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(54) **MULTIVARIABLE ACTUATOR PRESSURE CONTROL**

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(51) **Int. Cl.**

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F15B 15/08	(2006.01)
F15B 15/14	(2006.01)
F15B 11/10	(2006.01)

(52) **U.S. Cl.**

CPC ***F15B 15/088*** (2013.01); ***F15B 11/10*** (2013.01); ***F15B 15/1447*** (2013.01); ***F15B 15/28*** (2013.01)

(58) **Field of Classification Search**

CPC F15B 9/00; F15B 9/02; F15B 9/09; F15B 2211/6336

USPC 60/468, 494

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,421,155 A * 6/1995 Hirata B01D 53/28 60/426
6,662,705 B2 * 12/2003 Huang F15B 11/006 60/459

* cited by examiner

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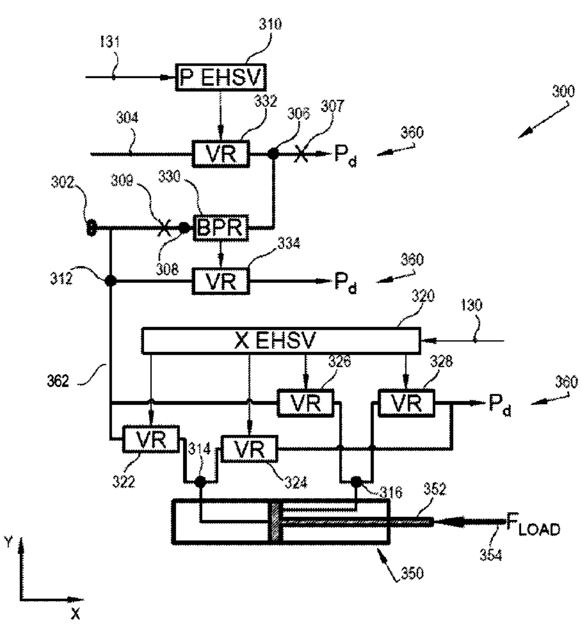
(57) **ABSTRACT**

Systems and methods for use with a variable pressure actuator control system for a gas turbine engine are provided. A variable pressure actuator control system for a gas turbine engine may comprise a controller, a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), including a variable restriction flow path, in electronic communication with the controller, a position regulating electro-hydraulic servo valve assembly (X-EHSV), including a network of flow paths, in electronic communication with the controller, a bypass regulator (BPR) in fluid communication with at least one of a pump, the P-EHSV, or the X-EHSV, the BPR configured to be controlled by the P-EHSV via a bypass pressure to vary an available pressure, and an actuator comprising an actuator piston. The variable pressure actuator control system may minimize pressure when possible to increase mission capability for a gas turbine engine.

18 Claims, 6 Drawing Sheets



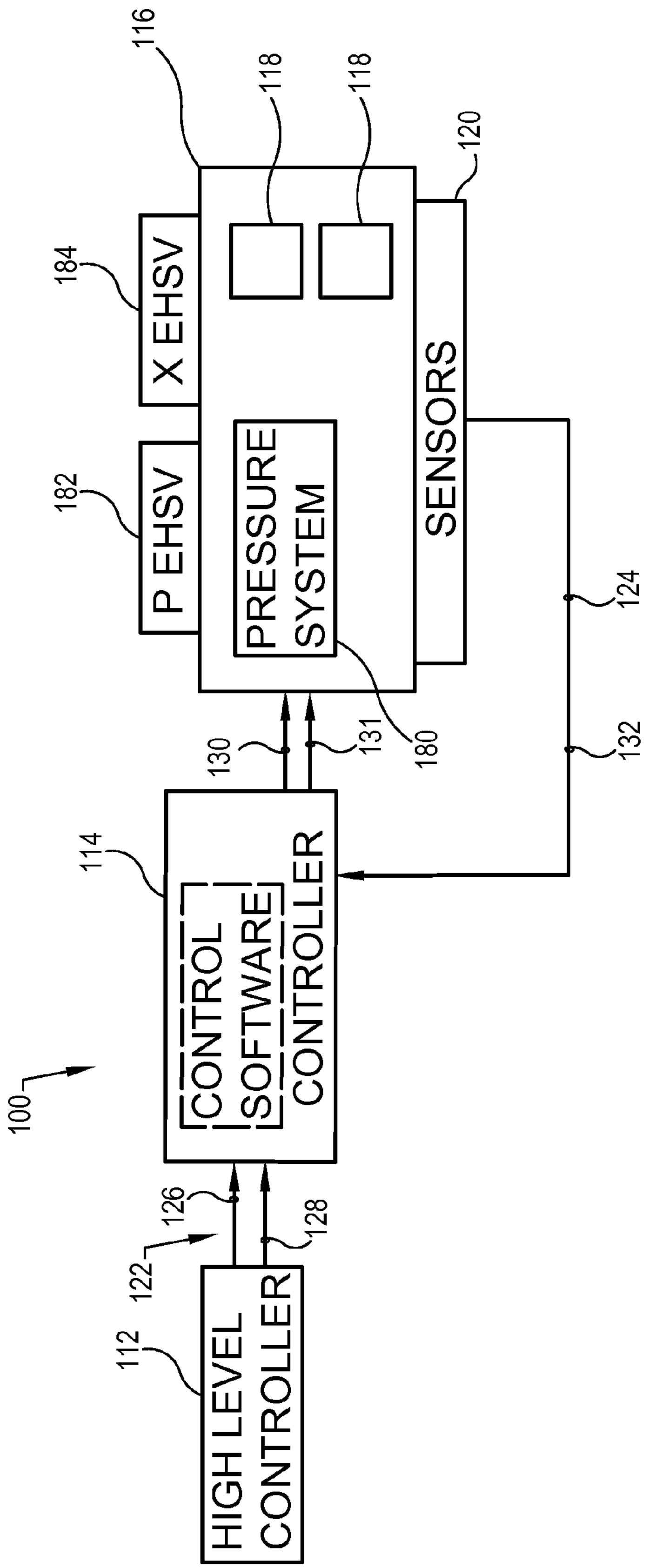

100
HIGH LEVEL CONTROLLER
112
122
126
128
CONTROL SOFTWARE
CONTROLLER
114
130
131
132
124
PRESSURE SYSTEM
180
P EHSV
182
X EHSV
184
SENSORS
120
116
118
118

FIG. 1

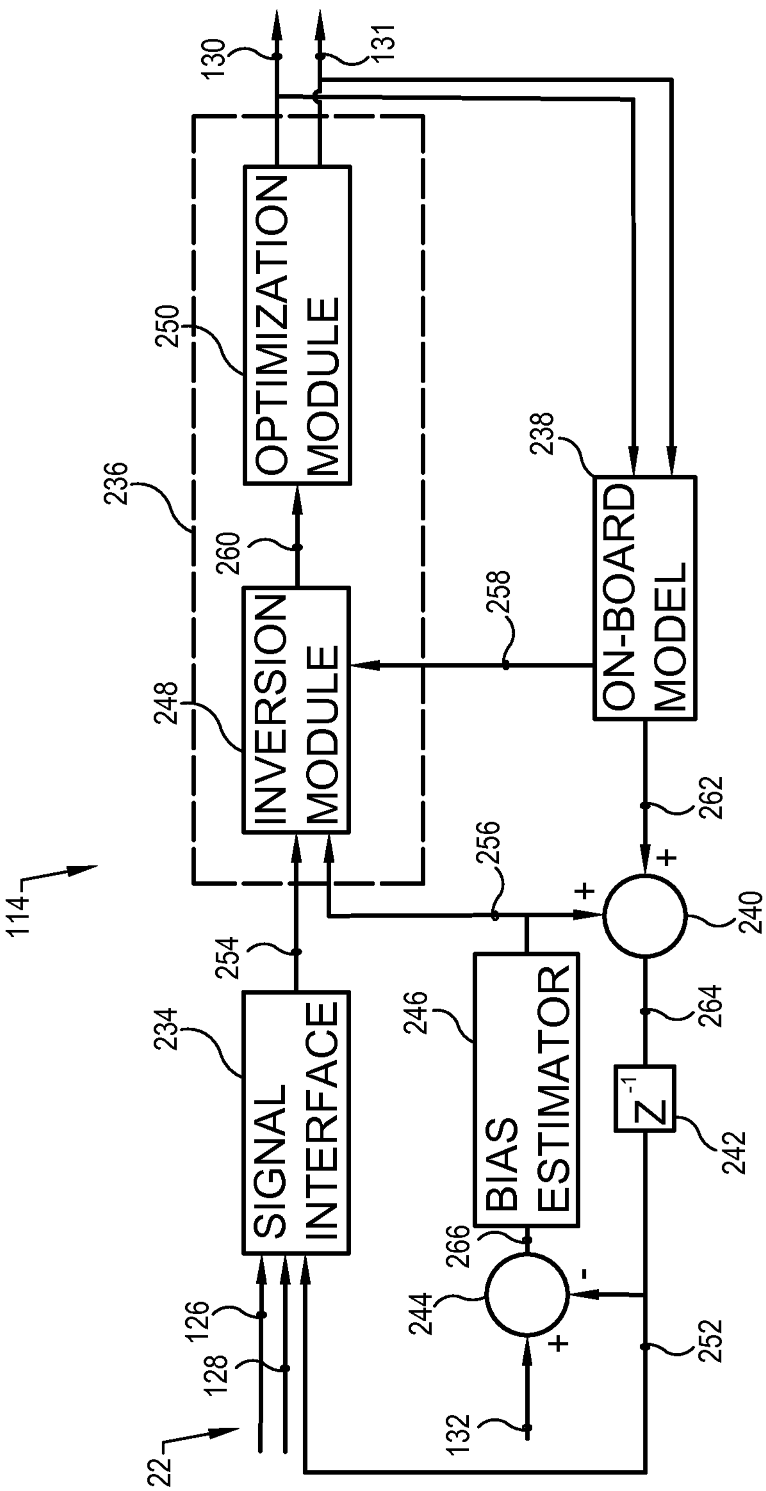

114
122
126
128
132
SIGNAL INTERFACE
234
254
BIAS ESTIMATOR
246
244
266
252
Z-1
242
264
240
256
262
236
INVERSION MODULE
248
258
ON-BOARD MODEL
238
260
OPTIMIZATION MODULE
250
130
131

FIG. 2

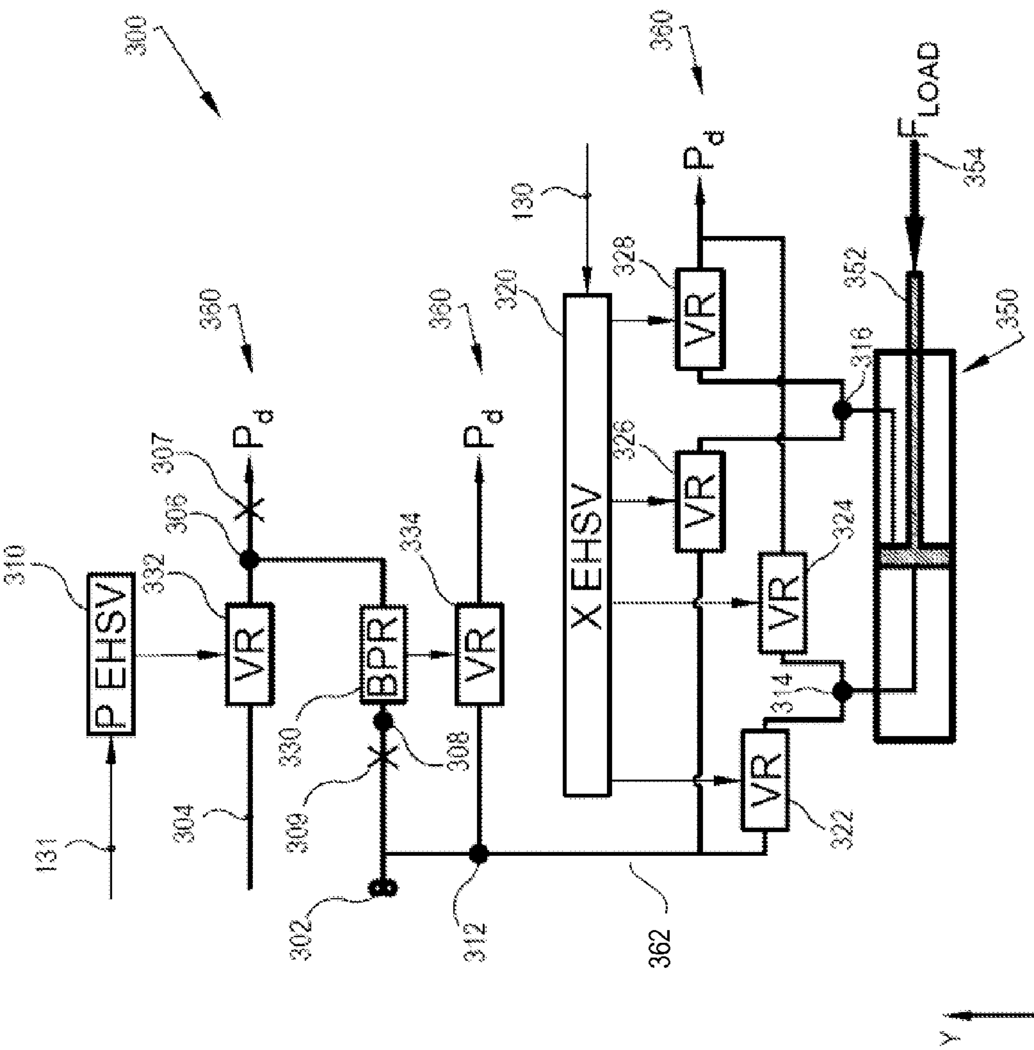

300
310
P EHSV
131
332
VR
306
307
Pd
360
304
330
BPR
308
309
302
334
312
362
320
X EHSV
130
326
328
322
324
314
316
350
352
354
FLOAD
X
Y

FIG. 3

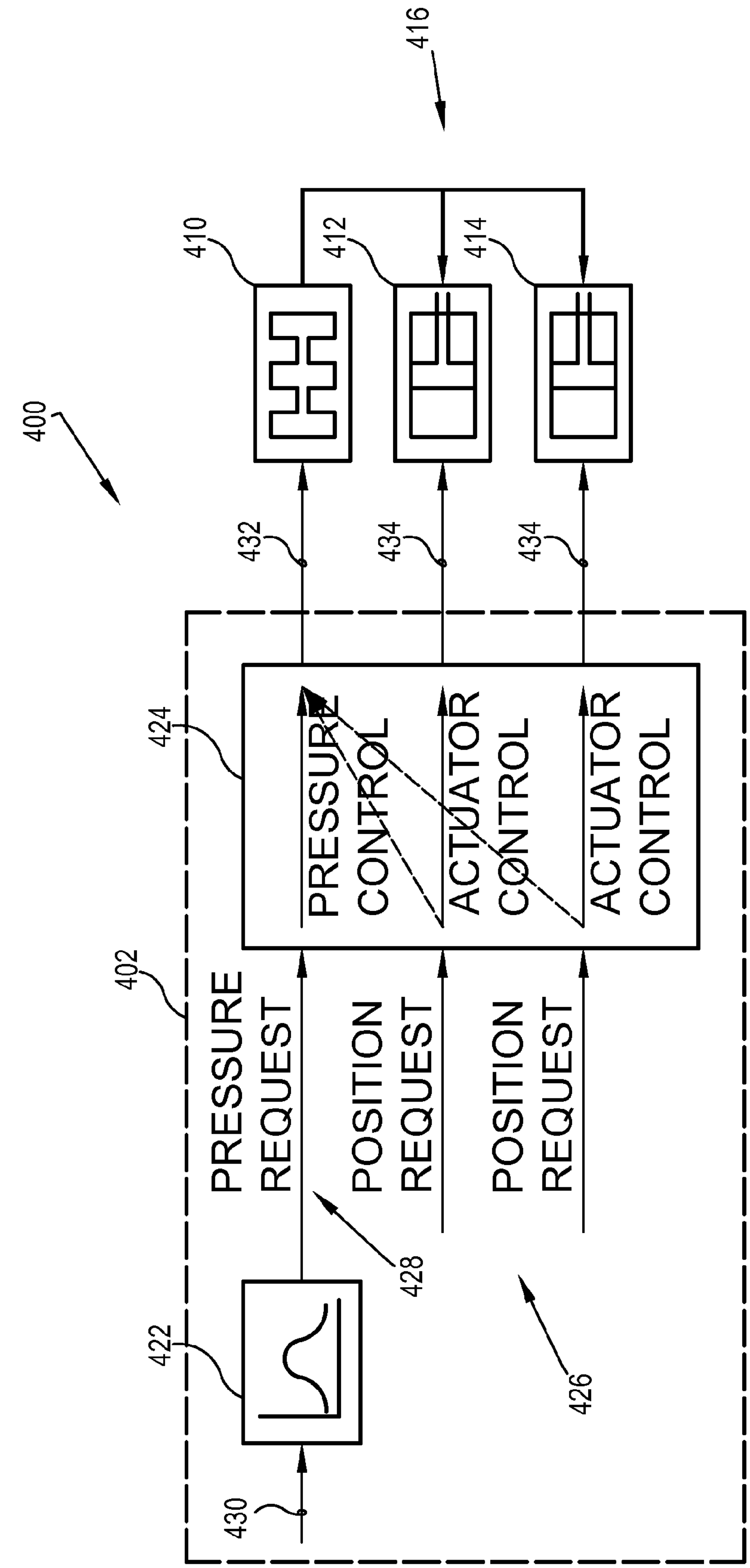

400
402
PRESSURE REQUEST
POSITION REQUEST
POSITION REQUEST
PRESSURE CONTROL
ACTUATOR CONTROL
ACTUATOR CONTROL
410
412
414
416
422
424
426
428
430
432
434
434

FIG. 4

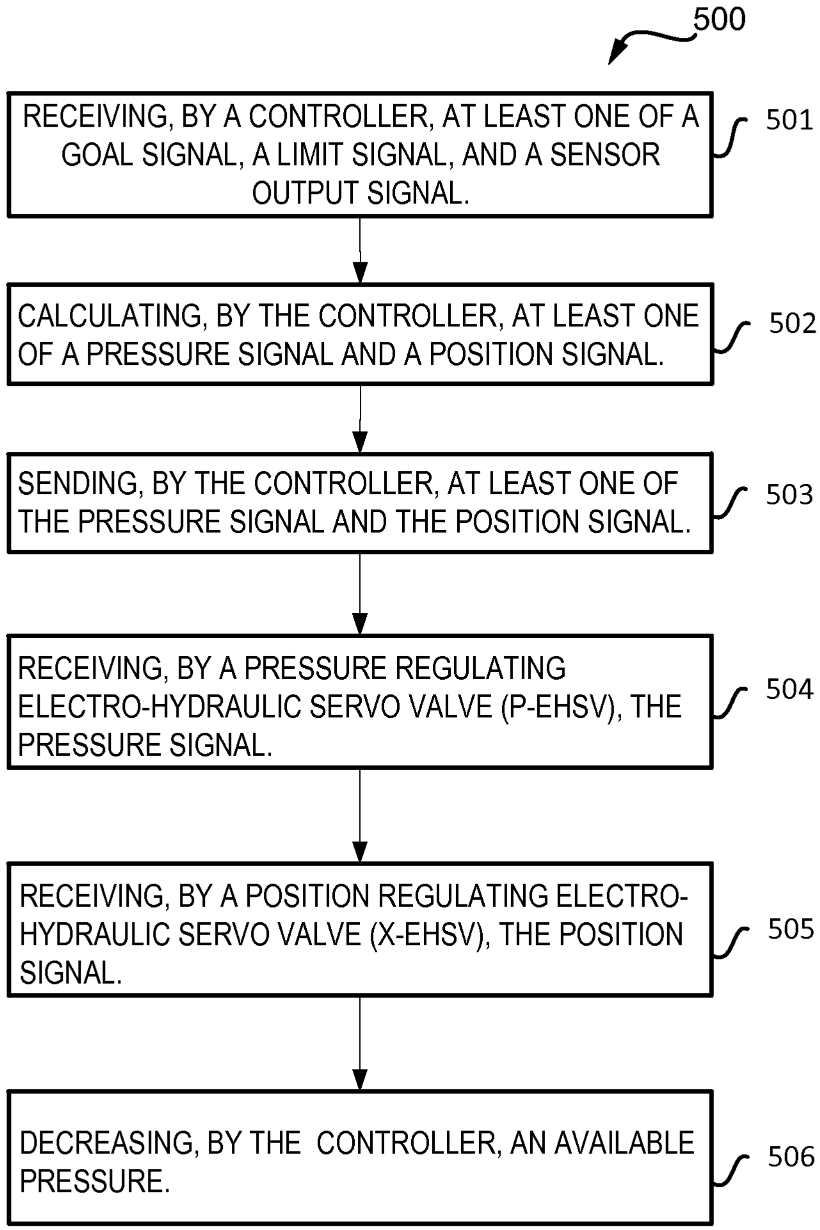

500
RECEIVING, BY A CONTROLLER, AT LEAST ONE OF A GOAL SIGNAL, A LIMIT SIGNAL, AND A SENSOR OUTPUT SIGNAL.
501
CALCULATING, BY THE CONTROLLER, AT LEAST ONE OF A PRESSURE SIGNAL AND A POSITION SIGNAL.
502
SENDING, BY THE CONTROLLER, AT LEAST ONE OF THE PRESSURE SIGNAL AND THE POSITION SIGNAL.
503
RECEIVING, BY A PRESSURE REGULATING ELECTRO-HYDRAULIC SERVO VALVE (P-EHSV), THE PRESSURE SIGNAL.
504
RECEIVING, BY A POSITION REGULATING ELECTRO-HYDRAULIC SERVO VALVE (X-EHSV), THE POSITION SIGNAL.
505
DECREASING, BY THE CONTROLLER, AN AVAILABLE PRESSURE.
506

FIG. 5

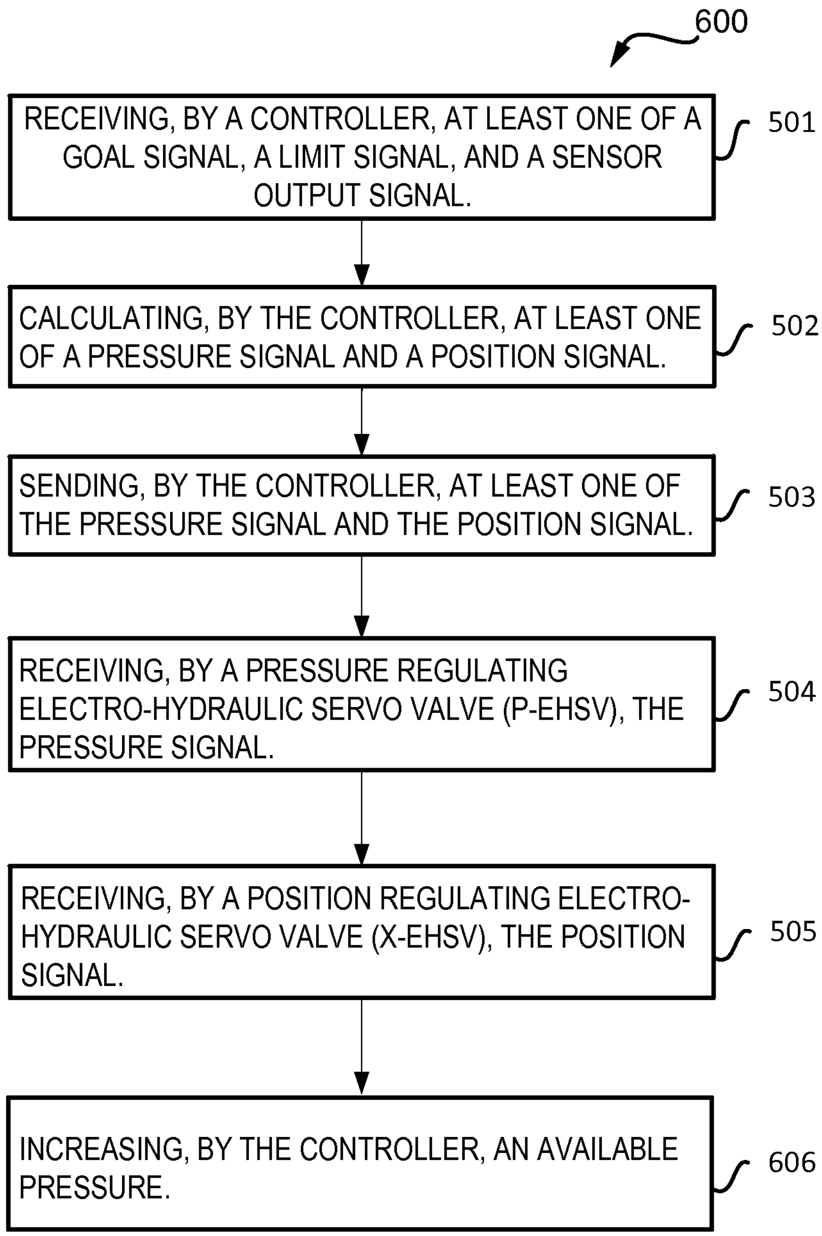

600
RECEIVING, BY A CONTROLLER, AT LEAST ONE OF A GOAL SIGNAL, A LIMIT SIGNAL, AND A SENSOR OUTPUT SIGNAL.
501
CALCULATING, BY THE CONTROLLER, AT LEAST ONE OF A PRESSURE SIGNAL AND A POSITION SIGNAL.
502
SENDING, BY THE CONTROLLER, AT LEAST ONE OF THE PRESSURE SIGNAL AND THE POSITION SIGNAL.
503
RECEIVING, BY A PRESSURE REGULATING ELECTRO-HYDRAULIC SERVO VALVE (P-EHSV), THE PRESSURE SIGNAL.
504
RECEIVING, BY A POSITION REGULATING ELECTRO-HYDRAULIC SERVO VALVE (X-EHSV), THE POSITION SIGNAL.
505
INCREASING, BY THE CONTROLLER, AN AVAILABLE PRESSURE.
606

FIG. 6

MULTIVARIABLE ACTUATOR PRESSURE CONTROL

FIELD

The present disclosure relates to gas turbine engine actuators, and, more specifically, to a system and method that compensates for changes in operating conditions of a multivariable system.

BACKGROUND

A gas turbine actuator control system can include a control system, a gas turbine engine having a plurality of engine actuators, a hydraulic (or fueldraulic) system, and a plurality of engine sensors. Generally, a fueldraulic system maintains a predetermined pressure available for actuator control. Typically, as the pressure increases in a fueldraulic system, the losses in the fueldraulic system increase. This drives a fuel temperature increase, which can lead to decreased mission capability for the gas turbine engine.

SUMMARY

A variable pressure actuator control system for a gas turbine engine may comprise a controller, a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), including a flow path, in electronic communication with the controller, a position regulating electro-hydraulic servo valve assembly (X-EHSV), including a network of flow paths, in electronic communication with the controller, a bypass regulator (BPR) in fluid communication with at least one of a pump, the P-EHSV, or the X-EHSV, the BPR configured to be controlled by the P-EHSV via a bypass pressure to vary an available pressure, and an actuator comprising an actuator piston.

In various embodiments, the network of flow paths may comprise a second flow path, a third flow path, a fourth flow path, and a fifth flow path, wherein an extend pressure exists between the second flow path and the third flow path and a retract pressure exists between the fourth flow path and the fifth flow path. At least one of the retract pressure and the extend pressure may be controlled by the X-EHSV. The X-EHSV may be configured to control the network of flow paths. The actuator piston may be configured to extend in response to an increase in extend pressure and retract in response to an increase in retract pressure. The available pressure may be configured to remain minimal in response to a minimal requested available pressure. The available pressure may be configured to increase in response to at least one of an increase in requested pressure or a feedback signal having reached a limit. The variable pressure actuator control system may use hydraulic fluid.

A gas turbine engine may comprise a variable pressure actuator control system. The variable pressure actuator control system may comprise a controller, a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), including a flow path, in electronic communication with the controller, a position regulating electro-hydraulic servo valve assembly (X-EHSV), including a network of flow paths, in electronic communication with the controller, a bypass regulator (BPR) in fluid communication with at least one of a pump, the P-EHSV, or the X-EHSV, the BPR configured to be controlled by the P-EHSV via a bypass pressure to vary an available pressure, and an actuator comprising an actuator piston.

In various embodiments, the network of flow paths may comprise a second flow path, a third flow path, a fourth flow path, and a fifth flow path, wherein an extend pressure exists between the second flow path and the third flow path and a retract pressure exists between the fourth flow path and the fifth flow path. At least one of the retract pressure and the extend pressure may be controlled by the X-EHSV. The X-EHSV may be configured to control the network of flow paths. The actuator piston may be configured to extend in response to an increase in extend pressure and retract in response to an increase in retract pressure. The available pressure may be configured to remain minimal in response to a minimal requested available pressure. The available pressure may be configured to increase in response to a feeback signal having reached a limit. The variable pressure actuator control system may use hydraulic fluid.

A method of controlling a variable pressure actuator control system for a gas turbine engine may comprise: receiving, by a controller, at least one of a goal signal, a limit signal, and a sensor output signal, calculating, by the controller, at least one of a pressure signal and a position signal, sending, by the controller, at least one of the pressure signal and the position signal, receiving, by a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), the pressure signal, receiving, by a position regulating electro-hydraulic servo valve assembly (X-EHSV), the position signal, and increasing, by the controller, an available pressure.

In various embodiments, the increasing may be in response to a feedback signal having reached a limit. In various embodiments, the method may further comprise decreasing, by the controller, the available pressure. In various embodiments, the decreasing may be in response to a decrease in desired pressure at an actuator piston.

The forgoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated herein otherwise. These features and elements as well as the operation of the disclosed embodiments will become more apparent in light of the following description and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the detailed description and claims when considered in connection with the figures, wherein like numerals denote like elements.

FIG. **1** illustrates a schematic view of a variable pressure actuator control system, in accordance with various embodiments;

FIG. **2** illustrates a schematic view of a control system, in accordance with various embodiments;

FIG. **3** illustrates a schematic view of an actuator pressure control system, in accordance with various embodiments;

FIG. **4** illustrates a schematic view of a variable pressure control system, in accordance with various embodiments;

FIG. **5** illustrates a method of controlling a variable pressure actuator control system, in accordance with various embodiments; and

FIG. **6** illustrates a method of controlling a variable pressure actuator control system, in accordance with various embodiments.

DETAILED DESCRIPTION

The detailed description of exemplary embodiments herein makes reference to the accompanying drawings, which show exemplary embodiments by way of illustration. While these exemplary embodiments are described in sufficient detail to enable those skilled in the art to practice the inventions, it should be understood that other embodiments may be realized and that logical changes and adaptations in design and construction may be made in accordance with this invention and the teachings herein. Thus, the detailed description herein is presented for purposes of illustration only and not of limitation. The scope of the invention is defined by the appended claims. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact. Surface shading lines may be used throughout the figures to denote different parts but not necessarily to denote the same or different materials. In some cases, reference coordinates may be specific to each figure.

In various embodiments, the variable pressure control system as disclosed herein includes a hydraulic system which is capable of varying available system pressure in response to a high level control request. Variable available system pressure may reduce system temperatures, resulting in higher engine operating efficiencies. According to the present disclosure, a pressure regulating electro-hydraulic servo valve assembly (P-EHSV) may control available pressure in a hydraulic system. A position regulating electro-hydraulic servo valve assembly (X-EHSV) may control the position of an actuator piston by controlling retract pressures and extend pressures in the system. An actuator may retract in response to an increase in a retract pressure and may extend in response to an increase in an extend pressure. Thus, a retract pressure and an extend pressure may be the pressure which the actuator experiences via a supplied fluid. A constrained model based controller may determine appropriate available pressure, while tending to minimize available pressure, to achieve various benefits.

The term "effector signal" is used herein to describe a command signal that controls operation of the engine through the engine actuators. The effector signals can be generated by processing goals and/or limits using a control algorithm such that at least some of the goals are satisfied, subject to each limit being held (i.e., no limit is violated). An example of a goal is to move an actuator at a predetermined rate to a predetermined position. An example of a limit (i.e., a maximum or minimum) is to prevent the hydraulic pressure applied at an actuator piston from exceeding a certain value. A limit is "active" when its limit value has been met; e.g., when a temperature of a component is, or is predicted to be, at or above a maximum limit temperature.

System program instructions and/or controller instructions may be loaded onto a non-transitory, tangible computer-readable medium having instructions stored thereon that, in response to execution by a controller, cause the controller to perform various operations. The term "non-transitory" is to be understood to remove only propagating transitory signals per se from the claim scope and does not relinquish rights to all standard computer-readable media that are not only propagating transitory signals per se. Stated another way, the meaning of the term "non-transitory computer-readable medium" and "non-transitory computer-readable storage medium" should be construed to exclude only those types of transitory computer-readable media which were found in *In Re Nuijten* to fall outside the scope of patentable subject matter under 35 U.S.C. §101.

In various embodiments, an electro-hydraulic servo valve (EHSV) as used herein may comprise a directional control valve, wherein the EHSV consists of a spool, or the like, inside of a cylinder which is electronically controlled. For example, an EHSV may receive actuation commands to open, partially open, partially close and/or close various flow paths. The movement of the spool restricts or permits the flow of a hydraulic fluid. As described herein a position regulating electro-hydraulic servo valve (X-EHSV) may comprise one or more inputs and four outputs, in accordance with various embodiments. In various embodiments, each output may comprise a port, orifice, valve, or the like, referred to herein as a flow path, which may comprise a variable restriction flow path. Similarly, a pressure regulating electro-hydraulic servo valve (P-EHSV) is provided, in accordance with various embodiments. The P-EHSV may comprise one or more inputs and one or more outputs, in accordance with various embodiments. In this light, an EHSV may comprise a valve assembly.

Referring to FIG. **1**, a variable pressure actuator control system **100** is schematically illustrated, in accordance with various embodiments. Variable pressure actuator control system **100** may include a high level controller **112** (e. g., a vehicle management system), a control system **114**, a gas turbine engine **116** having a plurality of actuators **118**, and a plurality of engine sensors **120**. In various embodiments, control system **114** may be referred to herein as a controller. The control system **114** is wired or wirelessly in communication with to the high level controller **112**, the gas turbine engine **116** via the engine actuators **118**, and the engine sensors **120**. The engine sensors **120** are disposed with the gas turbine engine **116**.

The control system **114** inputs one or more control signals **122** from the high level controller **112** and one or more sensor output signals **124** from the engine sensors **120**. The control signals **122** can include one or more goals **126** (also referred to as "command signals") and one or more limits **128**. A signal indicative of a command to move an actuator at a predetermined rate to a predetermined position, as indicated above, is an example of a goal. A signal indicative of a control limit (i.e., a maximum or minimum) to prevent a hydraulic pressure applied at an actuator piston from exceeding a certain pressure, as indicated above, is an example of a limit.

Although described herein as comprising separate controllers, in various embodiments, control system **114** and high level controller **112** may comprise a single controller. For example, control system **114** may refer to system program instructions and/or controller instructions which may be loaded onto a non-transitory, tangible computer-readable medium and high level controller **112** may refer to system program instructions and/or controller instructions which may be loaded onto the same non-transitory, tangible computer-readable medium. Thus, control system **114** and high level controller **112** comprising a single controller.

The control system **114** provides one or more effector signals **130**, **131** to one or more of the engine actuators **118**. The term "effector signal" is used herein, as indicated above, to refer to a command signal that controls operation of an engine actuator. Effector signal **130** and effector signal **131** are generated, as a function of the control and sensor output signals **122** and **124**, to control operation of the engine **116** by controlling the engine actuators **118**. Although illustrated in FIG. **1** as two separate signals, effector signal **130** and effector signal **131** may comprise a single signal, in accordance with various embodiments.

The engine sensors **120** monitor certain engine parameters such as temperature, pressure, actuator position, etc. The engine sensors **120** output measured parameter data **132** to the control system **114**, via the sensor output signals **124** (i.e., feedback signals), indicative of the monitored engine parameters. A signal indicative of temperature, pressure, or actuator position that is measured by an engine sensor is an example of a sensor output signal.

With respect to FIG. **2** and FIG. **3**, elements with like element numbering as depicted in FIG. **1** are intended to be the same and will not necessarily be repeated for the sake of clarity.

With reference to FIG. **2**, the control system **114** may include a control signal interface **234**, an effector signal generator **236**, an actuation system modeling device **238**, a prediction signal biasing device **240**, a memory storage device **242**, a comparator **244**, and/or a bias estimator **246**. The effector signal generator **236** may include a dynamic inversion module **248** and/or an optimization module **250**.

Although described herein as being implemented on control system **114**, it is contemplated that control signal interface **234**, effector signal generator **236**, actuation system modeling device **238**, prediction signal biasing device **240**, memory storage device **242**, comparator **244**, and bias estimator **246** may be implemented on one or more controllers and in any combination thereof.

The control signal interface **234** receives the control signals **122** (i.e., the goals **126** and limits **128**) from the high level controller **112** (see FIG. **1**), and stored parameter data **252** from the memory storage device **242**. The control signal interface **234** provides reference value data **254** to the dynamic inversion module **248**. The dynamic inversion module **248** receives bias estimates **256** from the bias estimator **246** and model term data **258** from the actuation system modeling device **238**. The dynamic inversion module **248** provides effector equation data **260** to the optimization module **250**. The optimization module **250** provides one or more effector signals **130**, **131** to one or more of the engine actuators **118** (see FIG. **1**), and the actuation system modeling device **238**. The actuation system modeling device **238** provides predicted parameter data **262** to the prediction signal biasing device **240**. The prediction signal biasing device **240** receives the bias estimates **256** from the bias estimator **246**, and provides biased predicted parameter data **264** to the memory storage device **242**. The predicted parameter data **264** includes predictions of the values of states and variables that have associated goals or limits at the next control process cycle. The comparator **244** receives the stored parameter data **252** from the memory storage device **242**, and the measured parameter data **132** from one or more of the engine sensors **120** (see FIG. **1**). The stored parameter data **252** includes estimates of the current values of states and variables that have associated goals or limits the comparator **244** provides prediction error data **266** to the bias estimator **246**, which processes this data to produce bias estimates **256**. The bias estimates correct for model error. The bias estimates include at least one bias which, when added to at least one predicted parameter data **262**, corrects the output for model error.

The control signal interface **234** is configured to generate the reference value data **254** by processing the goals **126**, the limits **128** and the stored parameter data **252** using a reference model. The reference model is operable to reflect a desired future dynamic response to possibly changing goals and limits. The reference value data **254** is indicative of a desired value of one or more goals and one or more limits, which are determined for a subsequent (e.g., the next) control process cycle (also referred to as a "program cycle" or "update"). A numerical value indicative of a hydraulic pressure that corresponds to an actuator position is an example of a goal value. In various embodiments, each goal can also be associated with one or more additional signals such as 1) a reference value of hydraulic pressure included in the reference value data **254** indicative of the desired hydraulic pressure dynamic response to the goal, 2) a model prediction of actual hydraulic pressure included in the predicted parameter data **262**, 3) a sensor measurement of actual hydraulic pressure included in the measured parameter data **132**, and/or 4) a hydraulic pressure bias to correct for model errors. A numerical value indicative of a maximum actuator displacement rate is an example of a limit value. In various embodiments, each limit can also be associated with one or more additional signals such as: a reference value of actuator piston displacement rate included in the reference value data **254** indicative of the desired actuator displacement rate dynamic response to the possibly changing limit value, a model prediction of actual actuator displacement rates included in the predicted parameter data **262**, a sensor measurement of actual actuator displacement rates included in the measured parameter data **132**, and/or a actuator displacement rate bias to correct for model errors.

With reference to FIG. **3**, an actuator pressure control system **300** is provided. An xy-axis is provided for ease of illustration. In various embodiments, an actuator pressure control system **300** may include a pump **302**, a pressure regulating electro-hydraulic servo valve assembly (P-EHSV) **310**, a position regulating electro-hydraulic servo valve assembly (X-EHSV) **320**, a bypass regulator (BPR) **330**, and at least one actuator **350**. In various embodiments, pump **302** may be a fixed displacement pump.

In various embodiments, P-EHSV **310** may include flow path **332**. In various embodiments, flow path **332** may comprise a variable restriction (VR) flow path.

In various embodiments, X-EHSV **320** may include flow path **322**, flow path **324**, flow path **326**, and/or flow path **328**. In various embodiments, flow path **322**, flow path **324**, flow path **326**, and/or flow path **328** may comprise a variable restriction (VR) flow path. Flow path **322** may be referred to herein as a second flow path. Flow path **324** may be referred to herein as a third flow path. Flow path **326** may be referred to herein as a fourth flow path. Flow path **328** may be referred to herein as a fifth flow path. Flow path **322**, flow path **324**, flow path **326**, and flow path **328** may be collectively referred to herein as a network of flow paths.

In various embodiments, BPR **330** may include flow path **334**. In various embodiments, flow path **334** may comprise a variable restriction (VR) flow path. Flow path **334** may be referred to herein as a sixth flow path.

In various embodiments, pump **302** may be in fluid communication with BPR **330**. In various embodiments, pump **302** may be in fluid communication with BPR **330** via fixed restriction **309**. In various embodiments, pump **302** may be in fluid communication with BPR **330** via conduit **362**. In various embodiments, pump **302** may be in fluid communication with X-EHSV **320**. In various embodiments, pump **302** may be in fluid communication with X-EHSV **320** via conduit **362**, for example. In various embodiments, BPR **330** may be in fluid communication with X-EHSV **320**. In various embodiments, BPR **330** may be in fluid communication with P-EHSV **310**. In various embodiments, BPR **330** may be in fluid communication with actuator piston **352** via X-EHSV **320**.

In various embodiments, P-EHSV **310** may be in electronic communication with control system **114** (see FIG. **1**). In various embodiments, P-EHSV **310** may comprise an electronics controller. In various embodiments, X-EHSV **320** may be in electronic communication with control system **114** (see FIG. **1**). In various embodiments, X-EHSV **320** may comprise an electronics controller.

In various embodiments, P-EHSV may receive effector signal **131**. Effector signal **131** may be a pressure command signal. In various embodiments, effector signal **131** may comprise a value or a current, such as a desired pressure, for example. P-EHSV **310** may be configured to one of restrict or permit hydraulic fluid to flow through flow path **332**, in response to effector signal **131**. In various embodiments, flow path **332** may receive pressurized hydraulic fluid at a regulated pressure **304**. In various embodiments, regulated pressure **304** may be maintained by an outside hydraulic system. In various embodiments, hydraulic fluid may flow through flow path **332** to drain **360** and/or to BPR **330**. A fixed restriction **307** may be located between drain **360** and flow path **332**. In various embodiments, drain **360** may comprise a tank. Flow path **332** may be configured to open in response to a command for an increase in bypass pressure **306** and close in response to a command for a decrease in bypass pressure **306**. Bypass pressure **306** may be configured to increase in response to effector signal **131** commanding more pressure to be applied at actuator piston **352**. Bypass pressure **306** may be configured to decrease in response to effector signal **131** commanding less pressure to be applied at actuator piston **352**. In various embodiments, bypass pressure **306** may be configured to control BPR **330**. For example, in various embodiments, a change in bypass pressure **306** may reduce the size of the flowpath for flow of hydraulic fluid through BPR **330**, thus increasing available pressure **312**.

Pump **302** may supply a constant flow of pressurized hydraulic fluid to actuator pressure control system **300**. Damping pressure **308** may exist between fixed restriction **309** and BPR **330**. Hydraulic fluid may flow from pump **302**, through flow path **334**, into drain **360**. BPR **330** may control flow path **334**. Flow path **334** may open to decrease available pressure **312**. Flow path **334** may close to increase available pressure **312**. Accordingly, BPR **330** and/or available pressure **312** may be controlled by P-EHSV **310**.

In various embodiments, hydraulic fluid may flow at available pressure **312** to flow path **322** and flow path **326**. Hydraulic fluid may flow through flow path **322**, through flow path **324**, and into drain **360**. Hydraulic fluid may flow through flow path **326**, through flow path **328**, and into drain **360**. Hydraulic fluid located between flow path **322** and flow path **324** may comprise extend pressure **314**. Hydraulic fluid located between flow path **326** and flow path **328** may comprise retract pressure **316**. Extend pressure **314** may be increased to extend actuator piston **352**. Retract pressure **316** may be decreased to extend actuator piston **352**. Retract pressure **316** may be increased to retract actuator piston **352**. Extend pressure **314** may be decreased to retract actuator piston **352**.

In various embodiments, X-EHSV **320** may receive effector signal **130**. Effector signal **130** may be a position command signal. In various embodiments, effector signal **130** may comprise a value or a current, such as an actuator position value, for example. X-EHSV **320** may be configured to one of restrict or permit hydraulic fluid to flow through flow path **322**, flow path **324**, flow path **326**, and/or flow path **328** in response to effector signal **130**. Stated another way, X-EHSV **320** may be configured to open and or close at least one of flow path **322**, flow path **324**, flow path **326**, and/or flow path **328** in response to effector signal **130**. Accordingly, actuator piston **352** may be configured to at least one of extend (in the positive x-direction) or retract (in the negative x-direction) in response to effector signal **130**. Accordingly, extend pressure **314** and/or retract pressure **316** may be controlled by X-EHSV **320**.

In various embodiments, extend pressure **314** and retract pressure **316** may be limited by available pressure **312**. For example, a limit may be reached by extend pressure **314** and thus X-EHSV **320** when extend pressure **314** has reached available pressure **312**. For example, extend pressure **314** may be equal to available pressure **312** when flow path **324** is in a closed position and flow path **322** is in an open position. Thus, the pressure of hydraulic fluid supplied to actuator **350** may be limited by available pressure **312**.

In various embodiments, available pressure **312** may be configured to increase in response to a feedback signal having reached a limit. Stated another way, available pressure **312** may be configured to increase in response to control system **114** (see FIG. **2**) having reached a limit. A feedback signal may include the value of an operating condition of actuator pressure control system **300**. In various embodiments, a feedback signal may include a rate of change of the position of actuator piston **352**. A feedback signal may include an error in the rate of change of the position of actuator piston **352**. A feedback signal may include an error of the position of actuator piston **352**. A feedback signal may include a rate of change of extend pressure **314** and/or retract pressure **316**. A feedback signal may include an error in the rate of change of extend pressure **314** and/or retract pressure **316**. A feedback signal may include an error in extend pressure **314** and/or retract pressure **316**. A feedback signal may include available pressure **312**. In various embodiments, a feedback signal may be supplied to a controller, such as control system **114** (see FIG. **2**) for example, via a sensor or the like. Accordingly, actuator pressure control system **300** may include one or more sensors.

Accordingly, available pressure **312** may be configured to remain minimal when minimal available pressure **312** is desired by actuator pressure control system **300**. Accordingly, available pressure **312** may be configured to decrease in response to a decrease in desired pressure applied to actuator piston **352**. Minimizing available pressure **312** may result in lower operating temperatures and better engine mission capability.

In various embodiments, load force **354** may be a force acting on actuator piston **352**. Load force **354** may be, for example, a force transmitted through an engine nozzle in response to exhaust pressure in the nozzle. In various embodiments, extend pressure **314** and retract pressure **316** may be configured to prevent actuator piston **352** from moving in response to load force **354**. In various embodiments, extend pressure **314** and retract pressure **316** may be configured to extend or retract actuator piston **352**, thus opening or closing an engine nozzle, for example. In various embodiments, the pressure applied to actuator piston **352** may be determined using load force **354**.

Hydraulic fluid in actuator pressure control system **300** may comprise fuel, or any other suitable fluid. Sensors may be used in actuator pressure control system **300** to detect parameters such as pressure, temperature, and position.

In various embodiments, FIG. **4** illustrates a variable pressure control system **400**. In various embodiments, variable pressure control system **400** may be similar to variable pressure actuator control system **100**. In various embodiments, variable pressure control system **400** may comprise model based controller (MBC) **402**, a hydraulic pressure system **410**, and a plurality of actuators such as actuator **412** and actuator **414**, for example. MBC **402** may comprise an on-board model **422** and actuation controller **424**.

In various embodiments, on-board model **422** may receive a plurality of signals **430**. Plurality of signals **430** may include signals such as pre-predicted model requests, position requests, actuator positions, and feedback signals, for example.

In various embodiments, actuation controller **424** may receive a plurality of signals including pressure request **428** and plurality of position requests **426**, for example. In various embodiments, actuation controller **424** may determine or calculate a plurality of effector signals such as pressure signal **432** and plurality of position signals **434**, for example. In various embodiments, actuation controller **424** may comprise a single loop system.

In various embodiments, plurality of position requests **426** may be used to determine pressure signal **432**. For example, if an increase in available pressure is desired to reach a predetermined position, the value of pressure signal **432** may be varied according to the desired pressure. Plurality of position signals **434** may be calculated based on plurality of position requests **426**. Plurality of position signals **434** may be calculated based on various parameters such as load forces, available pressure, rate of change limits, etc. In various embodiments, plurality of position signals **434** may control the position of actuator **412** and/or actuator **414**. Thus, actuator **412** and/or actuator **414** may be in electronic communication with MBC **402**.

In various embodiments, pressure signal **432** may be received by hydraulic pressure system **410**. Thus, hydraulic pressure system **410** may be in electronic communication with MBC **402**. In various embodiments, hydraulic pressure system **410** may supply hydraulic pressure to a plurality of actuators such as actuator **412** and actuator **414**, for example. Accordingly, hydraulic pressure system **410** may be in fluid communication with the plurality of actuators. In various embodiments, hydraulic pressure system **410** may be similar to actuator pressure control system **300**, as described herein.

With reference to FIG. **5**, a method **500** for controlling a variable pressure actuator control system is provided. Method **500** may comprise receiving, by a controller, at least one of a goal signal, a limit signal, and a sensor output signal (see step **501**). Method **500** may comprise calculating, by the controller, at least one of a pressure signal and a position signal (see step **502**). Method **500** may comprise sending, by the controller, at least one of the pressure signal and the position signal (see step **503**). The pressure signal may be sent to a pressure regulating electro-hydraulic servo valve assembly (P-EHSV). The position signal may be sent to a position regulating electro-hydraulic servo valve assembly (X-EHSV). Method **500** may comprise receiving, by a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), the pressure signal (see step **504**). The pressure signal may be received from the controller. Method **500** may comprise receiving, by a position regulating electro-hydraulic servo valve assembly (X-EHSV), the position signal (see step **505**). The position signal may be received from the controller. Method **500** may comprise decreasing, by the controller, an available pressure (see step **506**).

With respect to FIG. **6**, elements with like element numbering as depicted in FIG. **5**, are intended to be the same and will not be repeated for the sake of clarity. Method **600** as illustrated in FIG. **6** may be similar to method **500** as illustrated in FIG. **5**. In various embodiments, method **600** may comprise increasing, by the variable pressure actuator control system, an available pressure (see step **606**).

With reference now to FIG. **1** and FIG. **5**, step **501** may include receiving, by control system **114**, at least one of goals **126**, limits **128**, and sensor output signals **124**. Step **502** may include calculating, by control system **114**, at least one of effector signal **130** and effector signal **131**. Step **503** may include sending, by control system **114**, at least one of effector signal **130** and effector signal **131**. Effector signal **131** may be sent to pressure regulating electro-hydraulic servo valve assembly (P-EHSV) **182**. Effector signal **130** may be sent to a position regulating electro-hydraulic servo valve assembly (X-EHSV) **184**. Effector signal **130** and effector signal **131** may be sent to one or more of engine actuators **118** via at least one of P-EHSV **182** and X-EHSV **184**. Step **504** may include receiving, by P-EHSV **182**, effector signal **131**. Effector signal **131** may be received from control system **114**. Step **505** may include receiving, by X-EHSV **184**, effector signal **130**. Effector signal **130** may be received from control system **114**. Step **506** may include decreasing, by control system **114**, available pressure **312** (see FIG. **3**). With reference now to FIG. **1** and FIG. **6**, step **606** may include increasing, by control system **114**, available pressure **312** (see FIG. **3**).

Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the inventions. The scope of the inventions is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean "one and only one" unless explicitly so stated, but rather "one or more." Moreover, where a phrase similar to "at least one of A, B, or C" is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C.

Systems, methods and apparatus are provided herein. In the detailed description herein, references to "various embodiments", "one embodiment", "an embodiment", "an example embodiment", etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f), unless the element is expressly recited using the phrase "means for." As used herein, the terms "comprises", "comprising", or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

What is claimed is:

1. A variable pressure actuator control system for a gas turbine engine comprising:
- a controller;
- a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), including a variable restriction flow path, in electronic communication with the controller;
- a position regulating electro-hydraulic servo valve assembly (X-EHSV), including a network of flow paths, in electronic communication with the controller;
- a bypass regulator (BPR) in fluid communication with at least one of a pump, the P-EHSV, or the X-EHSV, the BPR configured to be controlled by the P-EHSV via a bypass pressure to vary an available pressure; and
- an actuator comprising an actuator piston;
- wherein the available pressure is configured to remain minimal in response to a minimal requested available pressure.

2. The system of claim **1**, wherein the network of flow paths comprise a second flow path, a third flow path, a fourth flow path, and a fifth flow path, wherein an extend pressure exists between the second flow path and the third flow path and a retract pressure exists between the fourth flow path and the fifth flow path.

3. The system of claim **2**, wherein at least one of the retract pressure and the extend pressure is controlled by the X-EHSV.

4. The system of claim **1**, wherein the X-EHSV is configured to control the network of flow paths.

5. The system of claim **1**, wherein the actuator piston is configured to extend in response to an increase in extend pressure and retract in response to an increase in retract pressure.

6. The system of claim **1**, wherein the available pressure is configured to increase in response to at least one of an increase in requested pressure or a feedback signal having reached a limit.

7. The system of claim **1**, wherein the variable pressure actuator control system uses hydraulic fluid.

8. A gas turbine engine comprising:
- a variable pressure actuator control system comprising:
  - a controller;
  - a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), including a variable restriction flow path, in electronic communication with the controller;
  - a position regulating electro-hydraulic servo valve assembly (X-EHSV), including a network of flow paths, in electronic communication with the controller;
  - a bypass regulator (BPR) in fluid communication with at least one of a pump, the P-EHSV, or the X-EHSV, the BPR configured to be controlled by the P-EHSV via a bypass pressure to vary an available pressure; and
  - an actuator comprising an actuator piston;
  - wherein the available pressure is configured to remain minimal in response to a minimal requested available pressure.

9. The gas turbine engine of claim **8**, wherein the network of flow paths comprise a second flow path, a third flow path, a fourth flow path, and a fifth flow path, wherein an extend pressure exists between the second flow path and the third flow path and a retract pressure exists between the fourth flow path and the fifth flow path.

10. The gas turbine engine of claim **9**, wherein at least one of the retract pressure and the extend pressure is controlled by the X-EHSV.

11. The gas turbine engine of claim **8**, wherein the X-EHSV is configured to control the network of flow paths.

12. The gas turbine engine of claim **8**, wherein the actuator piston is configured to extend in response to an increase in extend pressure and retract in response to an increase in retract pressure.

13. The gas turbine engine of claim **8**, wherein the available pressure is configured to increase in response to a feedback signal having reached a limit.

14. The gas turbine engine of claim **8**, wherein the variable pressure actuator control system uses hydraulic fluid.

15. A method of controlling a variable pressure actuator control system for a gas turbine engine comprising:
- receiving, by a controller, at least one of a goal signal, a limit signal, and a sensor output signal;
- calculating, by the controller, at least one of a pressure signal and a position signal;
- sending, by the controller, at least one of the pressure signal and the position signal;
- receiving, by a pressure regulating electro-hydraulic servo valve assembly (P-EHSV), the pressure signal;
- receiving, by a position regulating electro-hydraulic servo valve assembly (X-EHSV), the position signal; and
- increasing, by the controller, an available pressure.

16. The method of claim **15**, wherein the increasing is in response to a feedback signal having reached a limit.

17. The method of claim **15**, further comprising, decreasing, by the controller, the available pressure.

18. The method of claim **17**, wherein the decreasing is in response to a decrease in desired pressure at an actuator piston.

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