**. In some examples, integrated control module **60** may be a power electronic control module. The integrated control module **60** outputs control commands for components such as the pumping system **40**, the motorized adjuster **43**, the electric motor **50**, and the valve plate **44**. The integrated control module **60** also supplies driving electric power to the electric motor **50**. Control commands are generated according to various signals input to the integrated control module **60**. Such signals can be control signals from external controller such as a vehicle management computer (VMC), or signals of motor speed, swash plate angle, output force of the piston assembly **20**, or the like. For example, a position sensor **62** detects a position of the piston rod **22** and inputs the sensed position information as a signal to the integrated control module **60**. In some examples, the integrated control module **60** converts the control signal into a set-point value at which the electric motor **50** is commanded to drive the pumping system **40**. As depicted in FIG. **1**, position sensor **62** may be one of multiple elements comprising the integrated control module **60**. However, in some examples, positions sensor **62** may be an integral part of hydraulic the cylinder boss, piston rod **22**, or piston assembly **20**.

As shown herein, the thermal management layer **70** layer is formed to enclose the outer periphery of the electro-hydrostatic actuator **100**. In some examples, the thermal management layer **70** is disposed about the outer periphery of the electro-hydrostatic actuator **100** at selective areas known for needs of heat dissipating, depending on the particular inline configuration of the components of the electro-hydrostatic actuator **100**. For example, such heat sensitive areas can be the surfaces corresponding to the portions of the hydraulic cylinder **30** where at least one of the electric motor and the pump system are arranged. Such thermal management layer **70** can be made of any suitable materials exhibiting high thermal conductivity. For example, thermal layer materials include, but are not limited to, metals, carbon, graphite, epoxy fibers, ceramics, metal-matrix composites, carbon-matrix composites (e.g., Carbon-Nickel nanoparticles grown on carbon fibers), ceramic-matrix composites, or the like. In some examples, the thermal management layer **70** is treated with metallic lining to prevent fluid permeation. In various examples, hydraulic cylinder **30** can be made of any suitable materials such as carbon fiber composites, high performance lightweight alloys.

FIG. **2** illustrates an exploded perspective view of an example electro-hydrostatic actuator in accordance with one or more examples of the present disclosure. The electro-hydrostatic actuator **200** has various components arranged in an inline configuration along and about a central axis X at the line B-B. In various examples, electro-hydrostatic actuator **200** may be electro-hydrostatic actuator **100**. The electro-hydrostatic actuator **200** comprises an integrated hydraulic cylinder **210**. In some examples the integrated hydraulic cylinder **210** may be hydraulic cylinder **30**, and includes a piston assembly **208** moveably mounted inside a piston assembly housing of an integrated hydraulic cylinder **210**, with the piston rod end **202** extending to and retracting from a first end **200**A. The integrated hydraulic cylinder **210** may be housed and surrounded inside a reservoir enclosure **204** (or shell) having a bellow assembly enclosure (**206**) (or shell) configured thereinside, as more details being illustrated with reference to FIG. **3**.

The integrated hydraulic cylinder **210** may be coupled to hydraulic cylinder boss **211**. In some examples hydraulic cylinder boss **211** may be hydraulic cylinder boss **39**, and may include a flow control network (not shown), such as flow control network **38**. In various examples, an electro-hydrostatic actuator may be configured to house single, dual, triplex, or quad pumping systems depending on redundancy requirements. The flow control network (such as **38** or **420**) within a hydraulic cylinder boss **211** may be configured to accommodate the particular flow configuration. Hydraulic cylinder boss **211** may connect to a valve plate **212** with an optional adapter plate **218** disposed therebetween. In some examples, valve plate **212** may be integrated into the hydraulic cylinder boss **211** or machined as a separate part for assembly. The electro-hydrostatic actuator **200** further includes a rotating group comprising pump cylinder block **214** housing a plurality of pump pistons **216** coupled to a swash plate **224**, a pump bearing **222**, and a bearing race **220**. . At a second end **200**B, the electro-hydrostatic actuator **200** includes an electric motor and control modules **230** (not shown separately). The control module at **230** may be integrated control module **60**. The electric motor may be electric motor **50**.

As shown herein, with the inline configuration of various components in the direction along and about the center axis X, the electro-hydrostatic actuator **200** allows its center of gravity to be positioned on or near the center axis X to achieve better weight balancing. Furthermore, with the cylinder block **214** of the pump system also arranged about the center axis X, such a configuration also provides a rotation balance in driving of the pump. Both contribute to improved satisfaction of various vibration requirements for the electro-hydrostatic actuator **200**.

FIG. **3** illustrates a fragmentary schematic view of a bellow assembly **351** arranged within a reservoir **360** of an example electro-hydrostatic actuator, in accordance with one or more examples of the present disclosure. In some examples, reservoir **360** may be reservoir **36** previously described with reference to FIG. **1**. As shown herein, a reservoir **360** is formed between an inner surface **364**A of a reservoir wall **364** (such as that of reservoir enclosure **204**) and an outer surface **362**A of an outer periphery **362**A of a hydraulic piston assembly housing **362**. In some examples inner surface **364**A corresponds to surface **332** described in FIG. **1**. In some examples outer surface **362**A corresponds to surface **334** described in FIG. **1**.

The reservoir **360** has its interior subdivided into two pressure compartments **350**A and **350**B by a bellow assembly **351** that is alternately known as a separating member **351**. In some examples, the separating member **351** is a metallic or non-metallic membrane, such as membrane **330** described in FIG. **1**. In some other examples and as shown herein, the separating member **351** is a thin-walled metallic or non-metallic bellow, including an outer bellow **352** and an inner bellow **354**. The outer bellow **352** is fitted to surround and abut the inner surface **364**A of the reservoir wall **364**, while the inner bellow **354** is fitted to surround and abut the outer surface **362**A of the piston assembly housing **362**. In some examples, as the bellow assembly **351** contracts or expands, it is adapted to slide along the outer periphery **362**A of the piston assembly housing wall **362**, and along an inner periphery **364**A of the reservoir wall **364**.

The compartment **350**A is located towards the piston rod end (not shown herein), and the compartment **350**B is located towards the piston end (not shown herein) and in fluid communication with a hydraulic fluid chamber region and a flow control network. In some examples, compartment **350**A is filled with a gas typically under high pressure to provide pressure storage.

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In some examples, the interior of the bellow assembly **351** is a pressure storage chamber **356** which can be filled with a gas under high pressure and is not in fluid communication with either one of the two pressure components **350**A and **350**B. Such gas can be nitrogen gas or any other inert gas. The bellow assembly **351** can take any suitable form such as pleated bellow, metallic membrane, non-metallic membrane, or the like.

FIG. **4** illustrates a fragmentary cross section view of a pumping system disposed adjacent to a moveable valve plate and in fluid communication with a flow control network of an example electro-hydrostatic actuator in accordance with one or more examples of the present disclosure. In various examples, pumping system may be pumping system **40**, previously described with reference to FIG. **1**. As shown herein, the pumping system may be a variable displacement swash plate piston pump, comprising a swash plate **408** and a plurality of pump pistons **406** housed inside a pump cylinder block **402**. In some examples, swash plate **408**, pump pistons **406**, and pump cylinder block **402** comprise a rotating group and are contained within a pump housing **456**. In various examples, swash plate **408** may be a fixed or variable angle swash plate **408**. The plurality of pump pistons **406** are mounted to the swash plate **408** at their respective piston shoe assemblies **407** for axial sliding in their respective pump cylinder.

A valve plate **404** is disposed interfacing the pump cylinder block **402** and a flow control network **420** to provide fluid communication between the swash plate pump and an integrated hydraulic cylinder boss **421** (partially shown). In various examples, valve plate **404** defines a fluid inlet and a fluid outlet (further described in FIG. **5**) which are connected through passages in a backplate of the pump housing **456** or pump cylinder block **402** to the pump inlet port **432** and the pump outlet port **434**, respectively. In some examples, valve plate **404** may be anchored to the backplate or the pump housing **456**. In some examples, the backplate may be an integral part of pump housing **456**. However, in some examples, valve **404** is anchored to or configured as an integral part of the integrated hydraulic cylinder boss **421**. In some examples, valve plate **404** is anchored in a fixed position and

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does not move. In some examples, valve plate **404** may be a moveable valve plate which may rotate to align one or more inlet and outlet ports with any combination of passages in a black plate and ports **432** and **434** of the pump cylinder block **402**.

As partially shown herein, a pump shaft **410**, extending axially along the center axis X at the C-C line through the pump cylinder block **402**, is mounted in suitable bearings **452**-A in the moveable valve plate **404** and its base (not shown) for rotation by an electric motor (not shown). The pump shaft **410** may further be mounted in suitable bearings **452**-C in the pump housing **456**. The pump cylinder block **402** is adapted to rotate with the pump shaft **410** and in sliding engagement against the valve plate **404**. In some examples, the hydraulic pump cylinder block **402** may be rotatably coupled to valve plate **404** via shaft bearings **452**-B situated within a bearing plate **454**, which may facilitate the sliding engagement against valve plate **404**. In some examples, bearing plate **454** may be an integral part of pump cylinder block **402**. In some examples, bearing plate **454** may be an integral part of valve plate **404**. With the pump pistons **406** arranged annularly around and parallel to the pump shaft **410**, when the pump shaft **410** and the pump cylinder block **402** are rotated, the pump pistons **406** are caused to axially reciprocate through a stroke determined by the angular position of the swash plate **408**.

The swash plate **408** is mounted for tilting movement between a zero displacement position in which the swash plate is normal to the pump pistons **406**, and either a forward or a reverse full displacement position in which the swash plate **408** is controlled to tilt in either direction from the center axis (e.g., the center axis X) of the pump cylinder block **402**. As such, the swash plate **408** is a variable angle swash plate since the swash plate **408** may be tilted in different angles at various locations. In various examples, swash plate **408** does not rotate along with the other components of the rotating group. However, the piston shoe assembly **407** may be rotated with the pump cylinder block **402** and pump pistons **406** of rotating group on a well lubricated surface of the swash plate **408**.

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The pump may include a bi-directional or unidirectional configuration. A bi-directional pump may be a bi-directional positive displacement pump, which may cause rotating group to rotate in both a first direction and a reverse second direction to alternate the source of high pressure and low pressure hydraulic fluid. A fixed valve plate may be implemented in a bi-directional pump configuration. For example, in a bi-directional pump configuration, valve plate **404** may be anchored in a fixed position to the hydraulic cylinder boss **421** and the changing direction of the rotation of the rotating group causes variation of hydraulic pressures at appropriate outlet/inlet ports in valve **404**. In a unidirectional pump configuration, the rotating group rotates in only one direction, which causes high pressure and low pressure hydraulic fluid to be located in one relative portion of the rotating group. A moveable valve plate may be implemented with a unidirectional pump configuration. For example, a moveable valve plate **404** may be rotatably situated within hydraulic cylinder boss **421** and moveable valve **404** may be rotated to control hydraulic pressure flow.

As previously described, in some examples, swash plate **408** may be a fixed or variable angle swash plate. In a fixed displacement pump where swash plate **408** is a fixed swash plate, the angle of tilt and direction of tilt are not varied and the hydraulic pressure in each pump chamber is the same at a particular position in the rotation of the rotating group. In a variable displacement pump where swash plate **408** is a variable angle swash plate, the angle of tilt and direction of tilt of swash plate **408** may be controlled based on flow demand of the hydraulic fluid. Implementation of a fixed swash plate and a variable angle swash plate are discussed further with reference to FIG. **5**. As part of the swash plate pump control, an integrated control module, such as control module **60**, is located within the hydraulic cylinder for receiving a control electric signal which controls the direction of movement of the swash plate and the angle of tilt of the swash plate. In various examples, the direction of movement of the swash plate determines the direction of hydraulic fluid flow. Further, the flow magnitude of the hydraulic fluid into the

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hydraulic fluid chamber region **458** is controlled by an angle by which the swash plate is tilted.

The valve plate **404**, disposed between the pump cylinder block **402** and the flow control network **420** of hydraulic cylinder boss **421**, may be anchored to hydraulic cylinder boss **421** in a fixed position. In other examples, valve plate **404** may be a bi-directional rotating valve plate. Valve plate **404** includes a first port **432** and a second port **434**. In some examples, in association with the rotation of the cylinder block **402** about the center axis X by the pump shaft **410**, each of the plurality of pump pistons **406** revolves around the center axis X and reciprocates in the direction along the center axis X. In association with the revolution and reciprocation of the plurality of pump pistons **406**, hydraulic fluid is discharged or returned through the first port **432** or the second port **434**.

In particular, when the swash plate **408** is tilted in a first direction, as depicted in FIG. **4**, the first port **432** serves as a low pressure inlet, and the second port **434** as a high pressure outlet. In this operation, low pressure hydraulic fluid is suctioned through a first fluid passage **438** through the first port **432** of the valve plate **404** to return to the pump cylinder block **402**. High pressure fluid from the pump cylinder block **402** is discharged through the second port **434** and into second fluid passage **436** of the flow control network **420** to be supplied to the hydraulic fluid chambers of the actuator (not shown).

Conversely, when the swash plate **408** is tilted in a reverse second direction, the second port **434** serves as a low pressure inlet, and the first port **432** as a high pressure outlet. In this operation, low pressure hydraulic fluid is suctioned through a second fluid passage **436** through the second port **434** of the valve plate **404** to return to the pump cylinder block **402**. High pressure fluid from the pump cylinder block **402** is discharged through the first port **432** and through a first fluid passage **438** of the flow control network **420** to be supplied to the hydraulic fluid chambers of the actuator (not shown).

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As shown herein, a first check and anti-cavitation valve **426**, a second check and anti-cavitation valve **422**, and a shuttle valve **424** are disposed in the flow control network **420**, details of which are described below with respect to FIG. **5**.

Further, as shown herein, a valve plate shaft **412** is configured to extend axially through a bore of the pump shaft **410** and mechanically coupled to the center of the valve plate **404**. In association with the rotation of the valve plate shaft **412**, the valve plate **404** is operable bi-directionally. In particular, when the valve plate shaft **412** rotates in a first direction, the valve plate **404** is caused to rotate in the first direction to change the opening and closing of the first port **432** and the second port **434**. Conversely, when the valve plate shaft **412** rotates in an opposite second direction, the valve plate **404** is caused to rotate in the second direction to change the opening and closing of the first port **432** and the second port **434**.

In some examples, the valve plate **404** is driven by a valve driving motor. In some other examples, the valve plate **404** is driven by a piezomotor, which is disposed in the integrated hydraulic cylinder boss as a precision mechanism to drive the valve plate **404**. In some examples, the valve plate **404** is machined as a separate piece and mechanically attached to the hydraulic cylinder boss. In some other examples, the valve plate is machined as an integral part of the hydraulic cylinder boss.

In further detail, the valve plate **404** is configured with multiple semi-circular ports (kidneys) that control the inlet and outlet of fluid within the pump cylinder block **402**. As the pump cylinder block **402** rotates about the center axis X, the exposed ends of the plurality of pump pistons **406** are constrained to follow the surface of a tilted plane attached to swash plate **408**. Since the tilted plane is at an angle to the axis X of rotation, the plurality of pistons **406** reciprocate axially about the center axis X.

The axial motion of the pistons is sinusoidal causing the pistons **406** to operate in a reciprocating manner. During the rising portion of the pistons' reciprocation cycle, the pistons **406** moves toward the valve plate **404** and fluid trapped between the closed surface of the valve plate **404** and pistons **406** is vented to the pump's discharge port through one of the valve plate's semi-circular ports - the fluid is then pushed or displaced through the discharge port of the valve plate and pump housing.

As the reciprocation cycle continues, the connection between the trapped fluid chamber and the pump's discharge port is closed. Shortly thereafter, that same chamber becomes open to the pump's suction port. As the pistons **406** continues to precess about the cylinder block axis, they move away from the valve plate **404** thereby increasing the volume of the trapped chamber. As this occurs, fluid enters the chamber from the pump's suction port to fill the void. This process continues until the piston **406** reaches the bottom of the reciprocation cylinder block. The connection between the pumping chamber and suction port is closed. Shortly thereafter, the chamber becomes open to the discharge port again and the pumping cycle starts over.

FIG. **5** illustrates a schematic view of various operation fluid paths of an example electro-hydrostatic actuator in accordance with one or more examples of the present disclosure. As shown herein, an external load (not shown) is operable to move in a direction along the J arrow line away from the electro-hydrostatic actuator **500**, or in a direction along the K arrow line towards the electro-hydrostatic actuator **500**. The piston assembly **502**, having a piston head **502**B and a piston rod end **502**A, extends in a direction along the I arrow line, and retracts in a direction along the H arrow line. Thus, the hydraulic fluid movement traverses fluid passages in response to four (**4**) modes of actuator operation: retracting against loads; retracting with loads, extending against loads, and extending with loads.

In particular, valve plate **560** may be a fixed valve plate which is anchored in position. In order to retract the electro-hydrostatic actuator **500** by causing piston assembly **502** to move in the direction of the H arrow line, the pump (not shown herein) driven by a motor (not shown herein) rotates a rotating group, such as in pump system **40**, in a direction along the A curved arrow line (clockwise in FIG. **5**) to cause high pressure hydraulic fluid to be discharged from the second (outlet) port

564 of valve plate **560** through the first fluid passage **551** (along the direction of the C arrow line) and be supplied into a rod side chamber **506**. At the same time, with the second fluid passage **553** under lower pressure, check & anti-cavitation valve **552** restricts the uncontrolled fluid flow in the first fluid passage **551** from leaking into the second fluid passage **553**. Further, by use of the anti-cavitation valve **552**, the risk of cavitation damage to the pump in connection with insufficient inlet pressure can be reduced. A check valve of the check & anti-cavitation valve **552** between the first fluid passage **551** and the second fluid passage **553** causes the hydraulic fluid to flow to the pump if the inlet pressure to the pump becomes too low during the operation.

Conversely, in order to extend the hydraulic actuator **500** by causing piston assembly **502** to move in the direction of the I arrow line, the pump (not shown herein) driven by a motor (not shown herein) rotates in a direction along the B curved arrow line (counter clockwise in FIG. **5**) to cause high pressure hydraulic fluid to be discharged from the first (inlet) port **562** of the valve plate **560** through the second fluid passage **553** (along the direction of the E arrow line) and be supplied into a piston side chamber **504**. At the same time, with the first fluid passage **551** under lower pressure, check & anti-cavitation valve **554** restricts the uncontrolled fluid flow in the second fluid passage **553** from leaking into the first fluid passage **551**. Further, by use of the anti-cavitation valve **554**, the risk of cavitation damage to the pump in connection with insufficient inlet pressure can be reduced. A check valve of the check & anti-cavitation valve **554** between the first fluid passage **551** and the second fluid passage **553** causes the hydraulic fluid to flow to the pump if the inlet pressure to the pump becomes too low during the operation.

As depicted piston slot **565** is aligned with the second port **564**. Piston slot **565** may correspond to a piston chamber of the pump cylinder block at which high pressure hydraulic fluid is being generated by a pump piston. First port **562** and second port **564** may be additionally aligned with additional piston slots (not shown).

In some examples, the pump system includes a third (case drain) port **568** through valve plate **560** to cause at least one of the bypass and control hydraulic fluid to flow through a third fluid passage **555** (along the direction of the G arrow line) back to the fluid reservoir **508**. Generally, increased volume in the fluid flow at the third port **568** may indicate at least one of a reduction in pump efficiency and worn pump parts. Further, the fact that the degree of hydraulic fluid viscosity and the clearance between moving parts varies under different temperatures also contributes to the increased volume in the fluid flow at the third port **568**. In some examples, a pressure and temperature compensated flow control valve **558** is disposed in the third port **568** to give a warning when the third port **568** discharges a fluid flow of a volume exceeding a specified threshold.

In some example, the fluid reservoir **508** includes a bellow **510** configured thereinside, between an inner periphery of the reservoir wall and an outer periphery of the piston assembly housing, to provide for boosted pressure storage. As shown herein FIG. **5**, a flow control network **550** includes the first fluid passage **551**, the second fluid passage **553**, the third fluid passage **555**, the check valve of the check & anti-cavitation valve **552**, the check valve of the check & anti-cavitation valve **554**, the shuttle valve **556**, and the pressure and temperature compensated flow control valve **558**. In some examples, the flow control network may be implemented as the flow control network **38** or FIG. **1**, or the flow control network **420** of FIG. **4**.

In some examples, the electro-hydrostatic actuator **500** further comprises a position sensor **520** that monitors a position of the piston assembly **502**, according to which at least one of a speed and a direction of the electric motor of the electro-hydrostatic actuator **500** is controlled according to the position of the piston assembly **502**. In some examples, the piston position signals generated by the position sensor **520** is provided to the control module of the electro-hydrostatic actuator **500** for control of the at least one of the electric motor and the pumping system. In some examples, the position sensor is a linear variable differential transformer (LVDT).

In some examples, a shuttle valve **556** is used to reduce the fluid flow required to extend an unequal area actuator so that reduced actuation force may be permissible in one direction. When the retract line is pressurized the shuttle valve **556** shuttles across to isolate the retract line from the extend line. When the extend line is pressurized the shuttle valve **556** blocks the retract line allowing flow from the retract side of the piston to flow to the extend side.

As previously described, the pump system may be a unidirectional system in which rotating group may rotate in only one direction. A variable angle swash plate may be implemented in a unidirectional system and controlled to change hydraulic pressure at particular locations relative to valve plate **560**. A unidirectional pump system with a fixed or variable angle swash plate may also be implemented with a moveable valve plate. In some examples, a moveable valve plate may also be implemented in a bi-directional pump system.

In some examples, valve plate **560** may be a moveable valve plate, and movement of valve plate **560** may be controlled by a valve shaft, such as valve shaft **412**. In such examples, the pump (not shown herein) driven by a motor (not shown herein) may continuously rotate in a single direction along either the A or the B curved arrow line. Because the pump rotates in a singular direction, high pressure fluid may be generated at one side of the pump and low pressure fluid may be generated at another side of the pump based on the tilt of the swash plate (not shown). Thus swash plate **560** may rotate in either the A or the B curved arrow line in order to align either first port **562** or second outlet port **564** with fluid passageway **551** or **553** such that high pressured fluid may pass from piston chambers in a pump cylinder block through port **562** or **564** and into passageway **551** or **553**. Swash plate **560** may additionally or alternatively be aligned such that low pressure fluid may pass from fluid passageway **551** or **553** through port **562** or **564** and into piston chambers in the pump cylinder block.

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For example, based on the angle of tilt of a swash plate, such as swash plate **408**, high pressure fluid may be generated by pump pistons of the pump cylinder block located at a point at the left side of valve plate **560**. Valve plate **560** may be rotated in the direction of the A arrow line or B arrow line such that first port **562** is aligned with the pump pistons generating high pressure hydraulic fluid, allowing the high pressure hydraulic fluid to flow into second passageway **553** in the direction of the E arrow line. This may cause piston side chamber **504** to fill with fluid and cause actuator to extend in the direction of the I arrow line. As another example, valve plate **560** may be rotated such that a solid portion **563** may be aligned with the pump pistons generating high pressure hydraulic fluid, thereby blocking the high pressure fluid from entering into second passageway **553**.

Examples of Aircraft and Methods of Fabricating and Operating Aircraft

To better understand various aspects of implementation of the described systems and techniques, a brief description of an aircraft and aircraft wing is now presented. FIG. **6** is a schematic illustration of aircraft **600**, in accordance with some examples. As depicted in FIG. **6**, aircraft **600** is defined by a longitudinal axis (X-axis), a lateral axis (Y-axis), and a vertical axis (Z-axis). In various examples, aircraft **600** comprises airframe **650** with interior **670**. Aircraft **600** includes wings **620** coupled to airframe **650**. Aircraft **600** may also include engines **630** supported by wings **620**. In some examples, aircraft **600** further includes a number of high-level inspection systems such as electrical inspection system **640** and environmental inspection system **660**. In other examples, any number of other inspection systems may be included.

Aircraft **600** shown in FIG. **6** is one example of a vehicle of which components may be fabricated, modified, or machined to include at least one of actuators **100** and **200**, in accordance with illustrative examples. Although an aerospace example is shown, the principles disclosed herein may be applied to other industries, such as the automotive industry. Accordingly, in addition to aircraft **600**, the principles disclosed herein may apply to other vehicles, e.g., land vehicles, marine vehicles, space vehicles, etc.

Examples of the present disclosure may be described in the context of aircraft manufacturing and service method **700** as shown in FIG. **7** and aircraft **600** as shown in FIG. **6**. During pre-production, illustrative method **700** may include specification and design (block **704**) of aircraft **600** and material procurement (block **706**). During production, component and subassembly manufacturing (block **708**) and inspection system integration (block **710**) of aircraft **600** may take place. Described devices and assemblies, and corresponding methods, can be used in any of specification and design (block **704**) of at least one of aircraft **600**, material procurement (block **706**), component and subassembly manufacturing (block **708**), and inspection system integration (block **710**) of aircraft **600**.

Thereafter, aircraft **600** may go through certification and delivery (block **712**) to be placed in service (block **714**). While in service, aircraft **600** may be scheduled for routine maintenance and service (block **716**). Routine maintenance and service may include modification, reconfiguration, refurbishment, etc. of one or more inspection systems of aircraft **600**. Described devices and assemblies, and corresponding methods, can be used in any of certification and delivery (block **712**), service (block **714**), and routine maintenance and service (block **716**).

Each of the processes of illustrative method **700** may be performed or carried out by an inspection system integrator, a third party, or an operator (e.g., a customer). For the purposes of this description, an inspection system integrator may include, without limitation, any number of aircraft manufacturers and major-inspection system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

Apparatus(es) and corresponding method(s) shown or described herein may be employed during any one or more of the stages of manufacturing and service method (illustrative method **700**). For example, components or subassemblies corresponding to component and subassembly manufacturing (block **708**) may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **600** is in service (block **714**). Also, one or more examples of the apparatus(es), method(s), or combination thereof may be utilized during production stages (block **708**) and (block **710**), for example, by substantially expediting assembly of or reducing the cost of aircraft **600**. Similarly, one or more examples of the apparatus or method realizations, or a combination thereof, may be utilized, for example and without limitation, while aircraft **600** is at least one of in service (block **714**) and during maintenance and service (block **716**).

While the present disclosure has been particularly shown and described with reference to specific examples thereof, it will be understood by those skilled in the art that changes in the form and details of the disclosed examples may be made without departing from the spirit or scope of the present disclosure. It is therefore intended that the present disclosure be interpreted to include all variations and equivalents that fall within the true spirit and scope of the present disclosure. Although many of the components and processes are described above in the singular for convenience, it will be appreciated by one of skill in the art that multiple components and repeated processes can also be used to practice the techniques of the present disclosure.

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

1. An electro-hydrostatic actuator, comprising:

a piston assembly having a piston head and a piston rod extending from the piston head;

a hydraulic cylinder, wherein the piston assembly is located and movable within the hydraulic cylinder, the hydraulic cylinder including a hydraulic fluid chamber region including a piston side chamber and a rod side chamber;

a reservoir for storing hydraulic fluid located within the electro-hydrostatic actuator which is in fluid communication with the hydraulic fluid chamber region, wherein the reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure chamber and a second pressure chamber by a bellow assembly, wherein the first pressure chamber includes a first gas pressure chamber, wherein the second pressure chamber includes a fluid pressure chamber, wherein the bellow assembly includes a third pressure chamber different from the first and second pressure chambers, and wherein the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber;

a hydraulic pump system for moving the hydraulic fluid in the reservoir and the hydraulic fluid chamber region, the hydraulic pump system in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid flow within the hydraulic fluid chamber region; and

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an electric motor located within the electro-hydrostatic actuator for driving the hydraulic pump system.

2. The electro-hydrostatic actuator of claim **1**, further comprising an integrated control module located within the electro-hydrostatic actuator for receiving a control signal and converting the control signal into a set-point value at which the electric motor drives the hydraulic pump system.

3. The electro-hydrostatic actuator of claim **1**, wherein the electric motor rotates a fixed or variable angle swash plate to drive the hydraulic pump system.

4. The electro-hydrostatic actuator of claim **3**, wherein the direction of hydraulic fluid flow is determined by a direction of movement of the swash plate and the flow magnitude of hydraulic fluid flow is controlled by an angle through which the swash plate is tilted.

5. The electro-hydrostatic actuator of claim **4**, further including an integrated control module located within the electro-hydrostatic actuator for receiving a control signal which controls at least one of the direction of movement of the swash plate and the angle through which the swash plate is tilted.

6. The electro-hydrostatic actuator of claim **1**, wherein the electric motor comprises a unidirectional electric motor.

7. The electro-hydrostatic actuator of claim **1**, wherein the hydraulic pump system comprises a hydraulic pump cylinder block which is rotatable within the electro-hydrostatic actuator, the hydraulic pump cylinder block comprising a plurality of pistons which are coupled to a swash plate.

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8. The electro-hydrostatic actuator of claim **7**, wherein the plurality of pistons are coupled to the swash plate and slide within the hydraulic pump cylinder block along a direction of a center axis of the electro-hydrostatic actuator.

9. The electro-hydrostatic actuator of claim **1**, further comprising a pump housing containing a pump piston and a pump cylinder block.

10. The electro-hydrostatic actuator of claim **9**, wherein the pump housing further contains a swash plate.

11. The electro-hydrostatic actuator of claim **9**, wherein the pump housing further contains a piston shoe assembly.

12. The electro-hydrostatic actuator of claim **9**, wherein the pump housing further contains a first port and a second port.

13. The electro-hydrostatic actuator of any one of claims **1** to **12**, wherein the bellow assembly is movably disposed within the reservoir.

14. The electro-hydrostatic actuator of any one of claims **1** to **13**,

wherein the piston assembly is moved in a first direction from a retracted position to an extended position by pumping the hydraulic fluid from at least one of the rod side chamber and the reservoir into the piston side chamber and pushing the hydraulic fluid from the rod side chamber into the reservoir, and

wherein the piston assembly is moved in a second direction opposite to the first direction by pumping the hydraulic fluid from at least one of the piston side chamber and the reservoir into the rod side chamber and pushing the hydraulic fluid from the piston side chamber into the reservoir.

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15. The electro-hydrostatic actuator of claim **1**, wherein the hydraulic pump system includes a valve plate.

16. The electro-hydrostatic actuator of claim **15**, wherein a direction of fluid flow supplied by or returned to the hydraulic pump system is controlled by the valve plate.

17. The electro-hydrostatic actuator of claim **15**, wherein the valve plate is mechanically attached to or integral with the hydraulic cylinder boss.

18. The electro-hydrostatic actuator of claim **15**, wherein the valve plate is rotatable within the hydraulic cylinder boss.

19. The electro-hydrostatic actuator of claim **1**, wherein the electric motor is a servo motor and the hydraulic pump system is a bi-directional, positive displacement pump.

20. The electro-hydrostatic actuator of claim **19**, wherein a position of the piston assembly within the hydraulic cylinder and output force produced by the piston assembly are controlled by modulating one of: a speed of the servo motor, a speed of the positive displacement pump, or a combination thereof.

21. The electro-hydrostatic actuator of claim **19**, wherein a position of the piston assembly and output force produced by the piston assembly are controlled by changing a speed and direction of the servo motor.

22. The electro-hydrostatic actuator of any one of claims **1** to **21**, wherein the flow control network is integrated into the hydraulic cylinder boss.

23. The electro-hydrostatic actuator of any one of claims **1** to **22**, wherein the flow control network includes a first fluid passage and a second fluid passage

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separated by a check valve and an anti-cavitation valve, the check valve and anti-cavitation valve configured to restrict uncontrolled fluid flow between the first fluid passage and the second fluid passage.

24. The electro-hydrostatic actuator of claim **23**, wherein the anti-cavitation valve is further configured to reduce cavitation damage to the hydraulic pump system.

25. The electro-hydrostatic actuator of any one of claims **1** to **24**, further comprising a thermal management system, the thermal management system disposed to surround thermal hot spots on an outer periphery of the electro-hydrostatic actuator.

26. The electro-hydrostatic actuator of any one of claims **1** to **25**, further comprising a position sensor that monitors a position of the electro-hydrostatic actuator, wherein at least one of a speed and a direction of the electric motor is controlled according to the position of the electro-hydrostatic actuator.

27. The electro-hydrostatic actuator of any one of claims **1** to **26**, wherein the bellow assembly includes an outer bellow and an inner bellow.

28. The electro-hydrostatic actuator of any one of claims **1** to **27**, wherein the reservoir is configured to surround the outer periphery of the hydraulic fluid chamber region by being formed between an inner surface of a reservoir wall and an outer surface of an outer periphery of the hydraulic cylinder.

29. An integrated accumulator and manifold system of a hydrostatic actuator comprising:

an inner surface surrounding an outer periphery of a housing of a hydraulic cylinder, the hydraulic cylinder including a piston assembly having a piston head and a piston rod extending from the piston head, the housing including

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a hydraulic fluid chamber region including a piston side chamber and a rod side chamber;

an outer surface defining a reservoir between the inner surface and the outer surface, wherein the reservoir is in fluid communication with the hydraulic fluid chamber region, wherein the reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure chamber and a second pressure chamber by a bellow assembly, wherein the first pressure chamber includes a first gas pressure chamber, wherein the second pressure chamber includes a fluid pressure chamber, wherein the bellow assembly includes a third pressure chamber different from the first and second pressure chambers, and wherein the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber; and

a fluid flow control network in fluid communication with a hydraulic pump system of the hydrostatic actuator for controlling a direction and flow magnitude of hydraulic fluid flow within the hydraulic fluid chamber region, wherein the hydraulic pump system moves hydraulic fluid in the reservoir and the hydraulic fluid chamber region.

30. The integrated accumulator and manifold system of claim **29**, wherein the fluid flow control network comprises a valve plate interfacing the hydraulic pump system, the hydraulic fluid chamber region, and the reservoir.

31. The integrated accumulator and manifold system of claim **30**, wherein the valve plate is operated to control a direction of a fluid flow from or to the hydraulic pump system without changing a direction of a motor which drives the hydraulic pump system.

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32. The integrated accumulator and manifold system of any one of claims **29** to **31**, wherein the integrated accumulator and manifold system is integrated within the hydrostatic actuator.

33. The integrated accumulator and manifold system of any one of claims **29** to **32**, wherein the flow control network includes a first fluid passage and a second fluid passage separated by a check valve and an anti-cavitation valve, the check valve and anti-cavitation valve configured to restrict uncontrolled fluid flow between the first fluid passage and the second fluid passage.

34. The integrated accumulator and manifold system of claim **33**, wherein the anti-cavitation valve is further configured to reduce cavitation damage to the hydraulic pump system.

35. The integrated accumulator and manifold system of any one of claims **29** to **34**, wherein the bellow assembly includes an outer bellow and an inner bellow.

36. An aircraft having an electro-hydrostatic actuator comprising:

a piston assembly having a piston head and a piston rod extending from the piston head;

a hydraulic cylinder, wherein the piston assembly is located and movable within the hydraulic cylinder, the hydraulic cylinder including a hydraulic fluid chamber region including a piston side chamber and a rod side chamber;

a reservoir for storing hydraulic fluid located within the electro-hydrostatic actuator which is in fluid communication with the hydraulic fluid chamber region, wherein the reservoir is configured to surround an outer periphery of the hydraulic fluid chamber region and is subdivided into a first pressure

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chamber and a second pressure chambers by a bellow assembly, wherein the first pressure chamber includes a first gas pressure chamber, wherein the second pressure chamber includes a fluid pressure chamber, wherein the bellow assembly includes a third pressure chamber different from the first pressure chamber and the second pressure chamber, and the third pressure chamber includes a second gas pressure chamber separate from the first gas pressure chamber;

a hydraulic pump system for moving the hydraulic fluid in the reservoir and the hydraulic fluid chamber region, the hydraulic pump system in fluid communication with a flow control network in a hydraulic cylinder boss for controlling a direction and flow magnitude of hydraulic fluid flow within the hydraulic fluid chamber region; and

an electric motor located within the electro-hydrostatic actuator for driving the hydraulic pump system.

37. The aircraft of claim **36**, wherein the electro-hydrostatic actuator further comprises an integrated control module located within the electro-hydrostatic actuator for receiving a control signal and converting the control signal into a set-point value at which the electric motor drives the hydraulic pump system.

38. The aircraft of claim **36**, wherein the electric motor rotates a fixed or variable angle swash plate to drive the hydraulic pump system.

39. The aircraft of claim **38**, wherein the direction of hydraulic fluid flow is determined by a direction of movement of the swash plate and the flow magnitude of hydraulic fluid flow is controlled by an angle through which the swash plate is tilted.

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40. The aircraft of claim **36**, wherein the electric motor comprises a unidirectional electric motor.

41. The aircraft of any one of claims **36** to **40**, wherein the electro-hydrostatic actuator further comprises a pump housing containing a pump piston and a pump cylinder block.

42. The aircraft of any one of claims **36** to **41**,

wherein the piston assembly is moved in a first direction from a retracted position to an extended position by pumping the hydraulic fluid from at least one of the rod side chamber and the reservoir into the piston side chamber and pushing the hydraulic fluid from the rod side chamber into the reservoir, and

wherein the piston assembly is moved in a second direction opposite to the first direction by pumping the hydraulic fluid from at least one of the piston side chamber and the reservoir into the rod side chamber and pushing the hydraulic fluid from the piston side chamber into the reservoir.

43. The aircraft of claim **36**, wherein the electric motor is a servo motor and the hydraulic pump system is a bi-directional, positive displacement pump.

44. The aircraft of any one of claims **36** to **43**, wherein the electro-hydrostatic actuator further comprises a valve plate rotatable within the hydraulic cylinder boss.

45. The aircraft of any one of claims **36** to **44**, wherein the flow control network includes a first fluid passage and a second fluid passage separated by a check valve and an anti-cavitation valve, the check valve and anti-cavitation valve

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configured to restrict uncontrolled fluid flow between the first fluid passage and the second fluid passage.

46. The aircraft of claim **45**, wherein the anti-cavitation valve is further configured to reduce cavitation damage to the hydraulic pump system.

47. The aircraft of any one of claims **36** to **46**, wherein the bellow assembly includes an outer bellow and an inner bellow.

48. The aircraft of any one of claims **36** to **47**, wherein the reservoir is configured to surround the outer periphery of the of the hydraulic fluid chamber region by being formed between an inner surface of a reservoir wall and an outer surface of an outer periphery of the hydraulic cylinder.

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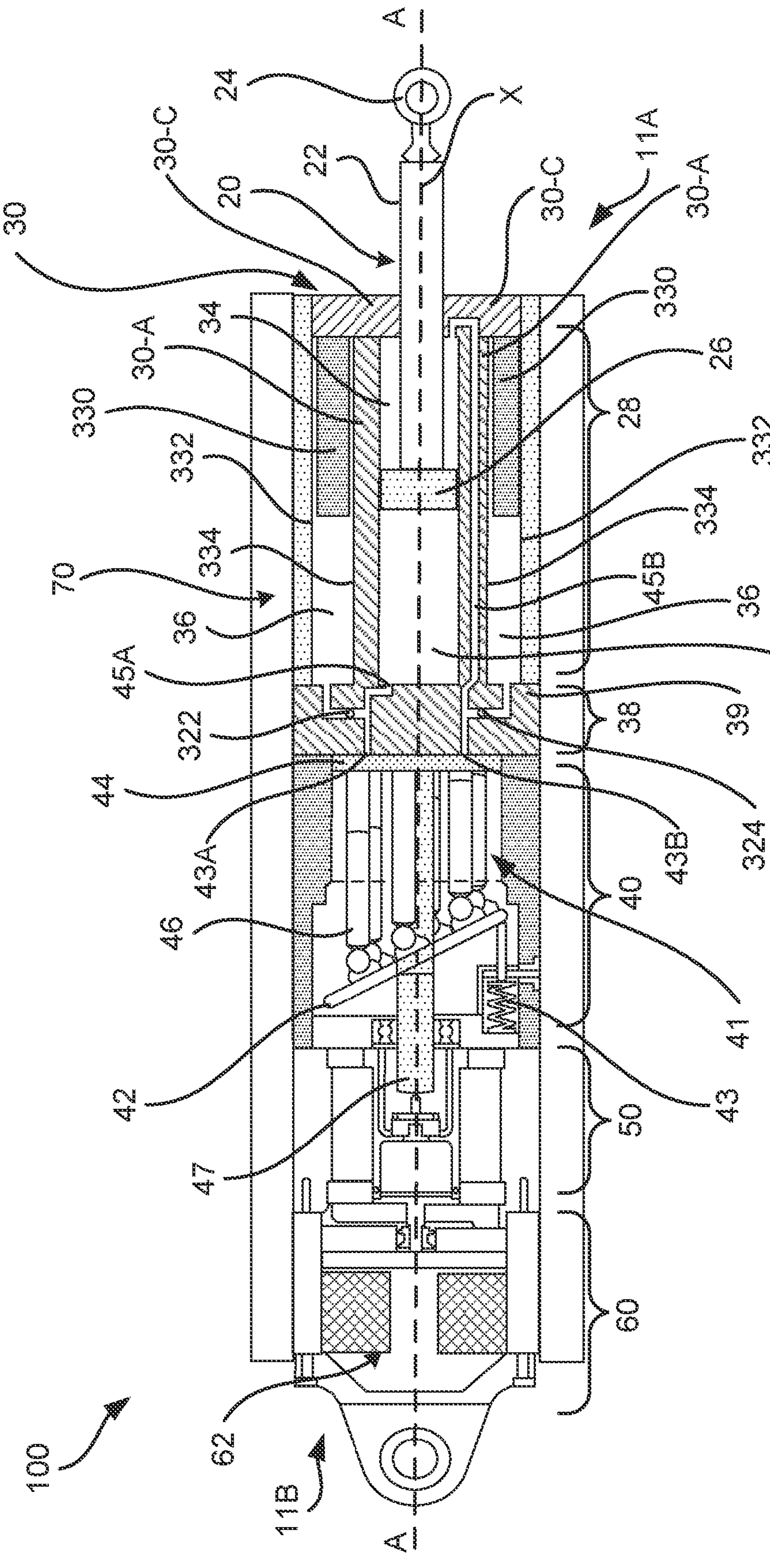

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FIG. 1

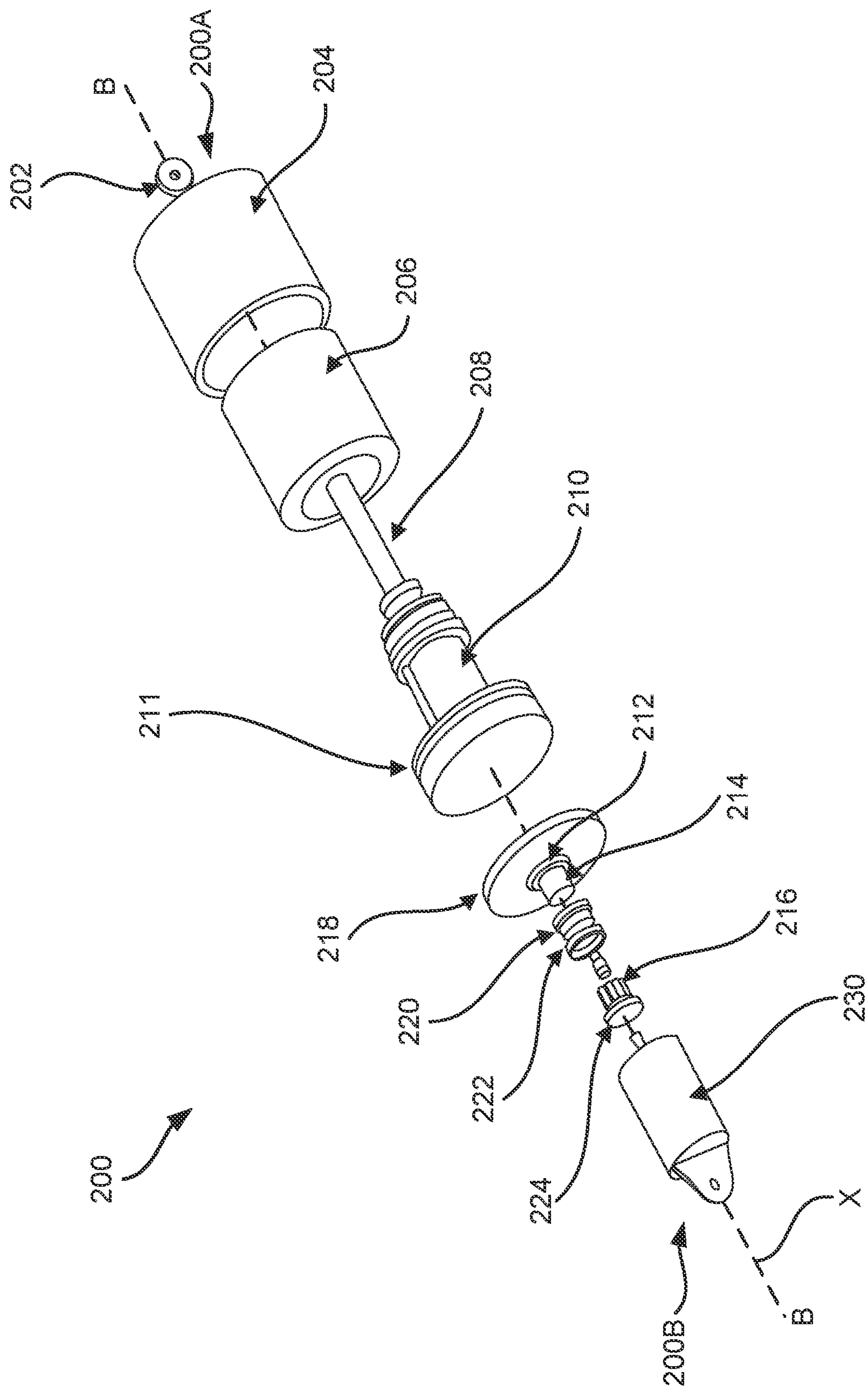
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FIG. 2

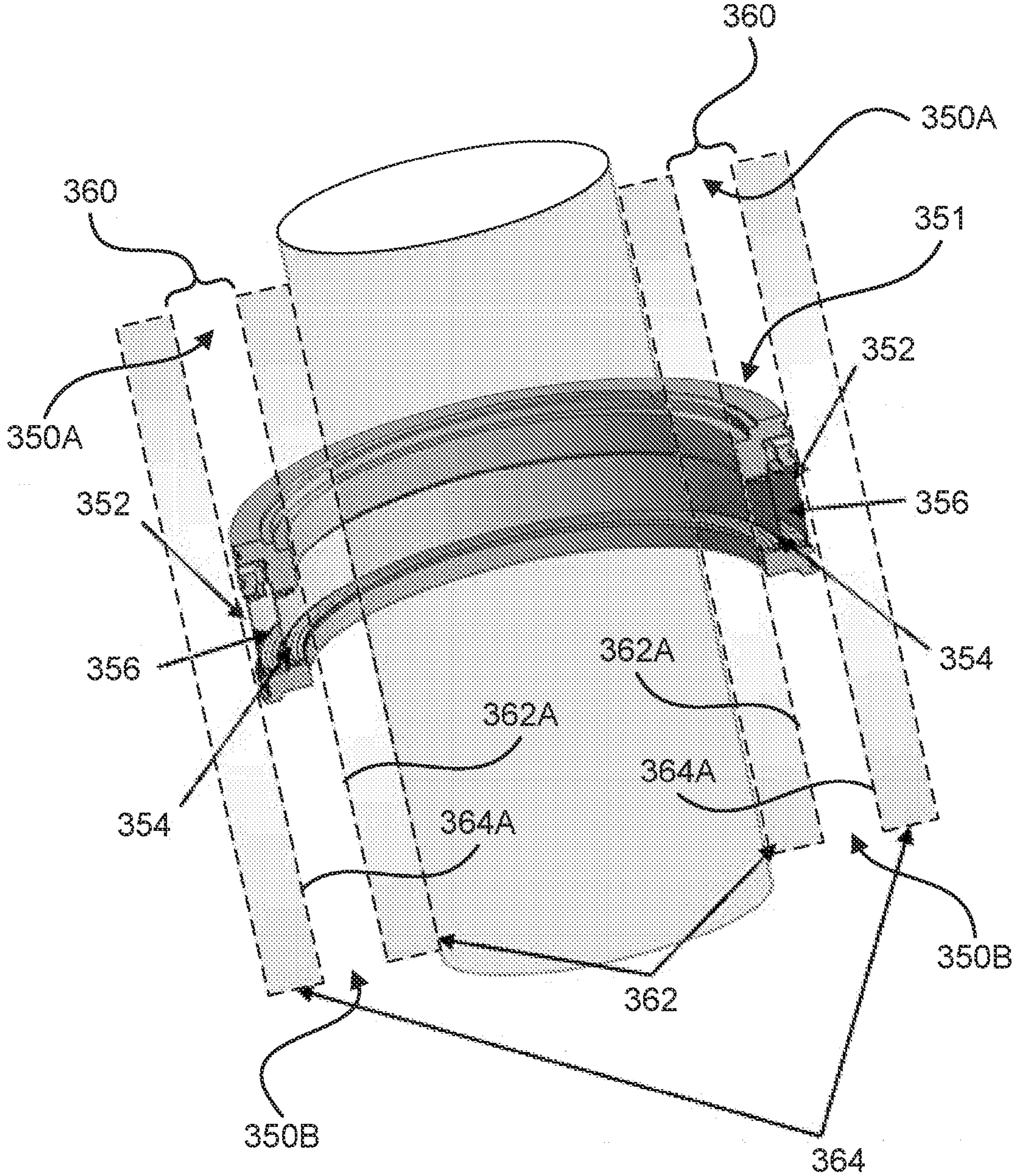
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FIG. 3

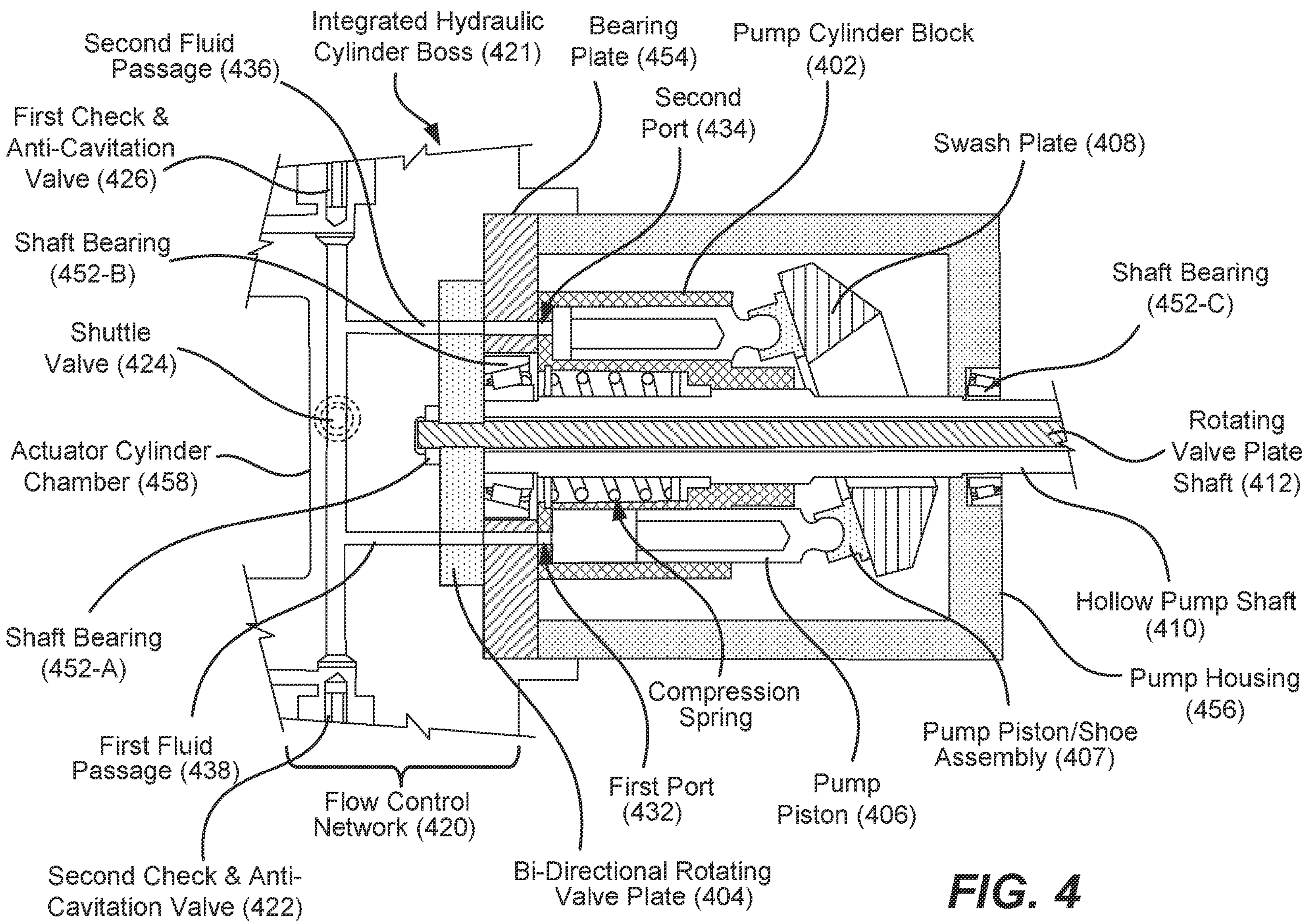

FIG. 4

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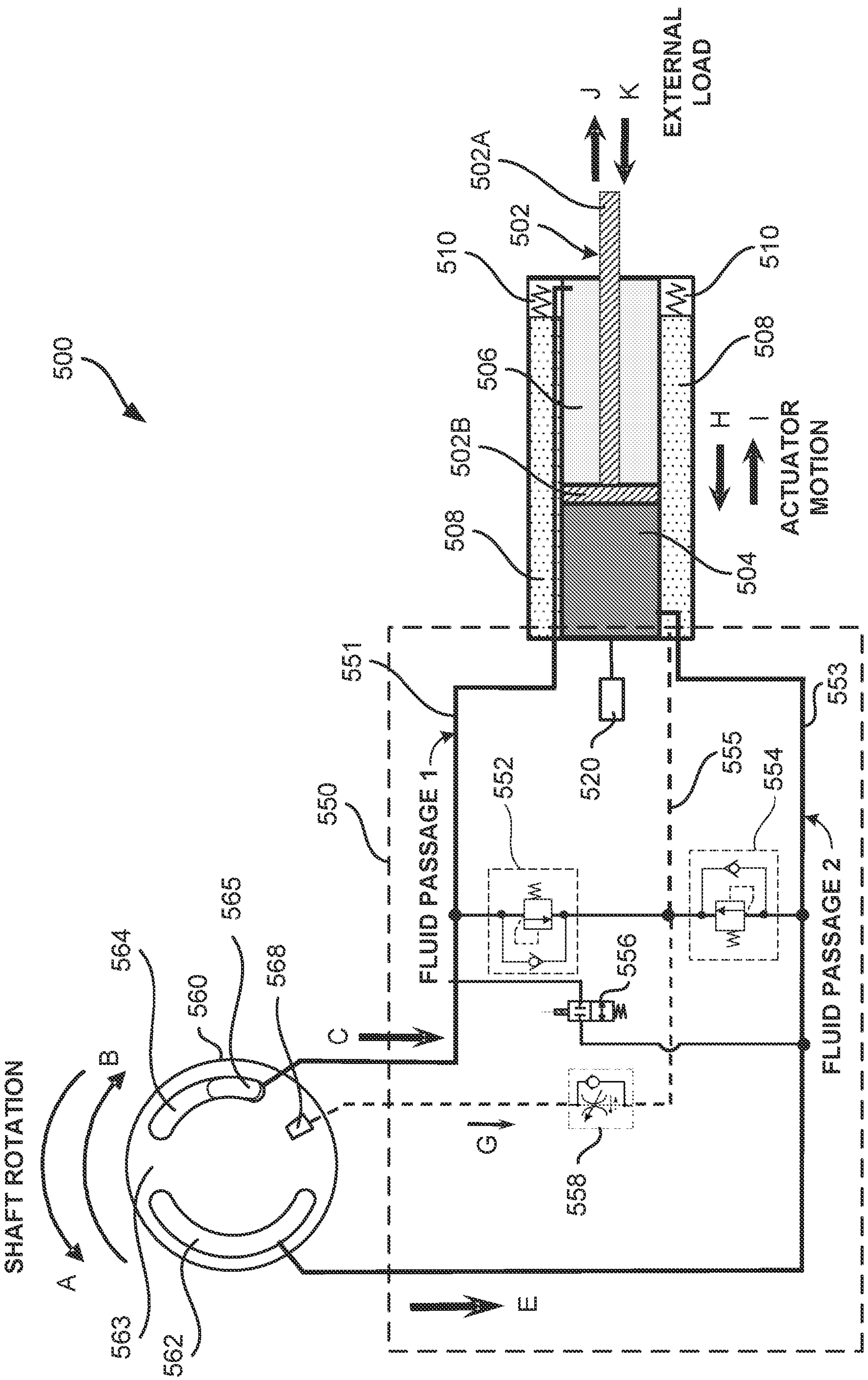
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FLUID PASSAGE 2
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ACTUATOR MOTION
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EXTERNAL LOAD

FIG. 5

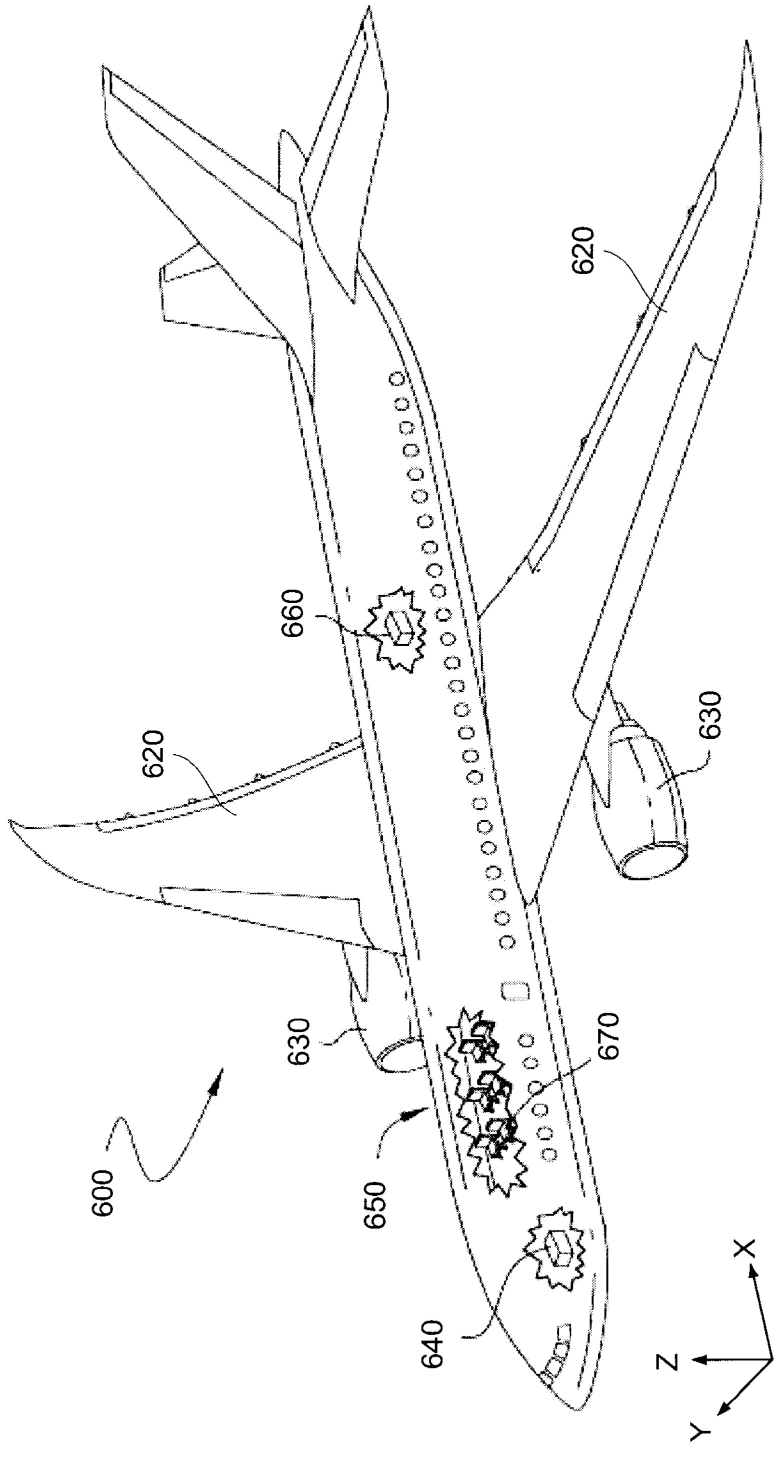
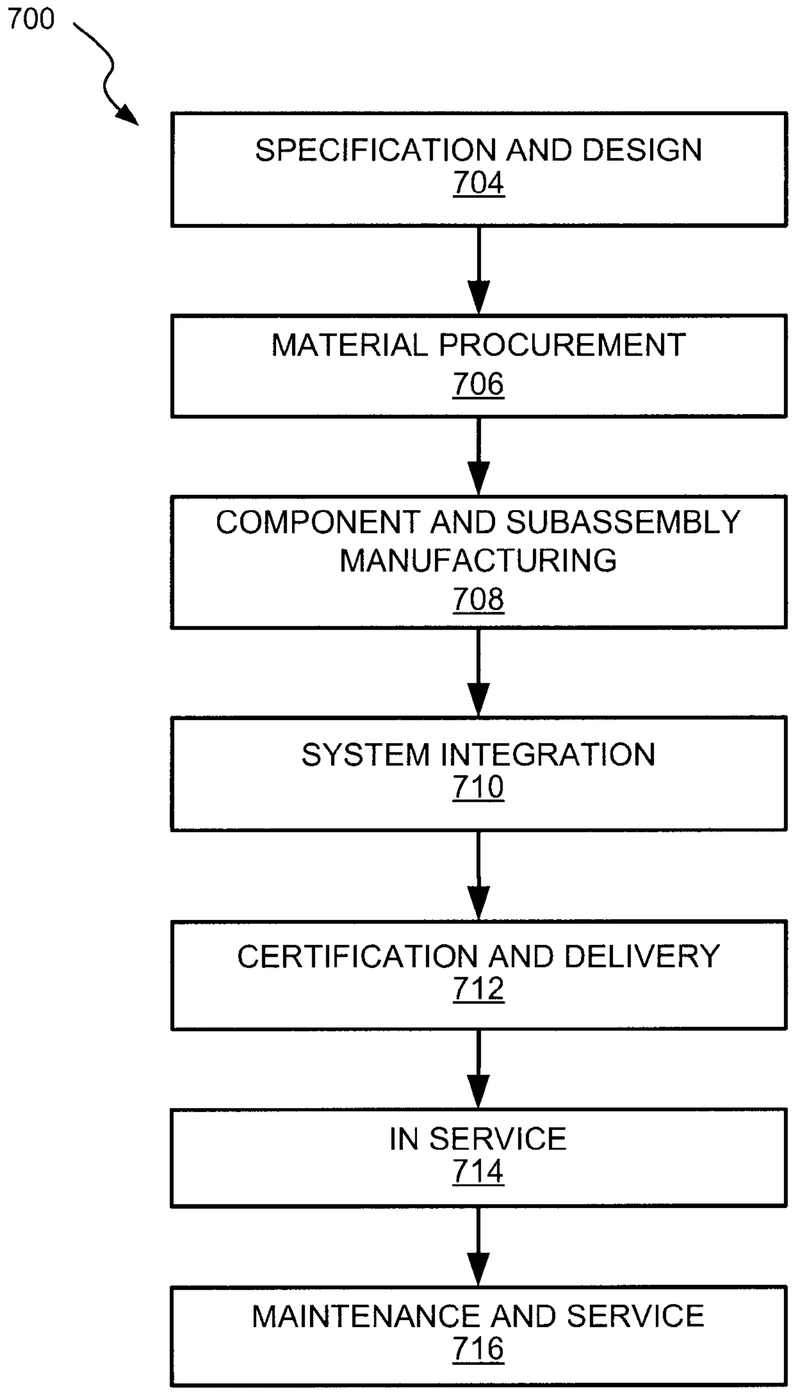


FIG. 6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COMPONENT AND SUBASSEMBLY MANUFACTURING
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SYSTEM INTEGRATION
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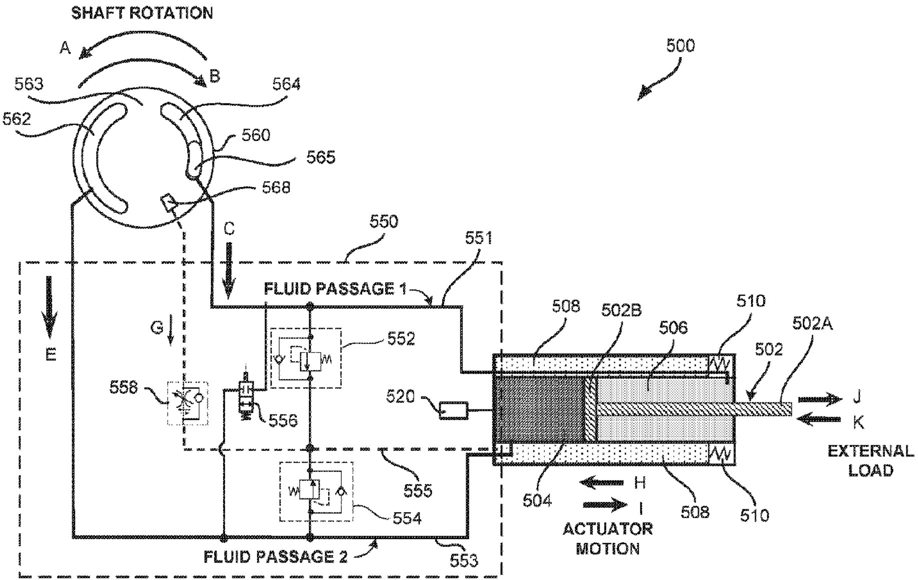
CERTIFICATION AND DELIVERY
712
IN SERVICE
714
MAINTENANCE AND SERVICE
716

FIG. 7



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