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(54) **PISTON CYLINDER ARRANGEMENT OF AN AEROSTATIC LINER COMPRESSOR**

(57) The present invention relates to a piston (1) and cylinder (2) assembly that can reduce efficiency losses due to the gas in a linear compressor with aerostatic bearings. The space between the piston (1) and cylinder(2) in the piston-cylinder assembly was therefore designed to decrease radial clearance (12) in the upper portion of the piston (1) when the piston approaches the headpiece (3), i.e., when the density of the gas not being used in the refrigeration process is the highest. The piston (1) and cylinder (2) assembly must exhibit such a geometric ratio that radial clearance (12) changes in inverse proportion to the density of the gas in the radial clearance (12).

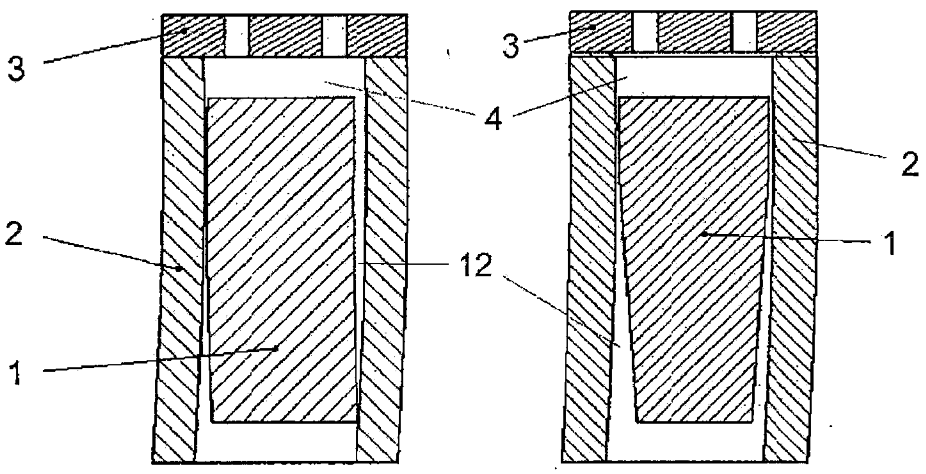

Fig. 10 Fig. 11

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Description

[0001] The present invention refers to a piston/cylinder assembly of a linear compressor for cooling with aerostatic bearing arrangement, more particularly to the dimension relationships of the assembly so as to minimize losses.

Description of the Prior Art

[0002] In general, the basic structure of a cooling circuit comprises four components, namely: the compressor, the condenser, the expansion device and the evaporator. These elements characterize a cooling circuit in which a fluid circulates so as to enable the reduction of the temperature of an internal environment, removing the heat from this medium and displacing it to an external environment through said elements.

[0003] The fluid that circulates in the cooling circuit generally follows this passage sequence: compressor, condenser, expansion valve, evaporator and again the compressor, which characterizes a closed circuit. During the circulation, the fluid undergoes pressure and temperature variations that are responsible for altering the state of the fluid, which may be either gaseous or in the liquid state.

[0004] In a cooling circuit, the compressor acts like a heart of the cooling system, creating the cooling fluid flow along the components of the system. The compressor raises the temperature of the cooling fluid through the rise in pressure inside it and forces the circulation of this fluid in the circuit.

[0005] Thus, the importance of a compressor in a cooling circuit is undeniable. There are various types of compressors applied to cooling systems, and in the field of the present invention attention will be focused only on the linear compressors.

[0006] Due to the relative movement between the piston and the cylinder, it is necessary to provide the piston with bearing arrangement. This bearing arrangement consists of the presence of a fluid in the clearance between the outer diameter of the piston and the inner diameter of the cylinder, preventing contact between them and the consequent premature wear of the piston and/or cylinder. The presence of the fluid between said two components serves also to decrease the friction between them, thus causing the mechanical loss of the compressor to be lower.

[0007] One of the ways of providing the piston with a bearing arrangement is by means of aerostatic bearings, which, in essence, consist in creating a gas bearing arrangement between the piston and the cylinder so as to prevent wear between these two components. One of the reasons for using this type of bearing arrangement is justified by the fact that the has a much lower viscous friction coefficient than any other oil, thus contributing to cause the energy spent in the aerostatic bearing system to be much lower than that of oil lubrication, thus achieving a better output of the compressor. One advantage resulting from the use of the cooling gas itself as a lubricating fluid is the absence of the oil pumping system.

[0008] In figures 1 and 2, it is possible to see that the gas compression mechanism takes place through the axial and oscillating movement of a piston inside a cylinder. At the cylinder top is the head, which, in conjunction with the piston and the cylinder, forms the compression chamber. At the head discharge and suction valves are positioned, which regulate the entry and exit of gas in the cylinder. In turn, the piston is actuated by an actuator that remains connected to the linear motor of the compressor.

[0009] The compressor piston actuated by the linear motor has the function of developing a linear alternating movement, causing the piston movement inside the cylinder to exert a compression action of the gas admitted by the suction valve, until it is in a position to be discharged to the high-pressure side through the discharge valve.

[0010] For the correct functioning of an aerostatic bearing arrangement, it is necessary to use a flow restrictor between the high-pressure region that involves the cylinder externally and the clearance between the piston and the cylinder. This restriction serves to control the pressure in the bearing arrangement region and to restrict the gas flow.

[0011] Between the various possible solutions, it is usual to employ the cooling-circuit gas itself for providing aerostatic bearing arrangement of the piston. In this way, the whole gas used in bearing arrangements represents a loss in efficiency of the compressor, since the gas is diverted from its original function, which is to generate cold in the evaporator of the cooling system. Thus, it is desirable for the gas flow rate employed in bearing arrangement to be as low as possible, so as not to impair the compressor efficiency.

[0012] In order for the functioning of a cooling compressor to be efficient, all the characteristic losses of this type of equipment should be kept as low as possible, as for example, mechanical losses (friction between components), electric losses (appearance of parasite currents, resistance to motor current passage or thermodynamic losses (leakages, flow of undesirable heat). With regard to gas compression, in order for the efficiency of the compressor to be high, it is necessary that all the work carried out on the gas should be employed in the cooling system. For this reason, any type of leakage or phenomenon that causes loss of gas after the compression of the latter is undesirable.

[0013] Anyway, there will always be leakages, because, in order to provide bearing arrangement, gas should be present between the cylinder walls and the piston walls. However, the efficiency logic requires the gas leakages to be kept as low as possible, in order not to affect the compressor efficiency significantly.

[0014] The main sources of leakages in a compressor are discharge valves and suction valves and the clearance between piston and cylinder. The clearance between the piston and the cylinder will be called perimeter clearance hereinafter.

[0015] For a better understanding of the phenomena that cause decrease in the compressor efficiency, the region between the piston top and the cylinder head is called compression chamber, and there is where the high pressures on the gas take place. The region that is between the piston bottom and the cylinder portion opposite the head is called low-pressure region.

[0016] In linear compressors that make use of aerostatic bearing arrangement, two phenomena related to loss of gas take place, which will he the object of observation for understanding the present technology.

Leakage

[0017] The phenomenon leakage is defined by the amount of gas that circulates between the high-pressure region (above the piston top) and the low-pressure region (below the piston bottom), through the perimeter clearance. This leakage phenomenon always occurs when the piston is in the compression phase, i.e., moving toward the head. When this piston movement takes place, the gas is compressed up to a discharge pressure (Pd) through the perimeter clearance, throughout the clearance length (Cf), reaching the suction-pressure region (Ps) located on the opposite side of the compression chamber. It should be noted that this gas does not come out of the compressor into the cooling system to play the main role, which is to generate cold.

Irreversibility

[0018] To thermodynamics, irreversibility is a characteristic of all the real processes and their sources are the dissipative processes. Systems provided with aerostatic bearing arrangement undergo the irreversibility phenomenon in the compression, caused by the presence of a small portion of gas in the clearance between the cylinder and the piston. Irreversibility can be understood as being the loss of energy resulting from the flow of the small portion of gas into and out of the perimeter clearance.

[0019] Considering the technology of linear compressors provided with bearing arrangement, a loss of load is always associated to a flow of gas, which inevitably consumes energy, the compressor being negatively influenced by this irreversibility phenomenon.

The problems

[0020] For a better understanding of the repercussions of the leakage and irreversibility phenomena, figure 5 shows experimental results that relate the power consumed by the said two effects as a function of the clearance between piston and cylinder. It should be noted that the losses due to irreversibility and leakage occur simultaneously.

[0021] The graph in figure 5 does not leave any doubt about the magnitude of the loss of efficiency, since the variation in dimension between piston and cylinder on the order of 5μm entails loss of power on the order of 2W-10W, that is, the greater the clearance in the piston/cylinder assembly, the greater the loss in power associated.

[0022] Therefore, there is no doubt that the technology of linear compressors provided with aerostatic bearing arrangement needs to have a solution that inhibits the enhanced loss of energetic efficiency due to the perimeter clearance.

[0023] Thus, at present there are no linear compressors provided with aerostatic bearing arrangement capable of effectively reducing the loss of efficiency due to the use of cooling gas for providing the piston with bearing arrangement. In other words, the present invention manages to achieve a geometric and dimensional relationship designed for inhibiting the loss of efficiency in providing bearing arrangement by reducing the specific perimeter clearance, as well as providing a solution of easy productive implementation, guaranteeing benefits for the final user and, by the result of better energetic efficiency, for the environment.

Objectives of the Invention

[0024] Therefore, it is an objective of the present invention to minimize the losses of efficiency that occur on the gas of a linear compressor provided with aerostatic bearing arrangement.

[0025] It is also an objective of the present invention to provide spacing between the piston/cylinder assembly, so as to decrease the clearance where there is higher gas density that is not employed in the cooling process.

[0026] It is a further objective of the present invention to provide a dimensional relationship and of the form in the piston/cylinder assembly so as to guarantee maximum efficiency of a linear compressor provided with aerostatic bearing arrangement.

Brief Description of the Invention

[0027] The objectives of the present invention are achieved by means of a piston/cylinder assembly, the piston being displaceably positioned within the cylinder, the piston moving between a top dead center and a bottom dead center, wherein there is a perimeter clearance between the inner wall of the cylinder and the outer wall of the piston for providing the piston with aerostatic bearing arrangement, wherein the minimum perimeter clearance occurs in at the upper portion of the piston when the piston is at its top dead center, and a linear compressor comprising the piston/cylinder assembly described.

[0028] The objectives of the present invention are also achieved by means of a piston/cylinder assembly for a linear compressor, the piston being displaceably positioned within the cylinder, the piston moving between a high-pressure portion and a low-pressure portion, the high-pressure portion having higher gas density than the low-pressure portion, a perimeter clearance being defined between the inner wall of the cylinder and the outer wall of the piston for providing the piston with aerostatic bearing arrangement with gas, the dimension of the perimeter clearance varying in an inversely proportional manner with respect to the gas density in the perimeter clearance.

Brief Description of the Drawings

[0029] The present invention will now be described in greater detail with reference to examples of embodiment represented in the drawings. The figures show:

Figure 1 is a sectional view of a linear compressor provided with aerostatic bearing arrangement of the prior art.
Figure 2 is a sectional view of a linear compressor provided with aerostatic bearing arrangement of the prior art showing the gas pressures.
Figure 3 is a sectional view of a linear compressor provided with aerostatic bearing arrangement of the prior art showing the gas pressures at instant i).
Figure 4 is a sectional vie of a linear compressor provided with aerostatic bearing arrangement of the prior art showing the gas pressures at instant ii).
Figure 5 is a graph of power loss due to the clearance between cylinder and piston.
Figure 6 is a graph of the pressure profile in the piston/cylinder clearance as a function of the pressure, position and time.
Figure 7 is a graph of the gas-mass flows in the piston/cylinder clearance in the top and bottom region of the piston.
Figure 8 is a graph of the gas-mass flows in the piston/cylinder clearance in the top region of the piston.
Figure 9 is a graph of the gas-mass flows in the piston/cylinder clearance in the bottom region of the piston.
Figure 10 is a sectional view of a piston/cylinder assembly presenting an efficient solution.
Figure 11 is a sectional view of a possible embodiment of the piston/cylinder assembly of the present invention.
Figure 12 is a sectional view of a possible embodiment piston/cylinder assembly of the present invention.
Figure 13 is a sectional view of a possible embodiment of the piston/cylinder assembly of the present invention.
Figure 14 is a sectional view of a possible embodiment of the piston/cylinder assembly of the present invention.

Detailed Description of the Figures

[0030] The present invention proposes a technological advance in the piston/cylinder assembly of linear compressors with aerostatic bearing arrangement, both in the energetic efficiency and in the productive process.

[0031] According to the functioning principle of a cooling circuit and as shown in figure 1, preferably, the gas compressing mechanism occurs by the axial and oscillating movement of a piston 1 inside a cylinder 2. At the head 3, one positions the discharge valve 5 and suction valve 6, which regulate the entry and exit of gas into/out of the cylinder 2. It should be further noted that the piston 1 is actuated by means of an actuator 7 connected to the linear compressor motor, and the latter is not the subject of further explanations in this document.

[0032] The piston 1 of a compressor, when actuated by the linear motor, has the function of developing a linear alternating movement, providing a movement of the piston 1 inside the cylinder 2 that exerts a compression of the gas admitted by the suction valve 6 to the extent in which the gas can be discharged to the high-pressure side through the discharge valve 5.

[0033] The cylinder 2 is mounted within the block 8, and a cover 9 with the discharge passer 10 and the suction passer 11, which connect the compressor to the rest of the system.

[0034] As said before, the relative movement between piston 1 and cylinder 2 requires the bearing arrangement of the piston 1, which consists of the presence of a fluid in the perimeter clearance 12 between the two walls, for the purpose of separating them during the movement. An advantage of using the gas itself as a lubricating fluid is the absence of an oil pumping system.

[0035] Preferably, the gas used for the bearing arrangement may be the gas itself that is pumped by the compressor and sued in the cooling system. In this case, the gas is diverted, after compression, from the discharge chamber 13, from the cover 9 through the channel 14, to the pressurized region 15 around the cylinder 2, wherein the pressurized region 15 is formed by the outer diameter of the cylinder 2 and inner diameter of the block 8.

[0036] From the pressurized region 15 the gas passes through the restrictors 16, 17, 18, 19 inserted into the cylinder wall 2 toward the perimeter clearance 12 existing between the piston 1 and the cylinder 2, forming a gas cushion that prevents contact between the piston 1 and the cylinder 2.

[0037] With a view to restrict the gas flow between the pressurized region 15 and the perimeter clearance 12, it is necessary to make use of a restrictor 16, 17, 18, 19. This restriction serves to control the pressure in the bearing-arrangement region and to restrict the gas flow, since the whole gas used in the bearing arrangement represents a loss of efficiency of the compressor, since the main function of the gas is to be sent to the cooling system and generate cold. Thus, it should be pointed out that the gas diverted to bearing arrangement should be as little as possible, so as not to impair the efficiency of the compressor.

[0038] In order to maintain the balance of the piston 1 within the cylinder 2, at least three restrictors 16, 17, 18, 19 are preferably necessary in a given section of the cylinder 2 and at least two regions of restrictor 16, 17, 18, 19 are necessary on the cylinder 2. The restrictors should be in such a position that, even with oscillation movement of the piston 1, the restrictors 16,17, 18, 19 will never be uncovered, that is, the piston 1 will not come out of the actuation area of the restrictor 16, 17, 18, 19.

[0039] Figure 2 presents information relating to the expressions existing inside the cylinder/piston 1 assembly. The instant of figure 2 corresponds to a gas compression movement effected by the piston 1. At this instant there is a gas discharge pressure that is much higher than the pressure existing in the opposite region of the piston 1.

[0040] For a better understanding of the phenomena that entail the decrease in efficiency of the compressor, the region between the piston 1 top and the cylinder head 3 will be called high-pressure region. The piston cylinder head 3 will be called low-pressure region.

[0041] In turn, when the piston 1 top is at the point closest to the cylinder head 3, this is called top dead center (TDE/PMS) and when the piston 1 top is at the point farthest from the cylinder head 3 this is called (LDE/PMI). Thus, the piston 1 travels a linear movement between the top dead end (TDE/PMS) and the lower dead end (LDE/PIM).

[0042] Of course the gas pressure at the moment of compression will be higher in the high-pressure region. This gas flows to the perimeter clearance 12, defined by the difference between the piston diameter (Pd/Dp) and the cylinder diameter (Cd/Dc), travelling the whole length of the clearance (Cf) which, in this case, corresponds to the length of the piston 1. For a better definition of the invention, for the purpose of the expressions existing in the perimeter clearance 12, one should understand that the top of the perimeter clearance 12 and the bottom of the perimeter clearance 12 vary throughout the clearance (Cf).

[0043] As already demonstrated, the size of the clearances between piston 1 and cylinder 2 entails a loss of efficiency of the compressor in a considerably high relationship. In order to assess the better solution, one should detect which of the factors leakage and irreversibility has more influence on the loss of efficiency. For this purpose, we use theoretical models.

[0044] Anyway, before the explanation on the result of the simulation, it is necessary to comment a few characteristics on the behavior of a gas. Thus, the heat exchange of a cooler is based on the "General Equation of the Perfect Gases", which demonstrates that in a gaseous mass the volumes and pressures are directly proportional to their absolute temperatures and inversely proportional to each other.

[0045] Additionally, it is necessary to synthesize a few characteristics on the gas flow, which is established by the perimeter clearance 12:

- as it is the case for any fluid, the gas flow within the clearance exhibits a loss of load;
- the gas is a compressible fluid, so that the loss of load causes the gas pressure to vary throughout the clearance and, as a result, its density varies;
- the pressure profile, consequently the gas density, in the perimeter clearance 12 throughout the piston length assumes different forms depending on the instant of the compression cycle.

[0046] According to the characteristics described, two different instants were considered for working out the theoretical model. The instant 1 corresponds to figure 3 and occurs when the piston is at its top dead end. In turn, the instant 2 corresponds to figure 4 and occurs at the moment when the piston 1 is at the beginning of its suction movement.

[0047] Figure 6 shows the pressure profile in the perimeter clearance as a function of the pressure, position and time of the piston 1 with respect to the cylinder 2. This graph shows that an oscillation movement cycle of the piston 1 corresponds to the axis X, and it is possible to identify, around 150 ms, the instants 1 and 2, the dotted line (see indications i1 and i2). The growing variation at the axis Y corresponds to a position along the clearance of the cylinder 2 with the piston 1. Finally, the rise in pressure corresponds to the increase at the axis Z. This graph enables one to consider that:

i) at the instant 1 (i1), the pressure profile throughout the piston 1 and the minimum in the base region of the piston 1; in other words, the pressure at the bottom is always minimum, regardless of the pressure at the tope of the piston 1;

ii) at the instant 2 (i2), the pressure profile throughout the perimeter clearance 12 (dotted line) has its maximum value in the central region of the perimeter clearance 12, with the minimum pressure at the bottom and an intermediate pressure at the top of the perimeter clearance 12.

[0048] The gas mass flow through the perimeter clearance 12 between the piston 1 and the cylinder 2 behaves, at each moment, in accordance with the pressure profile shown in figure 6 and the gas density throughout the clearance 12. The diagram in figure 7 shows the mass flows in the bottom and top regions of the piston 1 throughout the time equivalent to an oscillation of the piston 1, indicating also the instants 1 and 2 (i1 and i2) already mentioned in the graph of figure 6.

[0049] The graph of figure 7 shows that the flow that comes out of the compression chamber 4 corresponds to the negative mass flow, that is, in the top region (TP) or at the bottom (BP) of the piston 1. A positive flow represents the gas that returns to the compression chamber 4.

[0050] One can notice that, during the larger part of the time, the mass flow at the top of the piston 1 is different from the mass flow at the bottom. One can further notice that, by the bottom region of the perimeter clearance 12, there is a constant leakage of gas (dotted line of negative values), further that the mass flow thereof varies a little throughout the oscillation of the piston 1.

[0051] The continuous line that corresponds to the mass flow in the perimeter clearance 12 in the top region of the piston 1 shows that the gas comes out of the compression chamber 4 and goes into the perimeter clearance 12 during a certain period of time (negative mass flow - continuous line below the abscissa axis).

[0052] Additionally, at the beginning of the suction motion, the gas that has remained in the perimeter clearance 12 is returned to the compression chamber 4. Such a pressure, in the direction opposite the suction pressure (Ps), which goes into the compression chamber 4 through the suction valve 6, impairs the entry of the gas into the compression chamber 4, thus interfering with the output of the compressor.

[0053] Examining attentively figures 3 and 4, which correspond to the instants 1 (i1) and 2 (i2), respectively, in the light of the graphs of figures 6 and 7 one can see that the at the instant 1 (i1) the piston is at the top dead center (PMS), where there is the highest mass flow (2.8E-10 kg/s) coming out of the compression chamber 4 and going into the perimeter clearance 12 in the top region of the piston 1, the leakage through the bottom region of the piston 1 being of 0.04E-10 k/s.

[0054] For the instant 2 the largest flow, of about 1.2E-10 kg/s, takes place in the gas return in the top region of the perimeter clearance 12 to the compression chamber 4. At the same instant, the leakage through the bottom is on the order of 0.094E-10 kg/s.

[0055] In other words, for both instants 1 and 2, the gas mass flow with high density (GAD) occurs in the top region of the perimeter clearance 12, the gas flows with low density (GBD) occurring in the bottom region of the perimeter clearance 12.

[0056] The diagrams of figures 8 and 9 show separately the same curves represented by the diagram of figure 7. By observing figure 8, which represents the mass flow in the top region of the piston, one concludes that the gas mass per compressor cycle that goes into the perimeter clearance 12 is equivalent to the area between the negative part of the mass flow curve and the abscissa axis (axis xx). In turn, further for figure 8 the gas mass that returns to the compression chamber 4 through the top of the diameter clearance 12 is equivalent to the portion of the graph represented above the abscissa axis.

[0057] The difference between these two amounts of mass, or graphically, the difference between the areas above and below the abscissa axis of figure 8 corresponds to the gas mass equivalent to the leakage of gas through the bottom of the piston 1, and the latter, in turn, is represented by the filled area of the graph in figure 9.

[0058] Therefore, one can conclude that of all the gas that goes into the perimeter clearance. 12 between the piston 1 and the cylinder 2 little will escape through the bottom region in the form of leakage. The largest part of the gas displaces between the perimeter clearance 12 and the compression chamber 4.

[0059] Thus, the greatest part of the power lost because of the perimeter clearance 12 existing between the piston 1 and the cylinder 2 shown in figure 5 comes from the irreversibility effect, not from the leakage effect.

[0060] The highest gas densities occur in the top region of the piston 1 when the latter is closest to the head 3, due to the fact that the high pressures in this region are capable of compressing the gas into a smaller volume.

[0061] On the basis of the identification of the region of the piston-1/ cylinder-2 assembly responsible for the greatest loss of efficiency of the compression, it is possible to achieve a solution of high energetic efficiency, which is the focus of the present invention.

[0062] The way to reduce the irreversibility effect caused by the clearance between the piston 1 and the cylinder 2 is by keeping the clearance as low as possible, so that here will be less volume available for the accumulation of gas at high pressure in the perimeter clearance 12 during the compression phase. In this way, it is possible to establish a smaller gas flow between the compression chamber 4 and the perimeter clearance 12.

[0063] However, the decrease of the perimeter clearance 12 between the piston 1 and the cylinder 2 finds its limits in the pressure limits of the manufacture process (machining processes) used for making the piston 1 and the cylinder 2.

[0064] As a rule, the perimeter clearance between the piston 1 and the cylinder 2 may be as follows: the lower the cylindricity errors on the outer surface of the piston 1 and the inner surface of the cylinder 2 the smaller the clearance. At present, this clearance in cooling compressors is of about a few microns.

[0065] Additionally, it should be noted that the cylindricity error obtained on parts like pistons 1 and cylinders 2 is dependent upon the length of the cylindrical surfaces, that is, on the length of piston 1 and cylinder 2. The relationship is established so that the longer the part length, the greater the cylindricity which it exhibits. Thus, an option of decreasing the cylindricity error to enable one to reduce the perimeter clearance 12 might be simply to reduce the length of the piston 1 and /or cylinder 2.

[0066] Figure 10 shows a piston/cylinder assembly with a large clearance in the top region of the piston 1 due to the high cylindricity error of the cylinder.

[0067] The decrease in length of piston 1 and cylinder 2, however, is not suitable for compressors that use aerostatic bearings instead of lubricating oil, because they need longer piston 1 and cylinder 2, so that the aerostatic bearings will provide the necessary support for the piston 1, preventing contact between the piston 1/cylinder assembly; otherwise, the assembly would undergo premature wear and, as a result, loss of efficiency.

[0068] The problem to be solved by the present invention is, therefore, one exclusive of compressors that use aerostatic bearings. On the one hand, there are the difficulties mentioned in the previous paragraph and, on the other hand, only compressors with aerostatic bearings have a perimeter clearance 12 through which the cooling gas flows.

[0069] Since it was not possible to reduce the length of the piston 1 and cylinder 2 to achieve a reduction of the cylindricity errors, due to the questions of stability and bearing arrangement of the piston 1 in the cylinder 2, a solution has been found which enables one to achieve the effect of a shorter piston 1 or cylinder 2. Such a solution results in a decrease in the perimeter clearance 12 between piston 1 and cylinder 2, without the need to reduce the length of one of the parts of the piston/cylinder assembly.

[0070] According to what was demonstrated by the results of the theoretical models, the smallest perimeter clearance 12 possible is all the more necessary and beneficial the closer to the piston 1 top, that is, the closer to the region of the piston 1 the decrease in the perimeter clearance 1 is carried out, the greater the effect of reducing irreversibility, since it is in this region that the largest gas-mass flows that go into and come out of the perimeter clearance 12 take place.

[0071] It is not necessary to reduce the perimeter clearance 12 throughout the clearance length (Cf), nor during the whole cycle of oscillatory movement of the piston 1, by rather at the moment when pressures close to the discharge pressure occur in the compression chamber 4, that is, when the piston 1 is close to the head 3.

[0072] In this regard, the problem of the perimeter clearance 12 can be solved by using a smaller clearance in the top region of the piston 1 than in the bottom region of the piston 1.

[0073] Preferably, but not compulsorily, a solution of the present invention for the irreversibility is by using components (piston and/or cylinder) with a varying cross-section, so as to create a specific portion in which the clearance will be effectively reduced. These regions have lengths that are quite shorter than the lengths of the components themselves and for this reason they will exhibit lower cylindricity errors than those of internal components.

[0074] Thus, exclusively in these regions the clearance between piston 1 and cylinder 2 can be reduced.

[0075] Figures 11 to 14 show a few possible embodiments of the piston/cylinder assembly that guarantee better compressor efficiency. The piston 1, due to its smaller bottom diameter, enables en increase in the clearance at the bottom of the piston/cylinder assembly and the consequent decrease in the top clearance of the piston 1.

[0076] It should be noted that whatever the solution the clearance in the top portion of the piston 1 is always smaller than in any other region of the piston/cylinder assembly. Additionally, the closest to the head 3 the piston 1 is the smaller the perimeter clearance.

[0077] Figures 11 to 14 show that one can find solutions in which the bottom diameter of the piston 1 is reduced with respect to the rest of its body (figure 11) The same result can be achieved through one of more variable sections of the piston 1 and cylinder 2, while achieving a perimeter clearance 12 that is reduced in the top region of the piston/cylinder assembly.

[0078] Figures 12 and 13 show possible geometrical embodiments of the piston 1/cylinder 2 assembly that make use of two different sections on one of the elements piston 1 or cylinder 2 with the objective of reducing the perimeter clearance 12 as the piston 1 gets close to the cylinder 2 top.

[0079] In figure 12, the piston 1 exhibits two different sections, the section adjacent the top region of the piston 1 having larger diameter than the region adjacent the lower portion of the piston 1, that is, the top portion of the piston has larger dimension than the rest of the piston 1. Thus, as the piston 1 moves to the top of a cylinder 2 that is slightly arched in its longitudinal direction, the diameter clearance 12 reduces to a minimum when the piston 1 is close to the cylinder 2 top. This slightly ached shape of the cylinder 2 in its longitudinal direction may be defined as a circle-segment top shape.

[0080] Figure 13 shows a situation analogous to figure 12, but this time it is the cylinder 2 that has two sections provided with different diameters. Naturally, in order to guarantee a smaller diameter clearance 12, the cylinder 2 undergoes a narrowing in the section at the portion located closer to the cylinder top (the top portion of the cylinder 2 has a smaller dimension than remaining portion of the cylinder 2), which provides the minimum necessary diameter clearance 12.

[0081] Figure 14 shows another of these possible embodiments, which can be achieved by means of a cylinder 2 that has a frustum-type geometry, wherein the portion of smaller diameter would be in the top region of the cylinder 2. Thus, as the top of the piston 1 gets closer to the top of the cylinder 2, the perimeter clearance 12 is reduced.

[0082] The solution of the present invention is, therefore, achieved when one ensures a relationship in which the dimension of the perimeter clearance 12 varies in an inversely proportional manner with respect to the density of the gas present in the perimeter clearance 12.

[0083] Preferred examples of embodiment having been described, one should understand that the scope of the present invention embraces other possible variations, being limited only by the contents of the accompanying claims, which includes the possible equivalents.

Claims

1. A piston/cylinder assembly, the piston (1) being displaceably positioned inside the cylinder (2),
the piston moving between a top dead center (TDC/PMS) and a bottom dead center (BDC/PMI),
between an inner wall of the cylinder (2) and an outer wall of the piston 91) there being a perimeter clearance (12) for aerostatic bearing arrangement (1),
the assembly being **characterized in that**:

- there is a minimum perimeter clearance (12) at the top portion of the piston (1) when the piston (1) is at its top dead center (TDC/PMS).

2. A piston/cylinder assembly according to claim 1, **characterized in that** the perimeter clearance (12) is variable from the bottom dead center (BDC/PMI) to the top dead center (TDC/PMS).

3. A piston/cylinder assembly according to claims 1 and 2, **characterized in that** the closer to the top portion of the piston (1) top the perimeter clearance (12) is, the smaller it is.

4. A piston/cylinder assembly according to claims 1 to 3, **characterized in that** the piston (1) has a variable cross-section.

5. A piston/cylinder assembly according to claims 1 to 4, **characterized in that** the cylinder (1) has a variable cross-section.

6. A piston/cylinder assembly according to claims 1 to 5, **characterized in that** the top portion of the piston (1) has a dimension larger than the remaining portion of the piston (1).

7. A piston/cylinder assembly according to claims 1 to 6, **characterized in that** the top portion of the cylinder (2) has a dimension smaller thant the remaining portion of the cylinder (2).

8. A piston/cylinder assembly according to claims 1 to 7, **characterized in that** the piston (1) is conical.

9. A piston/cylinder assembly according to claims 1 to 8, **characterized in that** the piston (1) has a circle-segment shape.

10. A piston/cylinder assembly according to claims 1 to 9, **characterized in that** the cylinder (2) has frustum-type geometry.

11. A piston/cylinder assembly according to claims 1 to 10, **characterized in that** the cylinder (2) has a circle-segment shape.

12. A linear compressor **characterized by** comprising a piston/cylinder assembly as defined in claims 1 to 11.

13. A piston/cylinder assembly for a linear compressor, the piston (1) being displaceably positioned within the cylinder (2),
the piston (1) moving between a high-pressure portion (Pd) and a low-pressure portion (Ps),
the high-pressure (Pd) having higher gas density than the low-pressure portion (Ps),
a perimeter clearance (12) being defined between an inner wall of the cylinder (2) and an outer wall of the piston (1) for aerostatic bearing arrangement (1) with gas,
the assembly being **characterized in that**:

the dimension of the perimeter clearance (12) varies in an inversely proportional manner with respect to the gas density in the perimeter clearance (12).

14. A piston/cylinder assembly according to claim 1, **characterized in that** the piston (1) has a variable cross-section.

15. A piston/cylinder assembly according to claims 13 and 14, **characterized in that** the cylinder (1) has a variable cross-section.

16. A piston/cylinder assembly according to claims 13 to 15, **characterized in that** the top portion of the piston (1) has a larger dimension than the remaining portion of the piston (1).

17. A piston/cylinder assembly according to claims 13 to 16, **characterized in that** the top portion of the cylinder (2) has a smaller dimension than the remaining portion of the cylinder (2).

18. A piston/cylinder assembly according to claims 13 to 17, **characterized in that** the piston (1) is conical.

19. A piston/cylinder assembly according to claims 13 to 18, **characterized in that** the piston (1) has a circle-segment shape.

20. A piston/cylinder assembly according to claims 13 to 19, **characterized in that** the cylinder (2) is conical.

21. A piston/cylinder assembly according to claims 11 to 20, **characterized in that** the cylinder (2) has a circle-segment shape.

22. A linear compressor **characterized by** comprising a piston/cylinder assembly according to claims 13 to 21.

23. A piston/cylinder assembly, the piston (1) being displaceably positioned within the cylinder (2),
the piston (1) moving between a top dead center (TDC/PMS) and a bottom dead center (BDC/PMI), between an inner wall of the cylinder (2) and an outer wall of the piston (1) there being a perimeter clearance (12) for aerostatic bearing arrangement of the piston (1),
the assembly being **characterized in that**:

- the perimeter clearance (12) is minimum when the piston (1) is at its top dead center (TDC/PMS) and the closer to the top portion of the piston (1) the perimeter clearance (12) is, the smaller it is.

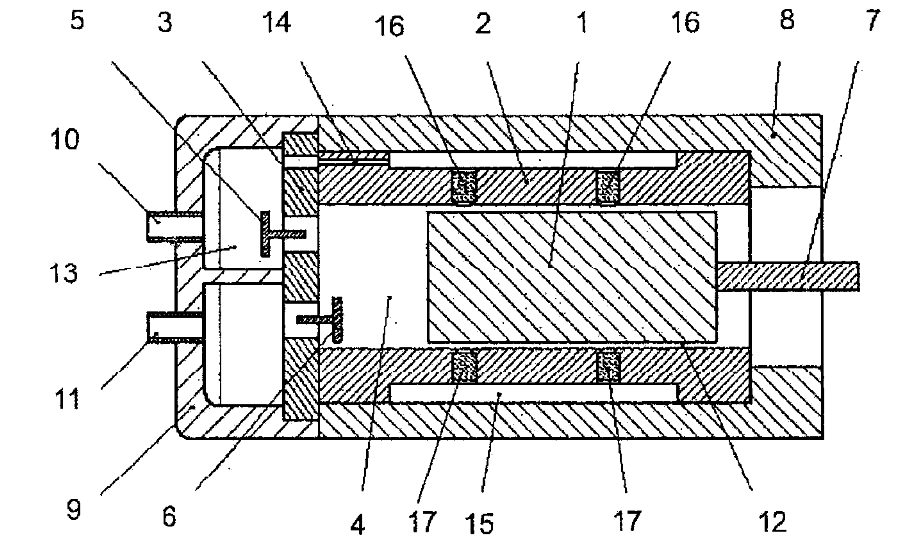


Fig. 1

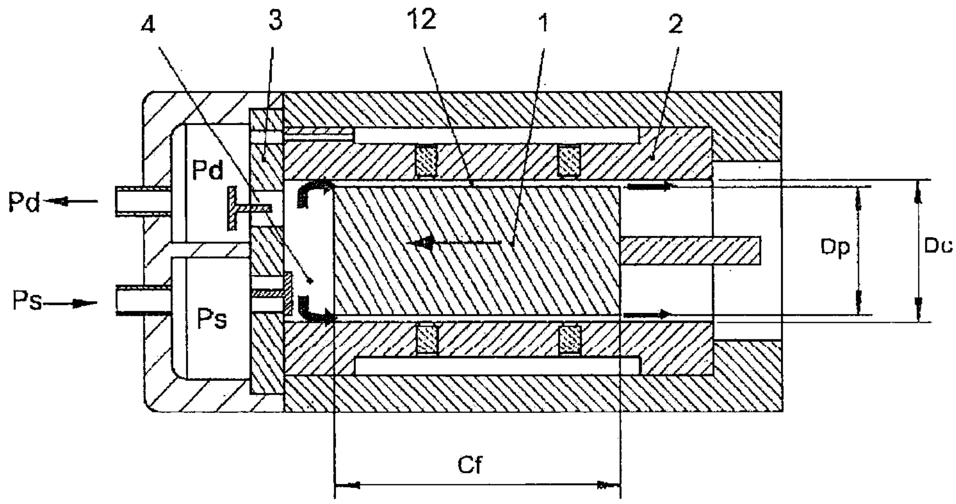


Fig. 2

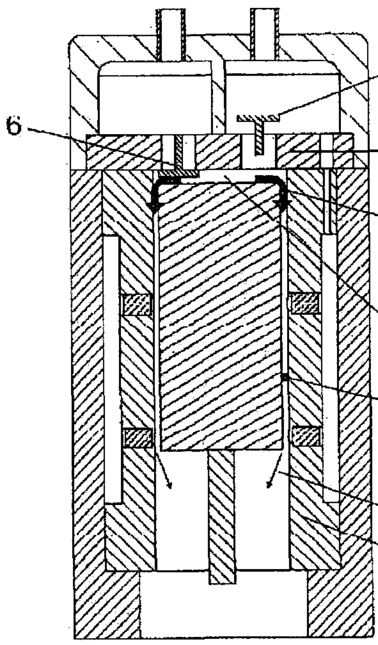


Fig. 3

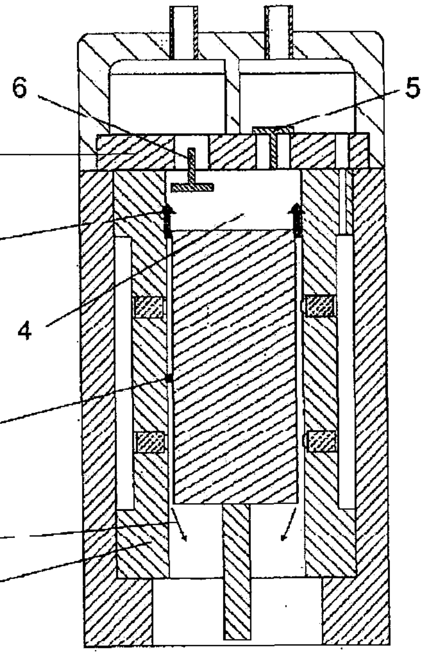


Fig. 4

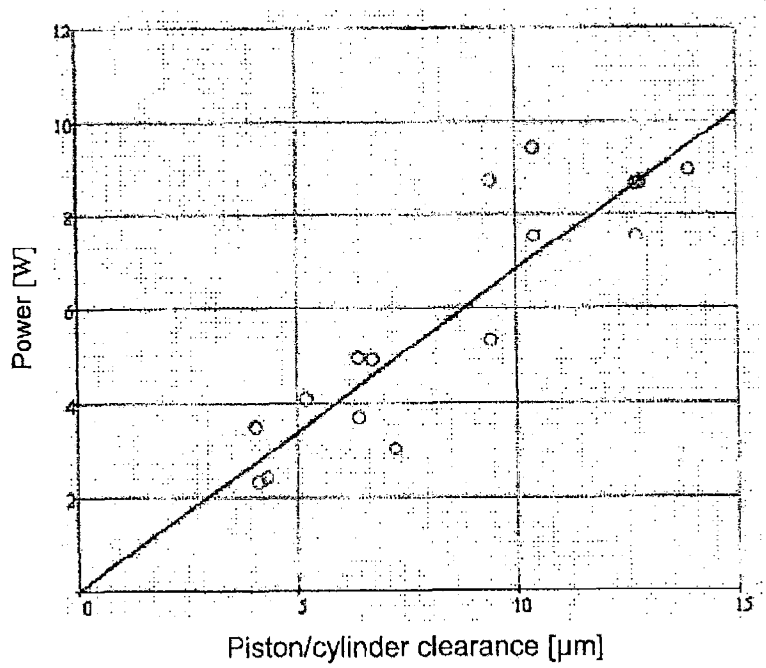


Fig. 5

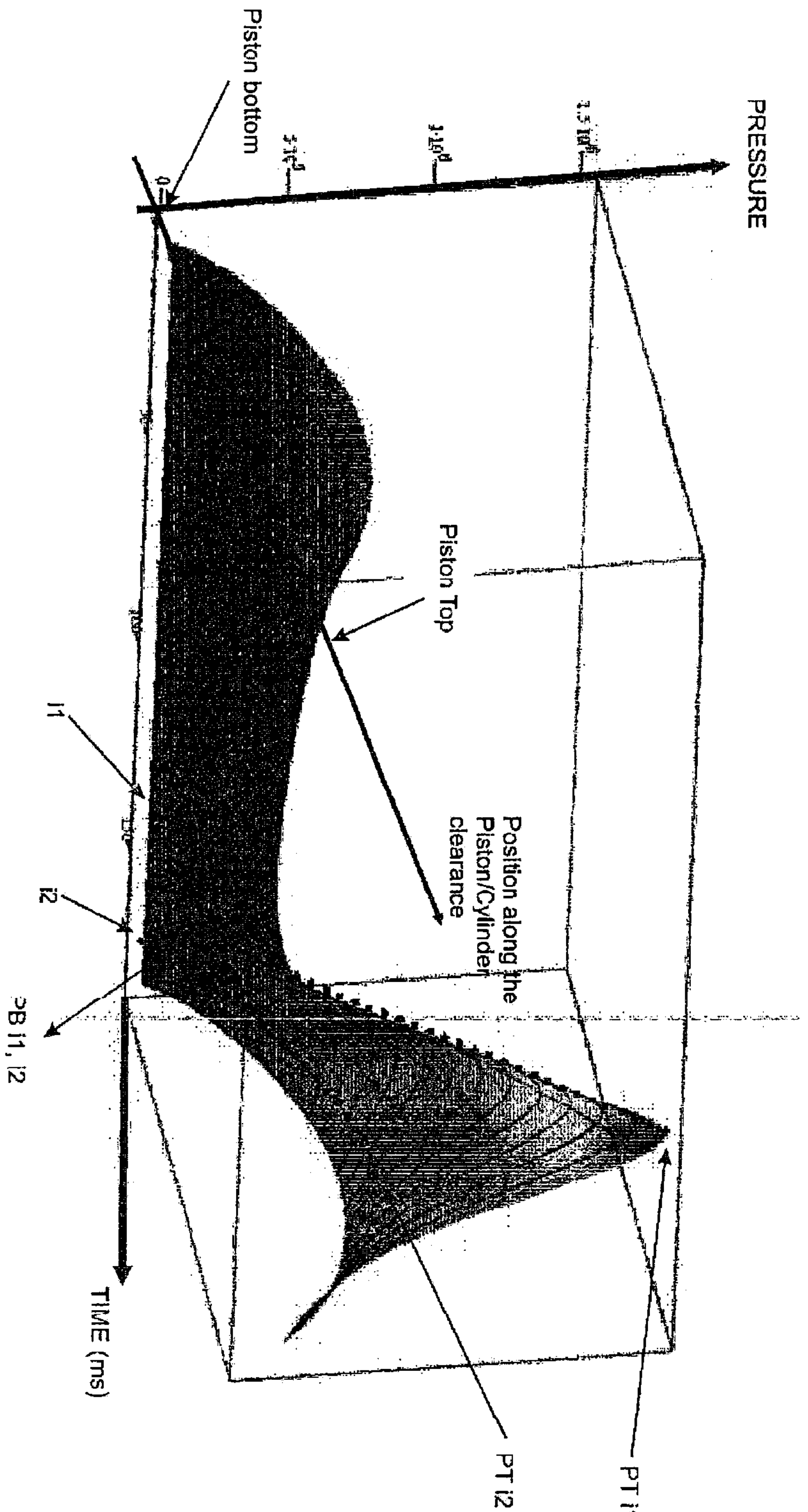
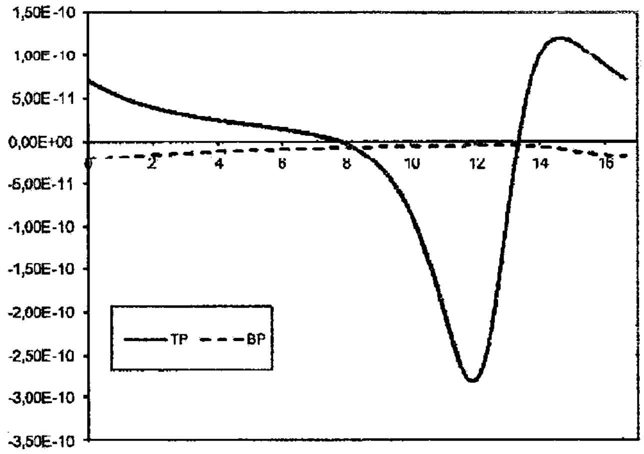

PRESSURE
Piston bottom
Piston Top
Position along the Piston/Cylinder clearance
i1
i2
PB i1, i2
TIME (ms)
PT i1
PT i2

Fig. 6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6
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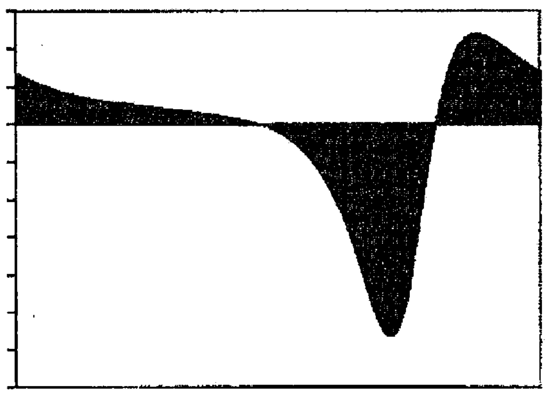
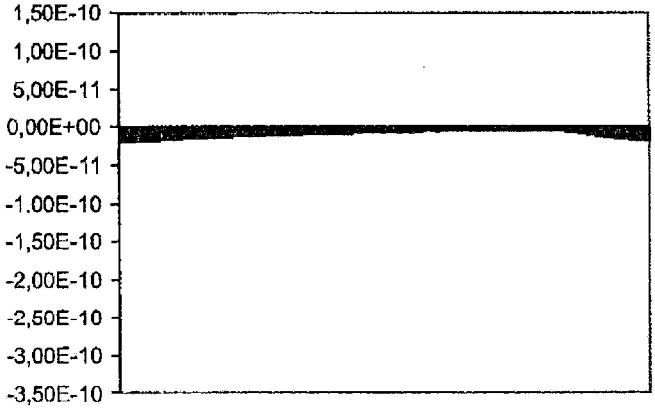
10
12
14
16
TP
BP

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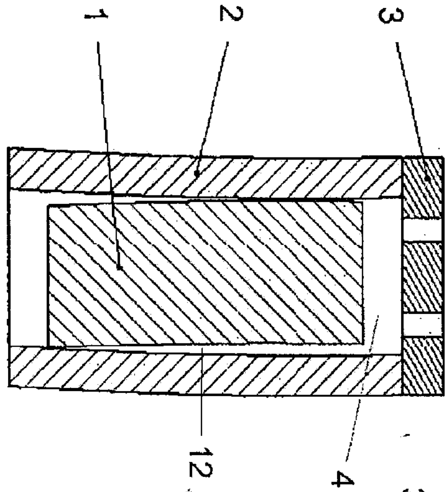

Fig. 10

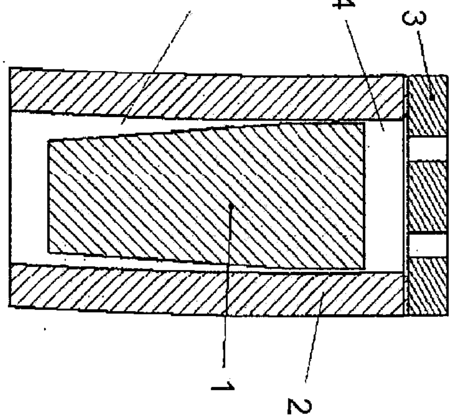

Fig. 11

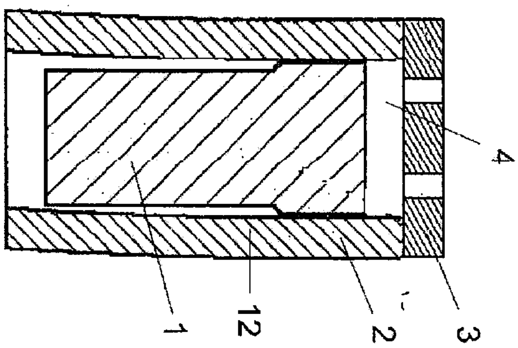

Fig. 12

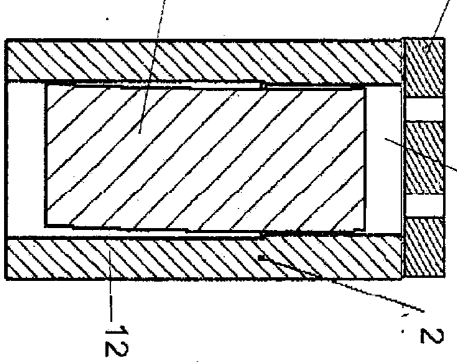

Fig. 13

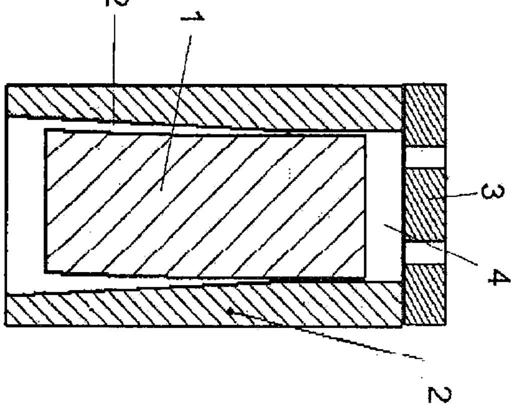

Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/BR2012/000450

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04B39/02 F04B39/12 F04B53/00
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)
F04B

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

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X	WO 2004/106737 A1 (FISHER & PAYKEL APPLIANCES LTD [NZ]; MCGILL IAN CAMPBELL [NZ]; BOYD JR) 9 December 2004 (2004-12-09)	1-4,6,8, 22
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A	DE 10 2006 052447 A1 (BSH BOSCH SIEMENS HAUSGERAETE [DE]) 8 May 2008 (2008-05-08) pages 18-22; figure 1 -----	1-22
A	WO 2007/009202 A1 (WHIRLPOOL SA [BR]; GRAF EGERHARDT [BR]; LINK RODRIGO [BR]; KLEIN FABIO) 25 January 2007 (2007-01-25) page 6, line 25 - page 8, line 17; figures 2-4 -----	1-22
	-/--	

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

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 March 2013	20/03/2013

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	Ziegler, Hans-Jürgen

INTERNATIONAL SEARCH REPORT

International application No
PCT/BR2012/000450

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

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