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Remarks:
Amended claims in accordance with Rule 137(2) EPC.

(54) **Hydraulic machine, in particular a hydraulic pressure exchanger**

(57) A hydraulic machine, in particular hydraulic pressure exchanger, is provided comprising a drum having a first end face and a second end face and being rotatable about an axis, said drum comprising at least a cylinder (4), a piston (15) being arranged in said cylinder (4), said piston (15) being moveable in a first moving direction and in a second moving direction opposite to said first moving direction, said piston dividing said cylinder in a first section opening in said first end face and a second section opening in said second end face.

Such hydraulic pressure exchanger should be operated with a low noise.

To this end braking means are provided for at least of said moving directions, said braking means braking said piston (15) before reaching an end stop.

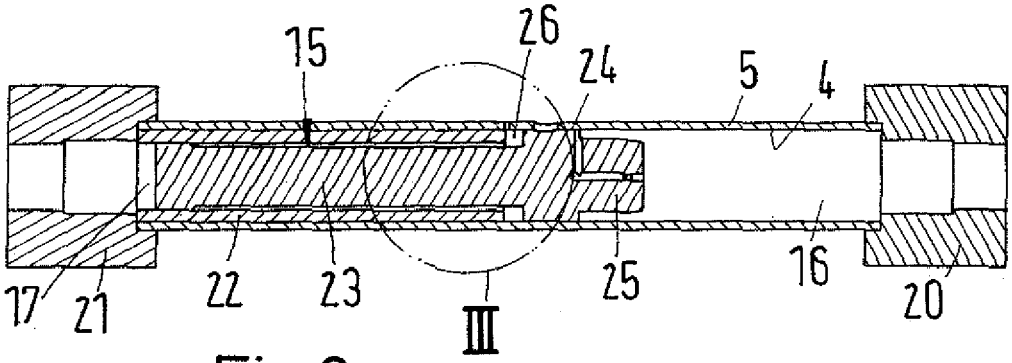

Fig.2

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Description

[0001] The present invention relates to a machine, in particular a hydraulic pressure exchanger, comprising a drum having a first end face and a second end face and being rotatable about an axis, said drum comprising at least a cylinder, a piston being arranged in said cylinder, said piston being moveable in a first moving direction and in a second moving direction opposite to said first moving direction, said piston dividing said cylinder in a first section opening in said first end face and a second section opening in said second end face.

[0002] Such a hydraulic pressure exchanger is known from
EP 1508 361 A1.

[0003] A pressure exchanger of this kind can be used in a reverse osmosis system. In such a system a liquid is pumped into a membrane unit. Part of the liquid passes the membrane. The remaining part of the liquid has to be wasted. However, the pressure exchanger can be used to recover the high pressure of this part of the fluid. To this end the pressure exchanger comprises a first front plate arrangement at the first end face of the drum and a second front plate arrangement at the second end face of the drum. The first front plate arrangement has a high pressure supply port and a low pressure return port. The second front plate arrangement comprises a high pressure return port and a low pressure supply port.

[0004] The operation of such a pressure exchanger can briefly be summarized as follows: a cylinder passing a first kidney-shaped opening in the first front plate arrangement connected to the high pressure supply port is filled with liquid under high pressure. The piston arranged in this cylinder is moved by the incoming liquid in a direction from the first end face towards the second end face of the drum. The second section of the cylinder has previously been filled with fresh liquid from the low pressure supply port. This fresh liquid is outputted to the second front plate arrangement via the high pressure return port. When the drum continues rotating, the cylinder passes another kidney-shaped opening in the second front plate arrangement connected to the low pressure supply port so that this cylinder is filled with fresh liquid. This fresh liquid pushes the piston in a direction towards the first end face of the drum and outputs the liquid to be wasted.

[0005] The amount of fresh liquid which can be pressurized by the hydraulic pressure exchanger depends among other factors on the rotational speed of the drum. The faster the drum rotates, the more liquid can be pressurized. However, increasing rotational speed causes a corresponding increase of noise.

[0006] The object underlying the invention is to keep noise low.

[0007] This object is solved in that braking means are provided for at least one of said moving directions, the braking means braking said piston before reaching an end stop.

[0008] It has been discovered that part of the noise is caused by the pistons in the cylinder at the end of a piston stroke. When the rotational speed of the drum increases, the linear speed of the pistons has to be increased as well. However, a piston having a high speed produces a rather loud noise when it hits an end stop. The braking means reduce significantly such noise because the speed of the piston is reduced by said braking means before the piston reaches the end stop. The lower the speed of the piston when reaching the end stop, the lower the noise is.

[0009] In a preferred embodiment said braking means are hydraulic braking means. Since the pressure exchanger operates with a liquid, this liquid can be used to brake the piston before it reaches the end stop in order to reduce noise.

[0010] Preferably a braking chamber is provided for at least one of said moving directions, said braking chamber having an opening being open during a part of the movement of said piston and being closed a predetermined distance before said piston reaches said end stop, said closed braking chamber having a throttled outlet. The moving of the piston can be divided in a first part in which there is no hydraulic braking at all. In this part of the movement the braking chamber is open to allow liquid in the braking chamber to escape without being throttled. In a second part of the movement the braking chamber is closed so that the liquid can escape from the braking chamber only via the throttled outlet. The force which is necessary to drive the liquid through the throttled outlet is the force acting on the piston in a braking direction. The kinetic energy of the piston is changed into heat. However, this is no problem, since the heat is transported away by the liquid.

[0011] Preferably said throttled outlet comprises an orifice. This orifice can be dimensioned to achieve the desired braking effect. Furthermore, it is preferred that said throttled outlet comprises a valve, in particular a check valve. Such valve can be used to restrict the flow of fluid through the throttled outlet. Such a restriction can be a directional restriction, in case a check valve is used.

[0012] In a further preferred embodiment said throttled outlet comprises a leakage path. Such a leakage path can be formed between the piston and a part of the cylinder.

[0013] Preferably during closing of said braking chamber said piston gradually decreases said opening. The braking means are self-controlled. The movement of the piston increases a throttling behavior of the flow resistance of the throttled outlet.

[0014] Preferably said braking chamber is arranged between said piston and a wall of said cylinder. No additional parts are necessary to form a limitation of said braking chamber.

[0015] In a preferred embodiment a first braking chamber having a first opening and a first throttled outlet is provided for said first moving direction and a second braking chamber having a second opening and a second

throttled outlet is provided for said second moving direction, said first throttled outlet and said second throttled outlet being separate from each other. The two throttled outlets do not form a short circuit so that the two braking means can be operated independently from each other.

[0016] In a preferred embodiment said first opening is arranged in said wall of said cylinder. In this case the liquid in the braking chamber is displaced to the interior of the drum or to the interior of a housing in which the drum is accommodated.

[0017] In this case it is preferred that said first throttled outlet is arranged in said wall of said cylinder. In principle, it is sufficient to have two bores in the wall of the cylinder, said bores having a predetermined distance and different diameters. The larger bore is the opening of the first braking chamber and the smaller bore is the throttled output.

[0018] Furthermore, it is preferred that a sleeve is arranged within said cylinder reducing an inner diameter of said cylinder in said first direction, said piston comprising a projection being inserted into said sleeve, said first braking chamber being delimited by said piston, said sleeve and said wall of said cylinder. In this embodiment the two front faces of the piston have surface areas of different size. Due to the difference in size of the surface area the fluid in the second chamber can be pressurized to a pressure which is larger than the pressure in the first chamber. Furthermore, a simple construction of the machine is achieved.

[0019] Preferably said second opening is the opening of said cylinder in an end face. This makes the construction of the machine simple.

[0020] In this case it is preferred that said second throttled outlet runs through said piston. The braking chamber is connected to the opening of the cylinder in the second end face via a path running through the piston.

[0021] In this case it is preferred that said second throttled outlet opens into a low pressure side of said cylinder. In this case there is no pressure acting against the outlet via the throttled opening.

[0022] Preferably said second outlet has a section area smaller than a section area of said cylinder, said piston having a protrusion penetrating into said second outlet in a predetermined distance before said piston reaches said end stop. In this case the second opening is closed by the piston itself when the protrusion enters the second outlet.

[0023] In this case it is preferred that said protrusion comprises a tapered end at least on part of its circumference. This tapered end has the effect that the second opening is not suddenly closed, but it is gradually closed during a movement of the protrusion of the piston into said second opening. This is an additionally element for reducing noise.

[0024] A preferred example of the invention will now be described in more detail with reference to the drawing, wherein:

Fig. 1 is a schematic representation of a hydraulic pressure exchanger,

Fig. 2 is an enlarged sectional view of a cylinder,

Fig. 3 is a detail III of Fig. 2,

Fig. 4 is a perspective view of the cylinder of Fig. 2,

Fig. 5 is a sectional view of the cylinder showing the piston in another position,

Fig. 6 is a detail VI of Fig. 5 and

Fig. 7 is a perspective view of the cylinder of Fig. 5.

[0025] Fig. 1 shows schematically a hydraulic machine in the form of a hydraulic pressure exchanger 1 in a longitudinal section.

[0026] The pressure exchanger comprises a drum 2 rotatable about an axis 3. The term "drum" is used to facilitate the explanation. It is not necessary that this drum 2 is of cylindrical form. The main purpose of the drum 2 is to form a basis for cylinders 4. The drum 2 comprises a plurality of cylinders 4, two cylinders 4 being shown in Fig. 1. The drum 2 can also be termed as "cylinder carrier". Each cylinder 4 is limited in circumferential direction by a wall 5. The term "cylinder" is used to simplify the description. It is not necessary that the cylinder has a circular cross section.

[0027] A first front plate arrangement 6 is arranged at a first end face of the drum 2. A second front plate arrangement 7 is arranged at a second end face of the drum 2, said second end face being on the opposite side of the first end face of the drum 2.

[0028] The first front plate arrangement 6 comprises a first front plate 8 and a pressure shoe 9. The first front plate 8 comprises a high pressure supply port 10 and a low pressure return port 11. The high pressure return port 10 is connected to a high pressure channel 12 of the pressure shoe 9 by means of a sleeve 13. The drum 2 is rotatable supported within a housing 14. Means for driving the drum 2 are not shown in order to keep the illustration simple. However, a driving shaft can be passed through the second front plate arrangement 7.

[0029] Each cylinder 4 is provided with a piston 15. The piston 15 divides the cylinder 4 in a first chamber 16 and a second chamber 17. The piston 15 is moveable in a first direction from the first end face towards the second end face of the drum 2. Furthermore, the piston 15 is moveable in a second, opposite direction from the second end face towards the first end face of the drum 2.

[0030] The movement of the piston 15 is caused by pressure differences. In the illustration of Fig. 1 the upper piston is moved in the first direction under the influence of a hydraulic pressure present at the high pressure supply port 10. During this movement, liquid present in the second chamber 17 is displaced to a high pressure return port 18 in the second front plate arrangement 7. When

the drum 2 is further rotated, the cylinder 4 comes in an overlap to a low pressure supply port 19. Fresh liquid under a pressure which is higher than the pressure at the low pressure return port 11 is supplied to the second chamber 17 moving the piston 15 in the second direction towards the first front plate arrangement 6 and pushing liquid out of the first chamber 16 into the low pressure return port 11.

[0031] One way to increase the capacity of the hydraulic pressure exchanger 1 is to increase the rotational speed with which the drum 2 rotates. In this case the pistons 15 have to be moved rather fast since they should be moved from the first end face to the second end face or vice versa during less than a half rotation of the drum 2. The high speed movement of the pistons 15 could cause trouble since the pistons 15 are suddenly stopped when they hit end stops (not shown). Such a stop causes noise which should be avoided.

[0032] To this end, braking means are provided for both moving directions of the piston 15, such braking means are described in connection with Fig. 2 to 7.

[0033] Fig. 2 to 4 show the braking means for the first moving direction.

[0034] The cylinder wall 5 is arranged between a holder 20 at the first end face of the drum 2 and a holder 21 at the second end face of the drum 2. It is possible to use the holder 20 as end stop.

[0035] A sleeve 22 is arranged in the cylinder 4 surrounding the second chamber 17. The piston 15 comprises a section 23 which is guided in the sleeve 22. The inner diameter of sleeve 22 corresponds to the outer diameter of the section 23.

[0036] This has the additional effect that the piston 15 has an area difference between the front faces so that the fluid in the exchanger can be amplified and can, in a reverse osmosis system, for example avoid a booster pump. However, the difference between the front faces of the piston can be realized in other ways and is not limited to the embodiment shown.

[0037] The piston 15 comprises a further section 24 having a larger diameter. The diameter of the section 24 corresponds to the inner diameter of the cylinder 4.

[0038] Furthermore, the piston 15 comprises a protrusion 25 being directed towards the first holder 20.

[0039] A braking chamber 26 is limited by the cylinder wall 5, a circumferential face of the first section 23, a front face of the sleeve 22 and a front face of the second section 24 of the piston 15.

[0040] This braking chamber 26 is connected via a first opening 27 with the interior of the housing 14. During a first part of the movement of the piston 15, this first opening 24 allows an almost unrestricted flow of fluid out of the braking chamber 26 into the interior of the housing 14 which is filled with liquid under low pressure, said low pressure corresponding to a pressure between the pressure at the low pressure supply port 19 and the pressure at the low pressure return port 11.

[0041] The first opening 27, however, is open only during this first part of the movement of the piston 15 in the first direction. In other words, it is open only until the second section 24 of the piston 15 starts overlapping the first opening 27. During a further movement of the piston 15 in the first direction, the first opening 27 is gradually closed until the position shown in Fig. 2 to 4 is reached.

[0042] When the first opening 27 is closed, as shown in Fig. 2-4, the braking chamber 26 is connected to the interior of the housing 14 by means of a first throttled outlet 28 only. The first throttled outlet 28 allows escape of liquid out of the braking chamber 26, however, the flow out of the braking chamber 26 is restricted. This restriction converts the kinetic energy of the piston 15 into heat.

[0043] In principle, the first opening 27 can be made as a bore having a first diameter and the first throttled outlet 28 can be made by a bore having a second diameter, the second diameter being much smaller than the first diameter.

[0044] In a way not shown, the braking chamber 26 can be connected to the interior of the housing 14 by means of a check valve opening in a direction towards the braking chamber 26. Such a check valve facilitates refilling of the braking chamber 26 when the piston 15 is moved in the second direction.

[0045] The first throttled outlet out of the braking chamber 26 can be realized additionally or alternatively in other ways. Fig. 3 shows a leakage path 29 between the sleeve 22 and the first section 23 of the piston 15. This leakage path 29 can be made just by a clearance between the sleeve 22 and the first section 23 of the piston 15. It can also be made by a groove running in longitudinal direction of the first section 23 of the piston 15.

[0046] When the piston 15 is moved in the first direction, liquid escapes out of the braking chamber 26 through the first opening 27 until the second section 24 of the piston 15 starts closing the first opening 27. A further movement of the piston 15 makes smaller the first opening 27 thereby increasing gradually a flow resistance for the liquid to escape out of the braking chamber 26. When the first opening 27 is completely closed, the liquid can escape through the first throttled outlet 28 only or through the liquid path 29. Finally, the movement of the piston 15 stops before the piston 15 reaches an end stop which can in the present case be formed by the sleeve 22.

[0047] Fig. 5 to 7 show the braking means at the other end of the cylinder 4. The same elements are designated with the same reference numerals.

[0048] A second braking chamber 30 is formed between the wall 5 of the cylinder, the protrusion 25 of the piston 15, a front face of the second section 24 and a front face of the holder 20.

[0049] This second braking chamber 30 is open as long the protrusion 25 has not been inserted into a channel 31 in the holder 20 when the piston 15 moves in the second direction. The channel 31 is connected to the low pressure return port 11. In this way the second braking chamber 30 can unrestrictedly output the liquid in the first

chamber 16 of the cylinder 4 into the low pressure return port 11 as long as the second braking chamber is not closed.

[0050] The protrusion 25 comprises a tapered end 32. In Fig. 6 the tapered end 32 is shown to cover the complete circumference of the protrusion 25. However, in some cases it is sufficient that the tapered end extends only over part of the circumference.

[0051] The channel 31 forms a second opening through which the liquid can escape out of the first chamber 16 when the piston moves in the second direction. The size of this opening is decreased when the protrusion 25 enters the channel 31. The size of the opening decreases gradually because of the tapered end 32.

[0052] When the protrusion 25 has reached the position shown in Fig. 6 in which the channel 31 is completely closed by the protrusion 25, the only way for the liquid out of the second braking chamber 30 is through a second throttled outlet 33 running through the piston 15. The second throttled outlet 33 comprises an orifice 34 by means of which the throttling effect of the second throttled outlet 33 can be adjusted.

[0053] Generally, there will always be a leakage path between the parts of the piston 15 and the surrounding parts of the cylinder 4. This leakage path can be used as throttled outlet so that a specific orifice or bleed is not always necessary.

Claims

1. A hydraulic machine, in particular a hydraulic pressure exchanger (1), comprising a drum (2) having a first end face and a second end face and being rotatable about an axis, said drum (2) comprising at least a cylinder (4), a piston (15) being arranged in said cylinder (4), said piston (15) being movable in a first moving direction and in a second moving direction opposite to said first moving direction, said piston (15) dividing said cylinder in a first section (16) opening in said first end face and a second section (17) opening in said second end face, **characterized in that** braking means are provided for at least one of said moving directions, said braking means braking said piston (15) before reaching an end stop.

2. The hydraulic machine according to claim 1, **characterized in that** said braking means are hydraulic braking means.

3. The hydraulic machine according to claim 2, **characterized in that** a braking chamber (26, 30) is provided for at least one of said moving directions, said braking chamber (26, 30) having an opening (27, 31) being open during a part of the movement of said piston (15) and being closed a predetermined distance before said piston reaches said end stop, said closed braking chamber (26, 30) having at least a throttled outlet (28, 29; 33, 34; 5, 24).

4. The hydraulic machine according to claim 3, **characterized in that** is arranged in said throttled outlet (33) comprises an orifice (34).

5. The hydraulic machine according to claim 3 or 4, **characterized in that** said throttled outlet (28) comprises a valve, in particular a check valve.

6. The hydraulic machine according to any of claims 3 to 5, **characterized in that** said throttled outlet comprises a leakage path (29; 5, 24).

7. The hydraulic machine according to any of claims 3 to 6, **characterized in that** during closing of said braking chamber said piston (15) gradually decreases said opening (27, 31).

8. The hydraulic machine according to any of claims 3 to 7, **characterized in that** said braking chamber (26, 30) is arranged between said piston (15) and a wall (5) of said cylinder (4).

9. The hydraulic machine according to any of claims 3 to 8, **characterized in that** a first braking chamber (26) having a first opening (27) and a first throttled outlet (28, 29) is provided for said first moving direction and a second braking chamber (30) having a second opening (31) and a second throttled outlet (33, 34) is provided for said second moving direction, said first throttled outlet (28, 29) and said second throttled outlet (33, 34) being separated from each other.

10. The hydraulic machine according to claim 9, **characterized in that** said first opening (27) is arranged in said wall (5) of said cylinder (4).

11. The hydraulic machine according to claim 10, **characterized in that** said first throttled outlet (28) is arranged in said wall (5) of said cylinder (4).

12. A pressure exchanger according to claim 10 or 11, **characterized in that** a sleeve (22) is arranged within said cylinder (4) reducing an inner diameter of said cylinder (4) in said second section (17), said piston (15) comprising a section (23) being inserted into said sleeve (22), said first braking chamber (26) being delimited by said piston (15), said sleeve (22) and said wall (5) of said cylinder.

13. A pressure exchanger according to any of claims 9 to 12, **characterized in that** said second opening (31) is the opening of said cylinder (4) in an end face.

14. A pressure exchanger according to claim 13, **characterized in that** said second throttled outlet (33,

34) runs through said piston (15).

15. A pressure exchanger according to claim 14, **characterized in that** said second throttled outlet (33, 34) opens into a low pressure side of said cylinder (4).

16. A pressure exchanger according to any of claims 13 to 15, **characterized in that** said second opening (31) has a section area smaller than a section area of said cylinder (4), said piston having a protrusion (25) penetrating into said second opening (31) said predetermined distance before said piston (15) reaches said end stop.

17. A pressure exchanger according to claim 16, **characterized in that** said protrusion (25) comprises an end (32) tapered at least on part of its circumference.

Amended claims in accordance with Rule 137(2) EPC.

1. A hydraulic machine, in particular a hydraulic pressure exchanger (1), comprising a drum (2) having a first end face and a second end face and being rotatable about an axis, said drum (2) comprising at least a cylinder (4), a piston (15) being arranged in said cylinder (4), said piston (15) being movable in a first moving direction and in a second moving direction opposite to said first moving direction, said piston (15) dividing said cylinder in a first section (16) opening in said first end face and a second section (17) opening in said second end face, wherein braking means are provided for at least one of said moving directions, said braking means braking said piston (15) before reaching an end stop, wherein said braking means are hydraulic braking means **characterized in that** a braking chamber (26, 30) is provided for at least one of said moving directions, said braking chamber (26, 30) having an opening (27, 31) being open during a part of the movement of said piston (15) and being closed a predetermined distance before said piston reaches said end stop, said closed braking chamber (26, 30) having at least a throttled outlet (28, 29; 33, 34; 5, 24).

2. The hydraulic machine according to claim 1, **characterized in that** is arranged in said throttled outlet (33) comprises an orifice (34).

3. The hydraulic machine according to claim 1 or 2, **characterized in that** said throttled outlet (28) comprises a valve, in particular a check valve.

4. The hydraulic machine according to any of claims 1 to 3, **characterized in that** said throttled outlet comprises a leakage path (29; 5, 24).

5. The hydraulic machine according to any of claims 1 to 4, **characterized in that** during closing of said braking chamber said piston (15) gradually decreases said opening (27, 31).

6. The hydraulic machine according to any of claims 1 to 5, **characterized in that** said braking chamber (26, 30) is arranged between said piston (15) and a wall (5) of said cylinder (4).

7. The hydraulic machine according to any of claims 1 to 6, **characterized in that** a first braking chamber (26) having a first opening (27) and a first throttled outlet (28, 29) is provided for said first moving direction and a second braking chamber (30) having a second opening (31) and a second throttled outlet (33, 34) is provided for said second moving direction, said first throttled outlet (28, 29) and said second throttled outlet (33, 34) being separated from each other.

8. The hydraulic machine according to claim 7, **characterized in that** said first opening (27) is arranged in said wall (5) of said cylinder (4).

9. The hydraulic machine according to claim 8, **characterized in that** said first throttled outlet (28) is arranged in said wall (5) of said cylinder (4).

10. A pressure exchanger according to claim 8 or 9, **characterized in that** a sleeve (22) is arranged within said cylinder (4) reducing an inner diameter of said cylinder (4) in said second section (17), said piston (15) comprising a section (23) being inserted into said sleeve (22), said first braking chamber (26) being delimited by said piston (15), said sleeve (22) and said wall (5) of said cylinder.

11. A pressure exchanger according to any of claims 7 to 10, **characterized in that** said second opening (31) is the opening of said cylinder (4) in an end face.

12. A pressure exchanger according to claim 11, **characterized in that** said second throttled outlet (33, 34) runs through said piston (15).

13. A pressure exchanger according to claim 12, **characterized in that** said second throttled outlet (33, 34) opens into a low pressure side of said cylinder (4).

14. A pressure exchanger according to any of claims 11 to 13, **characterized in that** said second opening (31) has a section area smaller than a section area of said cylinder (4), said piston having a protrusion (25) penetrating into said second opening (31) said predetermined distance before said piston (15) reaches said end stop.

15. A pressure exchanger according to claim 14, **characterized in that** said protrusion (25) comprises an end (32) tapered at least on part of its circumference.

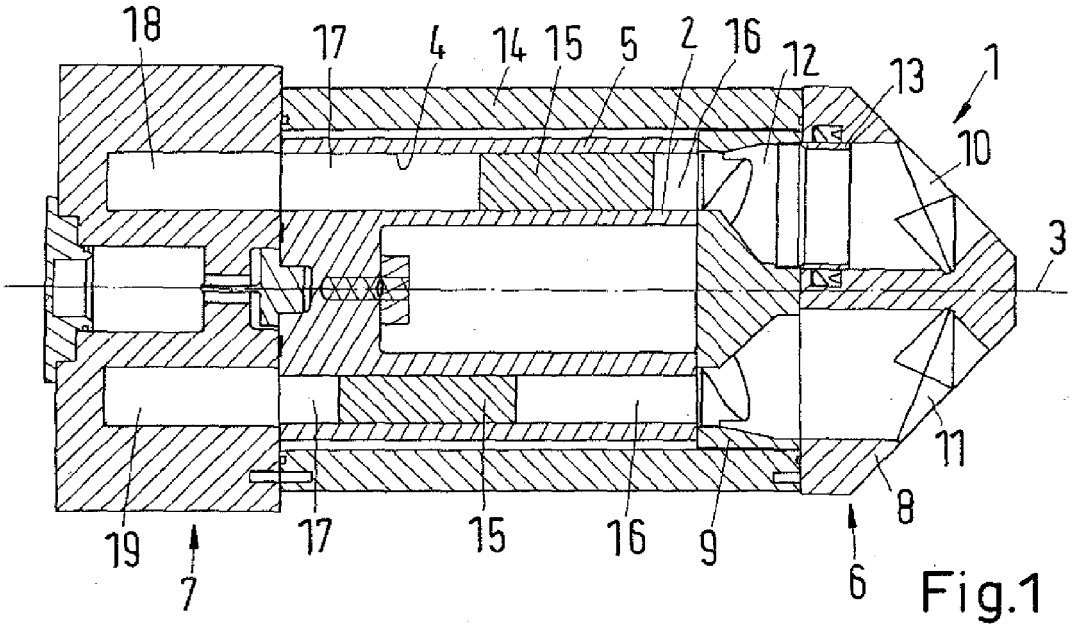

Fig.1

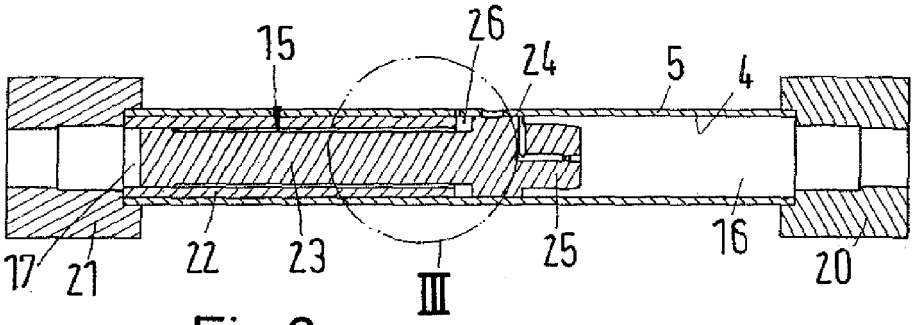

Fig.2

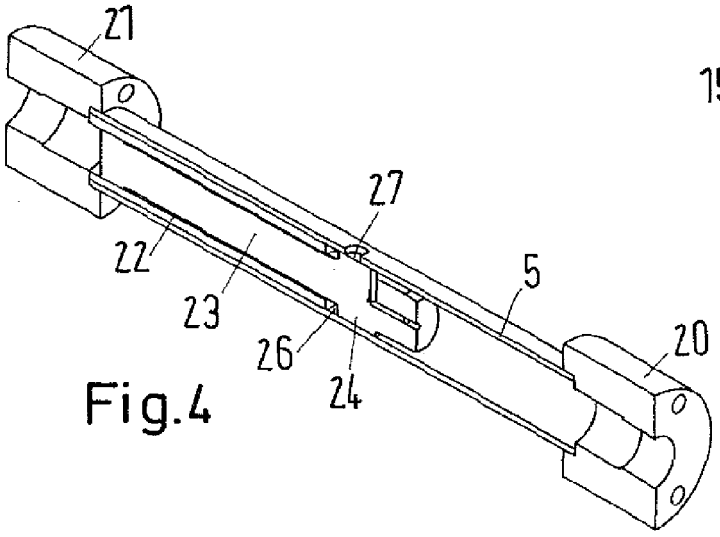

Fig.4

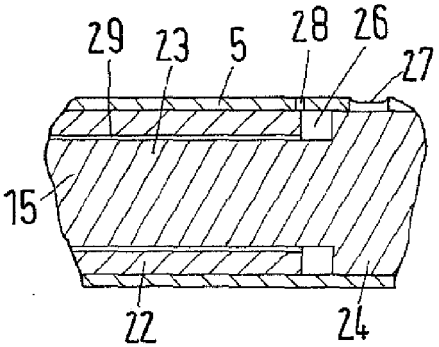

Fig.3

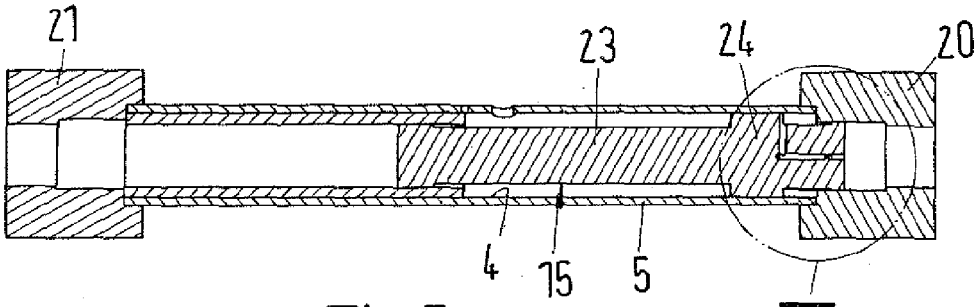

Fig.5

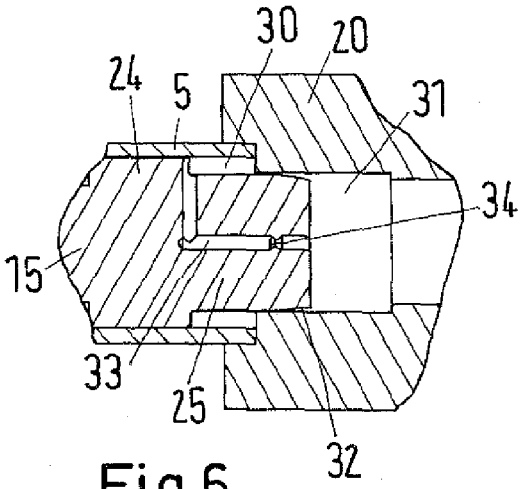

Fig.6

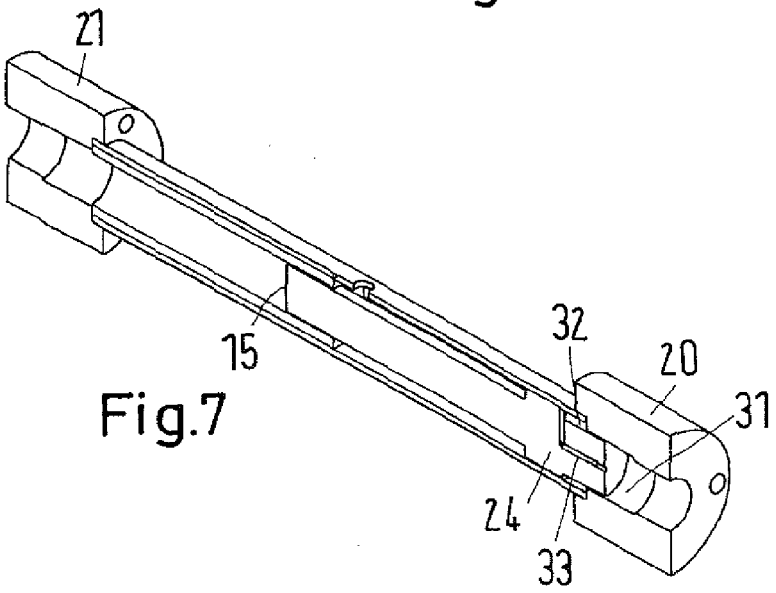

Fig.7

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EUROPEAN SEARCH REPORT

Application Number
EP 14 19 3210

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 91/19094 A1 (ABB MINERAL SLURRY TRANSPORT [AU]) 12 December 1991 (1991-12-12) * page 20, paragraph 2; figure 1 *	1,2	INV. F04B1/20 F04B9/117 F04F13/00
A,D	EP 1 508 361 A1 (DANFOSS AS [DK]) 23 February 2005 (2005-02-23) * the whole document *	1-15	
A	DE 10 2011 117081 A1 (BOSCH GMBH ROBERT [DE]) 2 May 2013 (2013-05-02) * paragraphs [0052] - [0054]; figure 6 *	1-3	

TECHNICAL FIELDS SEARCHED (IPC)
F04B
F04F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	27 April 2015	Ziegler, Hans-Jürgen

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 14 19 3210

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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