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(54) FLUID MACHINE

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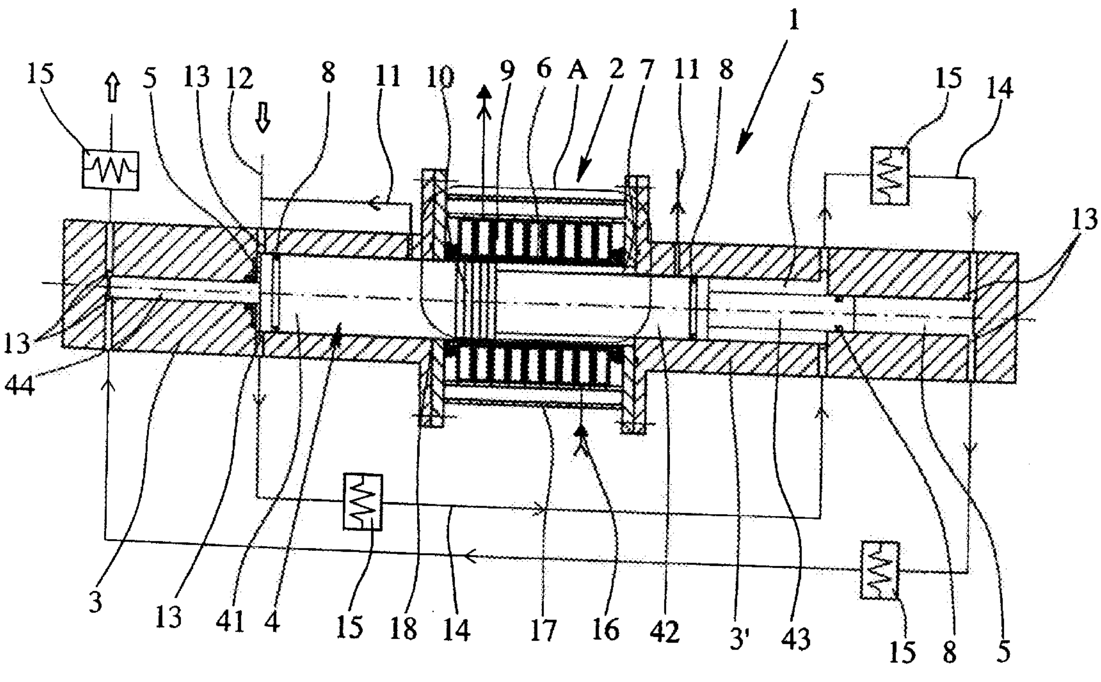
(57) **ABSTRACT**

A fluid machine for compressing or conveying fluids, in particular for compressing gases to high pressures, has a linear motor (**2**), at least one cylinder (**3**), a solid or liquid piston (**4**, **4'**) which can be moved axially in the cylinder (**3**), and at least one compression space (**5**) which is formed between the cylinder (**3**) and the solid or liquid piston (**4**, **4'**), wherein the linear motor (**2**) applies translational driving force to the solid or liquid piston (**4**, **4'**). For such a fluid machine, the leakage-free and lubricant-free compression and conveying of fluids, in particular a compression of gases to high pressures, and a rather simple construction is made possible owing to the fact that the solid or liquid piston (**4**, **4'**) is surrounded in the area of the linear motor (**2**) by a firmly attached pipe section (**6**).



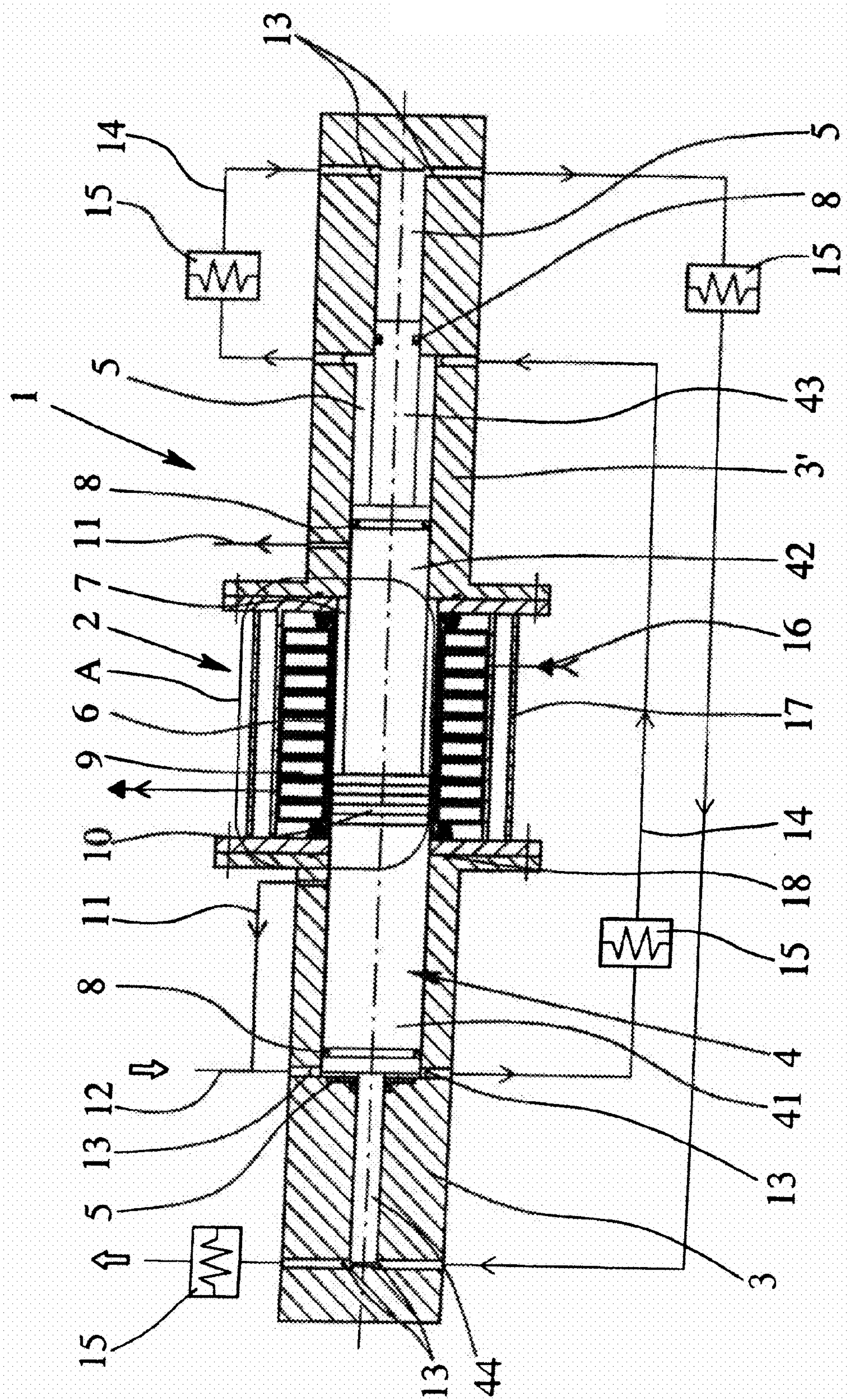


Fig. 1

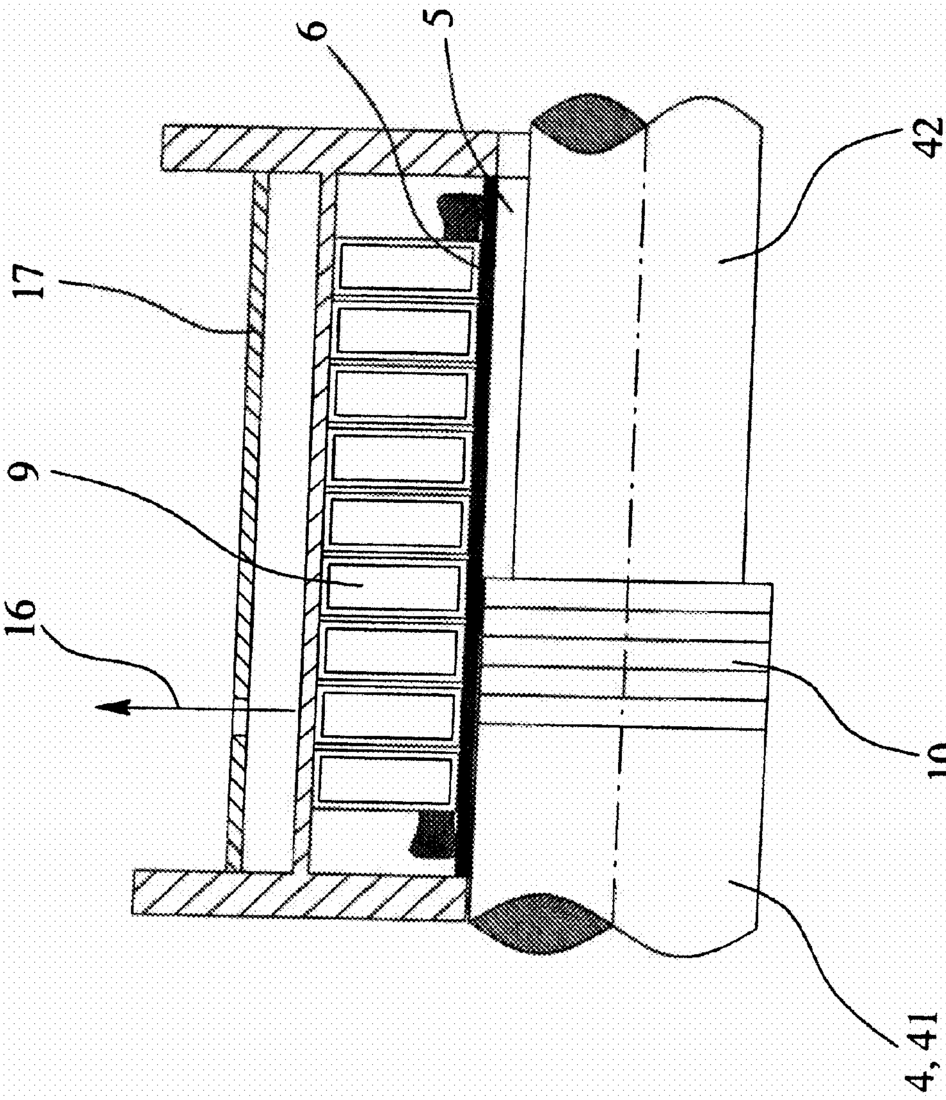


Fig. 2

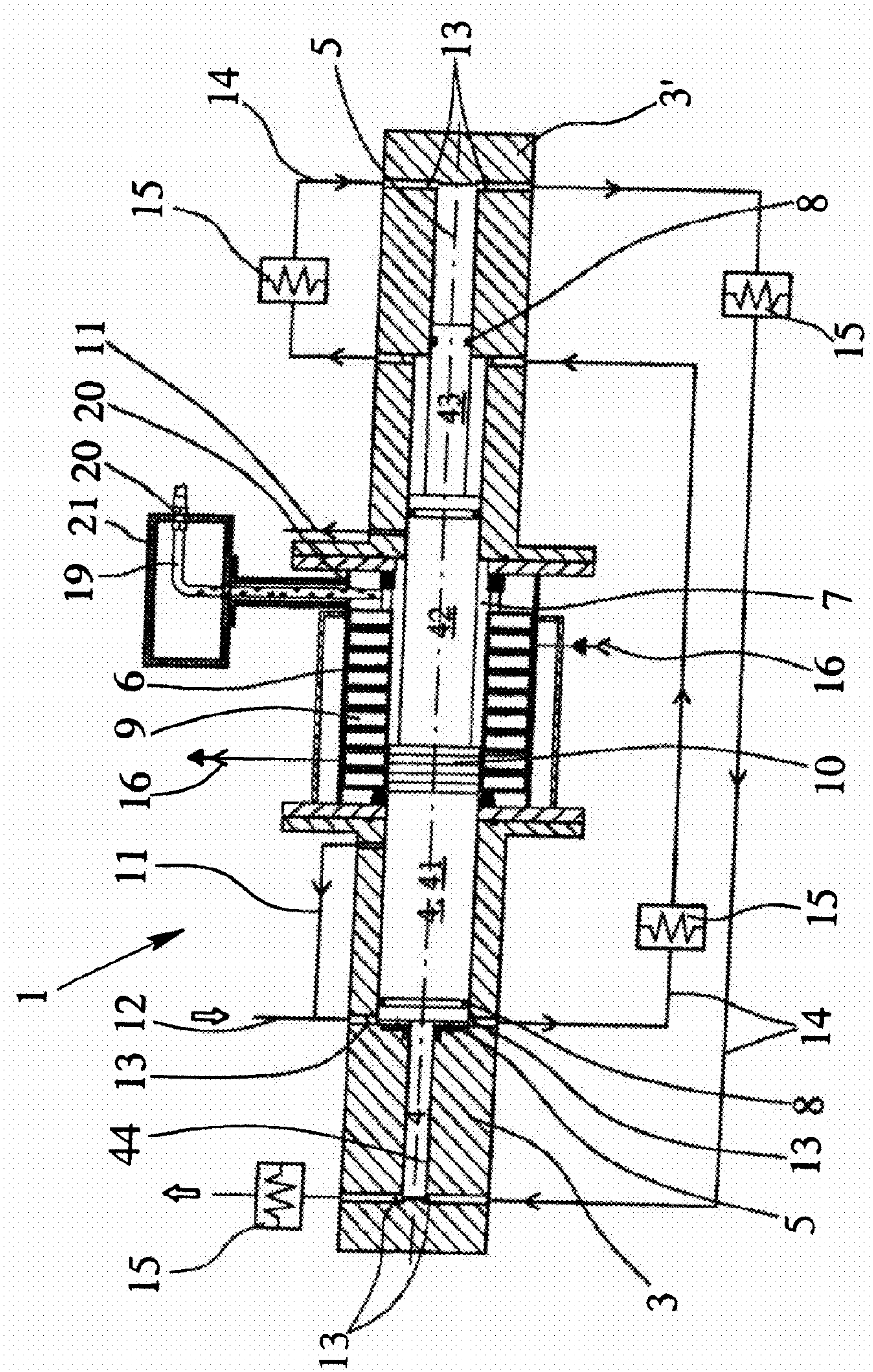


Fig. 3

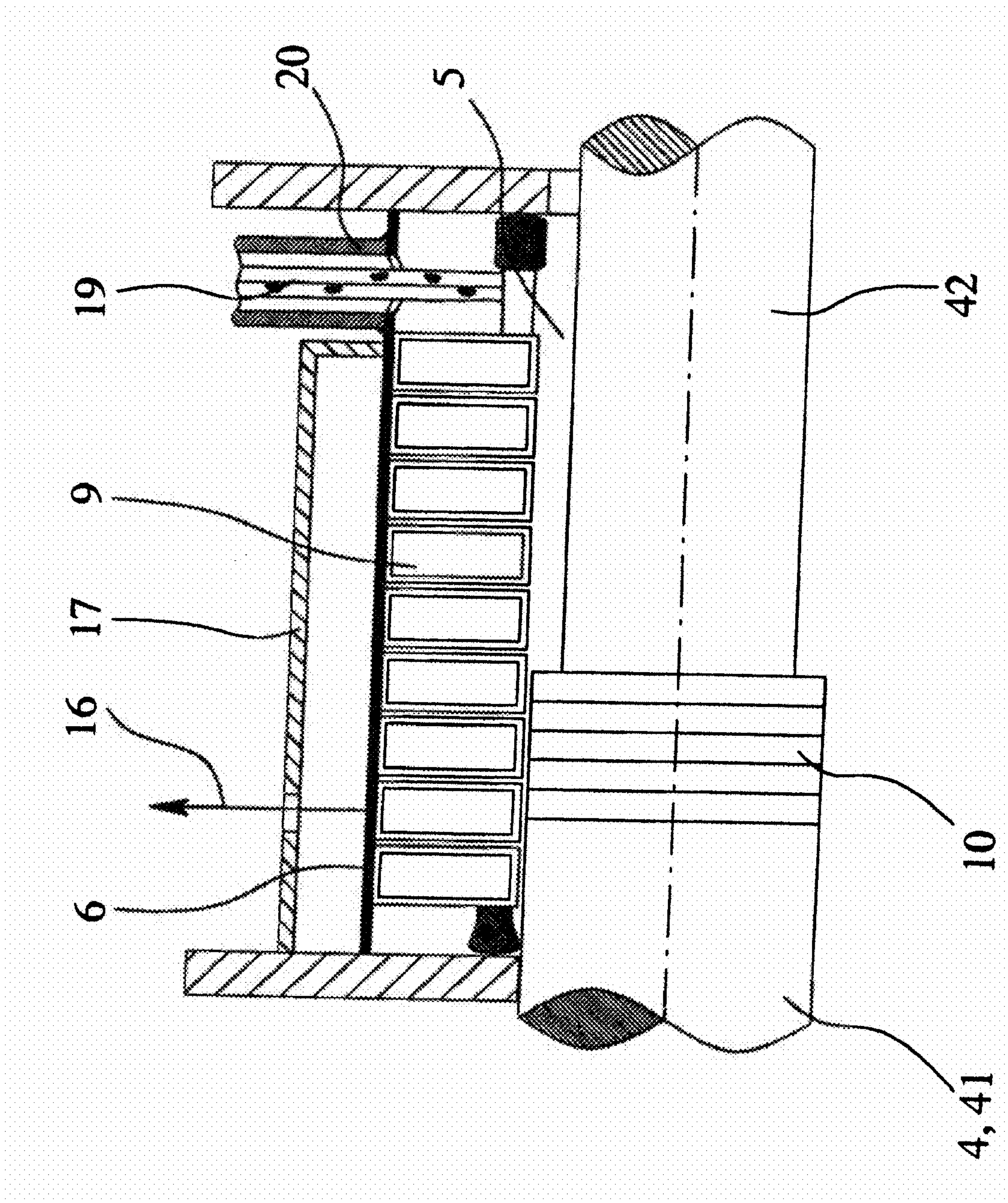


Fig. 4

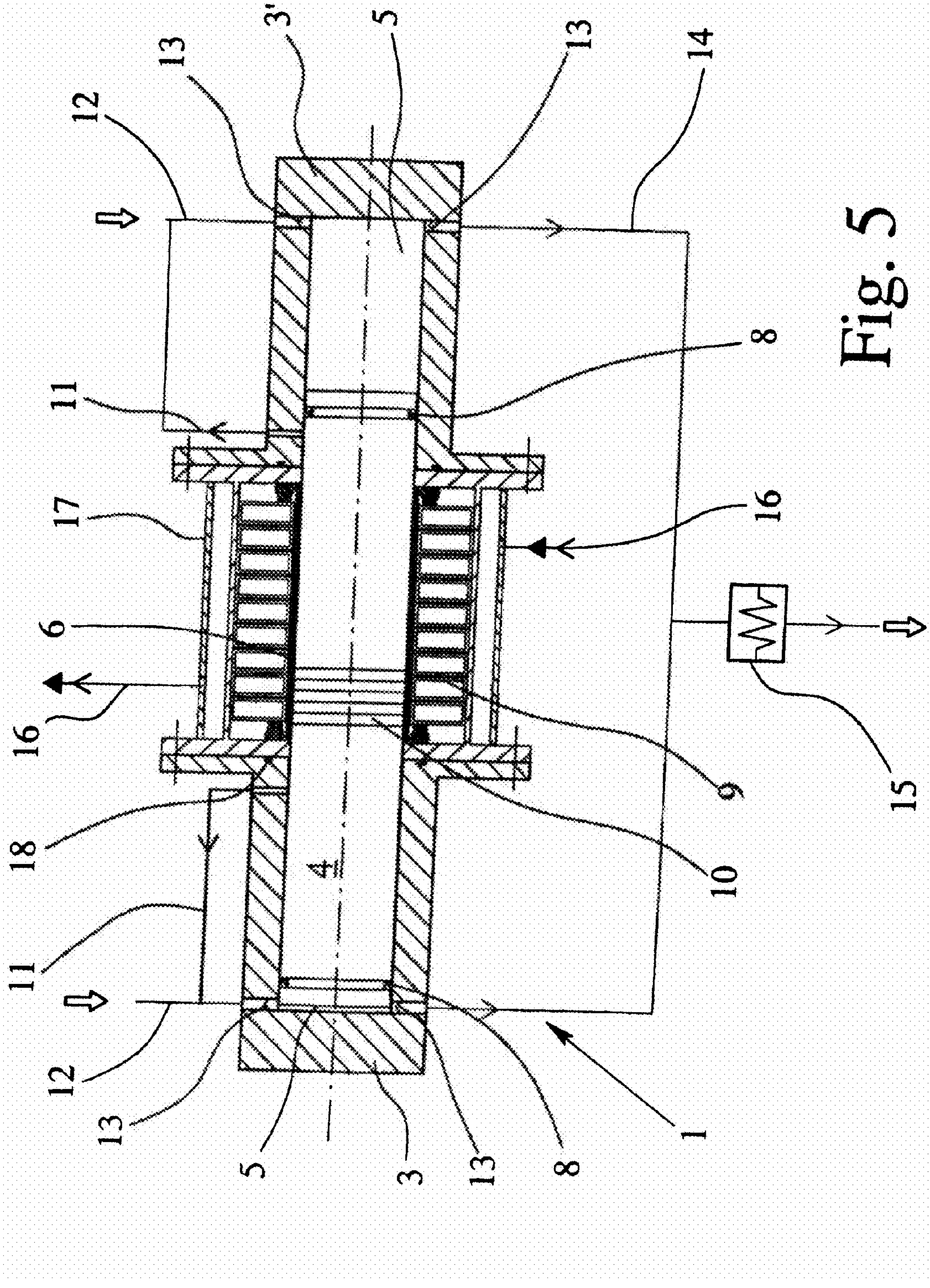


Fig. 5

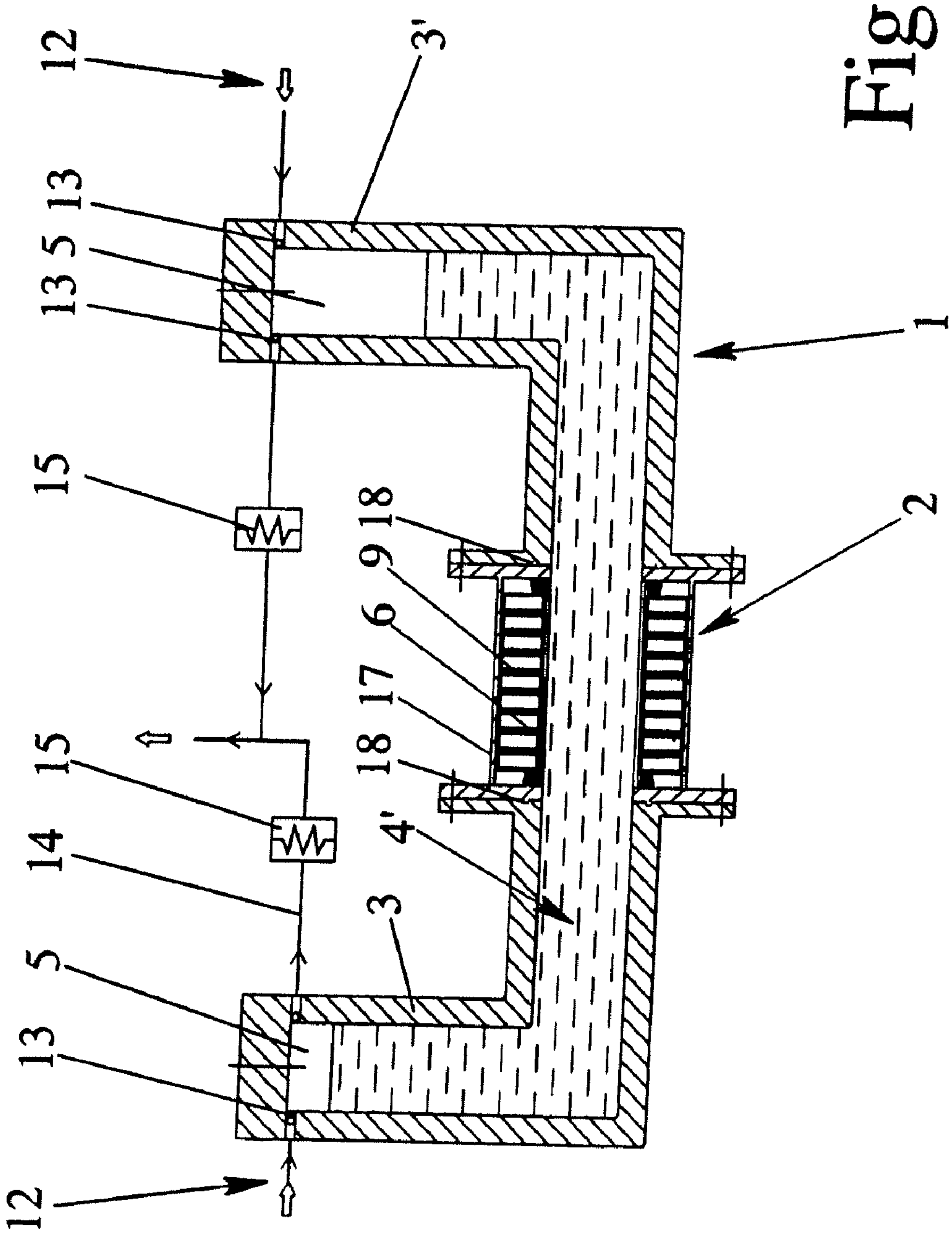


Fig. 6

FLUID MACHINE

BACKGROUND OF THE INVENTION

[0001] 1. Field of Invention

[0002] The invention relates to a fluid machine for compressing or conveying fluids, especially for compressing gases to high pressures, with a linear motor, at least one cylinder, a solid piston which can be moved axially in the cylinder, or an axially movable liquid piston and at least one compression space which is made between the cylinder and the solid piston and the liquid piston, the linear motor transferring a translational driving force to the solid piston or the liquid piston.

[0003] 2. Description of Related Art

[0004] Fluid machines are known in the prior art in different embodiments and versions. Fluid machines can be subdivided, first of all, according to whether they are intended for conveying or compressing liquids or gases. Fluid machines which are used for conveyance of liquids are generally also called pumps, while fluid machines for compressing gases are called compressors. Moreover fluid machines can also be distinguished depending on the type of driving force—hydraulic, electrical or electromagnetic, and according to the type of driving motion—rotational or translational.

[0005] This invention relates to a fluid machine in which the driving force is produced by a linear motor which applies a translational driving force directly to the piston which is guided in the cylinder, i.e., without conversion of rotary motion by way of gearing. If a gas is to be compressed with such a fluid machine, the machine can also be called a piston compressor or linear compressor. The linear motor here is essentially comprised of a stator and a rotor or actuator, and the linear motor as well as the synchronous motor can also be made as an asynchronous or synchronous linear motor. The linear motor then corresponds to an unwound asynchronous motor with a squirrel cage rotor or a permanently excited synchronous motor, a travelling field being produced by the coil or winding of the stator instead of a rotating field. Force is transferred as in a polyphase machine, either by voltage induction in a squirrel cage rotor of the asynchronous motor or by interaction with the field of the permanent magnets of the synchronous motor.

[0006] German Patent Application DE 10 2004 055 924 A1 discloses a linear compressor which has been described before, in which the magnet of the rotor is fastened to a magnet frame which is securely attached to one face side of the piston. In the known linear compressor, to cool the linear motor there is a cooling channel by which the coil of the stator attached to the coil holder is cooled with a coolant. To do this there is a pump which conveys oil within the receptacle which hermetically seals the linear compressor through the cooling channel to the coil or to the coil holder. The returning oil is collected in the lower part of the hermetically sealed receptacle.

[0007] German Patent Application DE 102 14 047 A1 discloses a compressor for a motor vehicle air conditioning system with a closed coolant circuit which has a compressor housing with a compression space made in it and a jacking piston which can move back and forth in it and in which the drive for the compressor is a linear motor with a variable trigger frequency, to whose reaction part the jacking piston is attached on the compressor space-side end face of the jacking piston. The known compressor is of simple structure, consists of only a few parts and is relatively small. Bearing, lubrication and sealing problems do not arise, in any case at a pressure level on the high pressure side between 80 and 160 bar. The sealing of the jacking piston relative to the compression space wall is effected by means of conventional ring seals on the jacking piston. Since, for these movable seals, leakages to the atmosphere in principle occur at least over time, the compressor known from German Patent Application DE 102 14 047 A1 is not suitable at least for sealing high pressures (>150 bar) and is not intended for this purpose either.

[0008] It was stated initially that the fluid machine has a solid piston which can be moved axially in a cylinder, or an axially movable liquid piston. A solid piston within the framework of the invention is defined as a (conventional) solid (metal) piston, as has been known for a long time. The above described compressors have these solid pistons. A liquid piston, conversely, within the framework of the invention, is defined as a liquid which is indeed liquid, but behaves like a solid when compression of the gas is achieved by changing the liquid level. Here, the liquid and the gas to be compressed are both in the cylinder, without however the liquid and gas mixing. The liquid piston thus assumes the function of a solid piston, the liquid piston as well as the solid piston being translationally driven by the travelling magnetic field of the linear motor which has been produced by means of coils.

[0009] A fluid machine with a liquid piston is known for example from German Patent Application DE 10 2004 046 316 A1 and corresponding U.S. Patent Application Publication 2007/0258828 A1. In the compressor disclosed there, preferably, an ionic liquid being used so that the compressor is also called an "ionic compressor". The known compressor has two cylinders which are connected to one another and in which one liquid and one gas to be compressed at a time are located. By means of a hydraulic pump the liquid levels in the two cylinders are varied such that one of the cylinders intakes the gas which is to be compressed, while compression of the gas occurs in the other cylinder.

SUMMARY OF THE INVENTION

[0010] The object of this invention is to provide the initially described fluid machine for compression or conveyance of fluids with a structure that is as simple as possible and enables leak-free and as much as possible also lubricant-free compression or conveyance of fluids, especially compression of gases to high pressures.

[0011] This object is achieved in the initially described fluid machine, first of all, in that the solid piston or liquid piston in the region of the linear motor is surrounded by a permanently arranged split pipe. Prevention of leakage to the atmosphere can be easily achieved by the arrangement of a split pipe. The leaks which occur on moving seals as dictated by principle when the solid piston is sealed to the drive, and thus, to the atmosphere are prevented by the split pipe. Sealing to the atmosphere can be achieved by the arrangement of the split pipe solely with static seals.

[0012] First of all, preferred embodiments of a fluid machine with a solid piston, i.e., with a massive piston, are described below. According to a first advantageous configuration of the invention, the split pipe in the radial direction is located between the rotor and the coil of the stator so that the split pipe surrounds the rotor. In this embodiment, the split pipe is located between the stator and the rotor. According to one alternative configuration of the invention, both the rotor and also the coil of the stator are located within the split pipe so that the split pipe surrounds the rotor and the stator.

[0013] In the first embodiment, the split pipe is thus used as a partition between the electrical drive system and the compression space in contact with the fluid and the moving solid piston, the split pipe being penetrated by a magnetic field for energy transmission. In this way, electrical losses as a result of eddy currents occur in the split pipe and the split pipe is heated so that the efficiency of the linear motor with the split-pipe located in between is less than the efficiency of a linear motor with a split pipe which lies outside. This disadvantage of greater losses does not occur in the second embodiment in which the split-pipe surrounds the rotor and the stator. This embodiment is at least theoretically advantageous unless corrosive media are to be compressed with the fluid machine. In this case, the coil for an outside split pipe would likewise be exposed to a corrosive medium; this can lead to an adverse effect on the service life of the coil.

[0014] The fluid machine in accordance with the invention can advantageously be easily built by the magnets of the rotor being located directly on the piston. Attaching the magnets of the rotor directly to the piston eliminates the need to make and arrange a separate magnet frame. Moreover, the radial dimensions of the fluid machine, especially of the cylinder, can be reduced by this configuration.

[0015] According to another preferred embodiment of the invention, the fluid machine is made in several stages, i.e., compression of the gas takes place in at least two, preferably in four stages. Alternatively single-stage compression is also possible, then preferably there being one equalization stage to keep the resulting forces necessary for compression low. If compression of the gas takes place in several stages, it is more advantageously provided that the solid piston has several sections with different diameters. The piston can be composed of several piston sections in terms of production engineering.

[0016] According to another advantageous configuration of the fluid machine in accordance with the invention with a solid piston, the compression space connected to the split pipe is connected to the fluid entry side, i.e., to the intake side of the fluid machine, directly or by way of a line or a channel made in the cylinder or in the housing. This measure reduces the pressure in the region of the split pipe to a low pressure on the fluid entry side. Internal leaks which occur along the moving piston seals are relieved to the intake pressure and discharged to the fluid entry side. In this way, the required wall thickness of the split pipe can be reduced, by which, in an arrangement of the split pipe between the rotor and the coil of the stators, electrical losses are reduced. A thick-walled or double-walled execution of the split pipe which is otherwise necessary at especially high pressures can thus be eliminated, But regardless, a double-walled split pipe can be used to increase safety, especially for dangerous gases (toxic, polluting, or radioactive gases.

[0017] To reduce electrical losses which can occur by using the split pipe, it is moreover possible to produce the split pipe from plastic or ceramic, not metal. In choosing the plastic or the ceramic, it must be noted that the split pipe can also reliably withstand the maximum pressure which occurs.

[0018] According to another configuration of the invention, as is fundamentally known in the prior art, there is at least one heat exchanger for re-cooling the fluid. In a multistage fluid machine, preferably, there is one such heat exchanger after each compression stage. The coolant required for re-cooling the gas by the heat exchanger can then preferably also be used for cooling the linear motor. Cooling takes place preferably from the outside, i.e., by way of the housing which surrounds the linear motor, so that neither the rotor nor the stator comes into direct contact with the coolant. Alternatively to using a separate coolant, both for re-cooling the fluid and also for cooling the linear motor the fluid itself can be used if it is in the correspondingly cold state. If it is a gas which is to be compressed, for example hydrogen, which is supercold in the liquid phase before compression, the gas can be used as a coolant in the liquid phase.

[0019] In a fluid machine for compressing gases to high pressures with a liquid piston the latter is preferably formed by a magnetizable liquid which does not have a vapor pressure so that molecules of the liquid do not mix with the gas to be compressed. The liquid for this liquid piston can be for example an ionic liquid. If such a liquid is used which does not mix with the gas to be compressed, as long as its decomposition temperature is not reached, subsequent separation of the liquid from the gas which is being compressed can be omitted.

[0020] In a fluid machine with a liquid piston, the split pipe is located in the radial direction preferably within the coil of the stator so that the split pipe surrounds the liquid which is acting as a rotor. In the region of the linear motor, the split pipe thus has the function of the cylinder wall.

[0021] By using a liquid piston instead of a solid piston, not only the use of a solid piston, but also the otherwise necessary piston seals, can be omitted. Sealing of the compression space takes place directly by the liquid which forms the liquid piston so that leakage to the atmosphere cannot occur. Moreover, by eliminating the piston seals, the maintenance cost of the fluid machine is also reduced since there are no wearing parts within the working space.

[0022] In contrast to the "ionic compressor" known from the prior art, in the fluid machine in accordance with the invention, the liquid level is changed, not by means of a hydraulic pump, but by a linear motor whose travelling magnetic field, which is produced by the coils, applies a translational motive force to the magnetizable liquid. By using a linear motor instead of a hydraulic pump, on the one hand, a higher maximum pressure of the gas to be compressed can be achieved, and on the other hand, the wear which occurs when using a hydraulic pump is avoided.

[0023] The use of a liquid piston also has the advantage that, by way of the liquid, at least partial discharge of the heat of compression which forms during compression, and at the same time, cooling of the linear motor, especially cooling of the coil of the stator, can take place. For this purpose, preferably, at least one heat exchanger is designed for re-cooling the liquid.

[0024] The above described fluid machine in accordance with the invention is especially suited for compressing gases to high pressures, especially for compression of hydrogen to 500 bar or more. Thus, such a linear compressor is especially suited for outfitting hydrogen filling stations.

[0025] In particular, there are a host of possibilities for embodying and developing the fluid machine in accordance with the invention as will be apparent from the following description of preferred embodiments in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. **1** shows a first embodiment of a fluid machine in accordance with the invention,

[0027] FIG. **2** is an enlarged view of the encircled region A of the fluid machine as shown in FIG. **1**,

[0028] FIG. **3** shows a second embodiment of a fluid machine in accordance with the invention,

[0029] FIG. **4** is an enlarged view corresponding to that of FIG. **2**, but of the corresponding region of the fluid machine as shown in FIG. **3**,

[0030] FIG. **5** shows a third embodiment of a fluid machine in accordance with the invention, and

[0031] FIG. **6** shows a fourth embodiment of a fluid machine in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0032] FIGS. **1**, **3**, **5** and **6** show four different embodiments of a fluid machine **1** in accordance with the invention, the figures being solely simplified representations, so that only the components important to the invention are shown. The fluid machines **1** shown in the figures are used for compressing gases, especially hydrogen, to a high pressure of 500 bar, for example. These fluid machines **1** can therefore advantageously be used especially for outfitting hydrogen filling stations.

[0033] The fluid machines **1** shown in FIGS. **1**, **3**, and **5** each have a linear motor **2** for driving a solid piston **4** which is movably located in a cylinder **3**. By using the linear motor **2** as a drive, a translational driving force is applied to the solid piston **4** so that the solid piston **4** can move back and forth axially within the cylinder **3**, **3'**. Within the cylinder **3** is at least one compression space **5** for the gas to be compressed, the size of the compression space changing depending on the position of the solid piston **4**.

[0034] In the two embodiments as shown in FIGS. **1** and **3**, the fluid machine **1** is made altogether in 4 stages, so that compression of the gas takes place in four succeeding stages. Accordingly, in these two embodiments, each of the four sections **41**, **42**, **43**, **44**, of the solid piston **4** has a different diameter. Corresponding thereto, the cylinder **3**, **3'** also has four different sections with different inside diameters so that altogether four compression spaces **5** are formed. In contrast, the fluid machine **1** as shown in FIG. **5** is made only with one stage, being a double-acting fluid machine **1** so that one compression space **5** is formed on each of the two sides of the solid piston **4**.

[0035] It is common to all three versions that the solid piston **4** is surrounded by a fixed split pipe **6** in the region of the linear motor **2**. The arrangement of the split pipe **6** ensures reliable sealing of the cylinder interior **7** so that, altogether, the desired absence of leakage of the fluid machine **1** is easily achieved. The absence of leakage to the atmosphere need no longer be implemented by the piston seals **8** which are located on the solid piston **4** and which fundamentally cannot ensure the absence of leakage due to their arrangement and execution as moving seals or cannot permanently do so and especially not without lubricant. The otherwise conventional execution of the piston rod to the drive is thus eliminated, likewise, the moving sealing systems required for this purpose. The absence of leakage to the atmosphere is then ensured exclusively with static seals **18**.

[0036] The linear motor **2** shown in FIGS. **1** to **5** has a stator with a coil **9** and a rotor with several magnets **10**, the magnets **10** being located directly on the solid piston **4**.

[0037] In the embodiment as shown in FIG. **1**, or according to the enlargement in FIG. **2**, the split pipe **6**, in the radial direction, is located between the rotor, i.e., the magnet **10** and the coil **9** of the stator, so that the split pipe **6** surrounds not only the solid piston **4**, but also the magnets **10** of the rotor. In this embodiment, the split pipe **6** is thus located between the stator and the rotor so that the split pipe **6** is penetrated by the magnetic field. In contrast thereto, in the embodiment as shown in FIG. **3** or according to the enlargement in FIG. **4**, both the rotor, i.e., the magnet **10** and also the coil **9** of the stator, are located within the split pipe **6**. In this embodiment thus not only the magnets **10**, but also the coil **9** is exposed to the fluid which in spite of the piston seal **8** enters the cylinder interior **7** in the region of the split pipe **6**.

[0038] FIGS. **1**, **3** and **5** indicate that the compression space **5**, connected to the gap space **6**, is connected by way of a line **11** to the fluid entry side **12** of the fluid machine **1**. This leads to internal leaks which occur in spite of the piston seals **8** between the outer periphery of the solid piston **4** and the inside wall of the cylinder **3** being relieved to the intake pressure and discharged to the fluid entry side **12**. In this way, the pressure in the cylinder interior **7** surrounded by the split pipe **6** is reduced, by which the split pipe **6** in the configuration as shown in FIGS. **1** & **2** and the coil **9** and the split pipe **6** in the embodiment as shown in FIGS. **3** & **4** are not unnecessarily loaded. By the reduction of pressure which has taken place in this way in the cylinder interior **7** surrounded by the split pipe **6**, a correspondingly smaller wall thickness for the split pipe **6** can be chosen, by which the eddy current losses which occur in the split pipe **6** are reduced.

[0039] Alternatively, the compression space **5** which is connected to the gap space **6** can also be directly connected to the fluid entry side **12**, i.e., the fluid enters in the compression space **5** which is connected to the gap space **6**. If the fluid to be compressed has a low temperature, the linear motor **2** can thus be cooled at the same time.

[0040] As known in the prior art, inlet and outlet of the gas to be compressed take place by way of valves **13** which are located in the region of the individual compression space **5** and are preferably made as plate (leaf spring) valves. Then, automatic opening and closing of the valves **13** take place by the prevailing differential pressures between the compression space **5** and the respective inlet and outlet. Since for the two embodiments as shown in FIGS. **1** & **3**, four-stage compression of the gas takes place, the fluid machines **1** each also have four inlet and outlet valves **13**.

[0041] FIGS. **1** & **3**, moreover, show that the individual compression spaces **5** are connected to one another by way of lines **14**, in the individual lines **14** there being a respective heat exchanger **15** for re-cooling of the compressed gas. Also, FIGS. **1**, **3** and **5** show that the fluid machine **1**, altogether, has a coolant circuit **16** for cooling the coil **9** of the stator and thus for cooling of the linear motor **2**. Cooling takes place here from the outside, i.e., by way of a housing **17** which surrounds the coil **9**, so that the coil does not come directly into contact with the coolant. The same coolant can be used both for re-cooling the compressed gas in the heat exchangers **15** and also for cooling the linear motor **2**.

[0042] Finally it is apparent from the figures that the illustrated embodiments of the fluid machine **1** each have two cylinders **3**, **3'**, the linear motor **2** with the split pipe **6** and the housing **17** surrounding the linear motor **2** being located between the two cylinders **3**, **3'**. Sealing between the face sides of the two cylinders **3**, **3'** and the corresponding face sides of the housing **17** takes place by way of static seals **18**.

[0043] FIGS. **3** & **4**, moreover, show that the electric lines **19** to the stator located within the split pipe **6** are routed using pressure-tight cable penetrations **20** without leaks to the terminal box **21**, the terminal box **21** also having pressure-tight cable penetrations **20** so that the absence of leaks to the atmosphere which is obtained by the split pipe **6** is not neutralized by the connection of the necessary lines **19**.

[0044] FIG. **6** shows an embodiment of a fluid machine **1** which, instead of a solid piston, has a liquid piston **4'**. The liquid which forms the liquid piston **4'** is located within the U-shaped housing which is formed from the two cylinders **3**, **3'** and the split pipe **6**. Above the liquid, in the two cylinders **3**, **3'**, there is a compression space **5** at each end of the liquid piston **4'** for the gas to be compressed, the size of the two compression spaces **5** changing depending on the level of the liquid, i.e., on the position of the liquid piston **4'**. The fluid machine **1** shown in FIG. **6**, like the fluid machine **1** as shown in FIG. **5**, is made with one stage, here its being a double acting fluid machine **1** so that on both sides of the liquid piston **4'** a compression space **5** at a time is formed.

[0045] In each of the two compression spaces **5**, there is a respective valve **13** at the inlet and at the outlet, the outlets of the two compression spaces **5** being connected to one another by way of lines **14** in which a respective heat exchanger **15** is located for re-cooling of the compressed gas. The linear motor **2** together with the split pipe **6** and the housing **17** which surrounds the linear motor **2** is located between the two cylinders **3**, **3'** so that the split pipe **6** constitutes the cylinder wall for the liquid in the region of the linear motor **2**.

[0046] The fluid machines **1** shown in the figures are especially suited for compression of gases, preferably of hydrogen, to high pressures of, for example, 1000 bar, so that these fluid machines **1** are especially well suited to outfitting of hydrogen filling stations.

1-16. (canceled)

17. Fluid machine for compressing or conveying fluids to high pressures, comprising

at least one cylinder,

a piston which is movable axially in the cylinder,

at least one compression space between the cylinder and the piston,

a linear motor, the linear motor apply a translational driving force to the piston,

wherein the piston is surrounded in a region of the linear motor by a permanently arranged split pipe.

18. Fluid machine as claimed in claim **17**, wherein the piston is a solid piston, wherein the linear motor has a stationary coil and at least one movable magnet connected with the piston, and wherein the split pipe is located between the magnet and the coil in a radial direction so that the split pipe surrounds the magnet.

19. Fluid machine as claimed in claim **18**, wherein the at least one magnet is located directly on the piston.

20. Fluid machine as claimed in claim **17**, wherein the piston is a solid piston, wherein the linear motor has a stationary coil and at least one movable magnet connected with the piston, and wherein the split pipe surrounds both the coil and the magnet.

21. Fluid machine as claimed in claim **20**, wherein the at least one magnet is located directly on the piston.

22. Fluid machine as claimed in claim **17**, wherein the piston is a multi-stage, solid piston for compressing a gas in several stages.

23. Fluid machine as claimed in claim **22**, wherein the solid piston has several sections of different diameters.

24. Fluid machine as claimed in claim **17**, wherein the piston is a solid piston, wherein a fluid inlet side of the compression space is connected to the split pipe.

25. Fluid machine as claimed in claim **17**, wherein the piston is a solid piston, and wherein a cooling circuit is provided for cooling the linear motor.

26. Fluid machine as claimed in claim **17**, wherein the piston is a solid piston and wherein at least one heat exchanger is provided for re-cooling the fluid acted upon by the piston.

27. Fluid machine as claimed in claim **25**, wherein at least one heat exchanger is provided for re-cooling the fluid acted upon by the piston and wherein the coolant circuit uses the same fluid to cool the linear motor and to recool the fluid acted upon by the piston.

28. Fluid machine as claimed in claim **17**, wherein the piston is a liquid piston for compressing gases to high pressures and wherein the liquid piston is formed of a magnetizable liquid which does not have a vapor pressure that will cause molecules of the liquid to mix with the gas to be compressed.

29. Fluid machine as claimed in claim **28**, wherein the liquid is an ionic liquid.

30. Fluid machine as claimed in claim **28**, wherein the split pipe is located within the coil in a radial direction so that the split pipe surrounds the liquid.

31. Fluid machine as claimed in claim **28**, wherein at least one heat exchanger is provided for re-cooling the liquid.

32. Fluid machine as claimed in claim **28**, wherein the liquid also cools the linear motor.

33. Fluid machine as claimed in claim **27**, wherein the at least one cylinder comprises two cylinders, and wherein the linear motor and the split pipe are located between the two cylinders.

34. Fluid machine as claimed in claim **27**, wherein the split pipe is made of one of a metal, a plastic and a ceramic.

35. Fluid machine as claimed in claim **17**, wherein the at least one cylinder comprises two cylinders, and wherein the linear motor and the split pipe are located between the two cylinders.

36. Fluid machine as claimed in claim **17**, wherein the split pipe is made of one of a metal, a plastic and a ceramic.

* * * * *