(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 November 2014 (06.11.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/178980 A1

(51) International Patent Classification:
*B21J 15/22* (2006.01) *F04B 37/12* (2006.01)
*F04B 9/123* (2006.01) *F15B 3/00* (2006.01)

(21) International Application Number:
PCT/US2014/032613

(22) International Filing Date:
2 April 2014 (02.04.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13/875,405 2 May 2013 (02.05.2013) US

(71) Applicant: **THE BOEING COMPANY** [US/US]; 100 North Riverside Plaza, Chicago, IL 60606-2016 (US).

(72) Inventor: **HIPPE, Daniel, A.**; Post Office Box 2515, Mail Code 110-SD54, Seal Beach, CA 90740 (US).

(74) Agents: **BLUMENKRANTZ, Mark** et al.; The Boeing Company, PO Box 2515, MC 110-SD54, Seal Beach, CA 90740-1515 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published**:

— *with international search report (Art. 21(3))*

(54) Title: HYDRAULIC PUMP AND PRESSURE MULTIPLYER

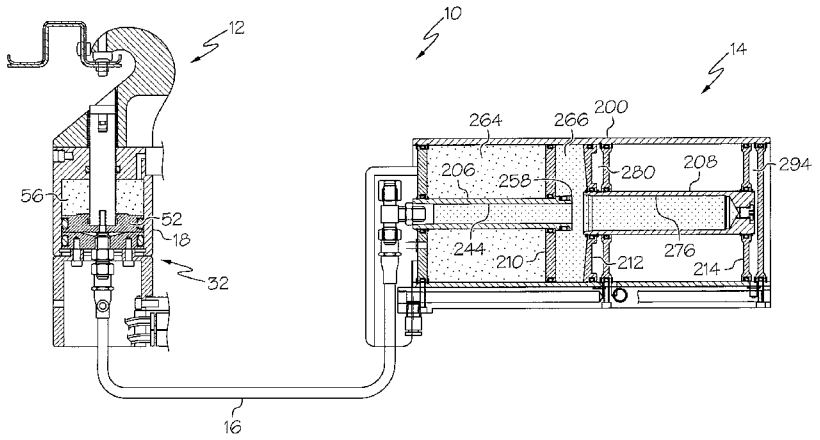


FIG. 6

(57) Abstract: A pump including a cylinder body having first and second ends and a cylinder bore, a plug shaft including first and second ends and a plug shaft bore, wherein the first end of the plug shaft is fixed relative to the cylinder body, and wherein the second end of the plug shaft includes a stop, a first piston received within the cylinder bore to partially bound a first gas chamber and a hydraulic fluid chamber, the first piston being received over the plug shaft and axially moveable relative to the plug shaft, a socket shaft including first and second ends and a socket shaft bore, the socket shaft bore being configured to sealingly receive the plug shaft, a second piston received within the cylinder bore to partially bound a second gas chamber and the hydraulic fluid chamber, the second piston being connected to the socket shaft.

WO 2014/178980 A1

# HYDRAULIC PUMP AND PRESSURE MULTIPLYER

## BACKGROUND

The aircraft manufacturing process typically involves joining together various component parts. A wide variety of joining techniques are used, such as riveting, welding, and the like. For example, two structural members of an aircraft may be joined by (1) aligning the structural members; (2) forming a hole through both aligned structural members; (3) inserting a rivet through the hole; and (4) squeezing the rivet such that the rivet is deformed/shaped, coupling the structural members.

The technique used to deform/shape a rivet depends on various factors, such as the location of the rivet and the overall size of the rivet. In many cases, a rivet squeeze tool may be used. An operator positions the rivet squeeze tool over the rivet prior to actuating the tool. Upon actuation, a pump powers a ram of the rivet squeeze tool to engage the rivet to shape the rivet against an anvil. However, commercially available pumps, capable of providing sufficient pressure for deforming/shaping rivets, are typically large and heavy, particularly when the rivets are large and/or formed from a hard durable material. Accordingly, the process of moving and properly positioning the equipment necessary for deforming/shaping rivets may be quite cumbersome and labor intensive.

## SUMMARY

In one example, the disclosed pump may include a cylinder body having a first end opposed from a second end along a longitudinal axis, wherein the cylinder body includes a cylinder bore, a plug shaft positioned in the cylinder bore, the plug shaft including a first end, a second end, and a plug shaft bore, wherein the first end of the plug shaft is fixed relative to the cylinder body, and wherein the second end of the plug shaft includes a stop, a first piston sealingly and slideably received within the cylinder bore to partially bound a first gas chamber and a hydraulic fluid chamber, the first piston being sealingly and coaxially received over the plug shaft and axially moveable relative to the plug shaft into engagement with the stop, a socket shaft positioned in the cylinder bore and axially aligned with the plug shaft, the socket shaft including a first end, a second end, and a socket shaft bore, the socket shaft bore being size and shaped to sealingly receive the plug shaft, a second piston sealingly and slideably received within the cylinder bore to partially bound a second gas chamber and partially bound the hydraulic fluid chamber, the second piston being connected to and moveable with the socket shaft.

In another example, the disclosed rivet squeeze assembly may include (1) a rivet squeeze tool that includes a jaw and a hydraulic cylinder connected to the jaw, the hydraulic cylinder including a piston and a shaft extending from the piston into engagement with the jaw, the piston defining a piston chamber and a shaft chamber within the hydraulic cylinder; (2) a

pump that includes a cylinder body having a first end opposed from a second end along a longitudinal axis, wherein the cylinder body includes a cylinder bore, a plug shaft positioned in the cylinder bore, the plug shaft including a first end, a second end, and a plug shaft bore, wherein the first end of the plug shaft is fixed relative to the cylinder body, and wherein the second end of the plug shaft includes a stop, a first piston sealingly and slideably received within the cylinder bore to partially bound a first gas chamber and a hydraulic fluid chamber, the first piston being sealingly and coaxially received over the plug shaft and axially moveable relative to the plug shaft into engagement with the stop, a socket shaft positioned in the cylinder bore and axially aligned with the plug shaft, the socket shaft including a first end, a second end, and a socket shaft bore, the socket shaft bore being size and shaped to sealingly receive the plug shaft, a second piston sealingly and slideably received within the cylinder bore to partially bound a second gas chamber and partially bound the hydraulic fluid chamber, the second piston being connected to and moveable with the socket shaft; and (3) a hydraulic fluid line extending from the pump to the rivet squeeze tool to fluidly couple the piston chamber of the rivet squeeze tool with the plug shaft bore of the pump.

In another example, disclosed is a method for actuating a hydraulic actuator that includes (1) in a first stage, supplying a first volume of hydraulic fluid to the hydraulic actuator, the first volume being supplied at a first pressure; and (2) in a second stage, supplying a second volume of hydraulic fluid to the hydraulic actuator, the second volume being supplied at a second pressure, wherein the second pressure is greater than the first pressure.

In yet another example, disclosed is a method for squeezing a rivet that includes (1) positioning the rivet in a rivet squeeze tool; (2) supplying a first volume of hydraulic fluid to the rivet squeeze tool at a first pressure to engage the rivet with the rivet squeeze tool; and (3) supplying a second volume of hydraulic fluid to the rivet squeeze tool at a second pressure to squeeze the rivet.

Other examples of the disclosed rivet squeeze assembly and method will become apparent from the following detailed description, the accompanying drawings and the appended claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a flow diagram of aircraft production and service methodology;

Fig. 2 is a block diagram of an aircraft;

Fig. 3 is a side elevational view, in section, of one example of the disclosed rivet squeeze assembly;

Fig. 4 is a side elevational view, in section, of the rivet squeeze tool of the rivet squeeze assembly of Fig. 3;

Fig. 5 is a side elevational view, in section, of the hydraulic intensifier pump of the rivet squeeze assembly of Fig. 3;

Fig. 6 is a side elevational view, in section, of the rivet squeeze assembly of Fig. 3 shown in a return configuration;

Fig. 7 is a side elevational view, in section, of the rivet squeeze assembly of Fig. 3 shown in a pre-load configuration; and

Fig. 8 is a side elevational view, in section, of the rivet squeeze assembly of Fig. 3 shown in a rivet squeeze configuration;

## DETAILED DESCRIPTION

The following detailed description refers to the accompanying drawings, which illustrate specific examples of the disclosure. Other examples having different structures, features and operations do not depart from the scope of the present disclosure. Like reference numerals may refer to the same element or component in the different drawings.

Referring more particularly to the drawings, examples of the disclosure may be described in the context of an aircraft manufacturing and service method 100, as shown in Fig. 1, and an aircraft 102, as shown in Fig. 2. During pre-production, example method 100 may include specification and design 104 of the aircraft 102 and material procurement 106. During production, component and subassembly manufacturing 108 and system integration 110 of the aircraft 102 takes place. Thereafter, the aircraft 102 may go through certification and delivery 112 in order to be placed in service 114. While in service by a customer, the aircraft 102 is scheduled for routine maintenance and service 116, which may also include modification, reconfiguration, refurbishment and the like.

Each of the processes of method 100 may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this

description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of venders, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Fig. 2, the aircraft 102 produced by example method 100 may include an airframe 118 with a plurality of systems 120 and an interior 122. Examples of high-level systems 120 include one or more of a propulsion system 124, an electrical system 126, a hydraulic system 128, and an environmental system 130. Any number of other systems may be included. Although an aerospace example is shown, the principles of the invention may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during any one or more of the stages of the production and service method 100. For example, components or subassemblies corresponding to production process 108 may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft 102 is in service. Also, one or more apparatus examples, method examples, or a combination thereof may be utilized during the production stages 108 and 110, for example, by substantially expediting assembly of or reducing the cost of an aircraft 102. Similarly, one or more of apparatus examples, method examples, or a combination thereof may be utilized while the aircraft 102 is in service, for example and without limitation, to maintenance and service 116.

Referring to Fig. 3, one example of the disclosed rivet squeeze assembly, generally designated 10, may include a rivet squeeze tool 12 and a hydraulic intensifier pump 14. A hydraulic fluid line 16 (e.g., a hose) may fluidly couple the hydraulic intensifier pump 14 to the rivet squeeze tool 12 such that the hydraulic intensifier pump 14 may supply pressurized hydraulic fluid to the rivet squeeze tool 12 to actuate the rivet squeeze tool 12.

Referring to Fig. 4, the rivet squeeze tool 12 may include a hydraulic cylinder 18, a jaw 20 and a handle assembly 22. The rivet squeeze tool 12 may be actuated (as described in greater detail below) to squeeze a rivet 24 extending through two members 26, 28, thereby joining the first member 26 to the second member 28.

The hydraulic cylinder 18 may include a barrel 30. In one example, the barrel 30 may extend along a longitudinal axis **A**, and may include a first end 31 and a second end 32 longitudinally opposed from the first end 31. A piston bore 34 may be provided in the barrel 30 and may longitudinally extend from proximate (at or near) the first end 31 of the barrel 30 to proximate the second end 32 of the barrel 30.

An end cap 36 may be closely received within the piston bore 34 proximate the second end 32 of the barrel 30. The end cap 36 may enclose the second end 32 of the barrel 30. Mechanical fasteners 38, such as screws, may secure the end cap 36 to the barrel 30. A sealing member 40, such as an O-ring, may be positioned between the end cap 36 and the barrel 30 to provide a fluid-tight seal. For example, the sealing member 40 may be received in an annular groove formed in the end cap 36, as shown in Fig. 4.

The end cap 36 may include a fluid port 42 that extends through the end cap 36. A coupling 44, such as a threaded coupling, may be fluidly coupled to and may extend from the fluid port 42. Therefore, the hydraulic fluid line 16 may be fluidly coupled to the fluid port 42 and, ultimately, to the hydraulic cylinder 18, by coupling the hydraulic fluid line 16 to the coupling 44.

Optionally, a shield 46 may be connected to, and may extend outward from, the second end 32 of the barrel 30. The shield 46 may provide protection to the coupling 44 and the hydraulic fluid line 16 coupled to the coupling 44.

The first end 31 of the barrel 30 may include a head 48 that closes off the barrel 30 proximate the first end 31. The head 48 may be integral with the barrel 30 (i.e., the head 48 and the barrel 30 may be formed as a single monolithic body). Alternatively, the head 48 may be separate from the barrel 30 and connected to the barrel 30, such as by a threaded engagement or with mechanical fasteners (e.g., the head 48 may be similar to the end cap 36). The head 48 may include a shaft bore 50 that may be axially aligned with the barrel 30.

A piston 52 may be closely and slideably received within the piston bore 34 of the barrel 30 to partially bound a piston chamber 54 and a shaft chamber 56. The piston 52 may be moveable relative to the barrel 30 along the longitudinal axis **A** in response to pressurization of the piston chamber 54 or the shaft chamber 56. Specifically, the piston 52 may move toward the first end 31 of the barrel 30 when the piston chamber 54 is pressurized with hydraulic fluid and the piston may move toward the second end 32 of the barrel 30 when the shaft chamber 56 is pressurized, such as with air.

The piston 52 may include an annular groove 58. A sealing member 60, such as an O-ring, may be received in the annular groove 58 to form a fluid-tight seal between a radial edge 62 of the piston 52 and the barrel 30. Therefore, the piston chamber 54 may be fluidly isolated from the shaft chamber 56, even as the piston 52 moves back and forth along the longitudinal axis **A**.

A shaft 64 may be connected to, and moveable with, the piston 52. The shaft 64 may include a first end 66 and second end 68.

The shaft 64 may be connected to the piston 52 or may be integral with the piston. In one specific, non-limiting example, the piston 52 may include a recess 70 and the second end 68 of the shaft 64 may be closely received in the recess 70 to connect the shaft 64 to the piston 52. A sealing member, such as an O-ring, may optionally be provided to ensure a fluid-tight seal between the second end 68 of the shaft 64 and the recess 70 of the piston 52. A mechanical fastener 72, such as a screw, may reinforce the connection between the shaft 64 and the piston 52.

The shaft 64 may axially extend from the piston 52, through the shaft chamber 56, through the shaft bore 50, through the shaft bore 88 of the jaw 20, and into engagement with the jaw 20. An annular groove 74 may be formed in the surface of the shaft bore 50. A sealing member 76, such as an O-ring, may be received in the annular groove 74 to form a fluid-tight seal between the shaft 64 and the head 48 of the cylinder 18.

The first end 66 of the shaft 64 may be the working end (the end that engages the rivet 24). The first end 66 of the shaft 64 may include a recess 78 and a plug 80 may be inserted into the recess 78. Various plugs may be insertable into the recess 78 depending on need or application. For example, the plug 80 may modify the length, shape, contour and/or smoothness of the working end of the shaft 64, as will be appreciated by those skilled in the art.

A fluid port 57 may be in fluid communication with the shaft chamber 56. The fluid port may be formed in the head 48 of the barrel 30. The fluid port 57 may selectively vent (e.g., to atmosphere) the shaft chamber 56 when the piston chamber 54 is being pressurized with hydraulic fluid to drive the shaft 64 into engagement with the rivet 24. The fluid port 57 may also selectively supply pressurized fluid (e.g., pressurized air) to the shaft chamber 56 to urge the piston 52 toward the second end 32 of the hydraulic cylinder 18 (corresponding to a return configuration of the rivet squeeze assembly 10, as shown in Fig. 6), such as after a rivet-squeezing operation.

The jaw 20 may be connected to the first end 31 of the barrel 30 proximate the head 48. For example, the jaw 20 may be connected to the barrel 30 with one or more mechanical fasteners 82, though it is also contemplated that the jaw 20 may be integral with the hydraulic cylinder 18.

The jaw 20 may include a base portion 84 and an anvil 86. The base portion 84 of the jaw 20 may be connected to the hydraulic cylinder 18. The anvil 86 may be opposed from the base portion 84. While the jaw 20 is shown in the drawings having a hook shape, those

skilled in the art will appreciate that various jaw configurations may be used without departing from the scope of the present disclosure.

The base portion 84 of the jaw 20 may include a shaft bore 88. The shaft bore 88 of the jaw 20 may be axially aligned with the shaft bore 50 of the hydraulic cylinder 18. Therefore, the shaft 64 of the hydraulic cylinder may extend through the shaft bore 88 of the jaw 20 and into engagement with the anvil 86 of the jaw 20. A bushing 89 may be positioned in the shaft bore 88 between the shaft 64 and the surface of the shaft bore 88.

Optionally, a die 90 may be interchangeably coupled to the anvil 86 of the jaw 20. The die 90 may be sized and shaped to receive the head of the rivet 24. Therefore, various dies 90 may be used and the selection of a particular die 90 (e.g., from a kit of dies 90) for connection to the anvil 86 may depend on the type of rivet being squeezed.

The handle assembly 22 may be connected to the hydraulic cylinder 18, such as with mechanical fasteners 92 (e.g., screws), to provide a structure for holding the rivet squeeze tool 12. Additionally, the handle assembly 22 may house an actuation assembly 94 for actuating the rivet squeeze tool 12.

The actuation assembly 94 of the handle assembly 22 may include a push button 150, a push rod 152, a stop 154, a biasing member 156 and a pneumatic valve 158. The push button 150 may be connected to the push rod 152, which may be connected to the stop 154. The biasing member 156, which may be a coil spring or the like, may urge the stop 154 in the direction shown by arrow **B**, which may urge the push rod 152 in the direction shown by arrow **B**, which in turn may urge the push button 150 outward (in the direction of arrow **B**).

Referring to Fig. 5, the hydraulic intensifier pump 14 may include a cylinder body 200, a first end cap 202, a second end cap 204, a plug shaft 206, a socket shaft 208, a first piston 210, a second piston 212, a third piston 214, and a baffle 216.

The cylinder body 200 may extend along a longitudinal axis **X**. The cylinder body 200 may include an open first end 220 and an open second end 222. The cylinder body 200 may include a cylinder bore 224 that longitudinally extends from proximate the first end 220 of the cylinder body 200 to proximate the second end 222 of the cylinder body 200. The cylinder bore 224 may at least partially bound a hollow internal volume 226 of the cylinder body 200.

The first end cap 202 may be closely received within the cylinder bore 224 proximate the first end 220 of the cylinder body 200. The first end cap 202 may enclose the first end 220 of the cylinder body 200. Mechanical fasteners 228, such as retaining rings, may secure the first end cap 202 to the cylinder body 200 to inhibit axial movement of the first end cap

202 relative to the cylinder body 200. A sealing member 230, such as an O-ring, may be positioned between the first end cap 202 and the cylinder body 200 to provide a fluid-tight seal. The sealing member 230 may be received in an annular groove 232 formed in the first end cap 202.

The second end cap 204 may be closely received within the cylinder bore 224 proximate the second end 222 of the cylinder body 200. The second end cap 204 may enclose the second end 222 of the cylinder body 200. Mechanical fasteners 234, such as retaining rings, may secure the second end cap 204 to the cylinder body 200 to inhibit axial movement of the second end cap 204 relative to the cylinder body 200. A sealing member 236, such as an O-ring, may be positioned between the second end cap 204 and the cylinder body 200 to provide a fluid-tight seal. The sealing member 236 may be received in an annular groove 238 formed in the second end cap 204.

The plug shaft 206 may include a first end 240 and a second end 242 longitudinally opposed from the first end 240. The plug shaft 206 may include a plug shaft bore 244 that longitudinally extends from proximate the first end 240 of the plug shaft 206 to proximate the second end 242 of the plug shaft 206. Therefore, the plug shaft 206 may be constructed as an elongated hollow tubular member.

The first end 240 of the plug shaft 206 may extend through an opening 246 in the first end cap 202. Mechanical fasteners 248, such as retaining rings, may fixedly secure the first end 240 of the plug shaft 206 to the first end cap 202 to inhibit axial movement of the plug shaft 206 relative to the first end cap 202.

A coupling 250, such as a T-fitting, may be fluidly coupled to the first end 240 of the plug shaft 206. For example, the coupling 250 may be threaded into engagement with the first end 240 of the plug shaft 206. The hydraulic fluid line 16 may be coupled to the first "T" end 252 of the coupling 250 such that the hydraulic fluid line 16 may be in fluid communication with the plug shaft bore 244. The second "T" end 254 of the coupling 250 may be sealed when not in use, such as with a screw-on cap 256.

The second end 242 of the plug shaft 206 may protrude into the internal volume 226 of the cylinder body 200 and may include a flanged portion 258. The flanged portion 258 may have a diameter that is greater (e.g., at least 5 percent greater) than the diameter of the non-flanged portion 259 of the plug shaft 206. The outer periphery of the flanged portion 258 may include an annular groove 260. A sealing member 262, such as an O-ring, may be received in the annular groove 260 to create a fluid-tight seal between the plug shaft 206 and

the socket shaft 208 when the plug shaft 206 is received in the socket shaft 208, as described in greater detail below.

The first piston 210 may be sealingly and slideably received within the cylinder bore 224 and may be closely and slideably received over (coaxially received over) the plug shaft 206 to define a first gas chamber 264 and a hydraulic fluid chamber 266. The hydraulic fluid chamber 266 may be filled with a hydraulic fluid, such as by way of the first "T" end 252 of the coupling 250. The first piston 210 may include an inner annular groove 209 and an outer annular groove 211. An inner sealing member 213, such as an O-ring, may be received in the inner annular groove 209 to form a fluid-tight seal between the first piston 210 and the plug shaft 206. An outer sealing member 215, such as an O-ring, may be received in the outer annular groove 211 to form a fluid-tight seal between the first piston 210 and the cylinder bore 224. Therefore, the first gas chamber 264 may be fluidly isolated from the hydraulic fluid chamber 266, even as the first piston 210 moves back and forth along the longitudinal axis **X**.

The first piston 210 may be moveable along the longitudinal axis **X** relative to the cylinder body 200 and the plug shaft 206. The flanged portion 258 of the plug shaft 206 may function as a stop, as shown in Fig. 5, which may inhibit axial movement of the first piston 210 beyond the flanged portion 258 when the first gas chamber 264 is pressurized (e.g., with air) by way of fluid ports 268, 270. The first piston 210 may axially move toward the first end cap 202 when the first gas chamber 264 is vented (e.g., to atmosphere) by way of fluid ports 268, 270, while the hydraulic fluid chamber 266 is pressurized, as described in greater detail below.

The socket shaft 208 may include a first end 272 and a second end 274 longitudinally opposed from the first end 272. The socket shaft 208 may include a socket shaft bore 276 that may longitudinally extend from proximate the first end 272 of the socket shaft 208 to proximate the second end 274 of the socket shaft 208. The socket shaft bore 276 may be open at the first end 272 of the socket shaft 208 and may be closed at the second end 274 of the socket shaft 208. Optionally, a removable plug 278 may seal the second end 274 of the socket shaft 208.

The socket shaft bore 276 may be sized and shaped to closely receive the plug shaft 206 therein, as shown in Fig. 8. Specifically, the socket shaft bore 276 may have an inner diameter that closely corresponds to the outer diameter of the flanged portion 258 of the plug shaft 206. Therefore, when the socket shaft 208 is urged over the plug shaft 206, the sealing member 262 of the flanged portion 258 of the plug shaft 206 may create a fluid-tight seal

between the plug shaft 206 and the socket shaft 208 that fluidly and sealingly couples the plug shaft bore 244 with the socket shaft bore 276, while fluidly isolating the coupled shaft bores 244, 276 from the internal volume 226 of the cylinder body 200.

The second piston 212 may be received over and connected to the first end 272 of the socket shaft 208. The second piston 212 may be closely and slideably received within the cylinder bore 224 to partially bound the hydraulic fluid chamber 266 and a second gas chamber 280. The hydraulic fluid chamber 266 may axially extend between the first piston 210 and the second piston 212. The second gas chamber 280 may axially extend between the second piston 212 and the baffle 216 in the annular region between the socket shaft 208 and the cylinder bore 224.

The first end 272 of the socket shaft 208 may extend through an opening 282 in the second piston 212 such that the socket shaft bore 276 opens toward, and is in fluid communication with, the hydraulic fluid chamber 266. Mechanical fasteners 284, such as retaining rings, may fixedly secure the second piston 212 to the first end 272 of the socket shaft 208 to inhibit axial movement of the second piston 212 relative to the socket shaft 208.

The second piston 212 may include an inner annular groove 286 and an outer annular groove 288. An inner sealing member 290, such as an O-ring, may be received in the inner annular groove 286 to form a fluid-tight seal between the second piston 212 and the socket shaft 208. An outer sealing member 292, such as an O-ring, may be received in the outer annular groove 288 to form a fluid-tight seal between the second piston 212 and the cylinder bore 224. Therefore, the second gas chamber 280 may be fluidly isolated from the hydraulic fluid chamber 266, even as the second piston 212 and the connected socket shaft 208 move back and forth along the longitudinal axis **X**.

The third piston 214 may be received over and connected to the second end 274 of the socket shaft 208. The third piston 214 may be closely and slideably received within the cylinder bore 224 to define a third gas chamber 294 and a vent chamber 296. The third gas chamber 294 may axially extend between the third piston 214 and the second end cap 204. The vent chamber 296 may axially extend between the third piston 214 and the baffle 216 in the annular region between the socket shaft 208 and the cylinder bore 224.

The second end 274 of the socket shaft 208 may extend through an opening 298 in the third piston 214. Mechanical fasteners 300, such as retaining rings, may fixedly secure the third piston 214 to the second end 274 of the socket shaft 208 to inhibit axial movement of the third piston 214 relative to the socket shaft 208.

The third piston 214 may include an inner annular groove 302 and an outer annular groove 304. An inner sealing member 306, such as an O-ring, may be received in the inner annular groove 302 to form a fluid-tight seal between the third piston 214 and the socket shaft 208. An outer sealing member 308, such as an O-ring, may be received in the outer annular groove 304 to form a fluid-tight seal between the third piston 214 and the cylinder bore 224. Therefore, the third gas chamber 294 may be fluidly isolated from the vent chamber 296, even as the third piston 214 and the connected socket shaft 208 move back and forth along the longitudinal axis **X**.

The baffle 216 may be received in the internal volume 226 of the cylinder body 200 and may be received over the socket shaft 208 to fluidly isolate the second gas chamber 280 from the vent chamber 296. The baffle 216 may be fixed relative to the cylinder body 200. For example, mechanical fasteners 310, such as retaining rings, may fixedly secure the baffle 216 to the cylinder body 200. The baffle 216 may include an outer annular groove 312 and a sealing member 314, such as an O-ring, may be received in the outer annular groove 312 to form a fluid-tight seal between the baffle 216 and the cylinder body 200.

The socket shaft 208 may extend through an opening 316 formed in the baffle 216. Therefore, the socket shaft 208 may pass though the opening 316 in the baffle 216 as the socket shaft 208 moves back and forth along the longitudinal axis **X**. The baffle 216 may include an inner annular groove 318 and a sealing member 320, such as an O-ring, may be received in the inner annular groove 318 to form a fluid-tight seal between the baffle 216 and the socket shaft 208.

Referring back to Fig. 4, the push button 150 is biased to the un-depressed position. When pressurized air is supplied to the rivet squeeze tool 12 (e.g., when a pressurized air line (not shown) is fluidly coupled to the rivet squeeze tool), the un-depressed position corresponds to the return configuration, shown in Fig. 6. Specifically, in the return configuration of the rivet squeeze tool 12, pressurized air is supplied to the shaft chamber 56 by way of the fluid port 57 to urge the piston 52 toward the second end 32 of the hydraulic cylinder 18 and, correspondingly, the first end 66 of the shaft 64 away from the rivet 24.

The rivet squeeze tool 12 may be actuated by depressing the push button 150 to either a partially depressed position or a fully depressed position. When an applied force **F** overcomes the biasing force of the biasing member 156 and moves the push button 150 to the partially depressed position, the shaft chamber 56 may be vented and the pneumatic valve 158 may cause pressurized air to be directed to the hydraulic intensifier pump 14 (Fig. 3) to actuate the hydraulic intensifier pump 14 to the pre-load configuration of the rivet squeeze

assembly 10 shown in Fig. 7, which is described in greater detail herein. Then, when the applied force **F** further moves the push button 150 to the fully depressed position, the shaft chamber 56 may remain vented and the pneumatic valve 158 may direct pressurized air to the hydraulic intensifier pump 14 to actuate the hydraulic intensifier pump 14 to the rivet squeeze configuration of the rivet squeeze assembly 10 shown in Fig. 8, which is described in greater detail herein. While a specific actuation assembly 94 is shown and described, those skilled in the art will appreciate that various techniques and apparatus (e.g., various valves and valve assemblies) may be employed to pneumatically actuate the hydraulic intensifier pump 14 to the "return," "pre-load" and "rivet squeeze" configurations described herein.

A manifold 218 may supply pressurized fluid (e.g., pressurized air) such that the hydraulic intensifier pump 14 selectively supplies pressurized hydraulic fluid to the rivet squeeze tool 12 (Fig. 4) by way of the hydraulic fluid line 16. A pressurized fluid line 322 (e.g., a pneumatic line) may be fluidly coupled to the manifold 218, such as at an air fitting 324. The manifold 218 may selectively distribute pressurized fluid (such as air pressurized to, e.g., about 100 psi) to the hydraulic intensifier pump 14 to selectively actuate the hydraulic intensifier pump 14 to the return configuration (Figs. 5 and 6), the pre-load configuration (Fig. 7), and the rivet squeeze configuration (Fig. 8). Specifically, depending on the configuration desired, the manifold 218 may supply pressurized fluid to the first gas chamber 264 by way of ports 268, 270, to the second gas chamber 280 by way of port 326, and to the third gas chamber 294 by way of port 328. The vent chamber 296 may be vented by way of a vent 330.

Referring to Figs. 5 and 6, with the push button 150 in the outward (undepressed) position and the rivet squeeze assembly 10 in the return configuration, pressurized fluid (e.g., air) is directed to the first gas chamber 264, while the second and third gas chambers 280, 294 are vented (e.g., to atmosphere). When the first gas chamber 264 is pressurized (e.g., 100 psi), the first piston 210 is urged toward the second end 222 of the cylinder body 200 until it comes into abutting engagement with the flanged portion 258 of the plug shaft 206.

Additionally, in the return configuration, the shaft chamber 56 of the rivet squeeze tool 12 is pressurized (as described above) to urge the piston 52 toward the second end 32 of the hydraulic cylinder 18, thereby causing hydraulic fluid in the piston chamber 54 to return to, and fill, (by way of hydraulic fluid line 16) the hydraulic fluid chamber 266 of the hydraulic intensifier pump 14. As the hydraulic fluid chamber 266 is filled with hydraulic fluid, the pressure within the hydraulic fluid chamber 266 urges the socket shaft 208 (and

associated second and third pistons 212, 214) away from the plug shaft 206 (i.e., toward the second end 222 of the cylinder body 200), to the return configuration shown in Fig. 6.

The hydraulic intensifier pump 14 may be actuated from the return configuration shown in Fig. 6 to the pre-load configuration shown in Fig. 7 when a force **F** (Fig. 4) is applied to the push button 150 (Fig. 4) of the rivet squeeze tool 12 and the force is sufficient to move the push button 150 to the partially depressed position.

Referring to Fig. 7, in the pre-load configuration, the first gas chamber 264 of the hydraulic intensifier pump 14 continues to be pressurized (e.g., 100 psi). However, in the pre-load configuration, the shaft chamber 56 of the rivet squeeze tool 12 is vented, thereby allowing the piston 52 to move toward the first end 31 of the hydraulic cylinder 18.

Additionally, in the pre-load configuration, the second gas chamber 280 may be pressurized (e.g., 100 psi), while the third gas chamber 294 may remain vented. With the first gas chamber 264 and the second gas chamber 280 pressurized, the force (pressure) acting on the second piston 212 may urge the second piston 212 (together with the connected socket shaft 208 and the third piston 214) toward the first piston 210, thereby compressing the hydraulic fluid chamber 266. As the hydraulic fluid chamber 266 is compressed, hydraulic fluid within the hydraulic fluid chamber 266 may be urged through the plug shaft bore 244, through the hydraulic fluid line 16 and, ultimately, into the piston chamber 54 of the rivet squeeze tool 12, thereby urging the shaft 64 of the rivet squeeze tool 12 into engagement with the rivet 24.

While the hydraulic fluid chamber 266 is compressed in the pre-load configuration, both the plug shaft bore 244 and the socket shaft bore 276 may remain in fluid communication with the hydraulic fluid chamber 266 (i.e., the plug shaft 206 may not yet be fully coupled with the socket shaft 208). Therefore, in the pre-load configuration, hydraulic fluid may flow from the hydraulic fluid chamber 266 into the plug shaft bore 244.

Thus, in the pre-load configuration, hydraulic fluid may be pumped from the hydraulic intensifier pump 14 to the rivet squeeze tool 12 to urge the shaft 64 of the rivet squeeze tool 12 into engagement with the rivet 24. However, the squeezing force (e.g., about 400 to about 500 lbs) applied to the rivet 24 in the pre-load configuration may not be sufficient to deform the rivet 24. Deformation may or may not occur when the hydraulic intensifier pump 14 is actuated from the pre-load configuration to the rivet squeeze configuration (Fig. 8).

The hydraulic intensifier pump 14 may be actuated from the pre-load configuration shown in Fig. 7 to the rivet squeeze configuration shown in Fig. 8 when the force **F** (Fig. 4)

applied to the push button 150 (Fig. 4) of the rivet squeeze tool 12 is sufficient to move the push button 150 to the fully depressed position.

Referring to Fig. 8, in the rivet squeeze configuration, the first gas chamber 264 may be vented, while the second and third gas chambers 280, 294 may be pressurized (e.g., 100 psi). The shaft chamber 56 (Fig. 4) of the rivet squeeze tool 12 may remain vented.

With the first gas chamber 264 vented, the first piston 210 may be moveable toward the first end 220 of the cylinder body 200 in response to pressure within the hydraulic fluid chamber 266. Furthermore, with the second and third gas chambers 280, 294 pressurized (or even just one of the second and third gas chambers 280, 294 pressurized), the forces (pressure) acting on the second and third pistons 212, 214, respectively, may urge the connected socket shaft 208 into coupled engagement with the plug shaft 206, thereby pumping hydraulic fluid through the hydraulic fluid line 16.

Thus, in the rivet squeeze configuration, hydraulic fluid at a significantly higher pressure may be pumped from the hydraulic intensifier pump 14 to the rivet squeeze tool 12 to deform the rivet 24. For example, while a squeezing force of only about 440 lbs may be applied to the rivet 24 in the pre-load configuration, a squeezing force of about 13,400 lbs may be applied to the rivet 24 in the rivet squeeze configuration.

Accordingly, the disclosed rivet squeeze assembly 10 may employ a two-stage approach to squeezing rivets. In the first stage, a first volume of hydraulic fluid at a first pressure may be supplied to the rivet squeeze tool 12 (a hydraulic actuator). In the second stage, a second volume of hydraulic fluid at a second pressure may be supplied to the rivet squeeze tool 12. The second volume may be less than the first volume. For example, the second volume may be at most 10 percent of the first volume. The second pressure may be greater than the first pressure. For example, the second pressure may be at least 20 times greater (e.g., about 30 times greater) than the first pressure.

Thus, in the first stage of operation (see the pre-load configuration of Fig. 7), a relatively low force may be used to expeditiously position the rivet squeeze tool 12 on a rivet 24. The speed of this operation is made possible by a relatively large volume of fluid in hydraulic fluid chamber 266. The force generated by the hydraulic intensifier pump 14 during the first stage may be sufficient to move the rivet squeeze tool 12 into touching engagement with the rivet 24 and possibly allow for some adjustment or repositioning of the rivet squeeze tool 12 relative to the rivet 24, but not sufficient to deform the rivet 24. In the second stage of operation (see the rivet squeeze configuration shown in Fig. 8), the hydraulic intensifier pump 14 may generate the force necessary to deform the rivet 24. Therefore, the

relatively large force required to deform the rivet 24 is only generated during the second stage of operation, which requires relatively little travel of the shaft 64 compared to the first stage. As such, the pressure remains relatively low during most of the stroke cycle and, therefore, the disclosed hydraulic intensifier pump 14 may be smaller, lighter and less expensive than traditional pumps used to deform rivets. Those skilled in the art will appreciate that a smaller and more lightweight pump may be advantageous for hand-held applications and for use on vehicles, such as aircraft, automobiles, boats and the like, where weight is a significant concern.

Illustrative, non-exclusive examples of inventive subject matter according to the present disclosure are described in the clauses A1-D24, below:

A1. A pump 14 comprising:

a cylinder body 200 having a first end opposed from a second end along a longitudinal axis, wherein the cylinder body 200 includes a cylinder bore 224;

a plug shaft 206 positioned in the cylinder bore 224, the plug shaft 206 including a first end, a second end, and a plug shaft bore 244, wherein the first end of the plug shaft 206 is fixed relative to the cylinder body 200, and wherein the second end of the plug shaft 206 includes a stop;

a first piston 210 sealingly and slideably received within the cylinder bore 224 to partially bound a first gas chamber 264 and a hydraulic fluid chamber 266, the first piston 210 being sealingly and coaxially received over the plug shaft 206 and axially moveable relative to the plug shaft 206 into engagement with the stop;

a socket shaft 208 positioned in the cylinder bore 224 and axially aligned with the plug shaft 206, the socket shaft 208 including a first end, a second end, and a socket shaft bore 276, the socket shaft bore 206 being sized and shaped to sealingly receive the plug shaft 206;

a second piston 212 sealingly and slideably received within the cylinder bore 224 to partially bound a second gas chamber 280 and partially bound the hydraulic fluid chamber 266, the second piston 212 being connected to and moveable with the socket shaft 208.

A2. The pump of Clause A1 further comprising a first end cap 202 sealingly connected to the first end of the cylinder body 200 and a second end cap 204 sealingly connected to the second end of the cylinder body 200.

A3. The pump of Clause A2 wherein the plug shaft 206 is connected to the first end cap 202.

A4. The pump of any of Clauses 1-3 further comprising a coupling in fluid communication with the plug shaft bore 244.

A5. The pump of Clause A4 wherein the coupling comprises a T-fitting connected to the plug shaft 206.

A6. The pump of any of Clauses A4-A5 further comprising a hydraulic fluid line 16 fluidly coupled to the coupling.

A7. The pump of any of Clauses A1-A6 wherein the stop comprises a flanged portion of the plug shaft 206.

A8. The pump of Clause A7 wherein the flanged portion is sized and shaped to be sealingly received in the socket shaft bore 276 to fluidly and sealingly couple the plug shaft bore 244 to the socket shaft bore 276.

A9. The pump of any of Clauses A7-A8 wherein the flanged portion includes an annular groove and a sealing member is received in the annular groove, and wherein the sealing member forms a fluid-tight seal between the plug shaft 206 and the socket shaft 208 when the plug shaft 206 is received in the socket shaft bore 276.

A10. The pump of any of Clauses A1-A9 wherein the second piston 212 is connected to the socket shaft 208 proximate the first end of the socket shaft 208.

A11. The pump of any of Clauses A1-A10 wherein the plug shaft bore 244 and the socket shaft bore 276 are in fluid communication with the hydraulic fluid chamber 266 when the plug shaft 206 is spaced from the socket shaft 208, and wherein the plug shaft bore 244 and the socket shaft bore 276 are fluidly coupled and fluidly isolated from the hydraulic fluid chamber 266 when the plug shaft 206 is received in the socket shaft bore 276.

A12. The pump of any of Clauses A1-A11 wherein both the first gas chamber 264 and the second gas chamber 280 are pressurized during a first stage of operation, and wherein the first gas chamber 264 is vented and the second gas chamber 280 is pressurized during a second stage of operation.

A13. The pump of Clause A12 wherein the first gas chamber 264 and the second gas chamber 280 are pressurized with air.

A14. The pump of any of Clauses A1-A13 further comprising a baffle 216 sealingly received within and connected to the cylinder bore 224 to partially bound the second gas chamber 280, the baffle 216 being sealingly and coaxially received over the socket shaft 208 such that the socket shaft 208 is axially moveable relative to the baffle 216.

A15. The pump of any of Clauses A1-A14 further comprising a third piston 214 sealingly and slideably received within the cylinder bore 224 to partially bound a third gas chamber 294, the third piston 214 being connected to and moveable with the socket shaft 208.

A16. The pump of Clause A15 wherein the third piston 214 is connected to the socket shaft 208 proximate the second end of the socket shaft 208.

A17. The pump of any of Clauses A15-A16 further comprising a first end cap 202 sealingly connected to the first end of the cylinder body 200 and a second end cap 204 sealing connected to the second end of the cylinder body 200, wherein the second end cap 204 partially bounds the third gas chamber 294.

A18. The pump of any of Clauses A15-A17 wherein the first gas chamber 264 and at least one of the second gas chamber 280 and the third gas chamber 294 are pressurized during a first stage of operation, and wherein the first gas chamber 264 is vented and both the second gas chamber 280 and the third gas chamber 294 are pressurized during a second stage of operation.

B19. A rivet squeeze tool 12 operatively connected to the pump 14 of Clause A1.

C20. A rivet squeeze assembly 10 comprising:

a rivet squeeze tool 12 comprising:

a jaw 20; and

a hydraulic cylinder 18 connected to the jaw 20, the hydraulic cylinder 18 comprising a piston and a shaft extending from the piston into engagement with the jaw 20, the piston defining a piston chamber and a shaft chamber within the hydraulic cylinder 18;

the pump 14 of Claim 1; and

a hydraulic fluid line 16 extending from the pump 14 to the rivet squeeze tool 12 to fluidly couple the piston chamber of the rivet squeeze tool 12 with the plug shaft bore 244 of the pump 14.

D21. A method of actuating a hydraulic actuator, the method comprising:

in a first stage, supplying a first volume of hydraulic fluid to the hydraulic actuator, the first volume being supplied at a first pressure; and

in a second stage, supplying a second volume of hydraulic fluid to the hydraulic actuator, the second volume being supplied at a second pressure,

wherein the second volume is less than the first volume and the second pressure is greater than the first pressure.

D22. The method of Clause D21 wherein the hydraulic actuator is a rivet squeeze tool 12.

D23. The method of any of Clauses D21-D22 wherein the second volume is at most 10 percent of the first volume.

D24. The method of any of Clauses D21-D23 wherein the second pressure is at least 20 times greater than the first pressure.

Although various examples of the disclosed hydraulic intensifier pump and associated rivet squeeze assembly have been shown and described, modifications may occur to those skilled in the art upon reading the specification. Therefore, it is to be understood that the disclosure is not to be limited to the specific examples provided and that such modifications are intended to be included within the scope of the appended claims.

What is claimed is:

1. A pump (14) comprising:

a cylinder body (200) having a first end opposed from a second end along a longitudinal axis, wherein the cylinder body (200) includes a cylinder bore (224);

a plug shaft (206) positioned in the cylinder bore (224), the plug shaft (206) including a first end, a second end, and a plug shaft bore (244), wherein the first end of the plug shaft (206) is fixed relative to the cylinder body (200), and wherein the second end of the plug shaft (206) includes a stop;

a first piston (210) sealingly and slideably received within the cylinder bore (224) to partially bound a first gas chamber (264) and a hydraulic fluid chamber (266), the first piston (210) being sealingly and coaxially received over the plug shaft (206) and axially moveable relative to the plug shaft (206) into engagement with the stop;

a socket shaft (208) positioned in the cylinder bore (224) and axially aligned with the plug shaft (206), the socket shaft (208) including a first end, a second end, and a socket shaft bore (276), the socket shaft bore (206) being sized and shaped to sealingly receive the plug shaft (206);

a second piston (212) sealingly and slideably received within the cylinder bore (224) to partially bound a second gas chamber (280) and partially bound the hydraulic fluid chamber (266), the second piston (212) being connected to and moveable with the socket shaft (208).

2. The pump of Claim 1 further comprising a first end cap (202) sealingly connected to the first end of the cylinder body (200) and a second end cap (204) sealingly connected to the second end of the cylinder body (200).

3. The pump of Claim 2 wherein the plug shaft (206) is connected to the first end cap (202).

4. The pump of any of Claims 1-3 further comprising a coupling in fluid communication with the plug shaft bore (244).

5. The pump of Claim 4 wherein the coupling comprises a T-fitting connected to the plug shaft (206).

6. The pump of any of Claims 4-5 further comprising a hydraulic fluid line (16) fluidly coupled to the coupling.

7. The pump of any of Claims 1-6 wherein the stop comprises a flanged portion of the plug shaft (206).

8. The pump of Claim 7 wherein the flanged portion is sized and shaped to be sealingly received in the socket shaft bore (276) to fluidly and sealingly couple the plug shaft bore (244) to the socket shaft bore (276).

9. The pump of any of Claims 7-8 wherein the flanged portion includes an annular groove and a sealing member is received in the annular groove, and wherein the sealing member forms a fluid-tight seal between the plug shaft (206) and the socket shaft (208) when the plug shaft (206) is received in the socket shaft bore (276).

10. The pump of any of Claims 1-9 wherein the second piston (212) is connected to the socket shaft (208) proximate the first end of the socket shaft (208).

11. The pump of any of Claims 1-10 wherein the plug shaft bore (244) and the socket shaft bore (276) are in fluid communication with the hydraulic fluid chamber (266) when the plug shaft (206) is spaced from the socket shaft (208), and wherein the plug shaft bore (244) and the socket shaft bore (276) are fluidly coupled and fluidly isolated from the hydraulic fluid chamber (266) when the plug shaft (206) is received in the socket shaft bore (276).

12. The pump of any of Claims 1-11 wherein both the first gas chamber (264) and the second gas chamber (280) are pressurized during a first stage of operation, and wherein the first gas chamber (264) is vented and the second gas chamber (280) is pressurized during a second stage of operation.

13. The pump of Claim 12 wherein the first gas chamber (264) and the second gas chamber (280) are pressurized with air.

14. The pump of any of Claims 1-13 further comprising a baffle (216) sealingly received within and connected to the cylinder bore (224) to partially bound the second gas chamber

(280), the baffle (216) being sealingly and coaxially received over the socket shaft (208) such that the socket shaft (208) is axially moveable relative to the baffle (216).

15. The pump of any of Claims 1-14 further comprising a third piston (214) sealingly and slideably received within the cylinder bore (224) to partially bound a third gas chamber (294), the third piston (214) being connected to and moveable with the socket shaft (208).

16. The pump of Claim 15 wherein the third piston (214) is connected to the socket shaft (208) proximate the second end of the socket shaft (208).

17. The pump of any of Claims 15-16 further comprising a first end cap (202) sealingly connected to the first end of the cylinder body (200) and a second end cap (204) sealing connected to the second end of the cylinder body (200), wherein the second end cap (204) partially bounds the third gas chamber (294).

18. The pump of any of Claims 15-17 wherein the first gas chamber (264) and at least one of the second gas chamber (280) and the third gas chamber (294) are pressurized during a first stage of operation, and wherein the first gas chamber (264) is vented and both the second gas chamber (280) and the third gas chamber (294) are pressurized during a second stage of operation.

19. A rivet squeeze tool (12) operatively connected to the pump (14) of Claim 1.

20. A rivet squeeze assembly (10) comprising:

a rivet squeeze tool (12) comprising:

a jaw (20); and

a hydraulic cylinder (18) connected to the jaw (20), the hydraulic cylinder (18) comprising a piston and a shaft extending from the piston into engagement with the jaw (20), the piston defining a piston chamber and a shaft chamber within the hydraulic cylinder (18);

the pump (14) of Claim 1; and

a hydraulic fluid line (16) extending from the pump (14) to the rivet squeeze tool (12) to fluidly couple the piston chamber of the rivet squeeze tool (12) with the plug shaft bore (244) of the pump (14).

21. A method of actuating a hydraulic actuator, the method comprising:

in a first stage, supplying a first volume of hydraulic fluid to the hydraulic actuator, the first volume being supplied at a first pressure; and

in a second stage, supplying a second volume of hydraulic fluid to the hydraulic actuator, the second volume being supplied at a second pressure,

wherein the second volume is less than the first volume and the second pressure is greater than the first pressure.

22. The method of Claim 21 wherein the hydraulic actuator is a rivet squeeze tool (12).

23. The method of any of claims 21-22 wherein the second volume is at most 10 percent of the first volume.

24. The method of any of claims 21-23 wherein the second pressure is at least 20 times greater than the first pressure.

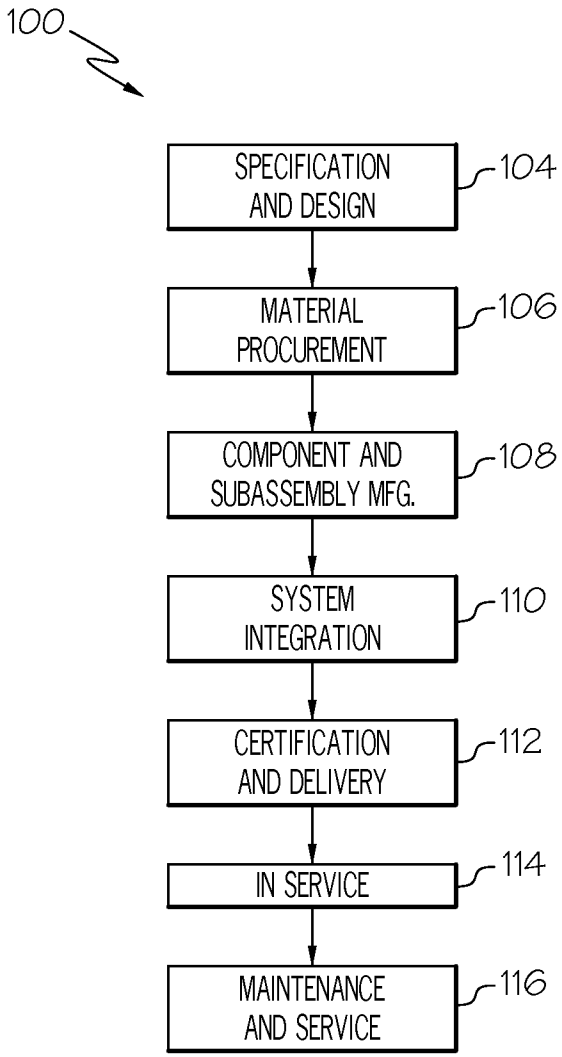
100
SPECIFICATION AND DESIGN
104
MATERIAL PROCUREMENT
106
COMPONENT AND SUBASSEMBLY MFG.
108
SYSTEM INTEGRATION
110
CERTIFICATION AND DELIVERY
112
IN SERVICE
114
MAINTENANCE AND SERVICE
116

FIG. 1

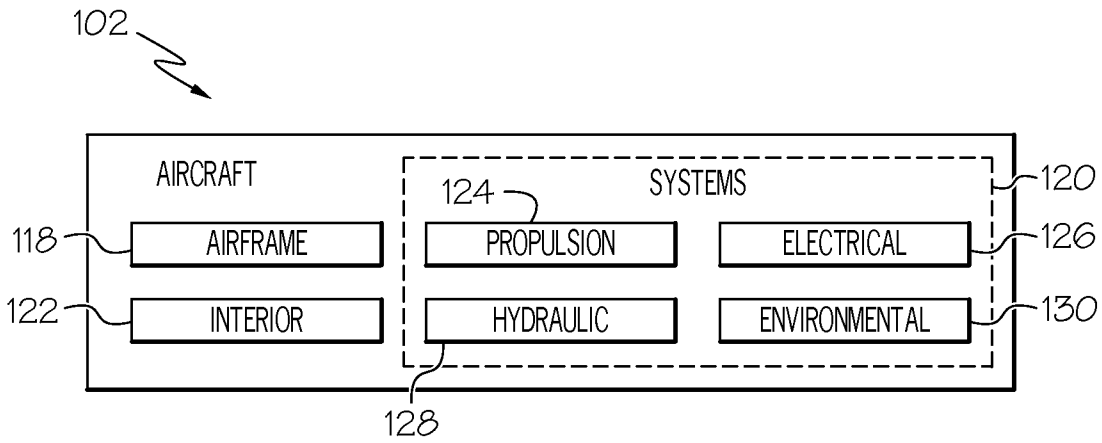
102
AIRCRAFT
SYSTEMS
120
124
118
AIRFRAME
PROPULSION
ELECTRICAL
126
122
INTERIOR
HYDRAULIC
ENVIRONMENTAL
130
128

FIG. 2

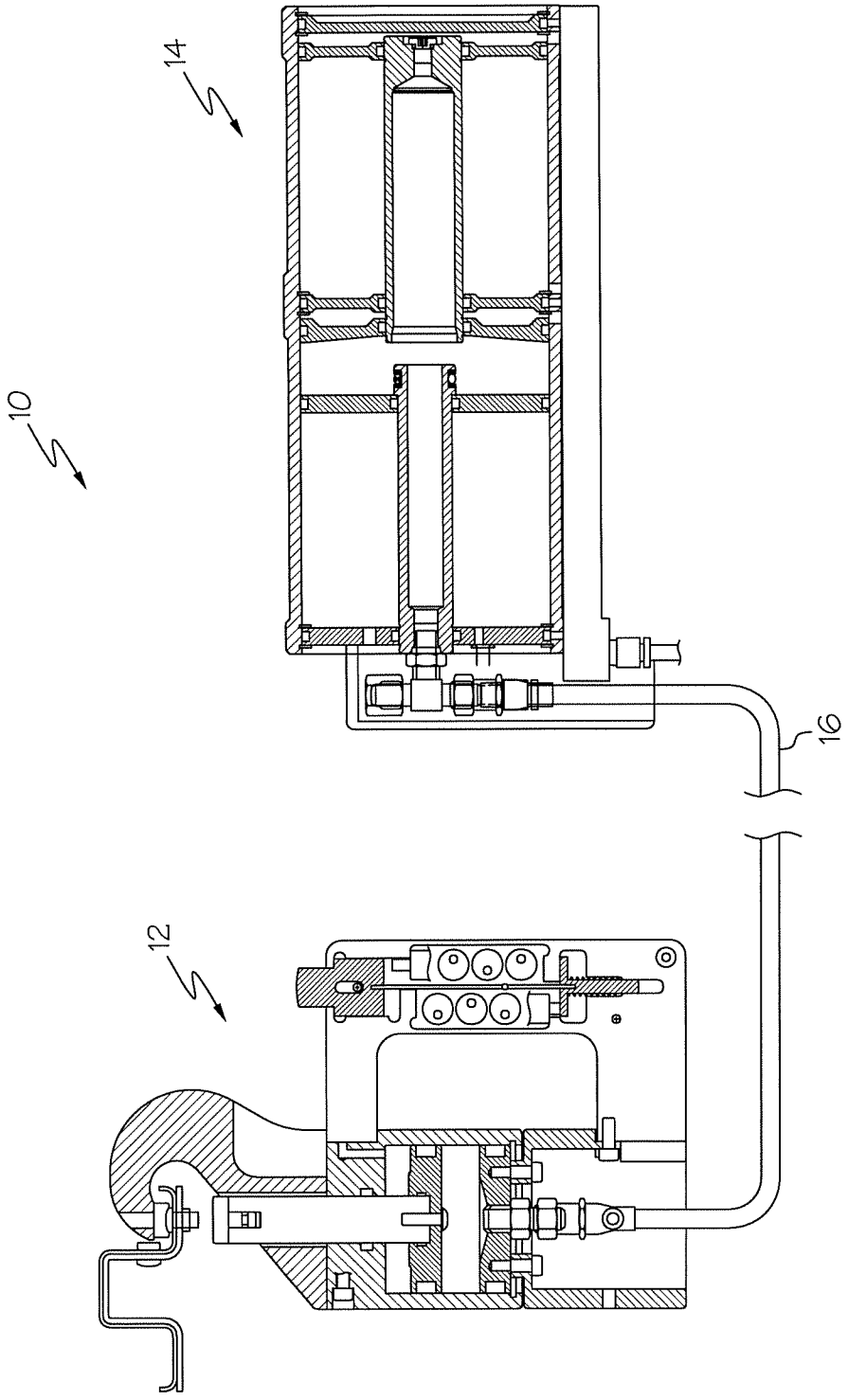


FIG. 3

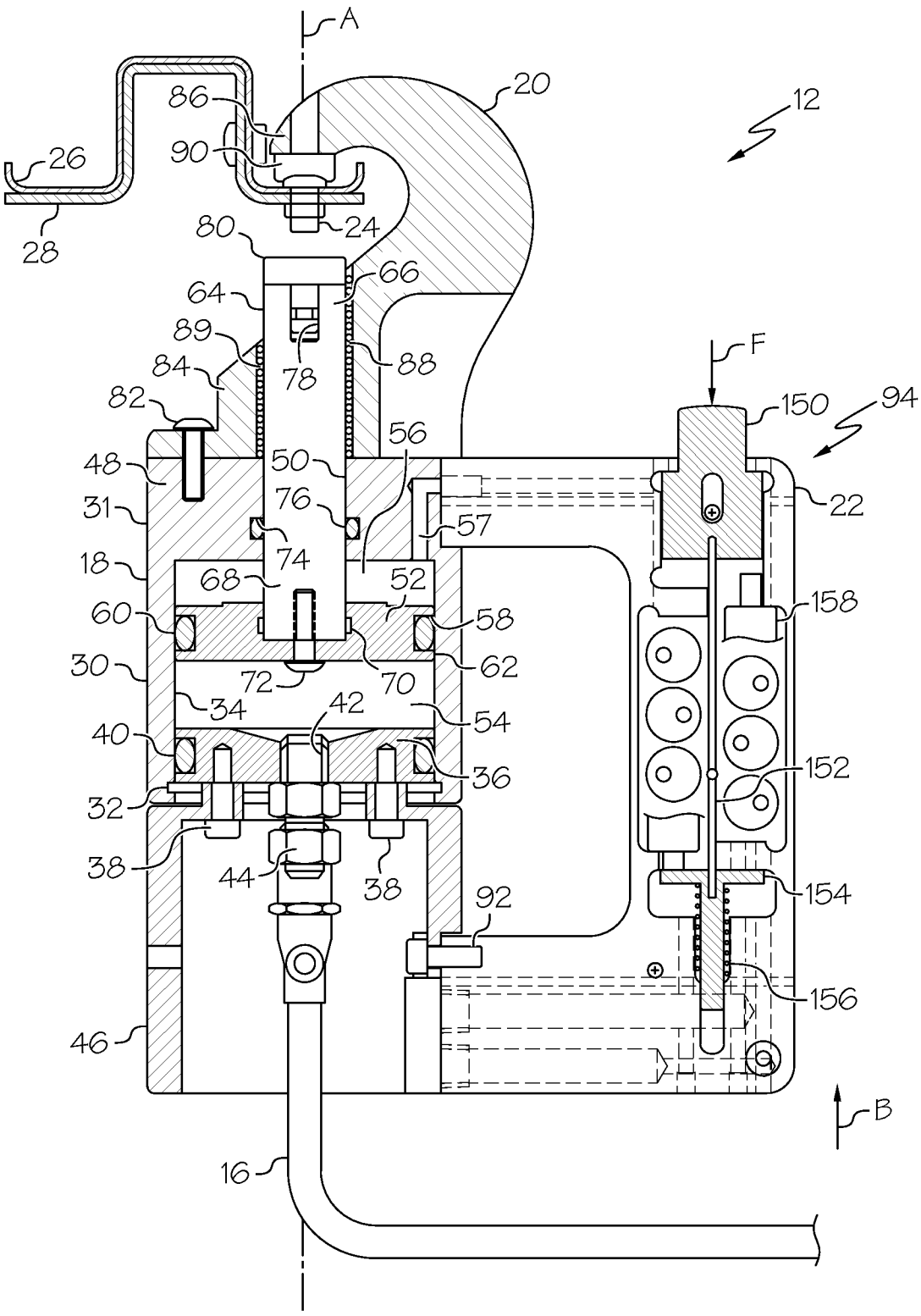
A
20
12
86
90
26
28
24
80
66
64
89
78
88
84
82
F
150
94
48
50
56
22
31
76
57
18
74
68
52
158
60
58
30
72
70
62
34
42
54
40
36
152
32
38
44
38
92
154
156
46
B
16

FIG. 4

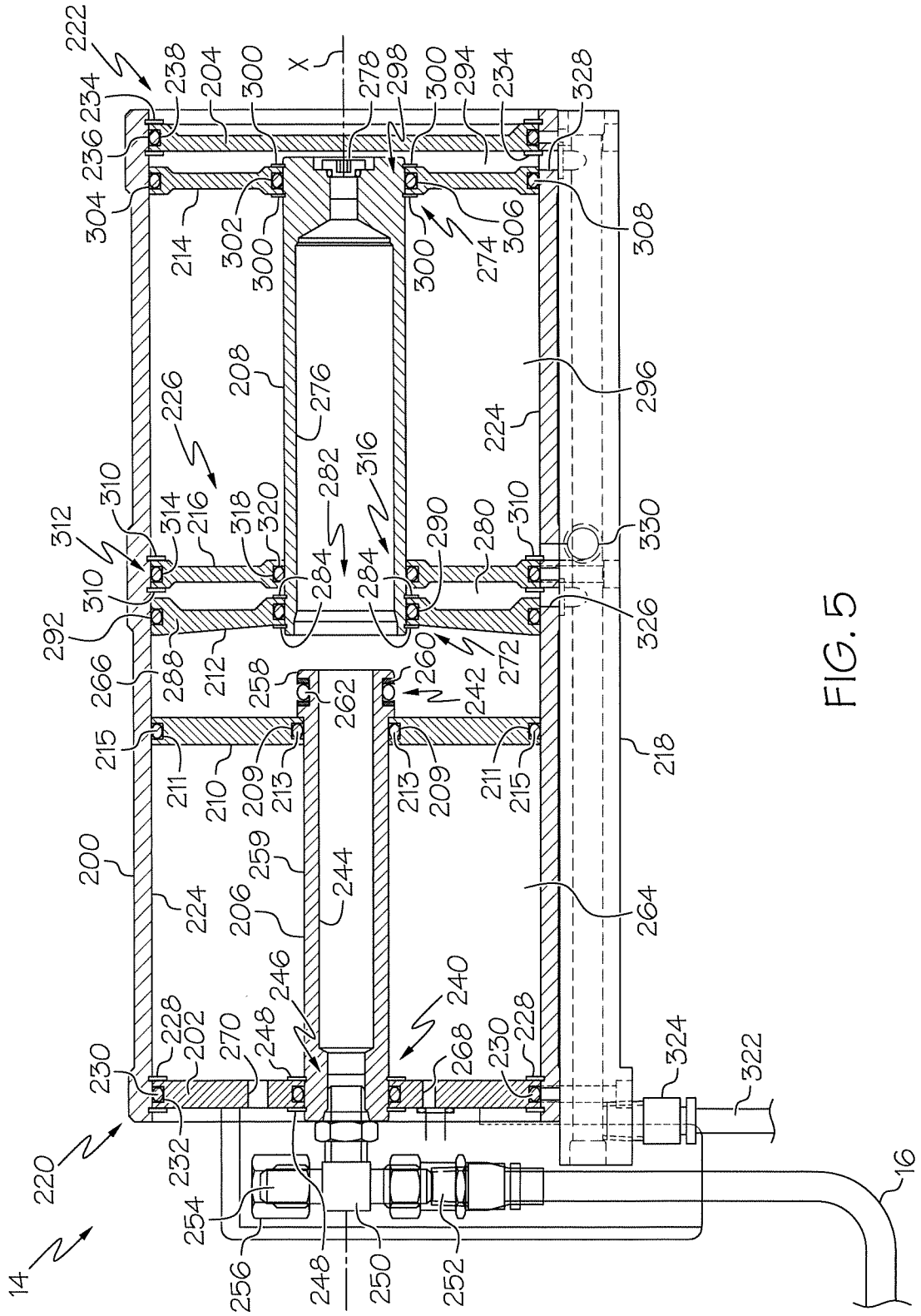
222
238
204
300
X
278
298
300
294
234
328
234
236
304
214
302
300
300
274
306
308
208
276
296
226
224
316
282
310
314
216
318
320
290
280
310
330
312
310
284
284
292
326
288
212
258
260
242
272
266
262
215
211
210
209
213
213
209
211
215
218
200
259
244
224
206
264
246
240
228
202
270
248
268
230
228
324
322
230
232
220
254
256
248
250
252
14
16

FIG. 5

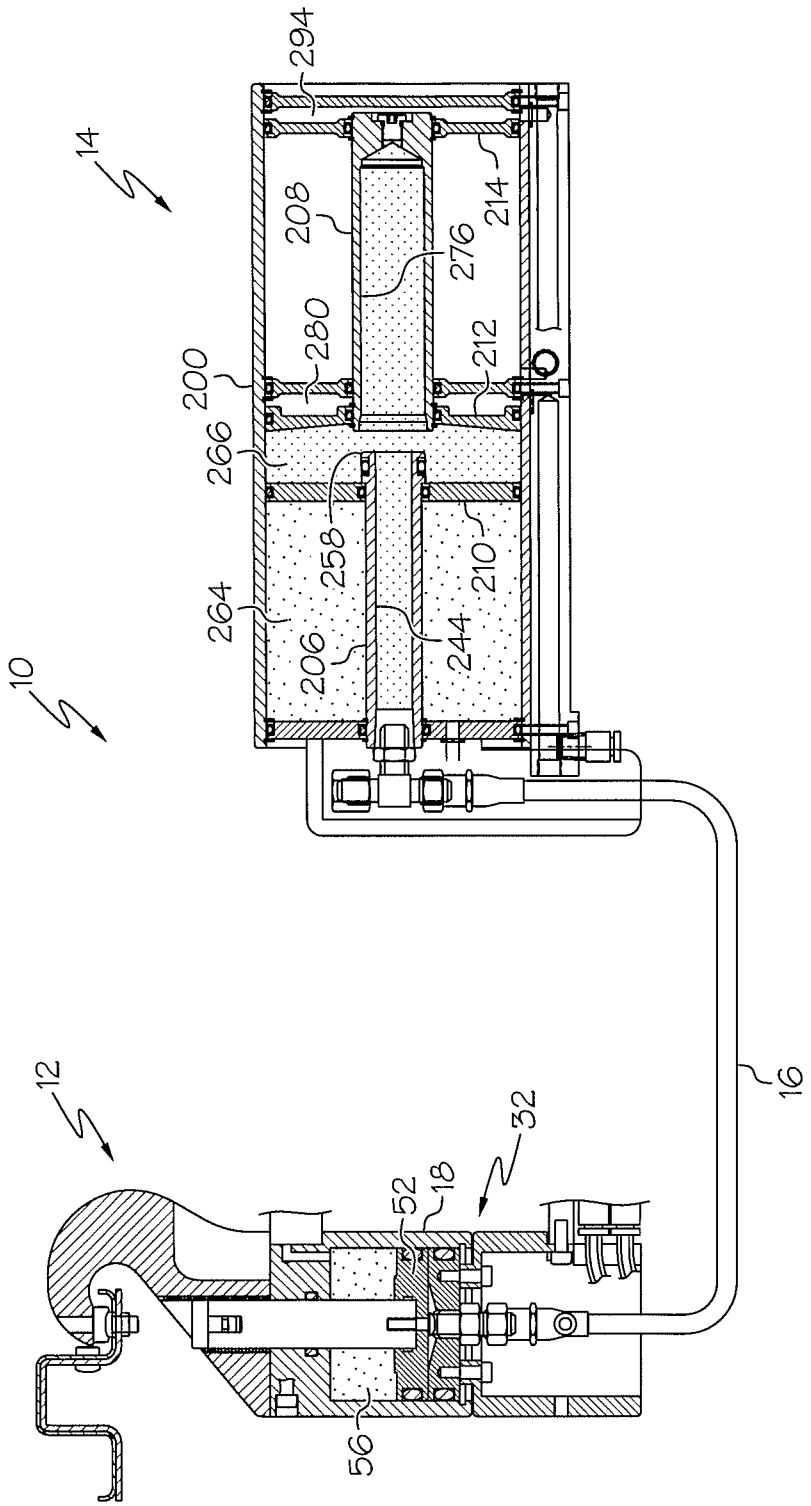
294
14
208
214
276
280
212
200
266
258
210
264
206
244
10
12
16
32
52
18
56

FIG. 6

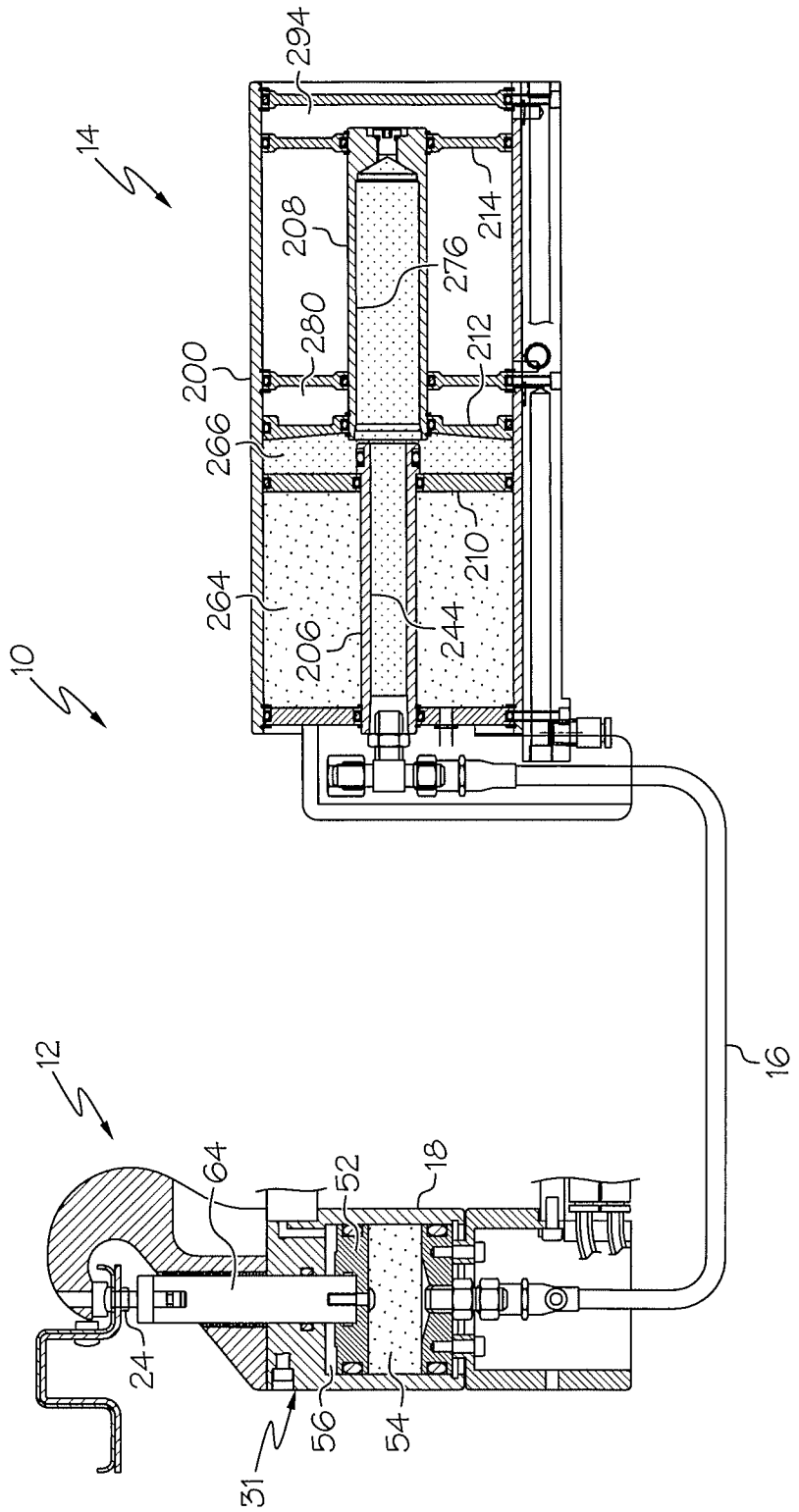
294
14
208
214
276
280
212
200
266
210
264
206
244
10
12
64
52
18
16
24
56
54
31

FIG. 7

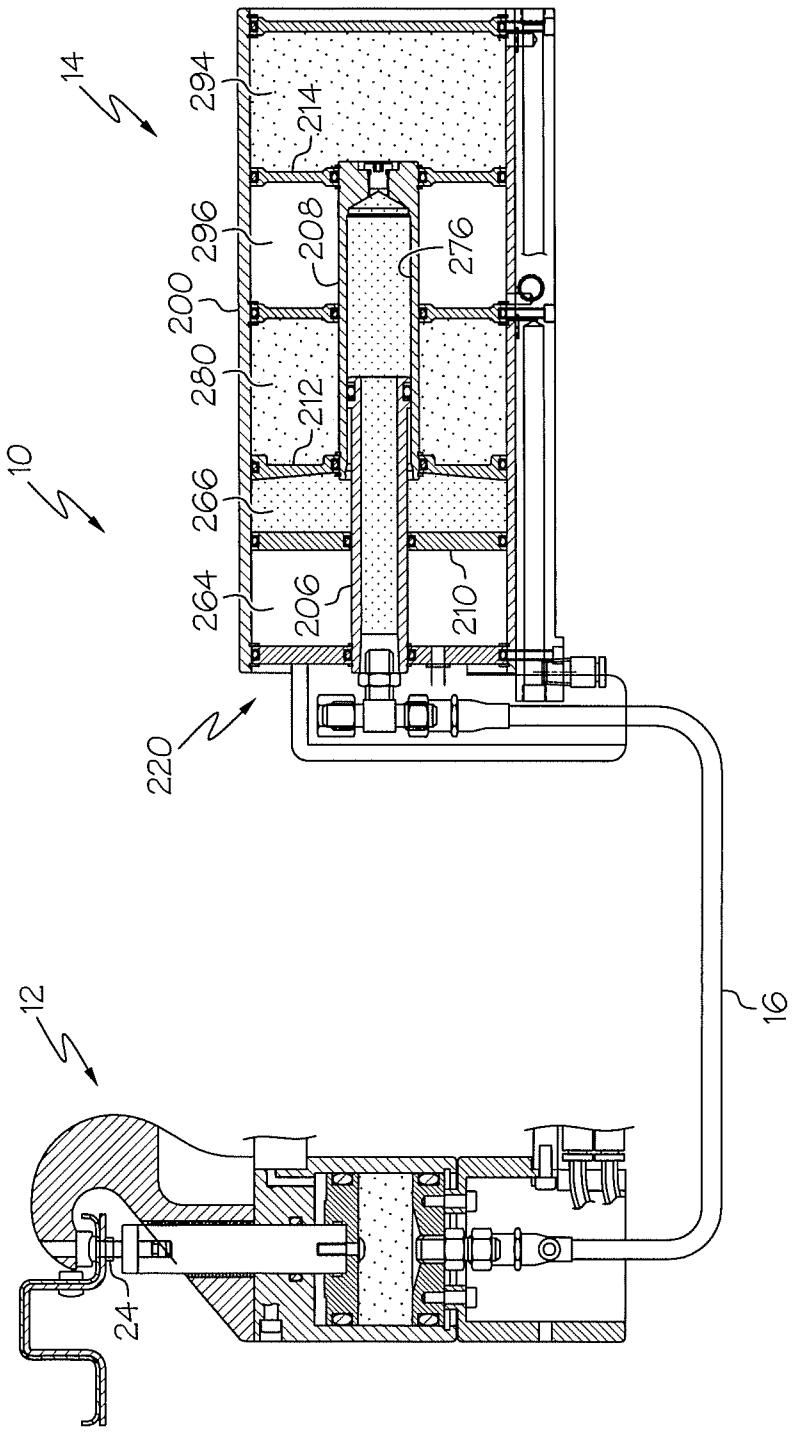


FIG. 8

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/032613

A. CLASSIFICATION OF SUBJECT MATTER
INV. B21J15/22 F04B9/123 F04B37/12 F15B3/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B21J F04B F15B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | DE 40 22 159 A1 (KOK JOHN DE [CA])<br>2 May 1991 (1991-05-02) | 21-24 |
| A | column 3, line 28 - column 4, line 63;<br>figures 1-3 | 1-20 |
| | ----- | |
| A | US 2013/098240 A1 (WU TSAI-CHAO [TW])<br>25 April 2013 (2013-04-25)<br>paragraphs [0015] - [0017] | 1-24 |
| | ----- | |
| A | DE 201 00 122 U1 (REIPLINGER GUENTER [DE])<br>21 June 2001 (2001-06-21)<br>the whole document | 19-22 |
| | ----- | |
| A | DE 19 06 977 A1 (HOERBIGER VENTILWERKE AG)<br>25 September 1969 (1969-09-25)<br>page 6; figure 3 | 1-24 |
| | ----- | |
| | -/-- | |

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 8 August 2014 | 19/08/2014 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Ziegler, Hans-Jürgen |

Form PCT/ISA/210 (second sheet) (April 2005)

# INTERNATIONAL SEARCH REPORT

International application No
PCT/US2014/032613

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | DE 32 06 613 A1 (KOEZPONTI BANYASZATI FEJLESZTE [HU]; BAKONYI BAUXITBANYA VALLALAT [HU])<br>1 September 1983 (1983-09-01)<br>page 9, line 10 - page 10; figure 1<br>----- | 1-20 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2014/032613

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| DE 4022159 A1 | 02-05-1991 | CA 2001707 A1 | 27-04-1991 |
| | | DE 4022159 A1 | 02-05-1991 |
| | | FR 2653834 A1 | 03-05-1991 |
| | | GB 2237604 A | 08-05-1991 |
| US 2013098240 A1 | 25-04-2013 | JP 3174240 U | 08-03-2012 |
| | | TW M423163 U | 21-02-2012 |
| | | US 2013098240 A1 | 25-04-2013 |
| DE 20100122 U1 | 21-06-2001 | AT 334314 T | 15-08-2006 |
| | | AU 2002234494 A1 | 16-07-2002 |
| | | DE 10200137 A1 | 12-09-2002 |
| | | DE 10290018 D2 | 04-12-2003 |
| | | DE 20100122 U1 | 21-06-2001 |
| | | EP 1423614 A2 | 02-06-2004 |
| | | WO 02053920 A2 | 11-07-2002 |
| DE 1906977 A1 | 25-09-1969 | AT 277772 B | 12-01-1970 |
| | | DE 1906977 A1 | 25-09-1969 |
| | | FR 2002772 A1 | 31-10-1969 |
| DE 3206613 A1 | 01-09-1983 | NONE | |