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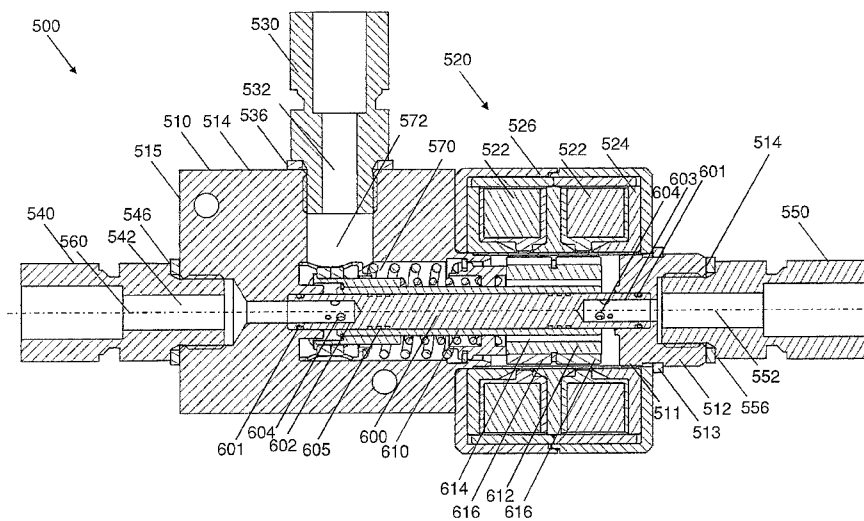
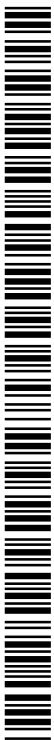


Figure 4

(57) Abstract: A flow divider valve, and a spool valve and a waste heat recovery system for an engine including a flow divider valve or a spool valve. The flow divider valve a housing, a spool and a solenoid assembly, the housing and solenoid assembly together defining a cavity, the housing defining an inlet, the spool being fixedly mounted in said cavity, the spool defining a first outlet and a second outlet, the flow divider valve further comprising a sleeve armature, the sleeve armature being slidably mounted about the spool in said cavity, and wherein said sleeve armature is configured for actuation by the solenoid assembly to open and close said first and second outlets to control fluid flow through the flow divider valve.



## FLOW DIVIDER VALVE

### TECHNICAL FIELD

[0001] The embodiments described below relate to components in waste heat recovery systems, and more particularly, to flow divider valves and spool valves for use in waste heat recovery systems.

### BACKGROUND

[0002] It is known to use valves to divide the flow of the working fluid to two or more boilers of a waste heat recovery (WHR) system. Such a valve may be termed a flow divider valve, in that the flow divider valve divides the flow of the working fluid to the two or more boilers.

[0003] It is necessary for such a flow divider valve to provide two flow regimes - variable during operation, and fixed division in the fail safe position. This may be achieved by arranging the fail safe position to be somewhere in mid travel. To achieve this requires a captivated single spring with traveling end guides or two springs with travel limits. Each of these solutions requires multiple parts and neither system provides a linear force along the travel, which is ideal for the reaction against a magnetic solenoid force. Accordingly, there is a need for an improved flow divider valve for use in a WHR system.

### SUMMARY

[0004] According to a first aspect of the present invention there is provided a flow divider valve comprising: a housing; a spool; and a solenoid assembly, the housing and solenoid assembly together defining a cavity; the housing defining an inlet, the spool being fixedly mounted in said cavity, the spool defining a first outlet and a second outlet, the flow divider valve further comprising a sleeve armature, the sleeve armature being slidably mounted about the spool in said cavity, and wherein said sleeve armature is configured for actuation by the solenoid assembly to open and close said first and second outlets to control fluid flow through the flow divider valve.

[0005] The flow divider valve integrates the valving functions into the sleeve armature of the solenoid assembly to simplify the construction of a flow divider valve.

[0006] Fluid containment is provided with no static or moving seals to the outside. The flow divider may thus be sealed for its working life. The flow division is fully variable between the first and second outlets during operation. The spool is pressure balanced and so the  
5 valve function is independent of inlet pressure.

[0007] The sleeve may be slidably mounted about the spool in a linear bearing system. This arrangement provides both low pressure drops, low power consumption and high durability. On a vehicle, the flow divider valve is subjected to significant vibration. With known flow  
10 divider valves, the armature needs to be stabilized and damping is required. The armature must slide accurately in its core tube, and the spool must also slide with it, accurately within the housing. Rather than attaching the armature and spool end to end, which would necessitate tight tolerances to avoid binding, or decoupling the armature and spool, which would necessitate further components, the armature and sleeve are provided as the same  
15 component. Furthermore the inertia of the flow divider valve is reduced, improving responsiveness and vibration survival.

[0008] The sleeve armature may be configured to carry at least one permanent magnet. The moving sleeve is thus also the armature of a permanent magnet, long travel solenoid.  
20 Normal solenoids have limited travel meaning a very large solenoid or a method of gearing is required to achieve low pressure drops with high flow rates. A pressure balanced spool allows for large flow sections through the valve, with low actuation forces (allowing for a smaller solenoid and no gearing). A pressure balanced spool requires relatively long armature travel. Permanent magnets on the armature provide the necessary travel, but these  
25 must be guided carefully to ensure a small consistent air gap across the core tube and in harmony with the spool sliding in its sleeve without the combination binding. Configuring the sleeve armature to carry at least one permanent magnet obviates the needs to provide a controlled air gap. The core tube is the tube that separates the valve internals from the atmosphere, between the armature and iron circuit. In solenoids without a permanent  
30 magnet, flux is directed across a small air gap to move the armature. This air gap is critical to the function of the valve and must be tightly toleranced. Thus by using permanent magnets, longer strokes may be actuated.

[0009] The sleeve armature may be a single body. Alternatively the sleeve armature may comprise a tubular sleeve body with an armature body mounted thereto.

5 [0010] The first outlet and the second outlet may be at opposite ends of the spool. This arrangement provides the maximum travel and therefore provides a long travel solenoid with greater fluid division control. Longer stroke means more linear travel per control increment and allows for more flexibility in the shapes of the fluid orifices to tune the flow to each outlet.

10 [0011] At least one of the first outlet or second outlet may be defined by a blind bore in an end of the spool, the blind bore being fluidly connected to the cavity via at least one radial bore provided in the spool. The blind bore may be fluidly connected to the cavity via a plurality of radial bores provided in the spool. Again, this arrangement supports the provision of greater fluid division control.

15 [0012] Both of the first outlet and second outlet may be defined by a respective blind bore in each end of the spool, the respective blind bores being fluidly connected to the cavity via at least one respective radial bore provided in the spool. A plurality of radial bores may be provided to supports the provision of greater fluid division control and allow for specifically  
20 tailored progressive or incremental fluid flow division.

[0013] The respective radial bores may define apertures in an external surface of the spool, and wherein the sleeve armature is configured to partially cover the apertures of both the first outlet and the second outlet when the sleeve armature is in a fail-safe position.

25 [0014] The outlet arrangement provides both variable flow division during operation of the solenoid actuated sleeve armature, as well as a fixed ratio division of the flow between the first and second outlets in the fail-safe rest position.

30 [0015] An external surface of the spool may have at least one circumferential groove to balance hydraulic pressure.

[0016] The flow divider valve may further comprise a spring arrangement, the spring arrangement comprising a first spring and a second spring, the first spring and the second

spring being configured to provide equal and opposed compression preloads to the sleeve armature to support the sleeve armature in a fail-safe position. Thus the two compression springs ensure a reliable return to the safe position whenever power is removed from the actuator device (whether controlled or due to failure). Each spring produces a reaction force on the moving parts of the valve and can be selected to provide the desired characteristic of the valve operating against the actuation force. Valves which return to failsafe when power is removed normally return to one end of travel and can be held against a hard end stop, in such a case a single spring can be used with a preload. However, when the valve must be held at some defined mid position with travel available in both directions from the safe position this simple solution cannot easily be used. The present arrangement minimises the power and size of the solenoid by ensuring equal starting forces and spring rates in either direction. Arrangements utilising a single spring are not able to provide a backlash free rest position. Other methods of holding a valve in a mid-position result in low or zero holding force in the safe position resulting in problems when external forces are applied. This can also result in lost motion at the point of transition.

[0017] According to a second aspect of the present invention there is provided a spool valve comprising a fixed element and a moveable element, the moveable element linearly moveable with respect to the fixed element to open and close at least one outlet port, the spool valve having a spring arrangement, the spring arrangement comprising a first spring and a second spring, the first spring and the second spring being configured to provide equal and opposed compression preloads to the moveable element to support the moveable element in a fail-safe position.

[0018] The first and second springs may be arranged concentrically. This allows for a compact arrangement.

[0019] The first and/or second spring may be coil springs. Alternatively, the first and/or second spring may be magnetic springs.

[0020] According to a third aspect of the present invention there is provided a waste heat recovery system for an engine, comprising a flow divider valve or spool valve as hereinbefore described.

[0021] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying Figures, in which:

#### BRIEF DESCRIPTION OF THE DRAWINGS

- 5 [0022] Figure 1 shows a schematic of a waste heat recovery system 100 for an engine 110 including a flow divider valve 500 according to an embodiment;  
Figure 2 shows a perspective view of the flow divider valve 500 according to an embodiment;  
Figure 3 shows a side elevation of the flow divider valve 500 according to an embodiment;  
10 Figure 4 shows a cross-sectional view of the flow divider valve 500 according to an embodiment;  
Figure 5 shows an enlarged cross-sectional view of the flow divider valve 500 of Figure 4; and  
Figure 6 shows the flow distribution function of the flow divider valve 500 as a graph of  
15 outlet areas with respect to valve position.

#### DETAILED DESCRIPTION

##### **Waste Heat Recovery System**

- [0023] Figure 1 shows a schematic of a waste heat recovery system 100 for an engine 110  
20 according to an embodiment. The waste heat recovery system 100 may be implemented for an engine 110 which may be mounted on a motor vehicle (not shown) to drive that vehicle, for example. Therefore, the engine 101 may comprise an IC engine, in particular a reciprocating piston engine. The vehicle may be an on-road truck, the operation of which is set out in the standard 'highway cycle' or World Harmonised Test Cycle (WHTC). Such a  
25 truck engine may particularly be powered by diesel or natural gas. According to an embodiment, the waste heat recovery system 100 may employ a fluid, such as water, an organofluorine such as Freon®, or a hydrocarbon such as ethanol, or the like as a working fluid. The fluid may change into different states such as liquid and gas as it recovers and converts waste heat from the engine 110 into work. For example, a Rankine cycle may be  
30 employed to convert heat into work. The particular fluid used may vary from one application to another.

[0024] The waste heat recovery system 100 includes two evaporators 120, 121, a bypass valve 125, and an expander 140 to recover and convert heat from the engine 110 into work.

The waste heat recovery system 100 also includes a condenser 150 and a reservoir 160 to cool the fluid for reuse in the waste heat recovery system 100. The waste heat recovery system 100 includes a fluid pump 170 and a flow divider valve 500 to control the flow of the fluid to the two evaporators 120 and through the waste heat recovery system 100 as will  
5 be described in the following prior to discussing the flow divider valve 500 in more detail.

[0025] The engine 110 is coupled to an exhaust pipe 112 which carries a vehicle exhaust 114. The vehicle exhaust 114 has waste heat generated by the engine 110. As depicted, the engine 110 may be an IC engine. As depicted, an exhaust pipe 112 carries the vehicle  
10 exhaust 114 which has the waste heat. Although the evaporators 120, 121 are depicted as recovering the waste heat from the vehicle exhaust 114 flowing through the exhaust pipe 112, any suitable source of waste heat generated by the engine 110 may be recovered by the waste heat recovery system 100. For example, heat may be recovered from the engine 110's exhaust gas recirculation system (EGR) or its charge air intercooler.

15

[0026] The evaporators 120, 121 use the waste heat from the engine 110 to convert the fluid to a vapor. Some or all of the vapor can be superheated. The evaporators 120, 121 may be any device suitable to convert the fluid. The evaporators 120, 121 are in fluid communication with the bypass valve 125 via a fluid lines 122, 123. The fluid lines 122,  
20 123 converge at fluid junction 124. The outlet of the evaporators 120, 121 may be a superheated vapor entering the bypass valve 125 at approximately 250°C and 25 bar although any suitable temperature and pressure may be employed. The foregoing temperatures and pressures are exemplary embodiments and do not limit the scope of this and other embodiments.

25

[0027] As depicted in Figure 1, the bypass valve 125 provides a fluid flow from the evaporators 120, 121 to the condenser 150 via the bypass or the expander 140. The expander inlet 132 fluid enters the expander 140 which converts heat energy in the fluid into work 144. The bypass condenser outlet 134 fluid flows to the condenser 150 without going  
30 through the expander 140. Heat energy in the fluid flowing by the bypass to the condenser 150 is not converted into work 144 by the expander 140.

[0028] Still referring to Figure 1, the expander inlet 132 fluid flows into the expander 140 where it may reduce in enthalpy while expanding. Therefore, the expander 140 can convert

at least some of the energy of the fluid to the work 144. The work 144 may be in the form of a mechanical motion. The expander 140 may comprise a variety of devices, such as a turbine, a piston engine or a rotary vane type vapor engine, etc. In the depicted embodiment the expander 140 may comprise a turbine.

5

[0029] The expander 140 can be mechanically coupled to the crankshaft or other suitable component of the engine 110 in order to add power to the engine 110. When the expander 140 is not generating work 144, the engine 110 may or may not be mechanically decoupled from the expander 140.

10

[0030] Still with reference to Figure 1, the fluid may flow from the expander 140 via the expander outlet 142 and combine with the bypass condenser outlet 134 fluid before flowing into the condenser 150. Although the bypass condenser outlet 134 and the expander outlet 142 fluids are depicted as combining before entering the condenser 150, the bypass condenser outlet 134 and the expander outlet 142 fluids may flow into the condenser 150 separately. For example, the bypass condenser outlet 134 may be coupled to the condenser 150 via a different port than the expander outlet 142.

15

[0031] The condenser 150 cools the working fluids to a temperature suitable for the reservoir 160, the fluid pump 170 and/or the flow control module 180. For example, the condenser 150 may cool the bypass condenser outlet 134 and/or the expander outlet 142 fluids to 10°C of sub cooling at the entry to the pump. As depicted, the condenser 150 employs a coolant 154 to cool the bypass condenser outlet 134 and/or the expander outlet 142 fluids. Heat may be transferred out of the condenser 150 to the coolant 154 to cool the fluid. The cooled fluid may flow from the condenser 150 to the reservoir 160 via the condenser outlet 152.

20

25

[0032] The fluid pump 170 draws the fluid out of the reservoir 160 via fluid line 172. The fluid pump 170 can elevate the pressure of the fluid from the reservoir 160 to a higher threshold pressure. In some embodiments, the fluid pump 170 may raise the pressure of the fluid to a threshold pressure of approximately 25 bar above the reservoir pressure, which may be at atmospheric pressure. However, other threshold pressures are certainly possible and the particular example pressure should in no way limit the scope of this and other embodiments. The fluid pump 170 may be driven by any suitable means. The fluid pump

30

170 may be driven by the engine 110 or may be driven by a separate electric motor. The fluid pump 170 provides the pressurized fluid to the evaporators 120, 121 via the flow divider valve 500 and fluid lines 173, 174 respectively. The fluid pump 170 may have variable speed to control flow rate a fluid supplied to the flow divider valve 500.

5

[0033] With a basic description of the overall waste heat recovery system 100 discussed in the foregoing, attention is now directed to the flow divider valve 500.

### Flow Divider Valve

[0034] Figures 2 to 5 show the flow divider valve 500. The flow divider valve 500  
10 comprises a housing 510, core tube 511, a housing cap 512, circlip 513, a solenoid assembly 520, an inlet port 530, a first outlet port 540 and a second outlet port 550. As shown best in Figure 3, the first outlet port 540 and second outlet port 550 are aligned along longitudinal axis 560.

15 [0035] The solenoid assembly 520 is ring shaped and comprises a pair of coils 522 mounted in a bobbin 524 and housed within an overmould 526.

[0036] The solenoid assembly 520 is arranged alongside the housing 510. The core tube 511 is welded to the housing 510 and housing cap 512. The solenoid assembly 520 is slid over  
20 the core tube 511 and retained against the housing 510 by circlip 513. Referring to Figure 4, the housing 510 and the solenoid assembly 520 define a cavity 570. The cavity 570 is substantially cylindrical and extends along the longitudinal axis 560. The cavity 570 terminates at one end in a first outlet opening 542 defined in an outer face 515 of housing 510. The cavity 570 terminates at another end in a second outlet opening 552 defined in an  
25 outer face 514 of housing cap 512. A bore 572 extends from an upper face 514 of the housing 510 to fluidly connect with cavity 570. The bore 572 defines an inlet opening 532 in the upper face 514 of the housing 510.

[0037] The first outlet port 540 is mounted in the first outlet opening 542. The second outlet  
30 port 550 is mounted in the second outlet opening 552. The inlet port 530 is mounted in the inlet opening 532. The first outlet port 540, the second outlet port 550 and the inlet port 530 are sealed to their respective openings 542, 552, 532 with respective gaskets 546, 556, 536, which are retained by respective threaded fittings on the respective ports 530, 540, 550.

Thus there are no static or moving seals to the outside of the flow divider valve 500. The flow divider valve 500 may be sealed for its working life.

5 [0038] Together, the bore 572 and the cavity 570 define the fluid pathways within the flow divider valve 500. During operation, the fluid pathways are wetted with working fluid.

10 [0039] A spool 600 is fixedly mounted to the housing 510 within the cavity 570. The spool 600 is a cylinder with a longitudinal axis. The longitudinal axis of the spool 600 is aligned with the longitudinal axis 560 of the cavity 570. O-ring seals 601 are used at either end to seal the spool 600 to the housing 510 and solenoid assembly 520. The spool 600 has a first and a second blind bore 602, 603. The first and second blind bores 602, 603 are centrally aligned and extend approximately  $\frac{1}{5}$  of the length of the spool 600, one from either end of the spool 600. The first blind bore 602 is in fluid communication with the first outlet port 540 and the second blind bore 603 is in fluid communication with the second outlet port 550.

20 [0040] Both first and second blind bores 602, 603 are further in fluid communication with the cavity 570 via a series of radially extending bores 604. The radially extending bores 604 define apertures in an outer surface of the spool 600. The apertures of the radially extending bores 604 fluidly connected to the first outlet port blind bore 602 are collectively termed first outlet apertures, and the apertures of the radially extending bores 604 fluidly connected to the second outlet port blind bore 603 are collectively termed second outlet apertures. The pattern of first outlet apertures and second outlet apertures are the same. In an alternate embodiment, the pattern of first outlet apertures and second outlet apertures are different.

25

[0041] A sleeve 610 is slidably mounted about the spool 600 within the central cavity 570. In the region of the solenoid assembly 520, a tubular armature 612 is mounted to the sleeve 610. The tubular armature 612 carries two permanent magnets 616. Each permanent magnet 616 is a single tubular magnet bonded to armature core 612. Each end is magnetically polarized radially in opposing directions i.e. left hand end has north pole on outer surface, right hand end has north pole on inner surface.

30

[0042] A series of longitudinal grooves 614 are formed in the inner face of the tubular armature 612, to define a series of fluid pathways between the tubular armature 612 and the sleeve 610.

5 [0043] The sleeve 610 is slidably mounted about the spool 600 in a linear bearing system. Thus an inner surface of the sleeve 610 provides a linear bearing surface with an outer surface of the spool 600 acting as the linear bearing counterpart. Linear motion of the sleeve 610 relative to the spool 600 is regulated by the spring assembly 700, as will be explained in more detail below.

10

[0044] A series of three circumferential grooves 605 are provided in the outer surface of the spool 600, proximate either end of the spool 600. The circumferential grooves 605 balance hydraulic pressure within the cavity 570.

#### Spring Assembly

15 [0045] Referring to Figure 5, the spring assembly 700 comprises two concentrically arranged springs: an inner spring 702, and an outer spring 704. The inner spring 702 and outer spring 704 are both coil springs and surround sleeve 610. The inner spring 702 is held between a travel stop 706 and a sensor magnet carrier 708. The outer spring 704 is held between the travel stop 706 and a spring guide 710. Both springs 702, 704 are held in  
20 compression.

[0046] The travel stop 706 is mounted to the sleeve 610 and abuts the armature 612 and is linearly slidable with the armature 612 and sleeve 610 relative to the spool 600 and housing 510. An annular groove 714 is defined within an inside surface of the housing 510 defining  
25 the cavity 570. A circlip 712 extends from the travel stop 706 and protrudes into the annular groove 714 to limit the travel of the travel stop 706.

[0047] The sensor magnet carrier 708 is mounted to the sleeve 610 and is linearly slidable therewith. A circlip 716 attached sensor magnet carrier 708 to sleeve 610. The sensor  
30 magnet carrier 708 support two annular sensor magnets 718 used to determine the position of the sleeve 610 relative to the spool 600. Whilst two annular sensor magnets 718 are shown, in an alternate embodiment a single annular magnet may be used.

[0048] The spring guide 710 abuts an end wall of cavity 570 and is therefore fixed with respect to the spool 600 and housing 510.

### Valve Operation

5 [0049] In operation the flow divider valve 500 receives working fluid from a single fluid line 172 and divides it via first and second outlet ports 540, 550 to fluid lines 173, 174. The flow division is fully variable between the first and second outlet ports 540, 550. A fixed ratio division between the first and second outlet ports 540, 550 is provided in the fail-safe (rest) position of the flow divider valve.

10 [0050] The spool 600 and sleeve 610 are the valving elements which distribute the working fluid flow from the inlet port 530 to the first and second outlet ports 540, 550.

[0051] The first outlet apertures and the second outlet apertures are arranged so that a fixed ratio flow path is provided to the first and second outlet ports 540, 550 when the sleeve 610  
15 is in the fail-safe position.

[0052] During operation, the solenoid assembly 520 is activated, which either attracts or repels the tubular armature 612, causing the sleeve 610 to move relative to the spool 600. Movement of the sleeve 610 relative to the spool 600 further exposes or further covers the  
20 first outlet apertures and the second outlet apertures to alter the division of fluid flow through the valve.

[0053] Figure 6 shows, the sum of cross-sectional areas (y-axis) of the first outlet apertures 810 and the sum of the cross-sectional areas (y-axis) of the second outlet apertures 820 with  
25 respect to valve position (x-axis). The total sum of the cross-sectional areas 830 (i.e. of both the first outlet apertures and the second outlet apertures) is also shown. The valve position (x-axis) equates to the percentage of displacement of the sleeve 610 from a mid-position relative to the spool 600.

30 [0054] When the sleeve 610 is between -80 and -100% displaced (i.e. to the left looking at Figure 4), the sleeve 610 completely covers the first outlet apertures such that there is no flow through first outlet port 540. Furthermore, the sleeve 610 completely exposes second

outlet apertures such there is full flow through second outlet port 550. This valve condition is shown of Figure 6 in the region 860.

5 [0055] When the sleeve 610 is between +80 and +100% displaced (i.e. to the right looking at Figure 4), the sleeve 610 completely covers the second outlet apertures such that there is no flow through second outlet port 550. Furthermore, the sleeve 610 completely exposes first outlet apertures such there is full flow through first outlet port 540. This valve condition is shown of Figure 6 in the region 870.

10 [0056] Thus the spool 600 and sleeve 610 arrangement provide a fully proportion flow divider valve.

[0057] When the sleeve 610 is centered, i.e. in the fail-safe position, the first outlet apertures have cross sectional area sum of approximately  $9\text{mm}^2$  and the second outlet  
15 apertures have a cross sectional area sum of approximately  $6\text{mm}^2$ .

[0058] Thus there is a fixed ratio flow path is provided to the first and second outlet ports 540, 550 when the sleeve 610 is in the fail-safe position.

20 [0059] In the particular embodiment shown in Figure 6 there is a bias of fluid flow to the first outlet port. Thus the flow division is equal when the valve position is set at approximately +5%.

### Spring Function

25 [0060] At rest inner spring 702 and outer spring 704 act on travel stop 706 and sensor magnet carrier 708 to provide a preload force holding the sleeve 610 without any free movement. The preload may be designed to hold the sleeve 610 in the safe position against external disturbance force such as vibration.

30 [0061] When the sleeve 610 is drawn to towards the solenoid assembly 520, (to the right as shown in Figure 5) the inner spring 702 will compress further as the sensor magnet carrier 708 moves with the sleeve 610. The travel stop 706 remains in position held by the circlip 712 abutting the annular groove 714. The outer spring 704 does not move as neither the spring guide 710 nor the travel stop 706 move.

[0062] When the sleeve 610 is urged away from the solenoid assembly 520, (to the left as shown in Figure 5) the outer spring 704 is compressed as the travel stop 706 moves to the left, pushed by the tubular armature 612 against the spring guide 710 which is fixed with respect to the housing 510. The inner spring 702 is not further compressed but moves to the left with both the travel stop 706 and sensor magnet carrier 708 moving to the left.

[0063] When the solenoid assembly 520 is de-activated, whichever spring has been compressed will produce the force to move the spool back to the fail-safe position.

[0064] Other methods of using two compression springs to hold the safe position result in a nonlinear characteristic during the transition of force from one direction to the other because at some point one or both springs are active.

#### 15 **Variants**

[0065] The invention may be used with ethanol WHR systems on vehicles, but could have wider industrial applications. The invention manages the return to known safe position function and integrates this feature into the armature of a long travel solenoid to simplify the construction of the valve. Appropriate selection of components can result in a symmetrical and balanced system for use with multiple directional valves. Whilst the above described embodiment is for a flow divider valve used in a WHR system, the skilled person will appreciate that such a flow divider valve may be used in any system where one inlet flow is divided into two outlet flows.

25 [0066] The device can be used with any working fluid for vehicle or industrial applications.

[0067] Altering the dimensions of the travel stop 706 changes the failsafe stop position such that valve may be manufactured with fail safe positions which bias flow in one direction and do not fully close either output port.

30 [0068] Choosing particular characteristic for the springs can result in linear and symmetrical valve control forces. However if non-linear or asymmetric forces are required, this may be provided by spring design.

CLAIMS

1. A flow divider valve comprising:  
5 a housing;  
a spool; and  
a solenoid assembly,  
the housing and solenoid assembly together defining a cavity;  
the housing defining an inlet, the spool being fixedly mounted in said cavity, the spool  
10 defining a first outlet and a second outlet,  
the flow divider valve further comprising a sleeve armature, the sleeve armature being  
slidably mounted about the spool in said cavity, and wherein said sleeve armature is  
configured for actuation by the solenoid assembly to open and close said first and second  
outlets to control fluid flow through the flow divider valve.  
15
2. A flow divider valve according to claim 1 wherein the sleeve is slidably mounted  
about the spool in a linear bearing system.
3. A flow divider valve according to claim 1 or claim 2 wherein the sleeve armature is  
20 configured to carry at least one permanent magnet.
4. A flow divider valve according to any of claim 1 to 3 wherein the sleeve armature is  
a single body.
- 25 5. A flow divider valve according to any of claim 1 to 3 wherein the sleeve armature  
comprises a tubular sleeve body with an armature body mounted thereto.
6. A flow divider valve according to any preceding claim wherein the first outlet and  
the second outlet are at opposite ends of the spool.  
30
7. A flow divider valve according to any preceding claim wherein at least one of the  
first outlet or second outlet is defined by a blind bore in an end of the spool, the blind bore  
being fluidly connected to the cavity via at least one radial bore provided in the spool.

8. A flow divider valve according to claim 7 wherein the blind bore is fluidly connected to the cavity via a plurality of radial bores provided in the spool.

9. A flow divider valve according to any of claims 1 to 6 wherein both of the first outlet and second outlet are defined by a respective blind bore in each end of the spool, the respective blind bores being fluidly connected to the cavity via at least one respective radial bore provided in the spool.

10. A flow divider valve according to claim 9 wherein the respective radial bores define apertures in an external surface of the spool, and wherein the sleeve armature is configured to partially cover the apertures of both the first outlet and the second outlet when the sleeve armature is in a fail-safe position.

11. A flow divider valve according to any preceding claim wherein an external surface of the spool has at least one circumferential groove to balance hydraulic pressure.

12. A flow divider valve according to any preceding claim, further comprising a spring arrangement, the spring arrangement comprising a first spring and a second spring, the first spring and the second spring being configured to provide equal and opposed compression preloads to the sleeve armature to support the sleeve armature in a fail-safe position.

13. A spool valve comprising a fixed element and a moveable element, the moveable element linearly moveable with respect to the fixed element to open and close at least one outlet, the spool valve having a spring arrangement, the spring arrangement comprising a first spring and a second spring, the first spring and the second spring being configured to provide equal and opposed compression preloads to the moveable element to support the moveable element in a fail-safe position.

14. A spool valve according to claim 13 wherein the first and second springs are arranged concentrically.

15. A spool valve according to claim 13 or claim 14 wherein the first and/or second spring are coil springs.

16. A spool valve according to claim 13 or claim 14 wherein the first and/or second spring are magnetic springs.

17. A waste heat recovery system for an engine, comprising a flow divider valve or  
5 spool valve as claimed in any preceding claim.

18. A flow divider valve substantially as hereinbefore described with reference to  
Figures 1 to 6.

10 19. A spool valve substantially as hereinbefore described with reference to Figures 1 to  
6.

20. A waste heat recovery system for an engine substantially as hereinbefore described  
with reference to Figures 1 to 6.

15

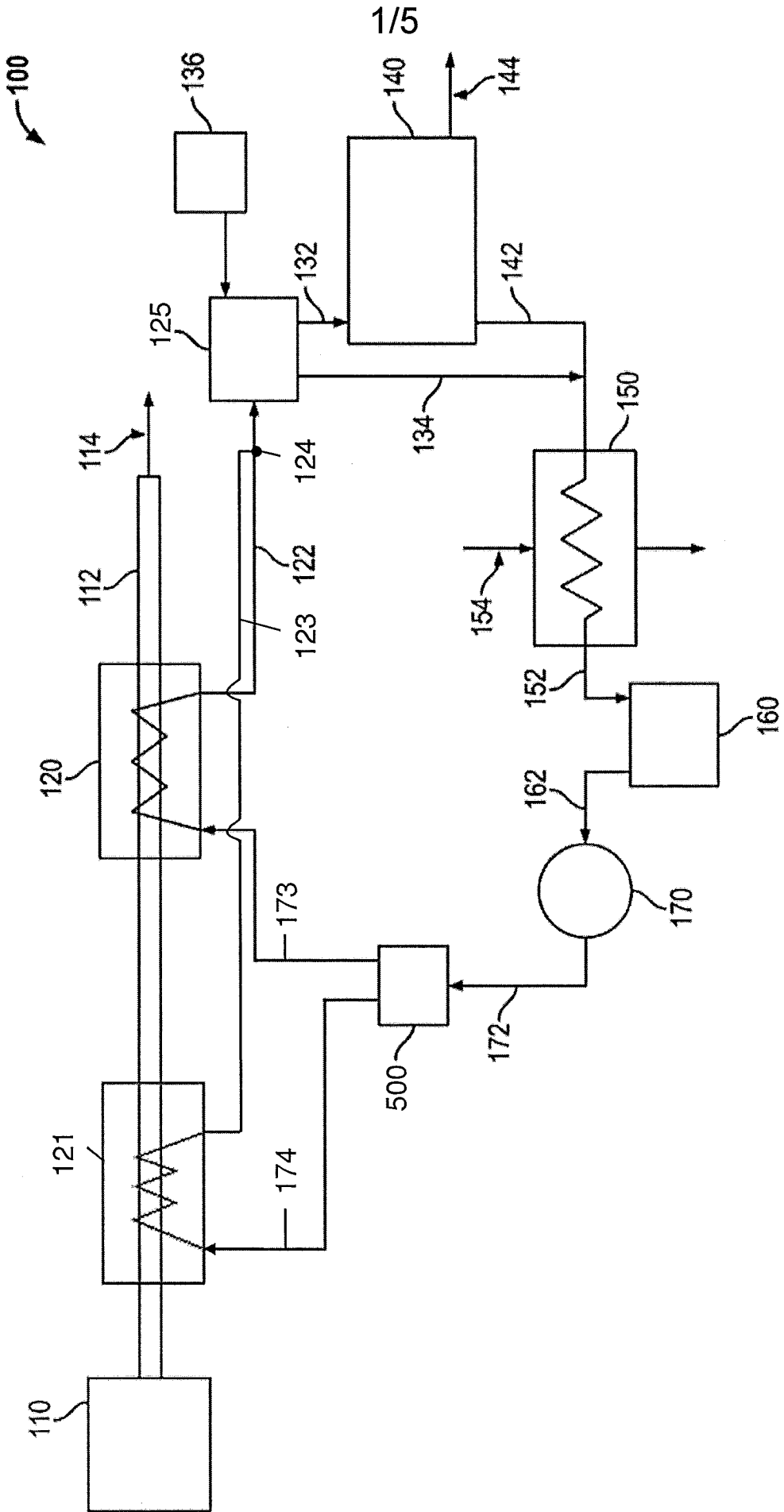


Figure 1

Figure 2

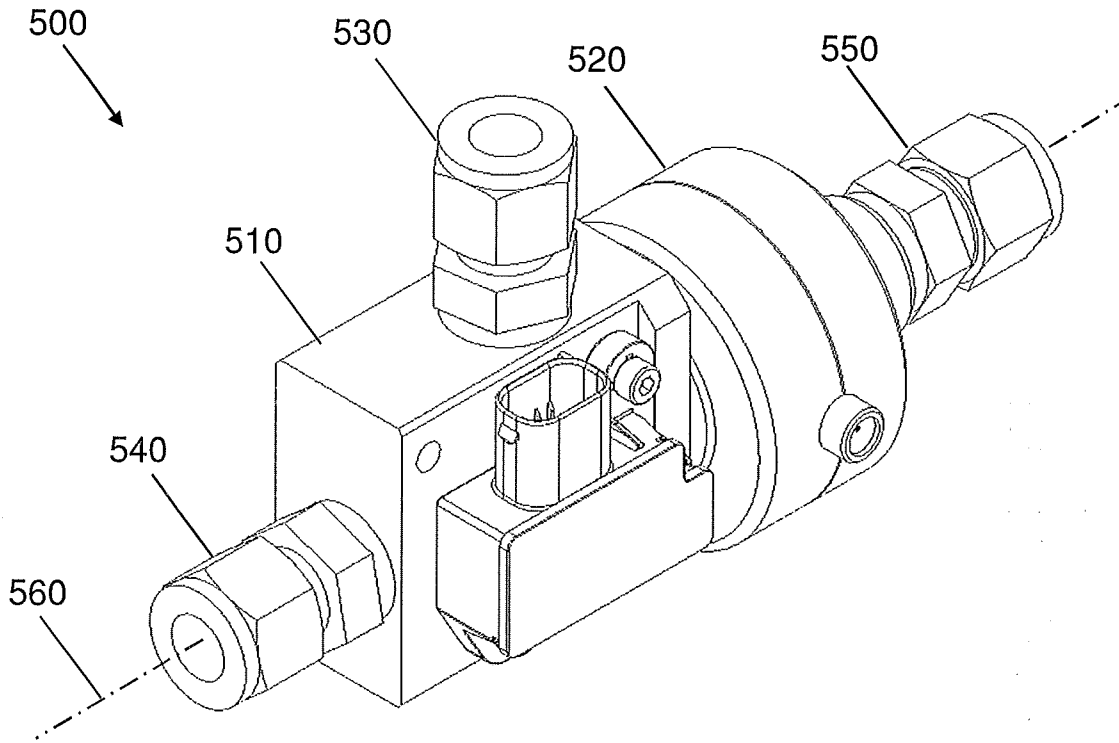
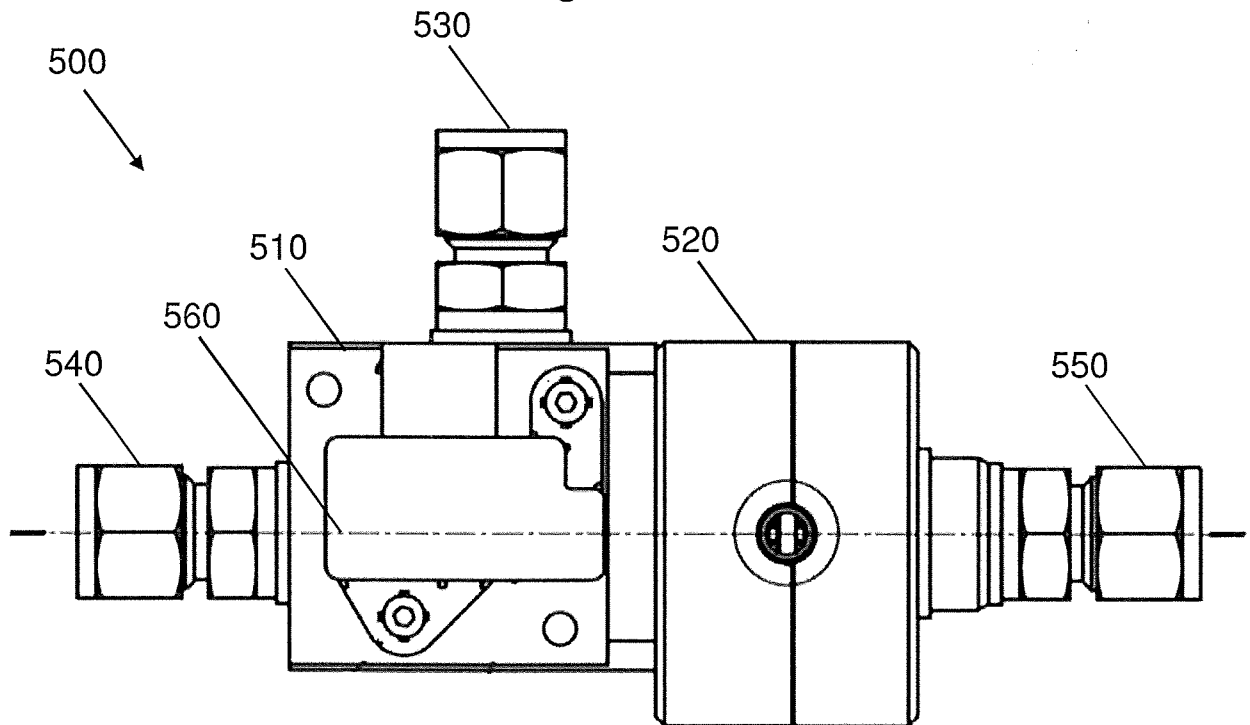


Figure 3



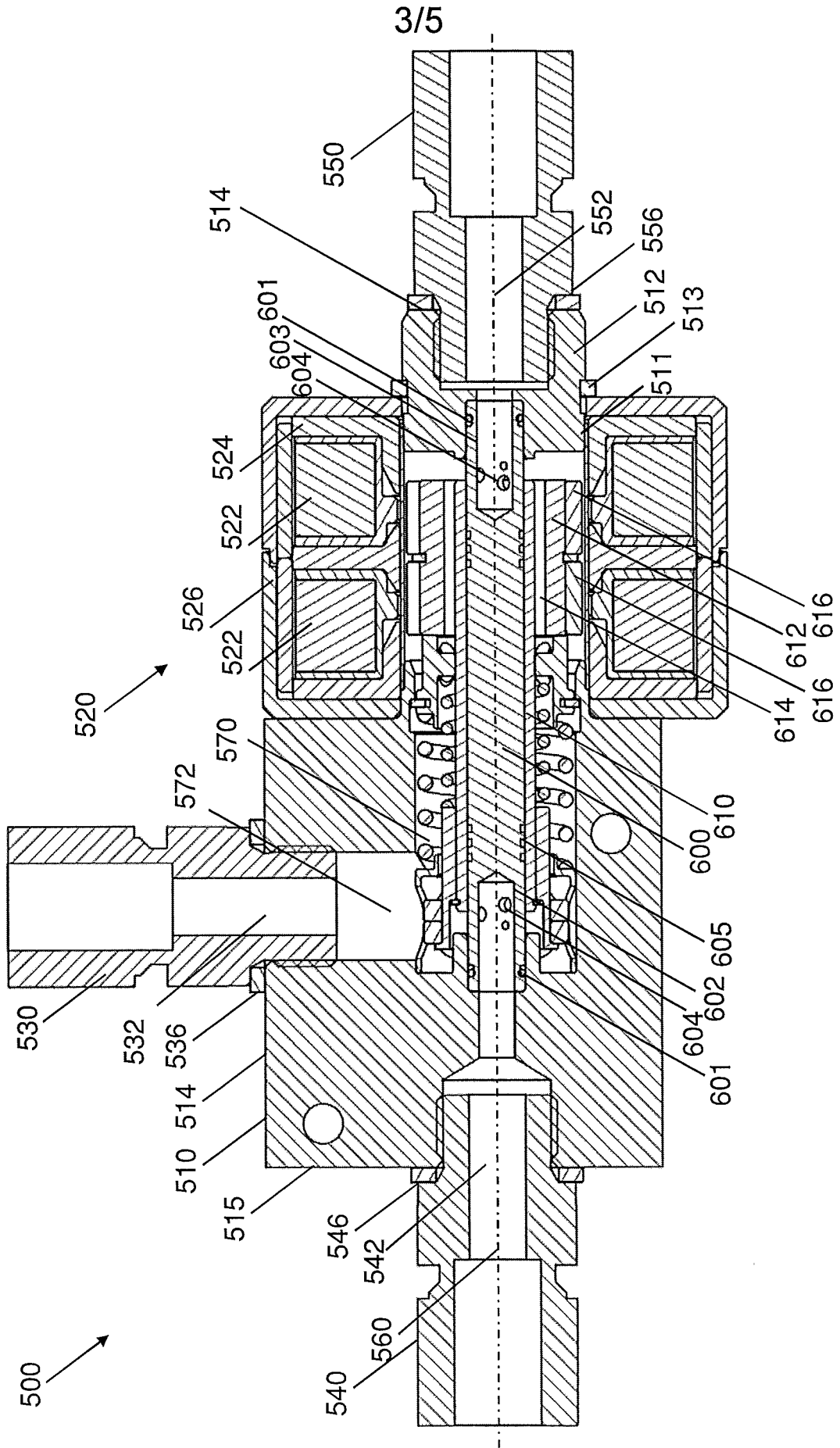


Figure 4

Figure 5

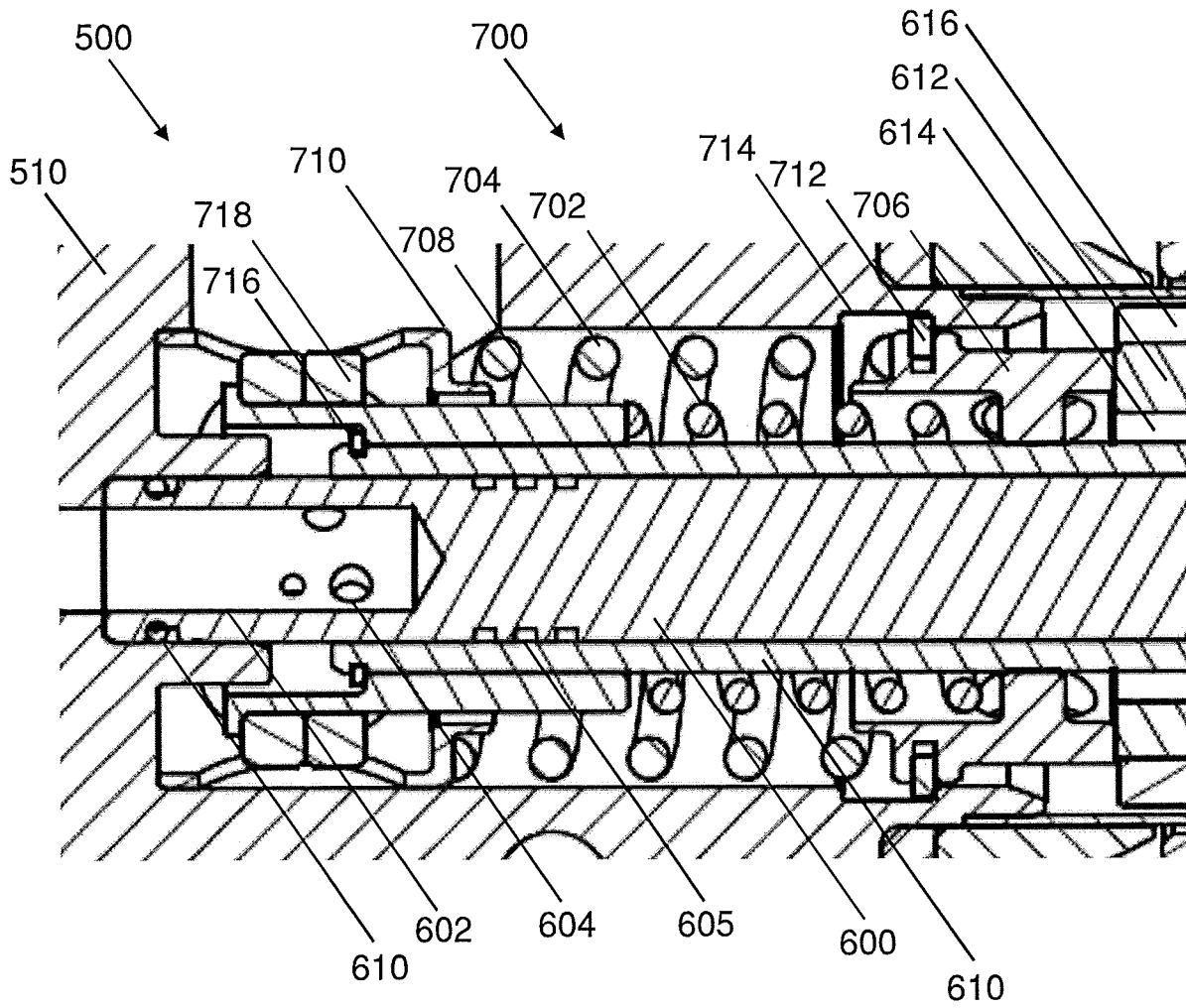
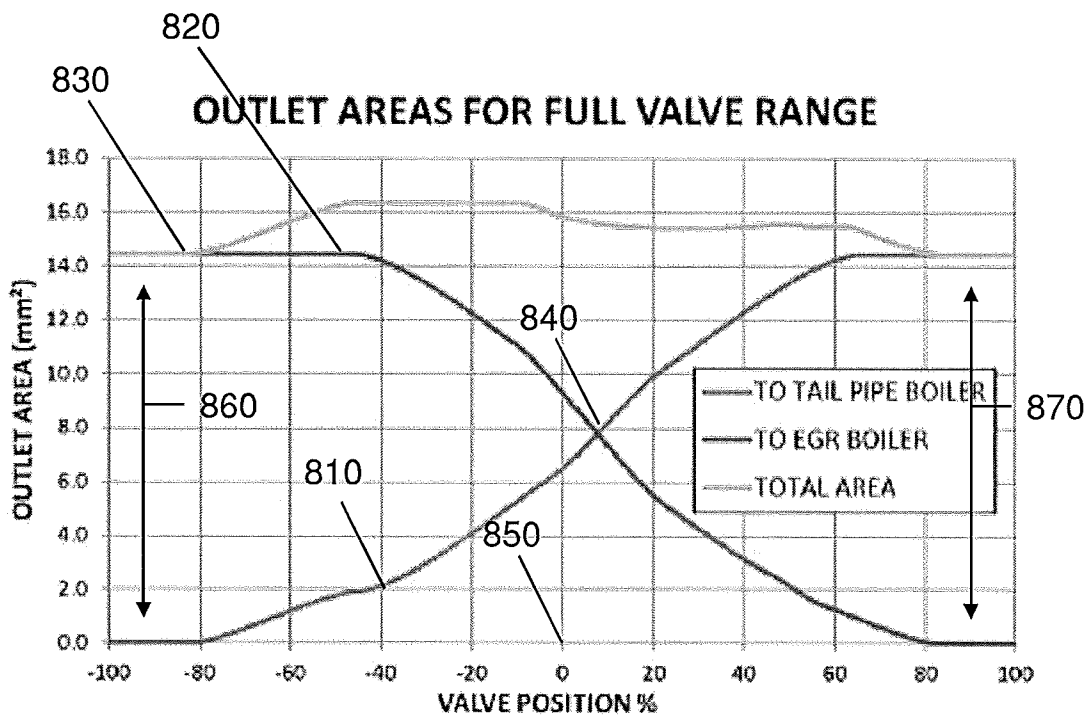


Figure 6



INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2017/050386

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F16K31/06 F16K11/07  
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)  
F16K

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	EP 1 764 535 A2 (EATON CORP [US]) 21 March 2007 (2007-03-21) the whole document	1-12, 18-20
X	US 5 584 323 A (YAMAMURO SIGEAKI [JP]) 17 December 1996 (1996-12-17) the whole document	1-5,7-9, 18-20
X	WO 2010/022868 A1 (BOSCH GMBH ROBERT [DE]; GRUEN JUERGEN [DE]) 4 March 2010 (2010-03-04) the whole document	1-4, 18-20
X	US 5 488 973 A (YAMAMURO SHIGEAKI [JP]) 6 February 1996 (1996-02-06) the whole document	1-4,6, 18-20
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Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search  17 May 2017	Date of mailing of the international search report  02/06/2017
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Schumacher, G
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# INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2017/050386

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International application No PCT/GB2017/050386
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