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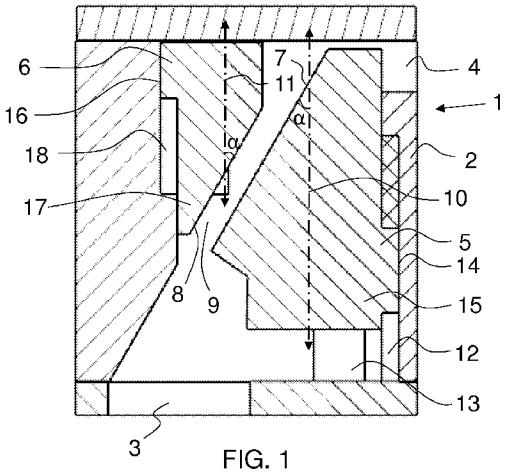

FIG. 1

(57) Abstract: The flow control valve (1) comprises a linearly movable valve member (5) having a first flow regulating surface (7), and a second flow regulating surface (8) facing the first surface (7), the first and the second surface (7, 8) being arranged so that the movement of the valve member (5) changes linearly the flow area be- tween the surfaces (7, 8). The valve (1) further comprises first positioning means (20), which are configured to move the valve member (5) for adjusting the distance between the first surface (7) and the second surface (8), and second positioning means (21), which are configured to switch the valve member (5) or the second surface (8) between a closed position, where the first surface (7) is against the second surface (8), and an open position, where the distance between the first and the second surface (7, 8) depends on the latest position of the valve member (5) determined by the first positioning means.

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Flow control valve and method for operating a flow control valve

Technical field of the invention

The present invention relates to a flow control valve in accordance with the preamble of claim 1. The invention also concerns a method of operating a flow control valve as defined in the preamble of the other independent claim.

Background of the invention

In certain applications it is important to be able to precisely control the flow rate of a fluid in addition to the ability to simply open and close the flow connection. One example of such a system is the fuel injection system of an engine that is operated on a gaseous fuel. Each cylinder of a gas engine is typically provided with a gas admission valve, which controls the fuel flow into an intake duct. During the intake stroke, the gas admission valve is opened for introducing gaseous fuel into the intake duct. Before the end of the intake stroke, the valve must be closed for preventing flow into the exhaust duct during the scavenging period. The power of the engine is controlled by the amount of the fuel that is introduced into the cylinders, and precise control of the fuel amount is thus needed. In present systems, the control of the fuel amount is usually implemented by controlling the duration of the time the gas admission valves are kept open. Also the pressure of the gas affects the amount of the fuel that is introduced into the cylinders during each cycle. The gas admission valves presently used in engines provide an accurate control within a narrow load range. However, when the engine load is low, it is difficult to accurately control the amount of the gaseous fuel that is introduced into the cylinders.

Another example of an application where it would be desirable to be able to precisely control both the flow rate and the opening and closing timing of a valve is the operation of an air by-pass valve of a turbocharged internal combustion engine, which controls the pressure of an intake air receiver by releasing intake air into an exhaust duct. Similar properties are required from waste gate valves, which regulate the maximum charge pressure in turbocharger systems by allowing part of the exhaust gas to by-pass the turbine of a turbo-

charger. There are also many other applications where accurate control of flow rate and opening and closing timing of a valve is needed.

An on/off function typically requires a fast-acting valve, whereas in flow rate regulation precise control is more important than the response time of the valve. These properties are difficult and expensive to include in a single valve.

Summary of the invention

An object of the present invention is to provide an improved flow control valve, which has both a flow rate regulating function and an on/off function. The characterizing features of the flow control valve according to the invention are given in the characterizing part of claim 1. Another object of the invention is to provide an improved method for operating a flow control valve comprising a valve body and having a first flow regulating surface and a second flow regulating surface facing the first flow regulating surface, the distance between the first flow regulating surface and the second flow regulating surface determining the smallest cross-sectional flow area through the flow control valve. The characterizing features of the method are given in the characterizing part of the other independent claim.

The flow control valve according to the invention comprises a valve body having an inlet and an outlet, a linearly movable valve member, which comprises a first flow regulating surface arranged inside the valve body, and a second flow regulating surface arranged inside the valve body and facing the first flow regulating surface, the first flow regulating surface and the second flow regulating surface being arranged so that the movement of the valve member changes linearly the cross-sectional flow area between the first flow regulating surface and the second flow regulating surface. The flow control valve further comprises first positioning means, which are configured to move the valve member for adjusting the distance between the first flow regulating surface and the second flow regulating surface, and second positioning means, which are configured to switch the valve member or the second flow regulating surface between a closed position, where the first flow regulating surface is against the second flow regulating surface, and an open position, where the distance between the first flow regulating surface and the second flow regulating surface depends on

the latest position of the valve member determined by the first positioning means.

The flow control valve thus provides a linear control of the flow rate through the valve. Because of the two sets of positioning means, the on/off function and the flow rate regulating function of the flow control valve can work independently of each other. It is thus easier to optimize the flow control valve to have a quick response time for opening and closing of the valve and precise control of the flow rate.

According to an embodiment of the invention, the flow control valve comprises a second movable valve member comprising the second flow regulating surface, and the second positioning means are configured to switch the second valve member between the closed position and the open position.

In the method for operating the flow control valve, the flow control valve is operated by using a flow rate regulating function by moving the first flow regulating surface linearly relative to the valve body to adjust the distance between the first flow regulating surface and the second flow regulating surface for changing the cross-sectional flow area between the first flow regulating surface and the second flow regulating surface in an open position of the flow control valve, and by using an on/off function by switching the position of the first flow regulating surface or the second flow regulating surface between a closed position, in which position the flow regulating surfaces are brought together for preventing flow through the flow control valve, and an open position, in which position the distance between the first flow regulating surface and the second flow regulating surface depends on the latest distance determined by the flow rate regulating function.

Brief description of the drawings

Embodiments of the invention are described below in more detail with reference to the accompanying drawings, in which

Fig. 1 shows a cross-sectional view of a flow control valve according to an embodiment of the invention with a minimum flow rate setting,

Fig. 2 shows the valve of Fig. 1 with a maximum flow rate setting,

Fig. 3 shows the valve of Fig. 2 in a closed position,

Fig. 4 shows a flow control valve with an actuator,

Fig. 5 shows a flow control valve with differently arranged actuators, and

Fig. 6 shows a flow control valve having only one movable valve member.

Description of embodiments of the invention

Figures 1 to 6 show simplified cross-sectional views of flow control valves 1 according to different embodiments of the invention. The flow control valve 1 is suitable for controlling the flow rate of a fluid, which can be gas or liquid, in any application that requires, in addition to the flow rate control function, also an on/off-function for selectively preventing and allowing flow through the valve 1. The flow rate is controlled by changing the cross-sectional flow area through the valve 1, but depends also on the pressure of the fluid. The flow control valve 1 could be used, for instance, in a piston engine, especially in a large internal combustion engine, such as a main or an auxiliary engine of a ship or an engine that is used at a power plant for producing electricity. The flow control valve 1 according to the invention is suitable, in particular, for controlling the injection of gaseous fuel into an intake duct of a gas engine. The flow control valve 1 could also be used as a waste gate valve of an engine for controlling the exhaust gas flow by-passing a turbine of a turbocharger, or as an air by-pass valve for controlling the pressure of an intake air receiver.

The flow control valve 1 comprises a valve body 2 having an inlet 3 for introducing fluid into the valve body 2 and an outlet 4 for discharging the fluid from the valve body 2 and for distributing it further in the system where the flow control valve 1 is used. In the embodiments of the figures, the valve body 2 is rectangular, but it could also have some other shape. For regulating the flow rate through the flow control valve 1, the flow control valve 1 is provided with a first flow regulating surface 7 and a second flow regulating surface 8. The flow regulating surfaces 7, 8 are planar and face each other. However, the flow regulating surfaces 7, 8 could also have some other shape. In the embodiments of the figures, the second flow regulating surface 8 is parallel to the first flow regulating surface 7. Each flow regulating surface 7, 8 extends from one side

wall of the flow control valve 1 to the opposite side wall. The cross-sectional flow area between the first flow regulating surface 7 and the second flow regulating surface 8 is determined by the distance between the two flow regulating surfaces 7, 8. Since the flow regulating surfaces 7, 8 are planar and parallel to each other, the flow area changes linearly as the distance between the flow regulating surfaces 7, 8 changes. A linear control could also be achieved with flow regulating surfaces 7, 8 that are not planar and parallel to each other. All the fluid flowing through the flow control valve 1 flows through the gap 9 that is formed between the first flow regulating surface 7 and the second flow regulating surface 8. The cross-sectional areas of the inlet 3, the outlet 4 and any part of the fluid passage between the inlet 3 and the outlet 4 are determined so that the cross-sectional flow area between the flow regulating surfaces 7, 8 determines the smallest cross-sectional flow area through the flow control valve 1. The flow rate is thus linearly changed over the whole flow rate range of the flow control valve 1.

The flow control valve 1 comprises a first movable valve member 5. The first valve member 5 is arranged inside the valve body 2 and can be moved linearly. The first flow regulating surface 7 forms part of the first valve member 5. The first valve member 5 is a wedge-shaped part tapering towards the outlet 4 of the flow control valve 1. The first flow regulating surface 7 forms an inclined front surface of the first valve member 5. The backside 14 and the sides 15 of the first valve member 5 are in contact with the walls of the valve body 2. The first valve member 5 does not need to be in direct contact with the walls of the valve body 2, but the flow control valve 1 can be provided with seals that are arranged between the valve body 2 and the first valve member 5. The first flow regulating surface 7 is at an angle α in relation to the moving direction of the first valve member 5, which is represented by arrow 10. The angle α is between 20 to 70 degrees.

The flow control valves 1 of figures 1 to 5 also comprise a second movable valve member 6. Also the second valve member 6 is arranged inside the valve body 2 and can be moved linearly. The second valve member 6 is a wedge-shaped part tapering towards the inlet 3 of the flow control-valve 1. The second flow regulating surface 8 forms part of the second valve member 6. The second flow regulating surface 8 forms an inclined front surface of the second valve member 6. The sides 17 and the backside 16 of the second valve member 6 are in contact with the walls of the valve body 2. The flow control valve 1

can be provided with seals that are arranged between the second valve member 6 and the valve body 2. The moving direction 11 of the second valve member 6 is the same as the moving direction 10 of the first valve member 5. Since the second flow regulating surface 8 is parallel to the first flow regulating surface 7, the angle α between the moving direction 11 of the second valve member 6 and the second flow regulating surface 8 is the same as the angle α between the moving direction 10 of the first valve member 5 and the first flow regulating surface 7. The angle α between the flow regulating surface 7, 8 and the moving direction 10, 11 of the valve member 5, 6 determines how sensitively the flow area between the flow regulating surfaces 7, 8 responds to the movements of the valve members 5, 6. The smaller the angle α is, the greater movement of a valve member 5, 6 is needed for achieving a certain change in the flow area. A smaller angle α thus means more accurate control of the flow rate, but slower response to a changing flow demand.

The first valve member 5 is used for steplessly regulating the flow rate through the flow control valve 1. The flow control valve 1 is provided with a first actuator 20, which is configured to move the first valve member 5. The first actuator 20 thus works as first positioning means for adjusting the distance between the first flow regulating surface 7 and the second flow regulating surface 8. The actuator 20 can be, for instance, a hydraulic or a pneumatic actuator comprising a cylinder and a piston. Instead of a pneumatic or a hydraulic actuator, the actuator 20 could be electrical. For example, the actuator 20 could be a solenoid or piezoelectric actuator, or the actuator 20 could comprise an electric motor, of which rotating motion is transformed into a linear motion by a cam, a lever system, or a lead screw. The actuator 20 could also be completely mechanical. In the embodiment of figure 4, the first actuator 20 is arranged inside the valve body 2 and below the first valve member 5 in the moving direction 10 of the first valve member 5. In the embodiment of figure 5, the first actuator 20 is arranged on the backside of the first valve member 5. The first actuator 20 should be able to provide a precise control of the movements of the first valve member 5 to allow accurate control of the flow rate. The required moving speed of the first valve member 5 depends on the application, but in many applications, such as in a fuel injection system of a large piston engine, the first valve member 5 can move relatively slowly. The flow control valve 1 is provided with a guide rail 12 and a guide groove 13, which are arranged inside the valve body 2 for guiding the movement of the first valve member 5 and thus

work as guide means. The guide rail 12 is on the backside of the first valve member 5 and the guide groove 13 is on the side of the first valve member 5. The opposite side can be provided with a similar guide groove. The first valve member 5 is provided with suitable mating surfaces cooperating with the guide rail 12 and the guide groove 13. In the embodiment of the figures, the guide rail 12 is arranged between the first valve member 5 and a wall of the valve body 2. However, the first valve member 5 could also be arranged to move along a guide rail 12, which goes through the first valve member 5. The flow control valve 1 can be provided with suitable stopper surfaces for limiting the movement of the first valve member 5 between a maximum flow rate position shown in figure 2 and a minimum flow rate position shown in figure 1. The movement range of the first valve member 5 could also be limited by the actuator 20. The flow control valve 1 can be provided with suitable seals between the first valve member 5 and the valve body 2.

The second valve member 6 is used as a closing means for opening and closing the fluid communication between the inlet 3 and the outlet 4 of the flow control valve 1. The flow control valve 1 is provided with a second actuator 21, which is arranged to move the second valve member 6. The second actuator 21 works as second positioning means, which switches the flow control valve 1 between an open position and a closed position. The actuator options listed above for the actuator 20 of the first valve member 5 are also suitable for the second valve member 6. However, since the flow rate through the flow control valve 1 is steplessly controlled by the first valve member 5, the movement of the second valve member 6 does not need to be accurately controlled, but the second actuator 21 may be optimized for providing a quick actuation of the second valve member 6. The second actuator 21 can be an on/off type actuator. The second valve member 6 is moved between an open position and a closed position. The open position of the second valve member 6 is fixed and shown in figures 1 and 2. In the open position, the second valve member 6 is retracted into a position maximizing the distance between the first flow regulating surface 7 and the second flow regulating surface 8. The distance and the flow area between the first flow regulating surface 7 and the second flow regulating surface 8 depends on the position of the first valve member 5. The actuation of the second valve member 6 does not affect the position of the first valve member 5.

The closed position of the second valve member 6 depends on the position of the first valve member 5. The closed position of the second valve member 6 with the maximum flow rate setting of the flow control valve 1 is shown in figure 3. When the maximum flow rate setting is in use, the second valve member 6 has to move a longer distance from the open position to the closed position than in a situation when the minimum flow rate setting is in use. In the closed position, the second flow regulating surface 8 is arranged against the first flow regulating surface 7. The first flow regulating surface 7 and/or the second flow regulating surface 8 can be provided with a seal. The second actuator 21 is configured to provide a sufficient force for keeping the second valve member 6 in the closed position, or the flow control valve 1 can be provided with separate retaining means, which are arranged to keep the second valve member 6 in the closed position even when there is a pressure difference over the flow control valve 1. The closing movement of the second valve member 6 can be provided by a passive device, such as a spring, which is arranged to push the second valve member 6 towards the first valve member 5. The opening movement can be implemented, for instance, by a solenoid, which can create a force exceeding the closing force of the passive closing device. Alternatively, the opening movement can be provided by a passive device and the closing movement is implemented by an active device. The flow control valve 1 is provided with a second guide rail 18 and a second guide groove 19, which are arranged inside the valve body 2 for guiding the movement of the second valve member 6. The second valve member 6 is provided with suitable mating surfaces cooperating with the second guide rail 18 and the second guide groove 19. The second guide rail 18 and the second guide groove 19 are similar to the guide rail 12 and the guide groove 13 that are provided for the first valve member 5.

The flow rate setting of the flow control valve 1 can be changed also when the valve 1 is closed. The second valve member 6 is arranged to follow the movement of the first valve member 5 and keep the flow control valve 1 closed even when the first valve member 5 is moved for changing the flow rate setting. When the second valve member 6 is switched to the open position, the flow area between the first and the second flow regulating surfaces 7, 8 corresponds to the setting that was selected by moving the first valve member 5 when the flow control valve 1 was closed. The first valve member 5 and the second valve member 6 can be moved even simultaneously for changing the

flow rate setting and for opening or closing the flow control valve 1 at the same time.

Because the flow rate regulation and the on/off function of the flow control valve 1 are implemented by using separate positioning means 20, 21, the operation of the positioning means 20, 21 can be easily optimized. The flow control valve 1 can thus provide both a quick response time and accurate flow rate regulation. Also the masses of the moving parts of the flow control valve 1 can be optimized and the dynamic behavior of the flow control valve 1 can thus be improved.

Instead of being arranged in the second movable valve member 6, the second flow regulating surface 8 could be a fixed surface. In that case, the second positioning means 21 should be configured to switch the first valve member 5 between an open position and a closed position. For instance, the first valve member 5 could be provided with two actuators, a first actuator being configured to provide the flow regulation and a second actuator being configured to provide the on/off function. Figure 6 shows an embodiment of the invention, where only the first flow regulating surface 7 is movable. The first flow regulating surface 7 is arranged in a first valve member 5 and the second flow regulating surface 8 is a fixed surface. In the embodiment of figure 6, the first valve member 5 is arranged above the second flow regulating surface 8. The flow control valve 1 comprises a positioning means 20 for precisely adjusting the flow rate and an actuator 21 functioning as an on/off device for providing quick closing and opening of the flow control valve 1. Both the positioning means 20 and the actuator 21 are arranged to move the first valve member 5. The positioning means 20 in the embodiment of figure 6 comprise a screw 22 for defining the maximum distance between the first flow regulating surface 7 and the second flow regulating surface 8. The actuator 21 can be, for instance, an electrical or hydraulic device that is capable of moving the first valve member 5 between a closed position and an open position. When the flow control valve 1 is closed, the actuator 21 moves the first valve member 5 against the second flow regulating surface 8. When the flow control valve 1 is opened, the actuator 21 moves the first valve member 5 to a retracted position determined by the screw 22 of the positioning means 20. In the open position of the flow control valve 1, rotation of the screw 22 moves the first valve member 5 and changes the flow area between the flow regulating surfaces 7, 8.

It will be appreciated by a person skilled in the art that the invention is not limited to the embodiments described above, but may vary within the scope of the appended claims.

Claims

1. A flow control valve (1) comprising
   - a valve body (2) having an inlet (3) and an outlet (4),
   - a linearly movable valve member (5), which comprises a first flow regulating surface (7) arranged inside the valve body (2), and
   - a second flow regulating surface (8) arranged inside the valve body (2) and facing the first flow regulating surface (7),

the first flow regulating surface (7) and the second flow regulating surface (8) being arranged so that the movement of the valve member (5) changes linearly the cross-sectional flow area between the first flow regulating surface (7) and the second flow regulating surface (8),

characterized in that the flow control valve (1) comprises
   - first positioning means (20), which are configured to move the valve member (5) for adjusting the distance between the first flow regulating surface (7) and the second flow regulating surface (8), and
   - second positioning means (21), which are configured to switch the valve member (5) or the second flow regulating surface (8) between a closed position, where the first flow regulating surface (7) is against the second flow regulating surface (8), and an open position, where the distance between the first flow regulating surface (7) and the second flow regulating surface (8) depends on the latest position of the valve member (5) determined by the first positioning means (20).

2. A flow control valve (1) according to claim 1, **characterized** in that the first and the second flow regulating surfaces (7, 8) are planar.

3. A flow control valve (1) according to claim 2, **characterized** in that the second flow regulating surface (8) is arranged in parallel with the first flow regulating surface (7).

4. A flow control valve (1) according to any of claims 1 to 3, **characterized** in that the flow control valve (1) comprises a second movable valve member (6) comprising the second flow regulating surface (8), and that the second positioning means (21) are configured to switch the second valve member (6) between the closed position and the open position.

5. A flow control valve (1) according to any of the preceding claims, **characterized** in that the first positioning means (20) comprise an actuator.

6. A flow control valve (1) according to any of the preceding claims, **characterized** in that the second positioning means (21) comprise an actuator.

7. A flow control valve (1) according to any of the preceding claims, **characterized** in that the second positioning means (21) comprise a passive device for creating a closing force for switching the flow control valve (1) to the closed position or for creating an opening force for switching the flow control valve (1) to the open position.

8. A flow control valve (1) according to claim 7, **characterized** in that the passive device is a spring.

9. A flow control valve (1) according to any of the preceding claims, **characterized** in that the flow control valve (1) comprises a guide means (12, 13, 18, 19) for guiding the first valve member (5) and/or the second valve member (6).

10. A flow control valve (1) according to claim 9, **characterized** in that the guide means (12, 13, 18, 19) comprise a guide rail (12, 18) and/or guide groove (13, 19).

11. A flow control valve (1) according to any of the preceding claims, **characterized** in that the first flow regulating surface (7) is at an angle of 20 to 70 degrees in relation to the moving direction (10) of the valve member (5).

12. A method for operating a flow control valve (1) comprising a valve body (2) and having a first flow regulating surface (7) and a second flow regulating surface (8) facing the first flow regulating surface (7), the distance between the first flow regulating surface (7) and the second flow regulating surface (8) determining the smallest cross-sectional flow area through the flow control valve (1), **characterized** in that the flow control valve (1) is operated

- by using a flow rate regulating function by moving the first flow regulating surface (7) linearly relative to the valve body (2) to adjust the distance between the first flow regulating surface (7) and the second flow regulating surface (8) for changing the cross-sectional flow area between the first flow regulating surface (7) and the second flow regulating surface (8) in an open position of the flow control valve (1), and
- by using an on/off function by switching the first flow regulating surface (7) or the second flow regulating surface (8) between a closed position, in which position the flow regulating surfaces (7, 8) are brought together

for preventing flow through the flow control valve (1), and an open position, in which position the distance between the first flow regulating surface (7) and the second flow regulating surface (8) depends on the latest distance determined by the flow rate regulating function.

13. A method according to claim 12, **characterized** in that in the flow rate regulating function the distance between the first flow regulating surface (7) and the second flow regulating surface (8) is adjusted by using first positioning means (20), and in the on/off function the switch between the closed position and the open position is implemented by using second positioning means (21).

14. A method according to claim 12 or 13, **characterized** in that in the flow rate regulating function a first valve member (5) comprising the first flow regulating surface (7) is moved, and in the on/off function a second valve member (6) comprising the second flow regulating surface (8) is moved.

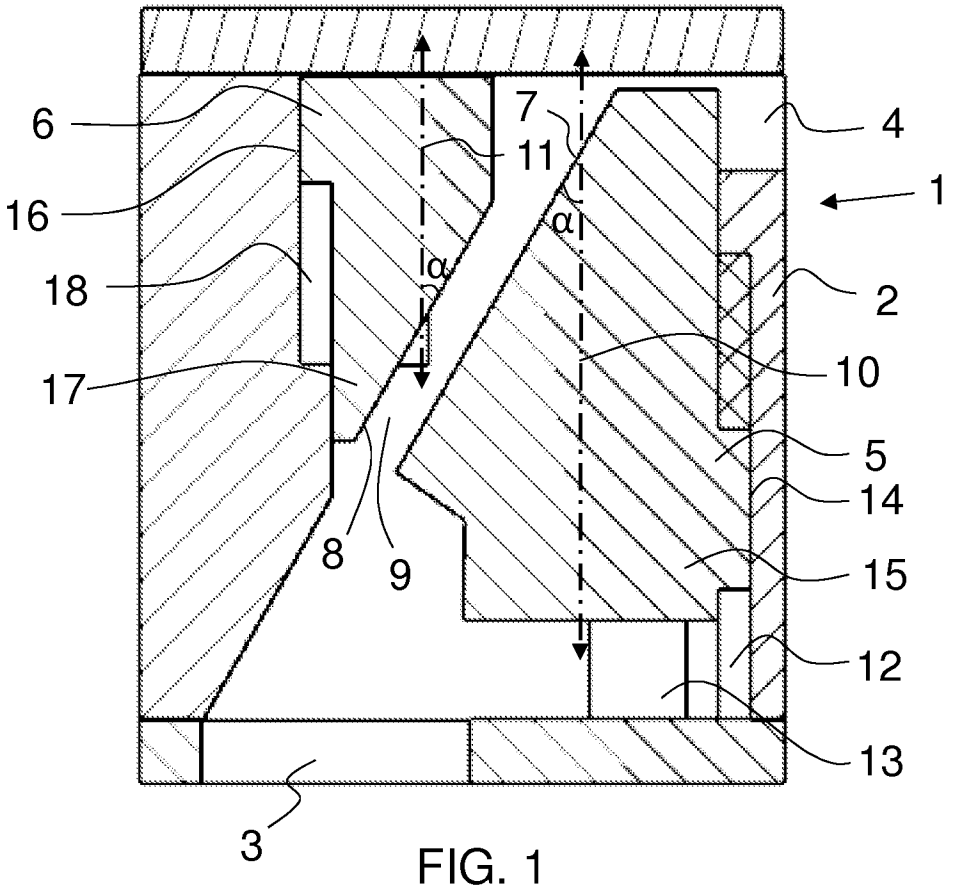
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FIG. 1

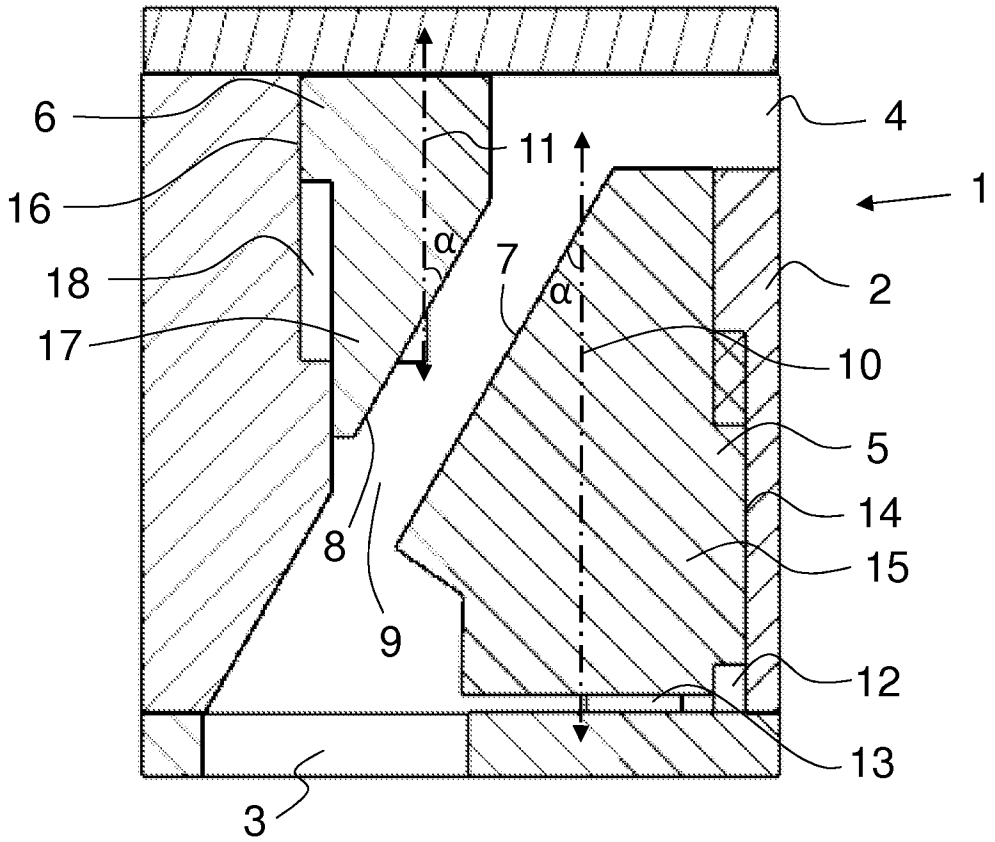
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FIG. 2

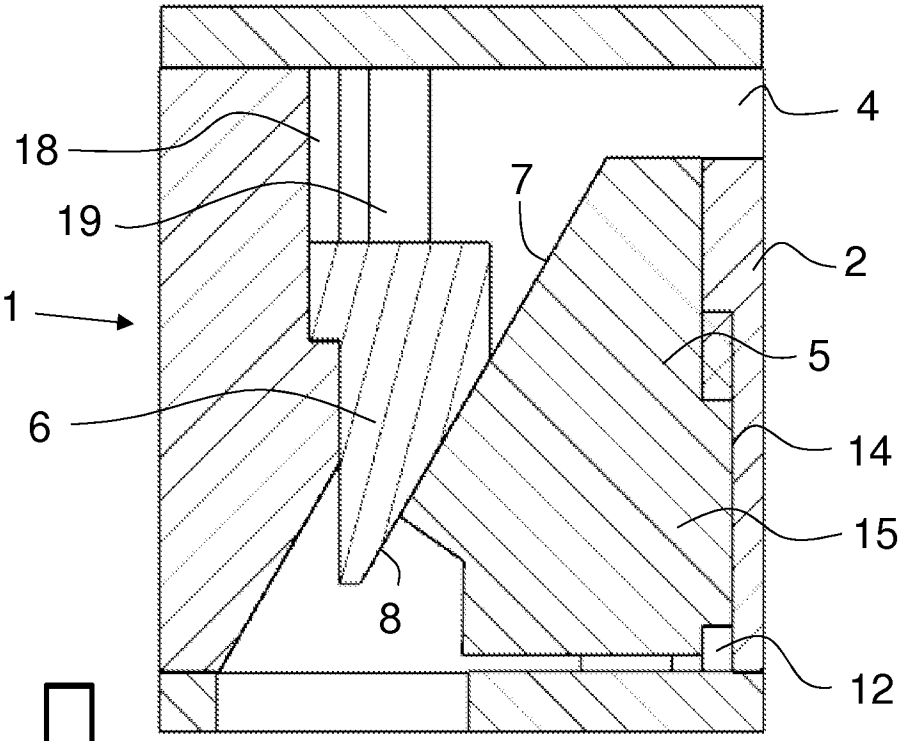

FIG. 3

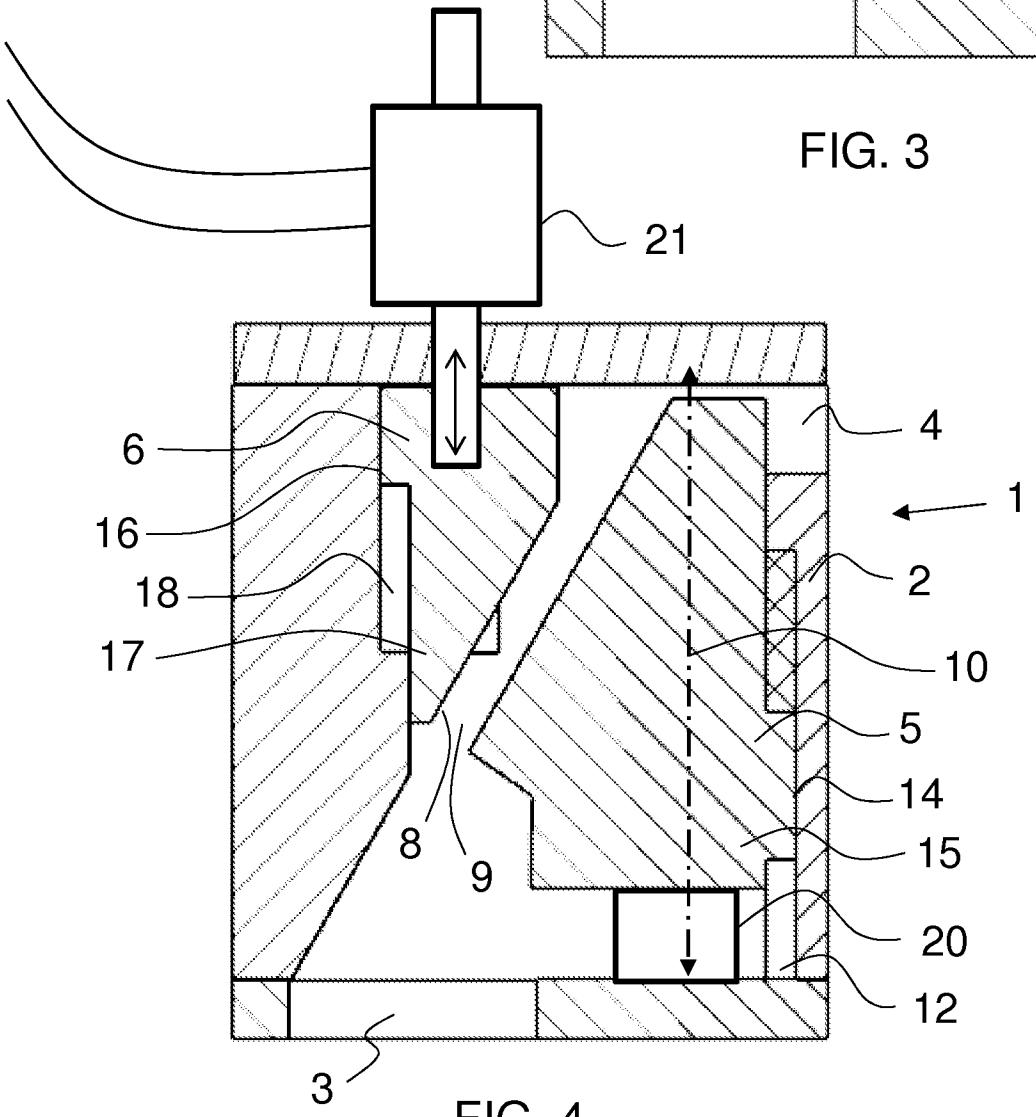

FIG. 4

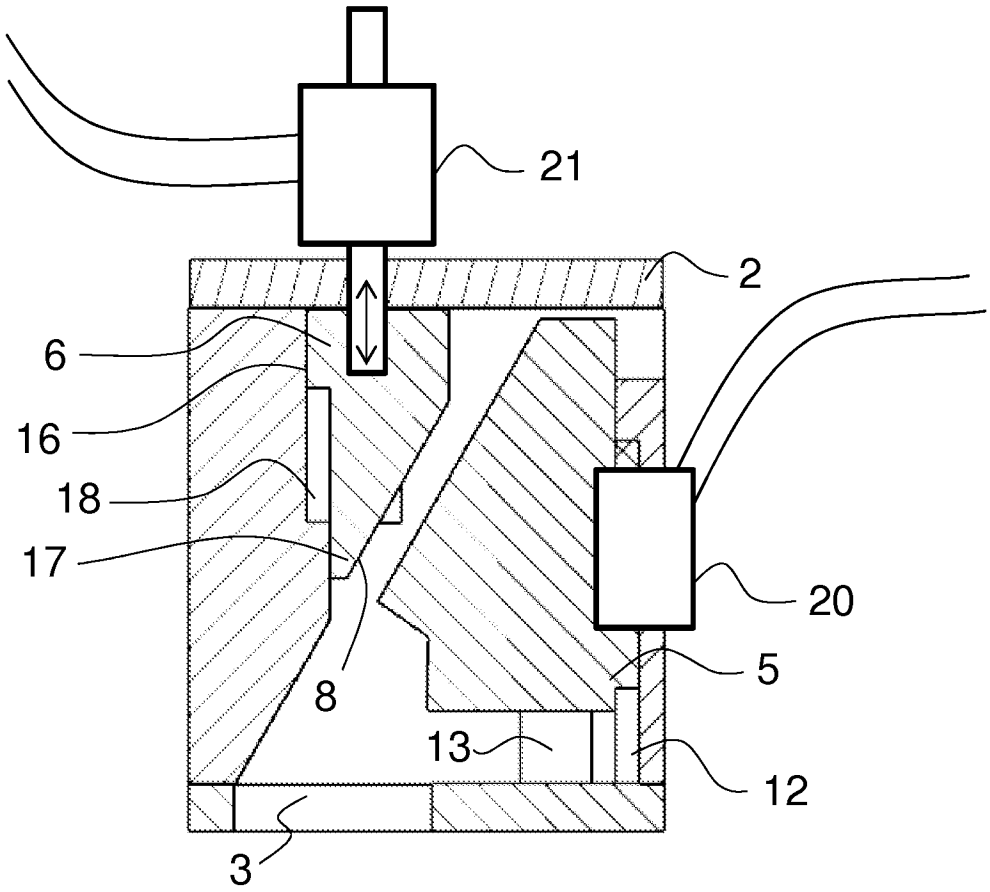

FIG. 5

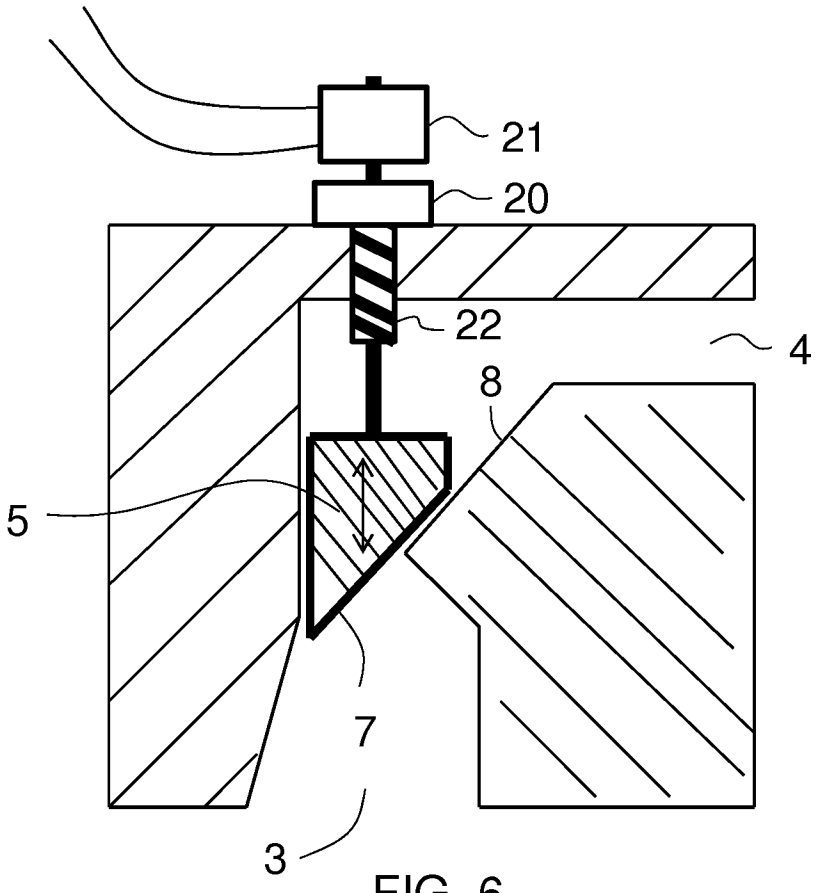

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2015/050192

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16K3/02 F16K3/32 F16K1/52 F16K3/12 F16K31/56
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	GB 1 248 958 A (YOUNG & CUNNINGHAM NEWCAST JAS) 6 October 1971 (1971-10-06) the whole document	1-3,5-13
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X	US 6 045 671 A (WU XIN DI [US] ET AL) 4 April 2000 (2000-04-04) column 16, line 33 - column 18, line 12; figures 5-8	1-6,9-14
X	US 2012/056114 A1 (BENNAUER MARTIN [DE] ET AL) 8 March 2012 (2012-03-08) the whole document	1-14

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

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
5 June 2015	12/06/2015

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

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INTERNATIONAL SEARCH REPORT

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