PATENT SPECIFICATION

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(54) CONTROL DEVICE FOR HOT-GAS RECIPROCATING MACHINE

(71) We, N.V. PHILIPS' GLOEILAMPENFABRIEKEN, a limited liability Company, organised and established under the laws of the Kingdom of the Netherlands, of Emmasingel 29, Eindhoven, the Netherlands do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a control device for a hotgas reciprocating machine of the kind having two or more working spaces, the volumes of which can be varied with a mutual phase difference by piston-like bodies coupled to a crankshaft, and in each of which a working medium performs a thermodynamic cycle during operation, of the machine, the control device having a housing comprising an inlet which can be connected to a source of pressurized working medium and a plurality of outlets, each of which can be separately connected to an associated one of the working spaces of the machine, the housing accommodating a control member which, when said inlet and outlets are so connected, during each revolution of the crankshaft, successively brings each of the outlets separately into communication with the inlet for a period during which the maximum cycle pressure occurs in the working space connected to the respective outlet.

A hot-gas reciprocating machine of the kind set forth is known from our prior United Kingdom Patent Specification No. 1,515,347.

In the context of the present invention the term "hot-gas reciprocating machine" is to be understood to mean a hot-gas reciprocating engine, a cold-gas refrigerating machine or a heat pump operating on the reversed stirling cycle. In such a machine, each of the working spaces comprises a compression space and an expansion space in which a gaseous working medium is alternately compressed and expanded and which communicate with one another *via* a regenerator through which the working medium can flow to-and-fro between the compression and expansion spaces, which spaces have mutually different mean temperatures during operation of the machine.

The piston-like bodies which vary the volumes of the working spaces are coupled to the crankshaft at different crank angles relative to each other. As a result, a mutual phase difference exists between the working spaces as regards the volume and pressure variations occurring in each working space.

The power of the machine can be increased by increasing the quantity of working medium present in the working spaces of the machine.

In the hot-gas reciprocating machine which is known from the aforesaid Patent Specification No. 1,515,347, the control device consists of a rotor, which is rotatable relative to the surrounding housing and which is coupled to a shaft of the machine, the rotor also being reciprocable in the axial direction under the influence of on the one side a pressure which corresponds to an instantaneous cycle pressure (for example, the minimum, the mean or the maximum cycle pressure) which periodically occurs in a working space, and on the other side, the pressure from the source of pressurized working medium.

When the power of this hot-gas reciprocating machine is increased, working medium is initially fed, exclusively by rotation of the rotor, to each working space during each revolution of the crankshaft for the period in which the maximum cycle pressure occurs in the relevant working space. Thus, the highest pressure of the working medium increases, so that the supplied working medium participates directly in the expansion, without the machine first having to perform compression work on the supplied medium, which would cause an initial decrease of the torque. Subsequently, a gradual change-over takes place from supplying working medium at maximum cycle pressure to supplying medium at minimum cycle pressure because, due on the one hand to the increasing continuous pressure acting on the rotor, representing the instantaneous cycle pressure, and on the other hand to the decreasing source pressure acting on the rotor, the rotor gradually assumes an axial position such that all outlet ports of the housing come into open communication with the inlet port.

The known hot-gas reciprocating machine has some drawbacks. For example the high working medium pressures necessitate proper sealing of the rotor shaft relative to the housing in order to prevent leakage of working medium to the surroundings. The service life of a high-pressure seal between mutually rotating parts, however, is short.

The control mechanism must satisfy very severe requirements as regards dimensional accuracy (for example, narrow ducts in the rotor must be in the correct position for the instantaneous feeding of the working medium).

Because a slip-free coupling between the rotor and a shaft of the machine is required, little freedom exists as regards choice of the position in which the control device is arranged.

In the control device according to the invention the control member is formed by a deformable annular body having a plurality of circumferentially spaced portions which can be subjected on one side, viewed radially of the body, to the source of pressurized working medium and which on the other side are each co-operable in a sealing manner with an associated one of the outlets so that the respective portion can be subjected to the variable cycle pressure occurring in the working space connected to that outlet, the body further being constructed so that said portions thereof close or open the outlets by changes in the shape of the body due to the variable forces acting on the body as a result of the variable differential pressures prevailing across said portions of the body.

In a preferred embodiment of the invention, the annular body consists of a flexible sleeve made of a synthetic material. This construction is very simple and cheap.

A hot-gas reciprocating machine of the kind set forth having a control device in accordance with the invention may be provided with a pressure-controlled change-over valve which is included in a main communication duct, one end of which is connected to the source of pressurized working medium, whilst its other end is connected to the working spaces *via* subsidiary communication ducts which are separately connected to the working spaces and each of which includes a non-return valve which opens forwards the associated working space, the change-over valve being arranged to shut off the control device and open the main communication duct when a given pressure level in the working spaces is exceeded and to close the main communication duct and bring the control device into operation when the pressure in the working spaces falls below said level.

When working medium is fed to the working spaces, the pressure level in the working spaces increases and the pressure of the working medium in the source decreases, so that it becomes increasingly difficult to feed working medium to a working space at maximum cycle pressure. The change-over valve ensures that at a given instant working medium is fed, *via* the main communication duct, to the working spaces during the period when the minimum cycle pressure occurs in the respective working space.

Some embodiments of the invention will be described in detail hereinafter with reference to the accompanying drawings, and in which

Figure 1 is a graph illustrating the pressure variations in the four thermodynamic cycles, phase-shifted 90° relative to each other, of a four-cylinder hot-gas reciprocating machine.

Figure 2 is a diagrammatic plan view of the four working spaces of a hot-gas reciprocating machine in which the thermodynamic cycles illustrated in Figure 1 are performed, the machine comprising a control device for supplying working medium from a storage vessel to the working spaces, and also comprising a pressure controlled change-over valve.

Figure 3*a* is a longitudinal sectional view of one embodiment of the control device,

Figures 3*b*, 3*c*, 3*d*, and 3*e* are cross-sectional views, taken along the line III—III of Figure 3a, of different operating conditions of the control device of Figure 3*a*,

Figure 4*a* is a longitudinal sectional view of a further embodiment of the control device,

Figure 4*b* is a cross-sectional view taken along the line IV*b*—IV*b* of Figure 4*a*,

Figure 4*c* is a cross-sectional view taken along the line IV*c*—IV*c* of Figure 4*a*,

Figure 5*a* is a longitudinal sectional view of yet another embodiment of the control device, and

Figure 5*b* is a cross-sectional view taken along the line V*b*—V*b* of Figure 5*a*.

Figure 1 shows the pressure P as a function of the time-dependent crankshaft angle α for the four cycles I, II, III and IV (denoted by an uninterrupted line, a dotted line, a dash line and a dash-dot line, respectively) of a four-cylinder hot-gas reciprocating machine, the cycles having a mutual phase difference in pressure of 90°.

The reference numerals 1, 2, 3 and 4 in Figure 2 denote the four working spaces of a hot-gas reciprocating machine in which the cycles I, II, III and IV, respectively, of Figure 1 are performed.

A control device 5 is connected *via* a duct 6 to a storage vessel 7 for pressurized working medium and *via* ducts 8, 9, 10 and 11 to the working spaces 1, 2, 3 and 4, respectively.

A pressure-controlled change-over valve 12 can interrupt the connection between the storage vessel 7 and the control device 5 and can connect the said vessel to a main duct 13 which is connected *via* separate subsidiary ducts 14, 15, 16 and 17 to the working spaces 1, 2, 3 and 4, respectively. Each of the ducts 14 to 17 includes a non-return valve 18, 19, 20 and 21, respectively, which opens towards the relevant working space.

Each of the non-return valves 18 to 21 opens if the cycle pressure occurring in the associated working space is lower than the pressure in the duct 13. Consequently in the duct 13 normally a pressure prevails which corresponds to the minimum cycle pressure.

The change-over valve 12 comprises a pressure-responsive movable valve element 22 which is subject on the one side to a compression spring 23 and to atmospheric pressure *via* an opening 24 in the housing 25, and on the other side to the pressure which prevails in a duct 26 connected to the working space 1. The duct 26 includes a flow resistance 27 which is constructed as a capillary. As a result, the valve element 22 senses the average cycle pressure of the working space 1.

The control device 5, yet to be described, is constructed so that during the interval A (Figure 1), in which P_I assumes its maximum value and is larger than P_{II}, P_{III} and P_{IV}, working medium is supplied from the storage vessel 7 exclusively to the working space 1.

Similarly, during the intervals B, C and D working medium is supplied exclusively to the working spaces 2, 3 and 4, respectively.

As a result of the supply of working medium to each working space during a part of the respective cycle in which the maximum cycle pressure occurs, the level of the maximum cycle pressure in the working spaces increases, whilst the pressure in the storage vessel 7 decreases. As a result, it becomes gradually more difficult to supply working medium to the working spaces at maximum cycle pressure. Under the influence of the increasing mean cycle pressure in the working space 1, the change-over valve element 22 gradually assumes a new position in which the connection between the storage vessel 7 and the control device 5 is interrupted and the storage vessel 7 is connected to the main duct 13. Each of the non-return valves 18 to 21 opens during the part of the associated cycle in which the cycle pressure is lower than that in the duct 13. Thus, *via* the duct 13, working medium is supplied to each working space during the period of minimum cycle pressure in this working space, from the instant at which the difference between the working medium pressure in the storage vessel 7 and the maximum cycle pressure in the working spaces has become so small that the supply of working medium at maximum cycle pressure is impeded.

Obviously, the change-over valve 12 may also have a different construction from that shown. Other control pressures may also be used, for example, pressures which correspond to the maximum or minimum cycle pressure.

The control device shown in Figures 3*a* to 3*e* comprises a housing 30 which consists of two portions 30*a* and 30*b* which are rigidly connected to each other by means of screws 31.

The housing 30 comprises a central inlet 32 and four outlets 33, 34, 35 and 36.

In the annular duct 37 between two housing portions 30*a* and 30*b* there is provided a flexible ring 38 of a synthetic material or of metal (for example, copper), the portions 38*a-b-c-d* thereof being capable of co-operating in a sealing manner with seats 39, 40, 41 and 42, respectively, surrounding apertures which open into the outlets 33, 34, 35 and 36, respectively. During operation, the inlet 32 is connected to the storage vessel 7 (Figure 2) and the outlets 33, 34, 35 and 36 are connected to the working spaces 1, 2, 3 and 4, respectively.

On the outer side of the portions 38*a-b-c-d* of the ring 38 which co-operates with the seats 39 to 42 the high pressure of the storage vessel prevails, whilst on the inner side of these portions the variable cycle pressure of the relevant working space prevails. In this case the maximum cycle pressure is lower than the pressure in the storage vessel.

The varying differential pressures prevailing across the said ring portions 38*a*-38*b*-38*c*-38*d* cause varying forces on the ring 38 which are directed radially inwards.

Because the phase of the cycle pressures differs by 90° relative to each other, the direction of the resultant of the four forces changes in the time.

During the interval A (Figure 1) $P_I > P_{II}$, P_{III}, P_{IV}. The instantaneous force on the ring portion 38*a*, therefore, is smaller that that on the ring portion 38*c*. Similarly, the instantaneous forces on the ring portions 38*b* and 38*d* are smaller than that on the ring portion 38*c*, even though they are larger than that on the ring portion 38*a*. As a result, whilst the ring portions 38*b*, 38*c* and 38*d* bear on the seats 40, 41 and 42, respectively, the ring portion 38*a*, due to the stresses produced in the ring as a result of the shape it assumes in bearing on the seats 40, 41 and 42, is spaced from the seat 39. Working medium then flows to the working space 1 *via* the outlet 33 (Figure 2).

During the intervals B, C and D (Figure 1), the situation is as shown in the Figures 3*c*, 3*d* and 3*e*, respectively, and working medium flows to the working spaces 2, 3 and 4, respectively. The control device shown in the Figures 4*a* to 4*c* is substantially similar to that shown in Figure 3. The same reference numerals, increased by the number 10, have been used for corresponding parts of the two embodiments. The operation of the device shown in Figures 4*a* to 4*c* is as described with reference to Figures 3*a* to 3*e*.

The same reference numerals, increased by the number 20, have been used for those parts of the control device shown in Figures 5*a* and 5*b* which correspond to parts of the control device shown in Figures 3*a* to 3*e*. In the device shown in Figures 5*a* and 5*b* the outlets are situated in the outer housing portion 50*a*. In addition to the central inlet 52, apertures 70 are provided in the portion 50*b*. The operation of this device is essentially the same as that of the device shown in the Figures 3*a* to 3*e*. In the case of the device shown in Figures 5*a* and 5*b* the variable forces acting on the ring portions 58*a* to 5*d* are directed radially outwards instead of radially inwards, and these ring portions are each time pulled off of the associated seat instead of being pushed off.

Other constructions of the control member are also possible. For example, an endless chain comprising links which are constructed to act as seals can also be used. The releasing and closing of the outlets is then effected by a lever action of the links on one another.

Although the described embodiments concern 4-cylinder machines, the invention can be used equally well for machines comprising a different number of cylinders. For a 2-cylinder machine, two oppositely situated outlets of the control device suffice. For a 3-cylinder machine with a phase difference of, for example, 120° between the three cycle pressures, three outlets can be spaced at an angle of 120° from each other.

WHAT WE CLAIM IS:—

1. A control device for a hot-gas reciprocating machine of the kind having two or more working spaces, the volumes of which can be varied with a mutual phase difference by piston-like bodies coupled to a crankshaft, and in each of which a working medium performs a thermodynamic cycle during operation of the machine the control device having a housing comprising an inlet which can be connected to a source of pressurized working medium and a plurality of outlets, each of which can be separately connected to an associated one of the working spaces of the machine, the housing accommodating a control member which, when said inlet and outlets are so connected, during each revolution of the crankshaft successively brings each of the outlets separately into communication with the inlet for a period during which the maximum cycle pressure occurs in the working space connected to the respective outlet, wherein the control member is formed by a deformable annular body having a plurality of circumferentially spaced portions which can be subjected on one side, viewed radially of the body, to the source of pressurized working medium and which on the other side are each co-operable in a sealing manner with an associated one of the outlets so that the respective portion can be subjected to the variable cycle pressure occurring in the working space connected to that outlet, the body further being constructed so that said portions thereof close or open the outlets by changes in the shape of the body due to the variable forces acting on the body as a result of the variable differential pressures prevailing across said portions of the body.

2. A control device as claimed in Claim 1, wherein the annular body consists of a flexible sleeve made of a synthetic material.

3. A hotgas reciprocating machine of the kind set forth having a control device as claimed in Claim 1 or 2 and provided with a pressure-controlled change-over valve which is included in a main communication duct, one end of which is connected to the source of pressurized working medium whilst its other end is connected to the working spaces *via* subsidiary communication ducts which are separately connected to the working spaces and each of which includes a non-return valve which opens toward the associated working space, the change-over valve being arranged to shut off the control device and open the main communication duct when a given

pressure level in the working spaces is exceeded and to close the main communication duct and bring the control device into operation when the pressure in the working spaces falls below said level.

4. A control device for a hot-gas reciprocating machine, the control device being constructed and arranged to operate substantially as herein described with reference to the accompanying drawings.

5. A hot-gas reciprocating machine of the kind set forth having a control device as claimed in any of Claims 1, 2 or 4.

R. J. BOXALL,
Chartered Patent Agent,
Mullard House,
Torrington Place,
London, WC2H 8AS,
Agent for the Applicants.

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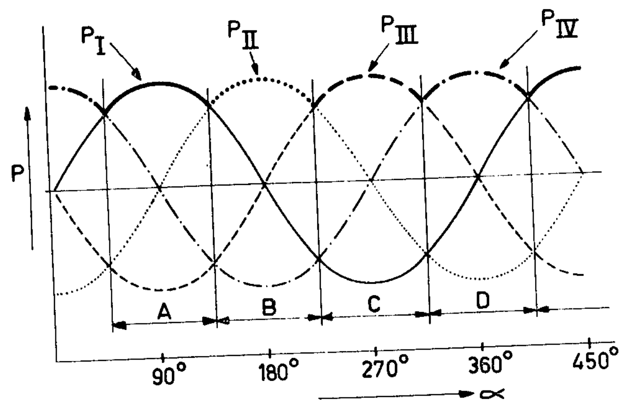

P
P_I
P_{II}
P_{III}
P_{IV}
A
B
C
D
90°
180°
270°
360°
450°
∝

Fig. 1

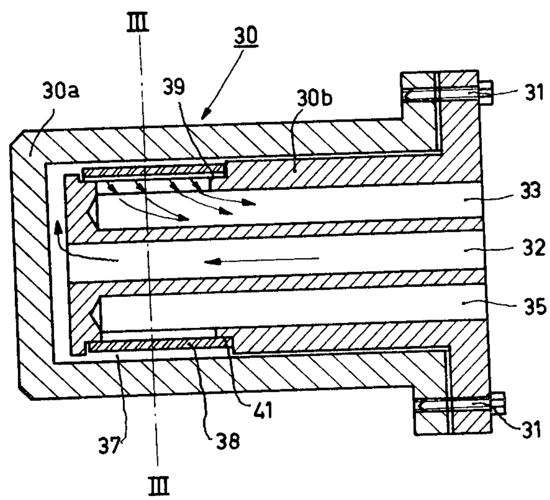

III
30
30a
39
30b
31
33
32
35
41
31
37
38
III

Fig. 3a

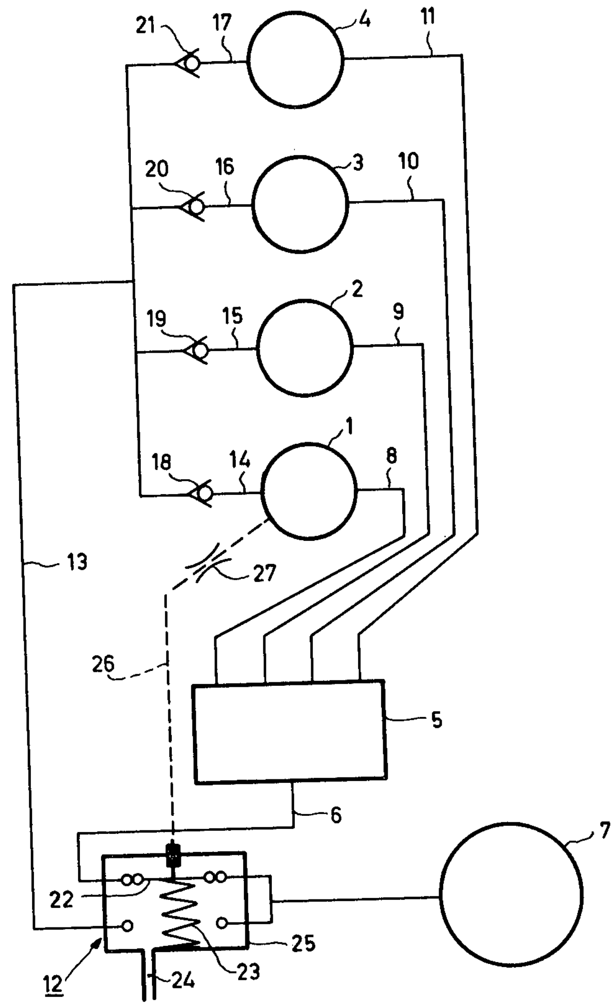
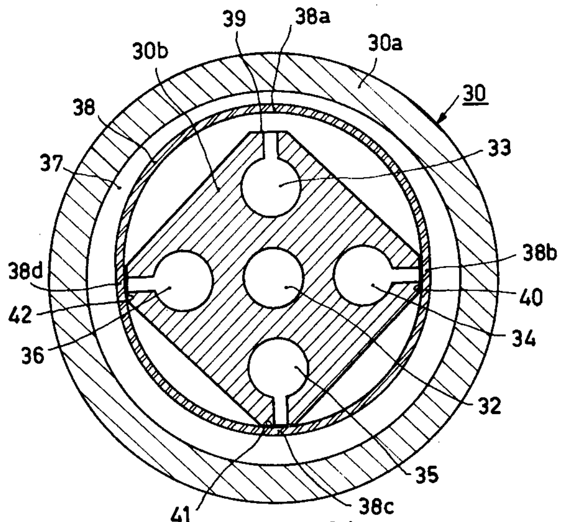
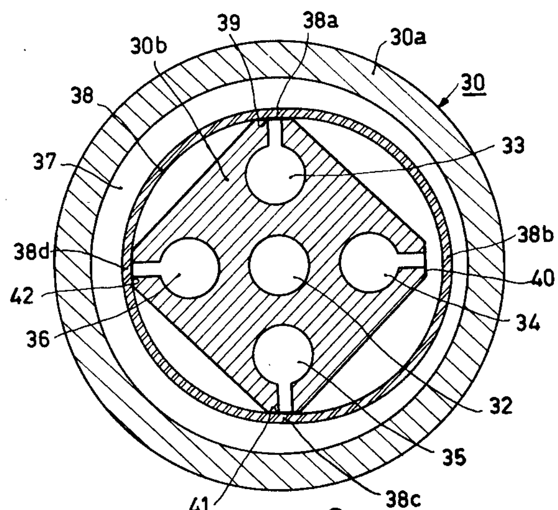
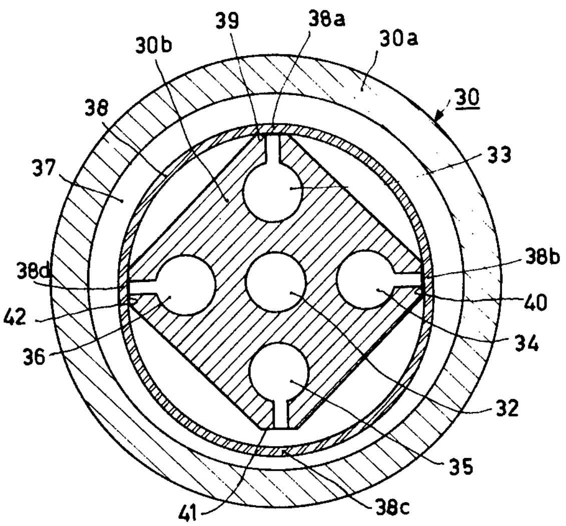


Fig. 2


39
38a
30b
30a
30
38
33
37
38b
38d
40
42
34
36
32
35
41
38c
Fig. 3b


39
38a
30b
30a
30
38
33
37
38b
38d
40
42
34
36
32
35
41
38c
Fig. 3c


39
38a
30b
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30
38
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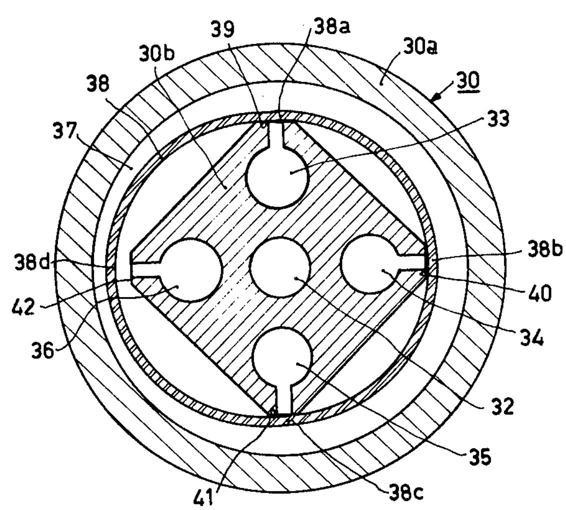
38b
38d
40
42
34
36
32
35
41
38c

Fig. 3d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38a
30b
30a
30
38
33
37
38d
38b
40
42
34
36
32
35
41
38c

Fig. 3e

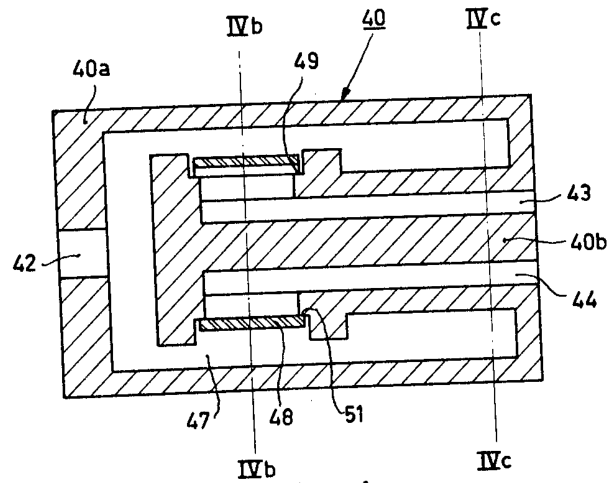

Fig. 4a

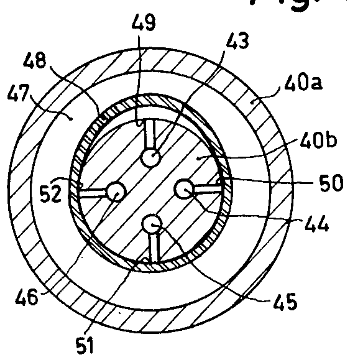

Fig. 4b

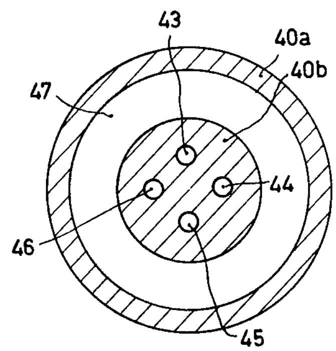

Fig. 4c

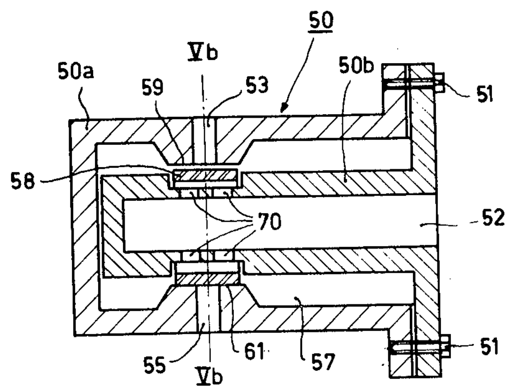
50
Vb
50a
59
53
50b
51
58
70
52
55
61
57
51
Vb

Fig. 5a

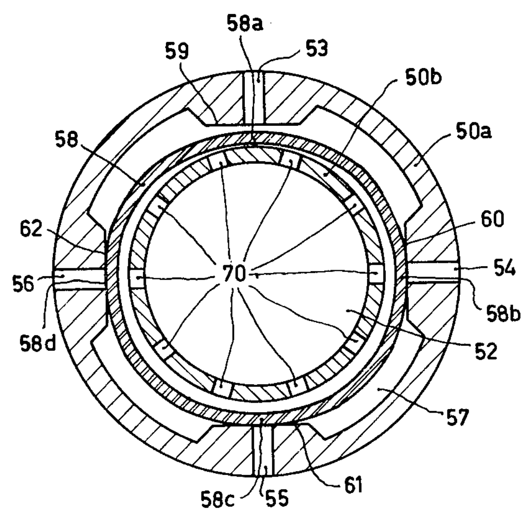
58a
59
53
50b
50a
58
60
62
54
56
70
58b
58d
52
57
58c
55
61

Fig. 5b