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(54) Title: ELECTROMAGNETIC COAXIAL VALVE

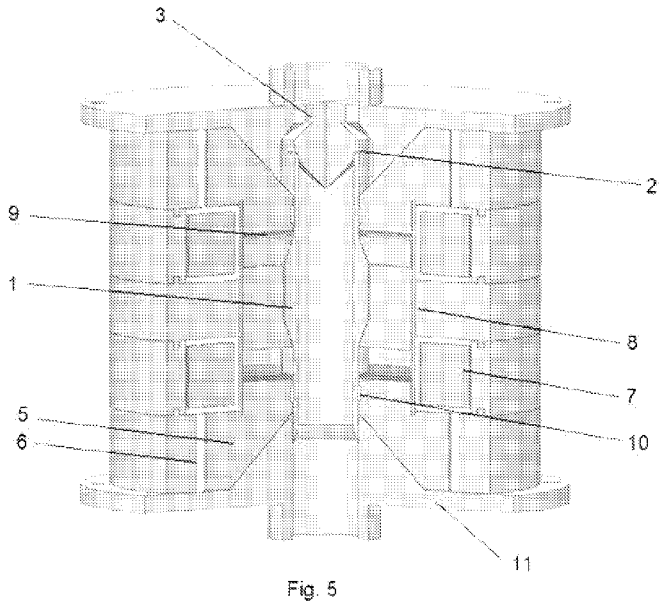

Fig. 5

(57) Abstract: The invention provides an electromagnetic coaxial valve, consisting of a tubular body (1) terminated by an abutting edge (2) configured to rest against a seat (3) located in a flow chamber, wherein the tubular body (1) is longitudinally movable in a housing (5). The housing (5) contains at least one pair of magnetic rings (6), and wherein the tubular body (1) is surrounded by at least one pair of mutually separated electrical windings (7).

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Electromagnetic coaxial valve

Field of Art

The invention relates to an electromagnetic coaxial valve consisting of a tubular body terminated by an abutting edge configured to rest against a seat in a flow chamber, wherein the tubular body is longitudinally movable in a housing. The housing has at least one pair of magnetic rings outside the flow chamber. The tubular body is loosely surrounded by at least one pair of mutually separated electrical windings.

Background Art

Electromagnetic valves are among the most frequently used members for control of fluid flows. They are characterized by simple construction and reliability. Electromagnetic valves consist of an electromagnetic actuator (drive), which controls the valve mechanism, ensuring the opening/closing of the flow chamber. In the traditional design of the electromagnetic valve, the actuator typically consists of an electric winding (cylindrical coil) located in a magnetic circuit with a movable magnetic body, which is mechanically connected using a rod to a movable closing body configured to rest against a seat situated in the flow chamber in such a way that the closure of the flow chamber of the valve occurs when the closing body rests against the seat. The actuator can be located both outside the valve housing. Typically, a rod secured by a seal passes through the wall of the flow chamber and connects the actuator to the closing body; the actuator can be located inside the valve housing. The actuator is usually designed to use at least one spring to ensure return movement (mono-stable design of the valve) or a blocking mechanism to ensure stable positions of the closing body (bi-stable design of the valve).

The basic concept of an electromagnetic valve in a coaxial (i.e., direct) design is described in EP0987478B1, wherein the valve consists of an inlet part and an outlet part connected by a flow chamber. The tubular body of the valve is axially movable inside the flow chamber using an electromagnetic actuator (drive), which closes and opens the flow chamber. Similar technical embodiments are described, for example, in EP3147545B1 and US20200332913A1. While EP3147545B1 describes a pressure-balanced design of a coaxial valve with low-pressure loss,

US20200332913A1 describes a valve design preventing too strong a shock to the closing part of the valve. However, all described designs allow movement of the valve body by the actuator in only one direction. In contrast, the return movement is ensured by a mechanical spring.

A different technical embodiment of an electromagnetic actuator in a valve of a coaxial design is described, for example, in US6361018B2, wherein the valve actuator is a servo motor connected to a transmission mechanism formed by a rocking lever. Unlike the above-described embodiments, the movement of the valve body is controlled in both operations - opening and closing of the valve. However, the connection of individual components of the mechanism is structurally challenging and prone to failure.

An example of a bi-stable coaxial valve is described in WO2018007166A1, wherein the valve body is guided inside a chamber sealed against the inlet and has a fluid connection with the outlet. The chamber between the seats is filled with a liquid to achieve a pressure corresponding to the pressure on the valve outlet. Unlike the above-described embodiments, the valve can be maintained in a stable position (open/closed) without the need to actuate the actuator coils, and the pressure of the liquid ensures a bi-stable mode. However, the bi-stable mode is disturbed when the pressure of the liquid changes, and thus the state of the valve changes.

No technical solutions are known which would provide a coaxial valve that is electromagnetically controlled during the entire operation of the valve (opening/closing) without the need for additional mechanisms while enabling mono-stable and bi-stable modes. Furthermore, the known embodiments also do not allow for regulation of the pressure of a medium behind the outlet of the valve. The invention aims to overcome these drawbacks of prior art.

Disclosure of the Invention

The invention reflects the structural drawbacks of the currently known embodiments of electromagnetic valves. The invention provides an original design of an electromagnetic coaxial valve, overcoming these drawbacks. The electromagnetic coaxial valve's topology, material, and construction achieve the electromagnetical control during the entire operation of the valve.

The invention provides significant advantages, including low energy consumption, a high response rate, and the possibility of eliminating failures. The design is based on two essential pre-requisites:

(i) the valve is fully electromagnetic - the electromagnetic field directly controls the primary function, and observation of the electromagnetic field allows to determine the current state of the valve;

(ii) the valve has a coaxial design - the liquid passes through the valve in an axial direction.

The electromagnetic coaxial valve uses magnetic rings to ensure a stable position of the valve body (valve open/closed) and an electrical winding to change its state (valve open/closed). A magnetic ring composed of rare earth permanent magnets, such as SmCo, NdFeB, and others, and an optimized valve magnetic circuit topology, such as magnetic stainless steel, allow for high energy density. The electric winding creates a magnetic induction flux to control the valve, and the valve achieves a high dynamic response with low power consumption.

To secure the tightness and sealing of the valve between the individual parts of the magnetic circuit, it is preferred to use a seal made of a composite material based on a magnetorheological elastomer, which reduces the magnetic resistance (reluctance) of the individual parts of the magnetic circuit and simultaneously increases the tightness due to its deformation due to the passing magnetic flux - the magnetic elastomer fills the air-filled gaps between magnetic circuit parts. Direct measurement of the inductance of the electrical winding can be used to determine the stable state of the valve (open/closed), and measurement of the induced voltage during valve switching (opening/closing) allows monitoring of the transition between the stable states.

In some embodiments, cyclic excitation of the electric winding allows rapid switching of the valve, thereby directly regulating the pressure of the medium in the outlet part of the valve.

In some embodiments, the magnetic rings produce asymmetric magnetic induction flux.

The invention provides an electromagnetic coaxial valve consisting of a tubular body terminated by an abutting edge configured to rest against a seat in a flow chamber, wherein the

tubular body is longitudinally movable in a housing. The housing contains at least one pair of magnetic rings outside the flow chamber. The tubular body is loosely surrounded by at least one pair of mutually separated electrical windings. The magnetic rings secure and stabilize the longitudinally movable tubular body in the stable (terminal) positions corresponding to the open/closed state of the valve. A change in the position of the longitudinally movable tubular body, and thus the change in the state of the valve - the open/closed state - is ensured by a pulse of electric current in the electric winding. The orientation of the current must create a magnetic induction flux that acts against the flow of the magnetic ring, ensuring the original position of the longitudinally movable tubular body. It is preferred that the electrical windings from each pair are located in mutually opposite positions.

In some embodiments, a compensating pressure tank ensuring a regulated flow of the medium is provided in the outlet part of the valve at one end of the flow chamber.

The medium is a medium passing through the valve. The medium may be a liquid or gaseous medium.

The valve of the invention is designed in a coaxial, i.e. direct, design. The flow chamber (or channel) extends along the central axis of the valve. It connects the valve to the inlet and outlet. The valve is a two-way valve, so the medium can be fed both under and above the valve seat. The valve seat is connected to a valve flange. In the closed state of the valve, the tubular body is placed (or rests) against the seat. The tubular body forms the valve channel. An O-ring seal on the valve seat ensures the tightness of the valve in the closed state.

The electromagnetic actuator (drive) for controlling the valve consists of a magnetic circuit with permanent magnets (magnetic rings), a movable tubular body, and cylindrical coils (electrical windings). The forces holding the movable tubular body in stable positions (open and closed valve position) are fully ensured by the magnetic rings. The excitation of the electrical winding ensures the transition between stable positions. The magnetic flux caused by the winding amplifies the magnetic flux of the magnetic ring and thereby changes the balance of forces in the stable positions of the movable tubular body (open/closed valve). In stable

positions, the movable tubular body rests on a pair of stops made of magnetorheological elastomer placed between the magnetic circuit and the corresponding edge of the moving body. In the basic design, the valve is bi-stable. The magnetic rings thus ensure the stable positions of the movable tubular body (open/closed valve). Using different magnetic rings (different numbers of permanent magnets) allows to achieve a mono-stable mode. In this case, the movable tubular body is maintained in an unstable position by the magnetic flux of the excited electric winding, and a magnetic ring ensures a stable position of the movable tubular body.

The advantages and advantageous features of the valve of the present invention are mainly due to the structural features of the controlling electromagnetic actuator. They may be summarized into the following points:

- The electromagnetic actuator is fully controlled by the magnetic flux caused by the electric winding. The valve does not need to contain springs or rods required for the function of the valve (e.g., to ensure reciprocating movement or a stable position of the valve).
- The actuator enables both bi-stable and mono-stable valve modes.
- The transition between the stable valve positions is performed by briefly exciting the electric winding of the electromagnetic actuator. It ensures a high rate of valve state change (open/closed) with low power consumption.
- Using a magnetic ring composed of permanent magnets based on rare earths and the topology of the electromagnetic actuator's magnetic circuit allows high energy density. The valve has a high response speed.
- The magnetic circuit design of the electromagnetic actuator enables the detection of the state of the valve (open/closed) without additional sensors, merely by measuring the inductance of the mutually separated electrical windings.
- The design of the valve flow chamber enables bi-directional operation of the valve (medium supplied above/under the seat). Pressure surges are eliminated if the valve is connected to the medium supply under the seat.
- The coaxial design of the valve ensures a low-pressure drop.
- The valve enables regulation of the medium pressure in the outlet part of the valve by a rapid cyclic excitation switching.

Brief Description of Drawings

Fig. 1 shows an example of the invention's electromagnetic coaxial valve in a partial sectional view in symmetry along the central axis.

Fig. 2a shows a sectional view of a part of the electromagnetic coaxial valve in the closed state.

Fig. 2b shows a sectional view of the same part of the electromagnetic coaxial valve in the open state.

Fig. 3a shows a sectional view of the valve at the seat. Cross-section A shows the embodiment of the body with a leading edge.

Fig. 3b is a view of a cross-section B showing the magnetic ring. This cross-section shows the electromagnetic coaxial valve in the open state, allowing controlled fluid flow through the flow chamber.

Fig. 4a shows a sectional view of the electromagnetic coaxial valve in the open state, and Fig. 4b shows a sectional view of the electromagnetic coaxial valve in the closed state.

Fig. 5 shows a valve 3D model according to the example, which was experimentally tested in a partial sectional view.

Example

The drawings show that the electromagnetic coaxial valve consists of a tubular body 1, which is terminated by an abutting edge 2. The abutting edge 2 faces a seat 3 or rests against a seat 3. The seat 3 is located in a flow chamber 4. The tubular body 1 is longitudinally movable in a housing 5. The housing 5 contains two magnetic rings 6 outside the flow chamber 4. The magnetic ring 6 is made of an NdFeB permanent magnet in this embodiment. The tubular body 1 is loosely surrounded by one pair of mutually separated electrical windings 7. A sliding member 8 made of non-magnetic material is incorporated between the electrical windings 7 and the tubular body 1. The housing 5 is provided with abutting stops 9 made of magnetic elastomer. The housing 5 is sealed against the flow chamber 4 by a seal 10. The housing 5 is provided with flanges 11 on both sides.

The magnetic rings 6 secure the longitudinally movable tubular body 1 in the stable terminal positions. A change in the position of the longitudinally movable tubular body 1, and thus the

change in the state of the valve - the open/closed state - is ensured by a pulse of electric current in the electric winding 7, wherein the orientation of the current must create a magnetic induction flux that acts against the flux of the magnetic ring 6 ensuring the original stable position of the movable tubular body 1. The magnetic flux excited by the winding 7 amplifies the magnetic flux of the magnetic ring 6, thereby changing the balance of forces in the stable positions of the moving tubular body 1. In the open state, the medium passes through the flow chamber 4 in the tubular body 1 arranged longitudinally in the housing 5. By abutting the abutting edge 2 of the tubular body 1 to the seat 3, the flow of medium through the flow chamber 4 in the tubular body 1 arranged longitudinally in the housing 5 is closed.

A compensating pressure tank 12 contains the medium. It ensures a regulated flow of the medium, and thus, control of pressure in the valve is provided in the outlet part V1 of the valve.

Industrial Applicability

The invention applies mainly to energy, heating, cooling, and water management to regulate the flow of liquid or gaseous media.

The embodiment of the valve with the function of medium pressure regulation is applicable, particularly in systems using gaseous media with low pipe clearance, where the valve may perform the function of a regulator, which would otherwise need to be installed as a separate device.

CLAIMS

1. Electromagnetic coaxial valve, consisting of a tubular body (1) terminated by an abutting edge (2) configured to rest against a seat (3) located in a flow chamber (4), wherein the tubular body (1) is longitudinally movable in a housing (5), **characterized in tha**t the housing (5) contains at least one pair of magnetic rings (6), and wherein the tubular body (1) is surrounded by at least one pair of mutually separated electrical windings (7).

2. Electromagnetic coaxial valve according to claim 1, which further comprises a compensating pressure tank (12) configured to provide a regulated flow of the medium controlled by fast cyclic valve switching, wherein the compensating pressure tank (12) is located in the outlet part (V1) of the valve at one end of the flow chamber (4).

3. Electromagnetic coaxial valve according to claim 1 or 2, wherein a sliding member (8) made of non-magnetic material is incorporated between the electrical windings (7) and the tubular body (1).

4. Electromagnetic coaxial valve according to any one of claims 1 to 2, wherein the housing (5) is provided with stops (9) made of magnetorheological elastomer.

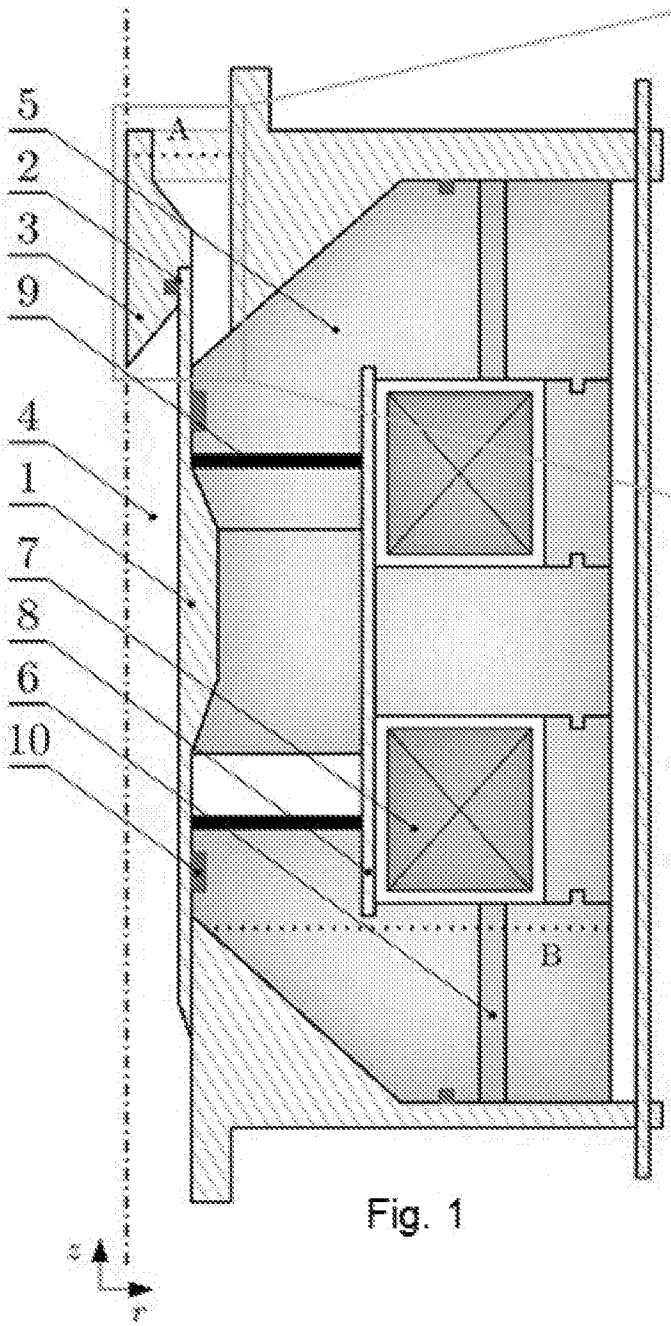
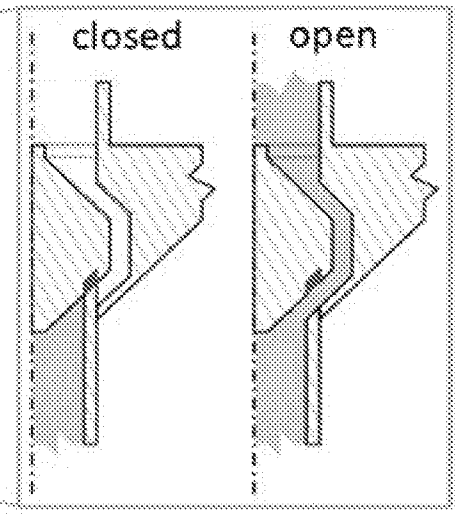


Fig. 1

Fig. 2a Fig. 2b



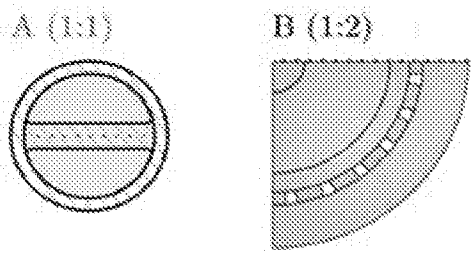


Fig. 3a Fig. 3b

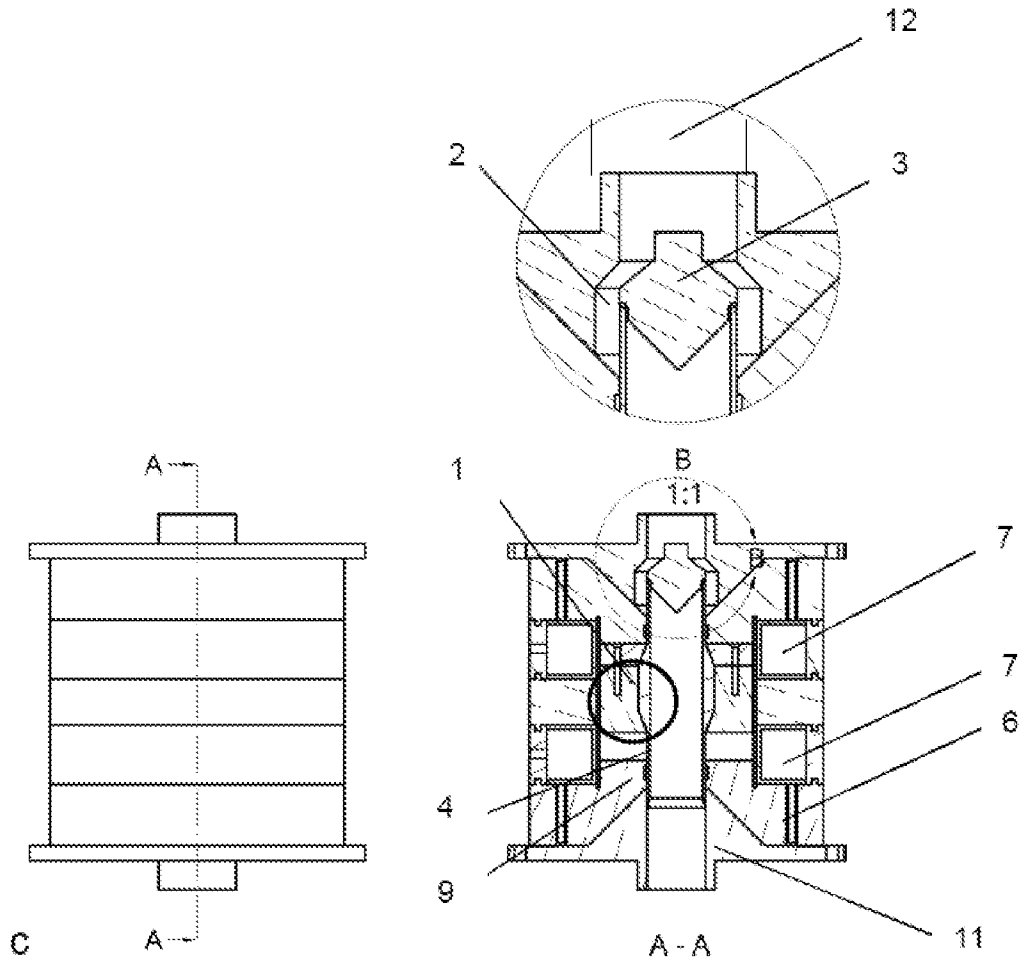


Fig. 4a

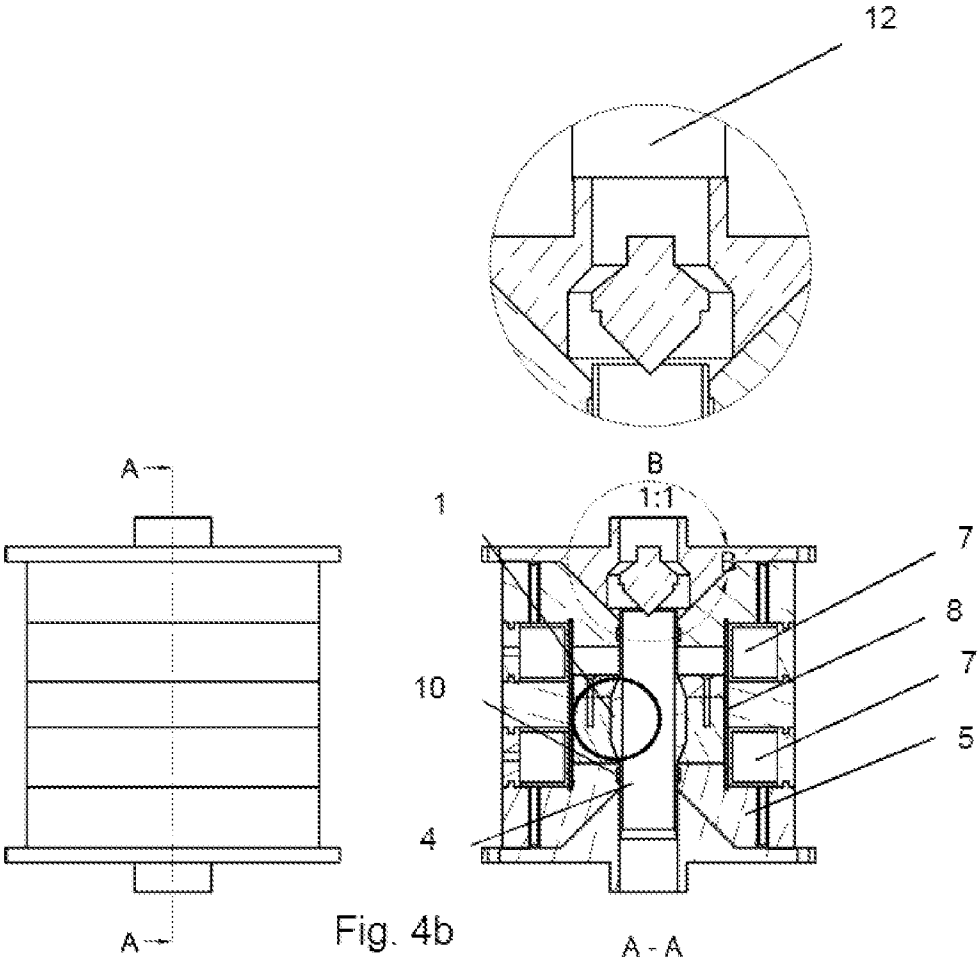


Fig. 4b

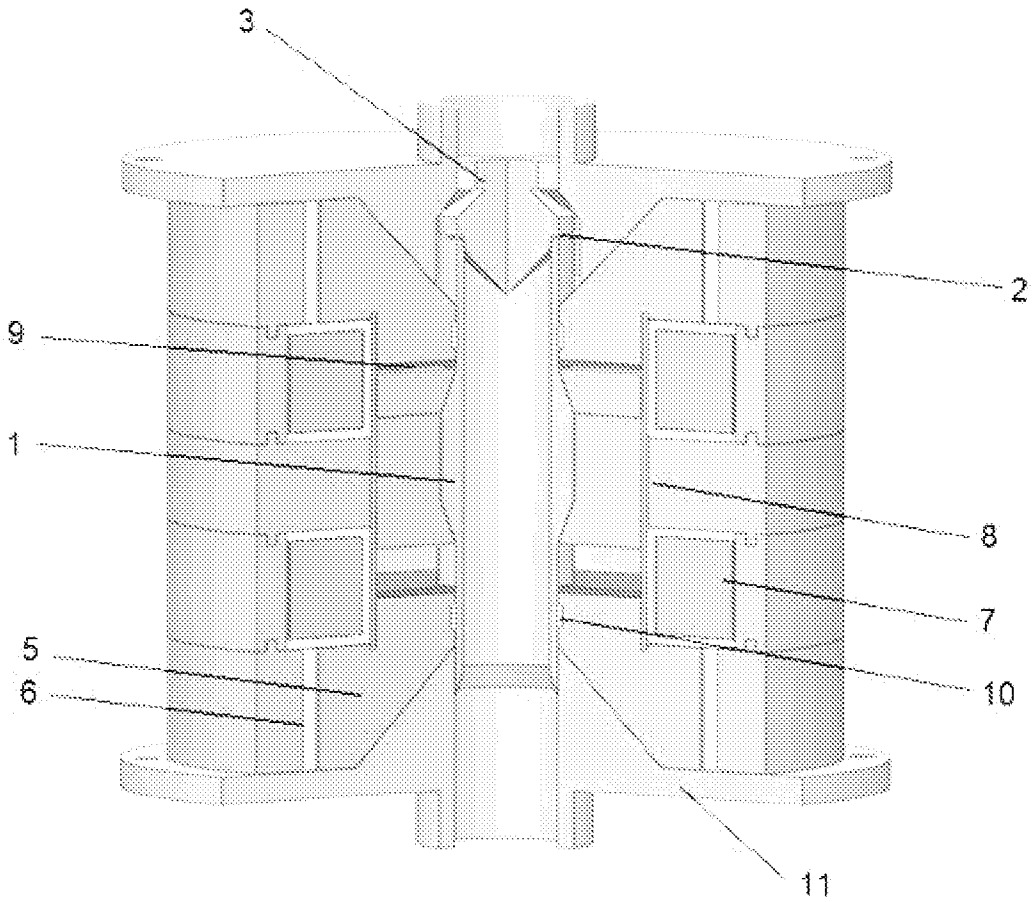


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2024/050041

A. CLASSIFICATION OF SUBJECT MATTER
INV. F16K1/30 F16K31/06 F16K31/08 F16K47/00
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 168 306 B1 (SFIM [FR]) 16 December 1987 (1987-12-16)	1-3
Y	column 1, line 64 - column 2, line 3; figures	4

X	DE 600 21 062 T2 (SIDEL LE HAVRE [FR]) 18 May 2006 (2006-05-18)	1-3
A	paragraph [0017] - paragraph [0028]; figures 1-3	4

Y	EP 2 486 368 B1 (ZEISS CARL INDUSTRIELLE MESSTECHNIK GMBH [DE]) 24 January 2018 (2018-01-24) paragraph [0016] - paragraph [0022]; figures 4, 5	4

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

[x] See patent family annex.

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

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Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2024	02/10/2024

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2024/050041

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 529 281 A (BRUDNICKI MYRON J [US] ET AL) 25 June 1996 (1996-06-25) column 3, line 8 - column 4, line 6; figures	1,4
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Information on patent family members

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