



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
14.11.2018 Bulletin 2018/46

(51) Int Cl.:
F01B 13/04^(2006.01)

(21) Application number: **18171404.9**

(22) Date of filing: **09.05.2018**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
 Designated Extension States:
BA ME
 Designated Validation States:
KH MA MD TN

(71) Applicant: **Leonardo Engineers for Integration Srl**
10128 Torino (IT)

(72) Inventor: **Bianchi, Pietro**
10129 Torino (IT)

(74) Representative: **Zanoli, Enrico et al**
Zanoli & Giavarini S.p.A.
Via Melchiorre Gioia, 64
20125 Milano (IT)

(30) Priority: **10.05.2017 IT 201700050406**

(54) **MACHINE FOR THE TRANSFORMATION OF THERMAL ENERGY INTO MECHANICAL WORK OR ELECTRICAL ENERGY**

(57) A machine for the transformation of thermal energy into mechanical work or electrical energy characterized by comprising cylindrical blocks provided with axial cavities housing a rotary member provided with cams having profiles such as to generate a coordinated movement of pistons housed in said cylindrical blocks; a series of cylindrical working chambers open towards said axial cavities of said cylindrical blocks provided with pistons acting on a roller in contact with said cams. Each chamber is also provided with communication channels with an external reservoir for a fluid working in the chambers,

and a plurality of distribution valves of the fluid between said appropriate communication channels and the working chambers. A first cylindrical block is exposed to a heat source (A) adapted to heat the working fluid in the working chambers while a second cylindrical block is thermally isolated from said heat source and placed in contact with a lower temperature heat source whereby it is cooled. The fluid carries out thermodynamic cycles of compression and expansion as a result of the motion of said pistons and the corresponding rotation of the cams and of the rotary shaft.

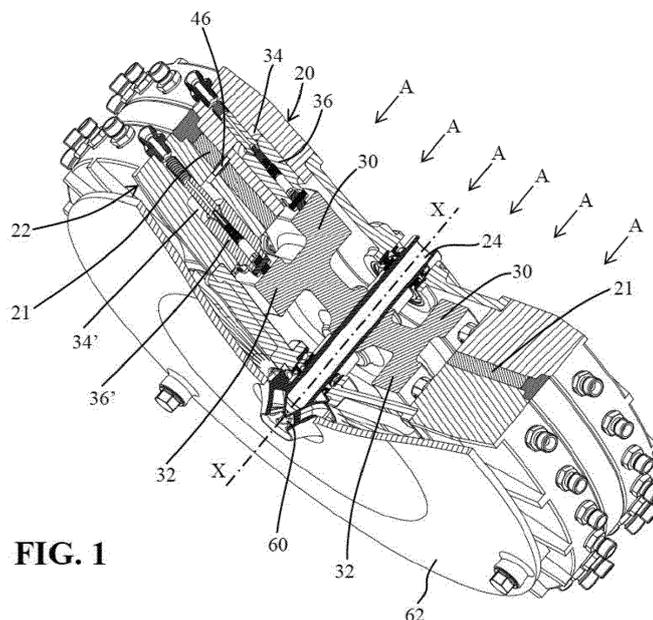


FIG. 1

Description

[0001] The present invention relates to a machine for the transformation of thermal energy into mechanical work or electrical energy through the evolution of a working fluid.

[0002] The high cost of fossil fuels and their limited availability has led to the production of machines capable of producing mechanical work and/or electrical energy from recovered heat or low temperature heat, but also heat produced by solar energy or other alternative energy sources. However, large scale use of these machines is restricted due to their dimensions and costs, which are often such that they limit the applications thereof.

[0003] US 2006/0053793 A1 relates to a heat regenerative engine that uses water as working fluid and as lubricant. This engine comprises, although enclosed in a single container, various subgroups of members separated from one another, each adapted to carry out a specific step of the thermodynamic cycle that uses heat to produce mechanical work. Therefore, the size and the production costs of this engine are quite substantial in relation to the supplied power.

[0004] In the state of the art indicated above, the problem of providing a compact machine with very limited costs for the transformation of thermal energy into mechanical work or electrical energy that is versatile as regards the source of thermal energy used, i.e. is able to use, besides heat produced by combustion, also recovery heat or low temperature heat or heat produced through solar energy or other alternative energy sources to fossil fuels, remains unresolved or resolved in an unsatisfactory manner.

[0005] Therefore, it would be desirable to provide a machine for the transformation of thermal energy into mechanical work or electrical energy adapted to use any form of heat source, whether of solar origin, produced by combustion or obtained as waste heat from processes of any kind, which is relatively small in size and compact in shape, and which is also suitable to be used for distributed energy generation.

[0006] Therefore, an aspect of the invention regards a machine for the transformation of thermal energy into mechanical work or electrical energy characterized by comprising:

- i) a first and a second cylindrical block, coaxial and side by side, separated by a cylindrical partition of insulating material, said cylindrical blocks and said insulating partition being provided with axial cavities housing a rotary member provided with a first and a second cam, each placed in correspondence of each of said cylindrical blocks;
- ii) a series of cylindrical working chambers in each of said cylinder blocks, each of said working chambers being open at the bottom towards said axial cavities of said cylindrical blocks and being provided with a single-acting piston provided with a contrast

spring and acting on an idle roller in contact with said cams of said rotary member, thereby defining a first series of working chambers in said first cylindrical block, a second series of working chambers in said second cylindrical block, a first series of pistons acting on a corresponding first series of rollers in contact with said first cam, and a second series of pistons acting on a corresponding second series of rollers in contact with said second cam;

iii) a plurality of communication channels between said first and second series of working chambers, each of said channels putting in communication a chamber of said first cylindrical block with a corresponding chamber of said second cylindrical block through said insulating partition, each of said chambers being also provided with communication channels with an external reservoir for a fluid working in said chambers, and a plurality of distribution valves of said fluid between said communication channels and said working chambers;

iv) said first cylindrical block being operatively exposed to a heat source adapted to heat said working fluid in said first working chambers, while said second cylindrical block is thermally isolated from said heat source and suitably cooled by a suitable heat dissipation system to a lower temperature, so that in said first and second working chambers said working fluid carries out thermodynamic cycles according to the laws of motion defined by the profile of said cams, said profiles of the two cams being defined, so as to produce, in said working chambers, following the movement of the related working cylinders and of the presence of said communication channels between the various cylinders, volume variations that determine the following thermodynamic transformations of the working fluid according to a cycle comprising the following steps:

- a. a rapid compression, approximately adiabatic, in the lower temperature cylinder;
- b. a transfer to the higher temperature cylinder and an approximately isothermal expansion;
- c. a second expansion step, approximately adiabatic;
- d. a transfer to the cold cylinder with consequent cooling and return to step a., conventionally assumed at the start of the cycle.

[0007] In the implementation of the invention described the difference in temperature between said cylinder blocks at higher temperature and at lower temperature is such that the thermodynamic equilibrium of the cycle described is positive, i.e. the torques transmitted during the expansion steps of said working fluid to said cams and, from these, to said movement (rotary) members, are higher than those transmitted in the opposite direction during the compression steps;

[0008] According to a preferred characteristic of the

invention, said cylindrical working chambers are oriented radially in each of said cylindrical blocks according to longitudinal axes incident on the longitudinal axis of said rotary member.

[0009] Another aspect of the invention regards the machine as defined above in the embodiment dedicated to the transformation of mechanical energy associated with said rotary shaft into electrical energy by providing a plurality of permanent magnets coupled to said rotary member in a radially distal location thereto, and a stator housed in the axial cavity of said cylindrical blocks between said permanent magnets and said rotary shaft, said stator being provided with electrical windings on which there are induced electromotive forces that support the production of electrical current exploitable directly or indirectly by electric utilities external to the machine.

[0010] Therefore, the machine according to the present invention allows the transformation of thermal energy deriving from any heat source into mechanical work and optionally, due to the arrangement of the aforementioned members of which it is composed, its transformation into electrical energy.

[0011] In a single very compact mechanical assembly, the machine performs thermodynamic cycles for the transformation of heat into work in a single mechanical assembly, contrary to what is known in the state of the art, in which the cycle consisting of compression, heating, expansion and cooling is performed in different components of a complex system, therefore with greater costs, size and weight.

[0012] As stated, this assembly can also comprise the electromechanical elements for direct transformation of the mechanical work produced into electrical energy, also in this case avoiding complex motion transfer systems and, ultimately, obtaining a device that is more efficient, of smaller size, lighter in weight and less expensive than those available in the state of the art.

[0013] The machine according to the present invention is applicable in any process for which it is useful to obtain energy in mechanical or electrical form from a heat source, in particular, due to the characteristics that will be illustrated in more detail hereinafter in the description, is suitable to exploit limited temperature gradients with acceptable thermodynamic outputs offering a useful tool for better exploitation of all energy sources, whether from fuel, from solar radiation or from recovery of heat dispersed by industrial processes. It is also suitable for small-scale use so as to allow a production of energy distributed in the territory.

[0014] The machine substantially comprises two cylindrical blocks kept at different temperatures, in which a working fluid, or evolving fluid, that evolves following the motion of a plurality of pairs of pistons that act on two cams, one for each cylindrical block, is input into variable volume working chambers. The chambers are arranged in the two cylindrical blocks and in communication with each other according to suitable connections. The profile of the cams is produced so that the motion of the pistons

generates variations of volume of the working chambers so as to carry out a predetermined thermodynamic cycle described in detail hereinafter in the description.

[0015] The work generated on the active surface of the pistons is then transferred to the cams and from these to a rotary member connected thereto and utilized mechanically, i.e., utilized to generate a rotary magnetic field that in turn generates an electromotive force in suitable stator windings.

[0016] In an embodiment dedicated to the production of electrical energy, the machine also comprises the electromechanical elements for direct transformation of the mechanical work produced into electrical energy, also in this case avoiding complex motion transfer systems and, ultimately, obtaining a product that is more efficient, of smaller size, lighter in weight and less expensive than those available in the state of the art.

[0017] Another aspect of the invention regards the use of the machine defined above to perform thermodynamic cycles of compression, heating, expansion and cooling of a working fluid, in which the thermal exchanges are carried out in the condition of variation of the state of aggregation of said fluid from liquid to vapor and vice versa.

[0018] Moreover, according to the conditions of application, the profile of the cams can be defined, without compromising the operation of the device described, so that the fluid performs a complete thermodynamic cycle several times during one revolution, in this way the rotation speed of the motion transfer members can be adapted to different operating needs, as the rotation speed is approximately inversely proportional to the number of cycles carried out during a rotation.

[0019] Some preferred embodiments of the machine according to the present invention will now be described with reference to the accompanying drawings, provided by way of non limiting example, wherein:

- Figs. 1 and 2 are partially sectional schematic perspective views of a first embodiment of the machine according to the invention;
- Fig. 3 is an enlarged sectional schematic view of a detail of Fig. 1;
- Figs. 4A and 4B are two sectional schematic views according to a transverse plane of the machine of Fig. 1;
- Fig. 5 is an enlarged sectional schematic view of a detail of Fig. 4;
- Fig. 6 is an enlarged sectional schematic view of a detail of the machine according to the invention;
- Figs. 7,7A and 8,8A are sectional views of details relating to the distribution valves of the machine according to the invention;
- Fig. 9 is a partially sectional perspective view of a second embodiment of the machine according to the invention;
- Fig. 10 is a schematic sectional view according to a transverse plane of the machine of Fig. 9;

- Fig. 11 is an enlarged sectional schematic view of a detail of Fig. 10;
- Fig. 12 is an exploded view of the machine according to the invention;
- Fig. 13 indicates the lift profiles of the cams of the machine according to the present invention;
- Fig. 14 represents a phase diagram of the cams of Fig. 13;
- Fig. 15 represents a phase diagram of the cold side of the machine according to the present invention;
- Fig. 16 represents a phase diagram of the hot side of the machine according to the present invention;
- Fig. 17A illustrates a longitudinal section in the direction of the rotation axis of the shaft of a second embodiment of the machine according to the invention;
- Fig. 17B illustrates a cross section perpendicular to the rotation shaft of the machine of Fig. 17A.

[0020] With reference to Figs. 1-3, the machine comprises a first cylindrical block 20 and a second cylindrical block 22, arranged coaxially and side by side along an axis X-X, but separated by a cylindrical partition of heat insulating material 21. The two cylindrical blocks 20, 22 and the insulating partition interposed between them are fixed to one another by means of tie rods, only schematically indicated.

[0021] The machine is operatively arranged so that the first cylindrical block 20 is exposed to a heat source capable of increasing the temperature of a working fluid in this block, as will be illustrated hereinafter in the description, while the second cylindrical block 22 is at a lower temperature, so that the working fluid can perform a thermodynamic cycle with production of work. The lower temperature condition of the cylindrical block 22 is acquired both due to the presence of the insulating partition 21 and due to the optional presence of a cooling system acting thereon. In the present description the first cylindrical block 20 is also defined "hot block" while the cylindrical block 22 is also defined "cold block".

[0022] In order to reach significant thermodynamic outputs, it is important for the thermal insulation to be very efficient. A particularly advantageous material as thermal insulation for producing the partition 21 is a solid foam known with the name "Aerogel".

[0023] Both the cylindrical blocks 20, 22 and the insulating partition 21 are provided with corresponding axial cavities according to the axis X-X, housing a rotary member comprising a rotary shaft 24 mounted on bearings 26, as is known in the art (Fig. 3). The bearings 26 are part of a fixed support 28

[0024] A first cam 30 and a second cam 32, which in the embodiment illustrated in the figures are made entirely in once piece, are fixed to the rotary shaft 24. Therefore, the cams 30, 32 rotate integrally with the shaft 24. The cam 30 is placed in correspondence of the cylindrical block 20 and the cam 32 is placed in correspondence of the cylindrical block 22. The cams 30, 32 are staggered

with respect to each other, as shown in Fig. 1.

[0025] Lubrication of the parts in reciprocal motion is obtained with a lubricating additive in the evolving fluid as in the case of some two-stroke engines, for example used for motorcycles. The state of the art provides numerous possibilities of choice of these lubricants as a function of the nature of the evolving fluid and of the cycle temperatures, and, in some cases, if these are very high and this is justified by the increase in available power, the device illustrated could be provided with auxiliary lubrication systems as known in the state of the art; the additional cost of this choice would in this case be justified by the greater thermodynamic output and consequently by an increase in available power.

[0026] With reference also to Figs. 4A, 4B and 5, it can be noted that Fig. 4A and 4B are cross sections of a cylindrical block 20 or 22, which are identical, so that Fig. 4A is designated as a cross section of the cylindrical block 20. Fig. 5 is an enlarged view of a detail of Fig. 4a. The term cross section is meant as a section according to a plane orthogonal to the axis X-X passing through the centerline of the cylindrical block 20 and coincident with the longitudinal axis of the rotary member 24.

[0027] Figs. 4A, 4B and 5 show that the cylindrical block 20 is provided with a series of cylindrical working chambers 34 oriented radially. The longitudinal axes Y-Y of the chambers 34 are all incident on the axis X-X of the rotary member 24 and are perpendicular to this axis X-X.

[0028] Corresponding cylindrical working chambers 34' are produced in the cold cylindrical block 22 (Figs. 1-3) so that each cylindrical working chamber 34 of the first cylindrical block 20 is side by side with a corresponding cylindrical working chamber 34' of the second cylindrical block 22. In the present description the working chambers 34, 34' are at times referred to as "corresponding" or "side by side" or "adjacent", these terms meaning that the two chambers 34, 34' are placed substantially at the same radial distance from the axis X-X, but with the interposition of the insulating partition 21 between the two blocks 20, 22.

[0029] In the following description the components of the second cylindrical block 22 are indicated using the same numbers used to indicate the components of the cylindrical block 20, with the addition of an inverted comma '<'>. Unless otherwise indicated, the description of the members and of the components of the second cylindrical block 22 is the same as that of the first cylindrical block 20 and is therefore described together with that of the first cylindrical block 20, with the addition of an inverted comma '<'>.

[0030] Each working chamber 34, 34' is open at the bottom towards the axial cavity of the cylindrical block and mounted slidably therein is a single-acting piston 36, 36', the rod 37, 37' of which extends into an upper cylindrical portion 35, 35' of the chamber 34, 34'. This cylindrical portion 35, 35' is of smaller diameter with respect to the diameter of the chamber 34, 34', so as to corre-

spond substantially to the diameter of the rod, 37, 37', with suitable clearance to allow the stroke of the rod and to form the sliding guide thereof. Housed at the top of the upper cylindrical portion 35, 35' is a coil spring 38, 38' that opposes the piston stroke. In a preferred embodiment the ratio between the surfaces of the walls of the chambers 34, 34' and the volume of these chambers is very high, the diameter of the chambers 34 and 34' having an *aspect ratio* with respect to the piston stroke so that during the heating and cooling steps the volume contained in the chambers is small with respect to their surface. In this way, due to their nature proportional to the surface through which they take place, the thermal exchanges are large with respect to the mass contained in the volume, so that the temperature of the fluid very rapidly approaches the temperature of the walls, meaning that this takes place in an interval of time during which the rotation angle of the cam varies by an extent that is less than the duration of each step. Fixed to the lower end of each piston 36, 36' is a roller 40, 40', in contact with the cams 30, 32, respectively. Each roller 40, 40' is mounted idle on a pin 42, 42' whose longitudinal axis is parallel to the axis X-X of the rotary shaft 24. The pin 42, 42' is fixed to the piston through a fork 44, 44', as shown in Fig. 3. The spring 38, 38' maintains the roller 40, 40' pressed constantly against the cam 30, 32, respectively.

[0031] With reference to Fig. 6, which is a cross sectional view of the cylindrical chambers 34, 34', in the cylindrical blocks 20, 22 and through the insulating partition 21 there is produced a communication channel 46 between each working chamber 34 of the first cylindrical block 20 and the corresponding adjacent working chamber 34' of the second cylindrical block 22. This channel 46 is preferably arranged according to a tangent common to the working chambers 34, 34', as indicated in Fig. 6, so as to generate a rotary flow field that promotes thermal exchange with the walls.

[0032] Each working chamber 34, 34' is also in communication with an external reservoir, destined to contain a fluid, through a central channel 48, 48' that extends axially in each piston 36, 36' and along the related rod 37, 37', and through a pair of channels 49, 49'. These channels 48, 48', 49, 49' are controlled by distribution valves that regulate their opening and closing as a function of the pressure conditions that occur in the working chambers 34, 34' and in the fluid reservoir. With reference to Fig. 11, these valves consist of a filling valve 45 and a maximum pressure valve 90.

[0033] According to a preferred embodiment, these distribution valves 45 and 90 are produced in the body of the piston 36, 36', as shown in Figs. 7, 7A and 8, 8A.

[0034] In this embodiment the channels 49, 49' are produced in the piston 36, 36' starting from the surface thereof facing the chamber 34, 34' and leading into the axial channel 47, 47'. Therefore, they place the central channel 48, 48' in communication with the working chamber 34, 34'. Considering by way of example the chamber 34, as shown in Fig. 7, the channels 49 put the chamber 34 in

communication with the central channel 48, which is in turn connected to an external reservoir, not illustrated, as indicated by the arrow B in Figs. 7 and 8. As is shown in Fig. 5, a bored through connector 50 for mounting a duct that leads to the reservoir is fixed to the upper end of the central channel 48, 48'.

[0035] The filling valve 45 is preferably installed in the first series of pistons 36 belonging to the first working chambers 34 in the hot block, while the control valve 90 of the maximum working pressure is preferably installed in the second series of pistons 36' belonging to the second working chambers 34' in the cold block.

[0036] As will be better explained hereinafter, the filling valves 45 are preferably located in the hot block so that the fluid introduced into the chambers 34 is already hot and increases the total enthalpy in the working fluid, while the maximum pressure valves are preferably arranged in the cold block, to reduce the enthalpy released by the fluid of the chambers 34' towards the reservoir. The configuration in which the position of the valves is inverted, as illustrated in the accompanying figures, is not detrimental to the operation of the machine according to the present invention.

[0037] The filling valve 45 is represented in Figs. 7, 7A. It is installed in the piston 36, inside a channel 47 that forms a first portion of the lower extension of the axial channel 48, with respect to which the lower extension 47 has a larger diameter so as to define an abutment seat 51 for the upper portion 57 of a moving element 50 housed slidably in the channel 47. A further lower extension 470 of the channel 47, of larger diameter with respect thereto, houses the widest portion of the moving element 50 with radial clearance. The filling valve also comprises a spring 52 housed inside a spacer 55 between the base of the moving element 50 and a lower closing cap 54. The moving element 50 is formed with a lower portion 56 and an upper portion 57, and is provided with an axial through hole 58. The lower portion 56 has a smaller diameter to that of the channel 470, thereby defining a gap for passage of the fluid.

[0038] With reference to Figs. 7, 7A, the filling valve is consequently in communication with the working chamber 34 through the two channels 49 and with the reservoir through the channel 48. When the pressure that the fluid present in the working chamber 34 exerts on the moving element 50 is greater than the resultant force of the load of the spring 52 and of the force exerted by the pressure of the reservoir, the moving element 50 is thrust towards the spacer 55 and its lower portion 56 abuts against it, thereby closing passage of the fluid towards the reservoir through the opening existing between the spacer 55 and the lower portion 56 of the moving element 50. In the opposite case, for example during the first operating steps, when the increase of the volume of the working chambers 34 causes a reduction of the pressure therein, the moving element 50 is moved away from the spacer 55 allowing passage of fluid from the reservoir to the chamber 34 through the clearance between the moving

element 50 and the channel 47, in particular between the lower portion 56 of the moving element 50 and the lower extension 470 of the channel 47.

[0039] The maximum pressure valve 90 is represented in Figs. 8, 8A. It is installed in the piston 36', inside a channel 47' that forms the lower extension of the axial channel 48', with respect to which the lower extension 47' has a larger diameter so as to define an abutment seat 51' for a moving element 50' housed slidably in the channel 47'. The moving element 50' is formed with a lower portion 56' and an axial through hole 58'. The filling valve further comprises a spring 52' housed between the base of the moving element 50' and a closing cap 54'.

[0040] The maximum pressure valve is also in communication with the working chamber 34' through the two channels 49', which are closed when the spring 52' thrusts the moving element 50' against the sealing seat 51', thus preventing passage of the fluid (Fig. 8). Instead, when the force exerted by the pressure in the chamber 34' overcomes the force of the spring 52', the moving element is displaced from the sealing seat and allows the outflow of fluid towards the communication channel 48' with the reservoir, as indicated by the arrow B.

[0041] The pressure of the fluid in the reservoir must be more or less the same as the minimum pressure provided in the cycle at the end of the expansion step or during cooling Operation of the machine according to the invention with reference to the embodiment described above is illustrated below.

[0042] As already stated, the two cylindrical blocks 20, 22 are maintained at different temperatures. The cylindrical block 20 is the hot block, and is therefore maintained at a higher temperature than the block 22, which is the cold block.

[0043] The hot block 20 is maintained at high temperature by any heat source. For example, the incident thermal power is considered to be represented by a radiant power such as concentrated solar power, represented by the arrows A of the Figs. 1, 2 and 3. The cold block 22 is instead cooled by a flow of air generated by a fan 60 aligned with the rotary shaft 24 (Figs. 1, 2 and 3). With reference to Fig. 3, the fan 60 produces a flow of cold air that strikes the cold block 22 according to the arrow C, in a cooling chamber defined between the block 22 and a wall 62 of the outer casing of the machine.

[0044] In other embodiments, cooling can be obtained through the passage of another cooling fluid or by a thermal exchange through natural convection in air. In any case the hot block 20 receives heat from an external source, is isolated from the cold block 22 through the insulating partition 21, and the cold block 22 is subjected to the cooling action of a suitable heat dissipation system.

[0045] There is introduced into the cylindrical working chambers 34 of the hot block 20 and into those 34' of the cold block 22, a working fluid that evolves therein and carries out a thermodynamic transformation. The volume of the working chambers 34, 34' is varied by the pistons 36, 36', whose stroke is defined by the cams 30, 32 that

rotate with the rotary shaft 24 about the axis X-X, and by the springs 38, 38' that ensure following of the profile of the cam. With each chamber 34 of the hot block 20 there corresponds at least a chamber 34' of the cold block 22 to which it is connected through the channel 46 through which the working fluid flows (Fig. 6). The stroke of the pistons 36 obliges the fluid to pass between the hot chambers 34, from which it receives heat, and the cold chambers 34', to which it transfers heat, according to the arrow D of Fig. 6. Moreover, the motion of the pair of pistons 36, 36' causes the volume of the working fluid to vary so that the thermodynamic cycle that the fluid performs generates, based on classic thermodynamic theory, mechanical work that is transferred from the pistons to the cams 30, 32, from which it is drawn through the coaxial shaft 24 and transferred to the user.

[0046] The channel 46 can be produced so as to generate suitable turbulence in the input motion into the chamber in order to improve the thermal exchange, for example positioning it parallel to a tangent common to the two cylindrical chambers, so as to promote the occurrence of a rotary flow of the fluid in the chamber downstream as indicated by the arrows D of Fig. 6.

[0047] The working principle of the machine is based on the fact that the same volume of fluid can be arranged in the hot chamber 34 or in the cold chamber 34', and therefore exchange heat in one direction or in the other towards the walls, appropriately positioning the two pistons of the adjacent chambers.

[0048] Moreover, to allow the thermodynamic cycle for the production of work to be performed rapidly, the surface of the walls must be as large as possible with respect to the volume of the chambers, and the thermal exchanges must preferably be carried out in the condition of variation of the state of aggregation of the fluid from liquid to vapor and vice versa. The first requirement is satisfied by the geometrical design of the chambers and the second by the choice of working fluid as a function of the temperatures of the sources. Therefore, it is possible to use organic fluids such as methanol, ethanol or butanol up to temperatures of the hot source in the order of 500 K, and water in the case of temperatures up to around 600 K. A class of working fluids known as "HFO", acronym for "Hydro-Fluor-Olefins", which have noteworthy properties for use in the machine according to the present invention, without negative or harmful effects for the environment, in particular for the earth's ozone layer, have recently become available in the art.

[0049] Transformation of the linear motion of the piston 36, 36' into rotary motion of the rotary shaft 24 takes place due to the profile of the cams 30, 32, against which the piston presses by means of the rollers 40, 40', as shown in Figs. 4A and 4B.

[0050] The cams are produced with lift profiles indicated qualitatively in Fig. 13, i.e., so that the displacement of the pistons is as described in Fig. 14 in correspondence of the steps indicated in the same figure.

[0051] The cams 30, 32 are provided with a profile such

as to cause the corresponding pistons of the two cylindrical blocks to perform a coordinated motion adapted to generate changes in the volume of the chambers 34 and 34' that subsequently result in a compression of the fluid carried out through a reduction of the volume of the chambers, preferably the cold chamber, followed by its displacement inside the cylinder at high temperature such that it can be heated, through a further reduction of the volume of the cold chamber and an increase of the volume of the hot chamber, such heating being further followed by an expansion obtained through an increase of the total volume of the chambers, preferably on the hot side, which is also followed by a further cooling, obtained with a displacement of the fluid in the cold chamber due to an increase of the volume of this latter and a reduction of the volume of the hot chamber, and finally a new compression, carried out as defined above to start the cycle again. The machine is also provided with a reservoir of the working fluid, not represented in the figures, as not essential to the description of the invention, which is put in communication with the chambers 34, 34' by the filling and control valves of the maximum working pressure, described previously (arrows B of Figs. 3, 7, 8).

[0052] The operating steps of the machine according to the invention are described below, where, for clarity of description, they have been clearly separated from one another, while in their effective implementation they can be partially overlapped in order to optimize the mechanical and thermodynamic output:

A. Compression, (continues from E):

The fluid is compressed rapidly to the minimum volume of the cycle and transferred entirely to the hot chamber 34, therefore the piston 36' of the cold chamber is at the top dead center, as near as possible to the upper end of the cold chamber 34' as the machining tolerances will allow, while the piston 36 of the hot chamber 34 is taken to a height corresponding to the minimum volume of the cycle, very near to the top dead center, in this step the torque generated on the cam is negative, and therefore it is necessary to supply mechanical work to the system to carry out compression (Figs. 15 and 16).

B. Heating:

With the piston 36' of the cold chamber 34' stopped at the top dead center, the piston 36 of the hot chamber 34 descends causing expansion of the fluid that, in this step absorbs heat from the walls of the chamber. The law of motion of the piston and therefore expansion of the fluid is such as to approximate as much as possible an isothermal expansion so as to maximize the output, approximating the theoretical Carnot cycle. In this step the torque generated on the cam is positive, and therefore useful work is generated. (Figs. 15 and 16)

C. Expansion:

After reaching the final heating conditions, the piston 36' of the cold chamber 34', and optionally the piston

36 of the hot chamber 34, is made to descend rapidly for a length corresponding to the desired expansion. In this step further useful work is generated (Fig. 3). In Figs. 14, 15 and 16, to simplify the description and to highlight the subsequent transfer described in step D, the case in which expansion is carried out only by the cylinder 36 of the hot chamber 34 is illustrated but, as a function of the process variables of each application, i.e., rotation speed, working fluid and size of the machine and of the communication channel between the chambers 34 and 34', the law of motion of the two pistons 36 and 36' that gives the maximum total output, total meaning the product of the mechanical and the thermodynamic output, must be calculated or defined experimentally.

D. Transfer and Cooling

The piston 36' of the cold chamber 34' is then taken towards the bottom dead center while the piston 36 of the hot chamber 34 is transferred to the top dead center expelling all of the fluid towards the cold chamber 34', where this transfers heat to the walls of the chamber.

The piston 36' of the cold chamber 34' is then slowed and its motion is reversed so as to perform an approximately isothermal cooling until reaching the condition in which compression starts. In this step the torque generated on the cams 30 and 32 is negative and it is necessary to supply work to the shaft 24 for its rotation (Figs. 15 and 16).

E. Compression:

The piston 36' of the cold chamber 34' is thrust to the top dead center while that of the hot chamber 34 descends until generating the volume indicated in step A. Also in this step work must be supplied to the shaft to carry out the compression step. The cycle starts again with step A (Figs. 15 and 16).

[0053] The chambers 34, 34' are put in communication with the reservoir of the working fluid by two distribution valves. As stated above, the valve located in the chambers 34' of the cold block 22 only opens when reaching the maximum design pressure, at the end of the compression step or during heating of the fluid, allowing outflow from the chambers 34' to the reservoir, thereby maintaining the maximum pressure of the cycle below acceptable values for the mechanical strength of the machine members.

[0054] The valve located in the chambers 34 of the hot block opens when the pressure in the chambers 34 drops below the pressure of the reservoir, allowing the outflow of fluid from the reservoir into the chambers 34. In this way, the amount of fluid in the chambers 34, 34' is regulated automatically as a function of the operating conditions.

[0055] The design of the cams 30, 32 and of their connection to the shaft 24 must take account of the existence of positive and negative torque phases and of the need to have regular rotation of the moving elements of the

distribution valves. It is therefore provided with suitable inertia so as to reduce the oscillations of the rotation speed of the shaft in correspondence of the changes of torque, while to start the machine it must be accelerated with an external means to the operating speed.

[0056] The profile of the cam is determined according to the known kinematic and dynamic techniques so as to make the compression and expansion steps as rapid as the contact stresses between roller and cam in the acceleration steps will allow and avoiding loss of contact between them during the deceleration steps. On the contrary, the motion of the piston during the heating and cooling steps is determined by the heat balance of the working fluid according to the criterion of better approximating the isothermal transformations in order to maximize the thermodynamic output of the cycle.

[0057] In the case in which the machine is used to produce mechanical work to be exploited directly, as indicated in the drawing B, the cam will be provided with a drive 350 (Fig. 3), parallel to the rotation axis X-X.

[0058] In an embodiment dedicated to the production of electrical energy the machine therefore also comprises the electromechanical elements for direct transformation of the mechanical work produced into electrical energy, also in this case avoiding complex motion transfer systems and, ultimately, providing a product that is more efficient, of smaller size, lighter in weight and less expensive than those available in the state of the art.

[0059] With reference to Figs. 9-11, there is illustrated an embodiment of the machine according to the invention dedicated to the production of electrical energy.

[0060] The description of the components of the machine is the same as the embodiment dedicated to the production of mechanical work, and therefore they will not be described in detail, apart from the following aspects.

[0061] Fixed integrally to the cams 30, 32 is a plurality of permanent magnets 70 while a plurality of stator windings 72 is mounted integrally to an axis 240 that supports the bearings 26 on which the cams 30 and 32 are mounted, the former being adapted to generate a rotary magnetic field that induces in the latter an electromotive force exploitable directly or indirectly by electric utilities external to the machine after suitable transformations through a plurality of electrical or electronic circuits derivable from the state of the art.

[0062] With reference to Figs. 17A and 17B, there is illustrated a second embodiment of the machine according to the invention in which the cylindrical working chambers are oriented longitudinally in each of said cylindrical blocks according to longitudinal axes (Y) parallel to the longitudinal axis (X) of the rotary member.

[0063] In this embodiment the cylinders, the pistons and the corresponding working chambers are arranged in a direction parallel to the rotation axis instead of concurrent with respect thereto and their motion is determined by a front cam instead of by a radial cam, as known in the state of the art. To simplify the description this

arrangement will be called "axial", while the version with concurrent axes on the rotation axis will be called "radial"; moreover, to highlight the correspondence between the two arrangements, in the description below the components of the axial version will be indicated with the corresponding number of the radial version followed by the suffix "5".

[0064] The thermodynamic working principle is identical to that of the radial version and therefore will not be described again.

[0065] In the axial embodiment the two cylinder blocks 20" and 22" separated by the insulating partition 21", are maintained at different temperature by fluids that circulate respectively in the chambers 80 and 81, these fluids representing the heat sources at different temperature that are the source of thermal energy whose transformation is the ultimate aim of the machine described. Said cylinder blocks 20" and 22" house the working chambers 34" and the pistons 36", these latter provided with return springs 38" and rollers 40". These rollers are engaged by two front cams 30" and 32", towards which they are thrust, in order not to lose contact by the springs 38". In this embodiment the chambers 34" inside which evolves the fluid involved by thermodynamic transformation aimed at the production of work, extend between the hot block and the cold block with continuity although it is possible to identify a portion 34A", which will be called hot chamber, in contact with the hot block 20" and a portion 34B", which will be called cold chamber, in contact with the cold block 22", the fluid being brought into contact with the hot or cold portions of the walls according to the position of the pistons 36", facing each other, and, therefore, to the steps of the cycle.

[0066] The cylinder blocks 20" and 22" house the bearings 26" on which the shaft 24" is assembled, which can therefore rotate with respect to said cylinder blocks 20" and 22".

[0067] The front cams 30" and 32" are assembled on the shaft 24" rigidly and determine, upon rotation thereof, the motion of the pistons 36" so that they produce in the working chambers 34" the changes of volume and the displacements of the fluid according to the diagram of the steps illustrated in Fig. 14.

[0068] The working chambers are put in communication with the reservoir of the working fluid with the channels 48" through control valves known in the state of the art. In this way, in correspondence of the maximum pressure of the cycle, i.e., at the end of compression and at the start of heating, all excesses are discharged into the fluid reservoir while, in correspondence of the minimum pressure of the same cycle, i.e., in correspondence of the end of expansion and during cooling, if the pressure drops below an appropriate limit, the fluid flows out of the reservoir and into the working chamber.

[0069] These communication openings can be closed by the piston during its motion. In fact, if this is advantageous, in order to improve the output of the cycle the piston could cover the communication hole with the

chamber so as to shut off the communication route with the reservoir.

[0070] In the case in which the machine is employed for the generation of mechanical work, this can simply be drawn from the shaft 24" through devices known in the state of the art such as cogwheels, belts or couplings for the direct transmission of motion. Instead, in the case in which the machine is used for the production of electrical energy, permanent magnets 70" or windings will be arranged on the shaft so as to generate a rotary magnetic field, while the cylinder blocks 20" and 22" can house stator windings 72" in which an electromotive force, employable in electrical utilities external to the machine of the present invention, will be generated through electromagnetic induction.

[0071] The present arrangement has advantages and disadvantages with respect to the radial configuration: the advantages consist of simpler construction, elimination of the communication channels 46 between the chambers, the possibility of obtaining higher compression ratios minimizing the distance between pistons at the end of compression, the possibility of closing the communication openings towards the reservoir and the possibility of displacing the fluid entirely into the appropriate working chamber according to the step of the cycle. On the other hand, the disadvantage consists of not being able to place several elements side by side on the same axis, placing the cylindrical bodies side by side, so as to permit a modular embodiment capable of covering subsequent levels of performance with several identical components.

[0072] The embodiments described above of the machine according to the invention show that it allows the transformation of thermal energy deriving from any heat source into mechanical work and optionally, due to the arrangement of the aforesaid members of the machine, the transformation of this latter into electrical energy.

[0073] It is therefore possible to carry out thermodynamic cycles for the transformation of heat into work in a single very compact mechanical assembly, which is thus lighter in weight and less expensive with respect to those of prior art systems, which are more complex and consequently have greater costs, size and weight.

Claims

1. A machine for the transformation of thermal energy into mechanical work or electrical energy **characterized by** comprising:

i) a first (20, 20') and a second (22, 22') coaxial and cylindrical block side by side, separated by a cylindrical partition (21) of insulating material, said cylindrical blocks (20, 22') and said insulating partition (21) being provided with axial cavity housing a rotary member (24) provided with a first (30) and a second (32) cam, each placed in

correspondence of each of said cylindrical blocks (20, 22) and having the two cam profiles such as to generate a coordinated movement of the pistons housed in said cylindrical blocks;

ii) a series of cylindrical working chambers (34, 34') in each of said cylinder blocks (20, 22), each of said working chambers (34, 34') being open at the bottom towards said axial cavity of said cylindrical blocks (20, 22) and being provided with a single-acting piston (36, 36') provided with a contrast spring (38, 38') and acting on an idle roller (40, 40') in contact with said cams (30, 32) of said rotary member (24), thereby defining a first series of working chambers (34) in said first cylindrical block (20), a second series of working chambers (34') in said second cylindrical block (22), a first series of pistons (36) acting on a corresponding first series of rollers (40) in contact with said first cam (30), and a second series of pistons (36') acting on a corresponding second series of rollers (40') in contact with said second cam (32);

iii) a plurality of communication channels (46) between said first and second series of working chambers (34, 34'), each of said channels (46) putting in communication a chamber (34) of said first cylindrical block (20) with a corresponding chamber (34') of said second cylindrical block (22) through said insulating partition (21), each of said chambers (34, 34') being also provided with communication channels (48, 48') with an external reservoir for a fluid working in said chambers, and a plurality of distribution valves of said fluid between said communication channels and said working chambers;

said first cylindrical block (20) being operatively exposed to a heat source (A) adapted to heat said working fluid in said first working chambers (34), while said second cylindrical block (22) is thermally isolated from said first cylindrical block (20) and placed in contact with a lower temperature heat source whereby it is cooled, such that in said first (34) and second (34') working chambers said working fluid carries out thermodynamic cycles of compression and expansion as a result of the motion of said pistons (36, 36') and the corresponding rotation of said cams (30, 32) and of said rotary shaft (24).

2. A machine for the transformation of thermal energy into mechanical work or electrical energy **characterized by** comprising:

iv) a first a (20") and a second (22") coaxial and cylindrical block side by side, separated by a cylindrical partition (21) of insulating material, said cylindrical blocks (20", 22") and said insulating partition (21") being provided with axial

cavity housing a rotary member (24") provided with a first (30") and a second (32") cam, each placed in correspondence of each of said cylindrical blocks (20", 22") and having the two cam profiles such as to generate a coordinated movement of the pistons housed in said cylindrical blocks;

v) a series of cylindrical working chambers (34") in said cylindrical blocks (20", 22"), each of said working chambers (34") being axially open towards the portion of said cylindrical block (20", 22") facing said cams (30", 32") and being provided each with a pair of single-acting pistons (36") provided with a contrast spring (38") and acting on an idle roller (40") in contact with said cams (30", 32") of said rotary shaft (24");

vi) said chamber (34") being further provided with communication channels (48") with an external reservoir for a working fluid in said chamber, and a plurality of distribution valves of said fluid between said communication channels and said working chambers;

said first cylindrical block (20") being operatively exposed to a heat source (A) adapted to heat said working fluid in a first portion (34A") of said working chambers (34") and being said second cylindrical block (22") thermally isolated from said first cylindrical block (20") and placed in contact with a lower temperature heat source whereby it is cooled, such that the working fluid in a second portion (34B") of said working chambers (34") is cooled and carries out thermodynamic cycles of compression and expansion as a result of the motion of said pairs of pistons (36") and the corresponding rotation of said cams (30", 322) and of said rotating shaft (24").

3. Machine according to claim 1, **characterized in that** said cylindrical working chambers (34, 34') are radially oriented in each of said cylindrical blocks (20, 22) along longitudinal axes (Y) incident on the longitudinal axis (X) of said rotating member (24).
4. Machine according to claim 2, **characterized in that** said cylindrical working chambers (80, 81) are oriented in the longitudinal direction in each of said cylindrical blocks (20", 22") according to longitudinal axes (Y) parallel to the longitudinal axis (X) of said rotary member (24").
5. Machine according to claim 1 or 2, **characterized in that** said distribution valves comprise a filling valve and a maximum pressure valve.
6. Machine according to claim 1, **characterized in that** said distribution valves (45, 90) are located inside said pistons (36, 36') of said first (34) and second (34') working chambers.

7. Machine according to claim 1 or 2, **characterized in that** the ratio between the heat exchange surface and the volume of working fluid in it is such as the working fluid achieves in a short time a temperature very close to that of the walls.
8. Machine according to claim 1, **characterized in that** said communication channel (46) between said chamber (34) of said first cylindrical block (20) and said chamber (34') of said second cylindrical block (20) is arranged parallel to a common tangent of said cylindrical chambers (34, 34'), thereby generating a rotary motion of the fluid in said chamber (34').
9. Machine according to claim 1 or 2, **characterized in that** it said cams are provided with a profile such as to cause the corresponding pistons of the two cylindrical blocks to perform a coordinated motion adapted to generate changes in the volume of the cylindrical working chambers that subsequently result in a compression of the fluid carried out through a reduction of the volume of the chambers followed by its displacement inside the cylinder at high temperature such that it can be heated, through a further reduction of the volume of the cold chamber and an increase of the volume of the hot chamber, such heating being further followed by an expansion obtained through an increase of the total volume of the chambers which is also followed by a further cooling, obtained with a displacement of the fluid in the cold chamber due to an increase of the volume of the latter and a reduction of the volume of the hot chamber, and finally a new compression, carried out as defined above to start the cycle again.
10. Machine according to claim 1 or 2, for the transformation of thermal energy into electric energy, **characterized in that** there are fixed to said rotary member (24, 24") a plurality of permanent magnets (70, 70") in a radially distal location to said rotary member (24, 24"), said machine further comprising a stator (72, 72") housed in the axial cavity of said cylindrical blocks (20, 22, 20", 22") between said permanent magnets (70, 70") and said rotary member (24, 24"), said stator (72, 72") being provided with electrical windings on which there are induced electromotive forces that support the production of electrical current exploitable directly or indirectly by electric utilities external to the machine.
11. Use of the machine according to one or more of the preceding claims to perform thermodynamic cycles of compression (A), heating (B), expansion (C) and cooling (D) of a working fluid, in which the thermal exchanges are carried out in the condition of variation of the state of aggregation of said fluid from liquid to vapor and vice versa.

12. Use according to claim 11, wherein said fluid is a mixture of components selected from the group consisting of methanol, ethanol, butanol, HFO and water.

5

10

15

20

25

30

35

40

45

50

55

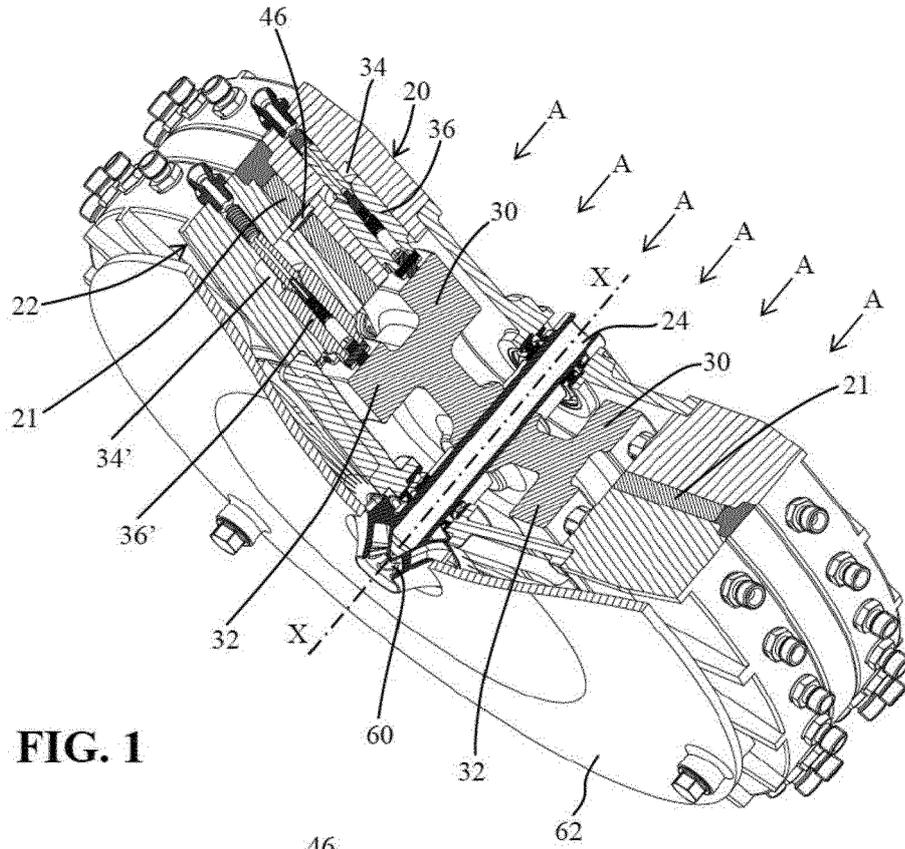


FIG. 1

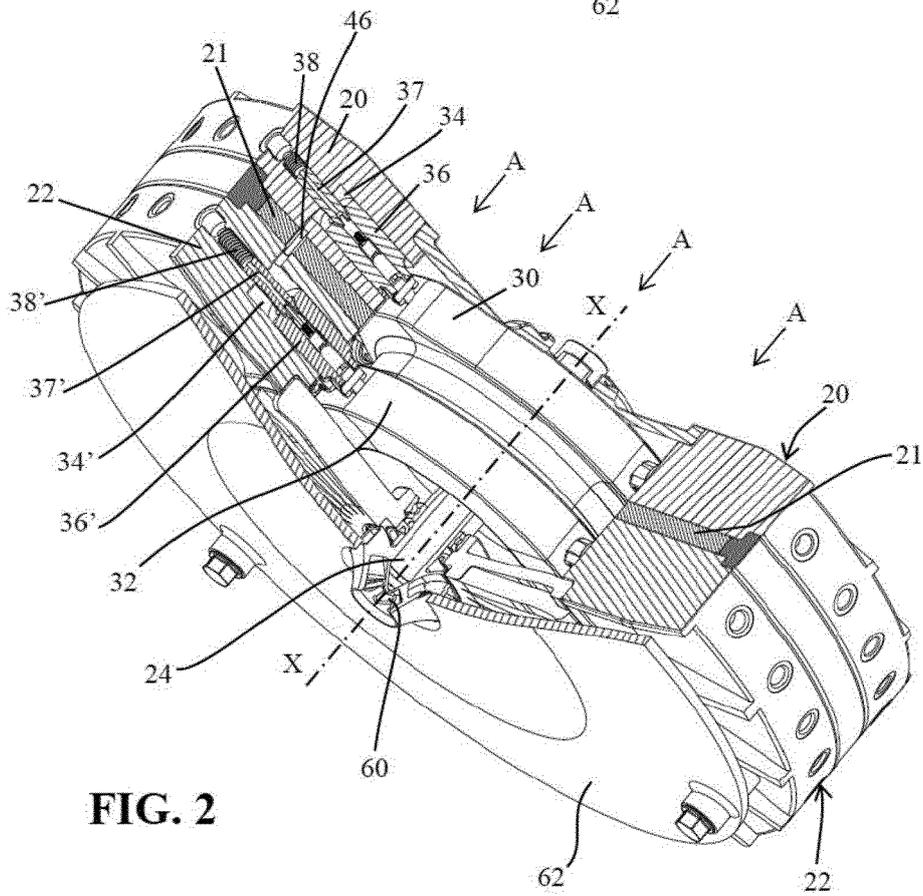


FIG. 2

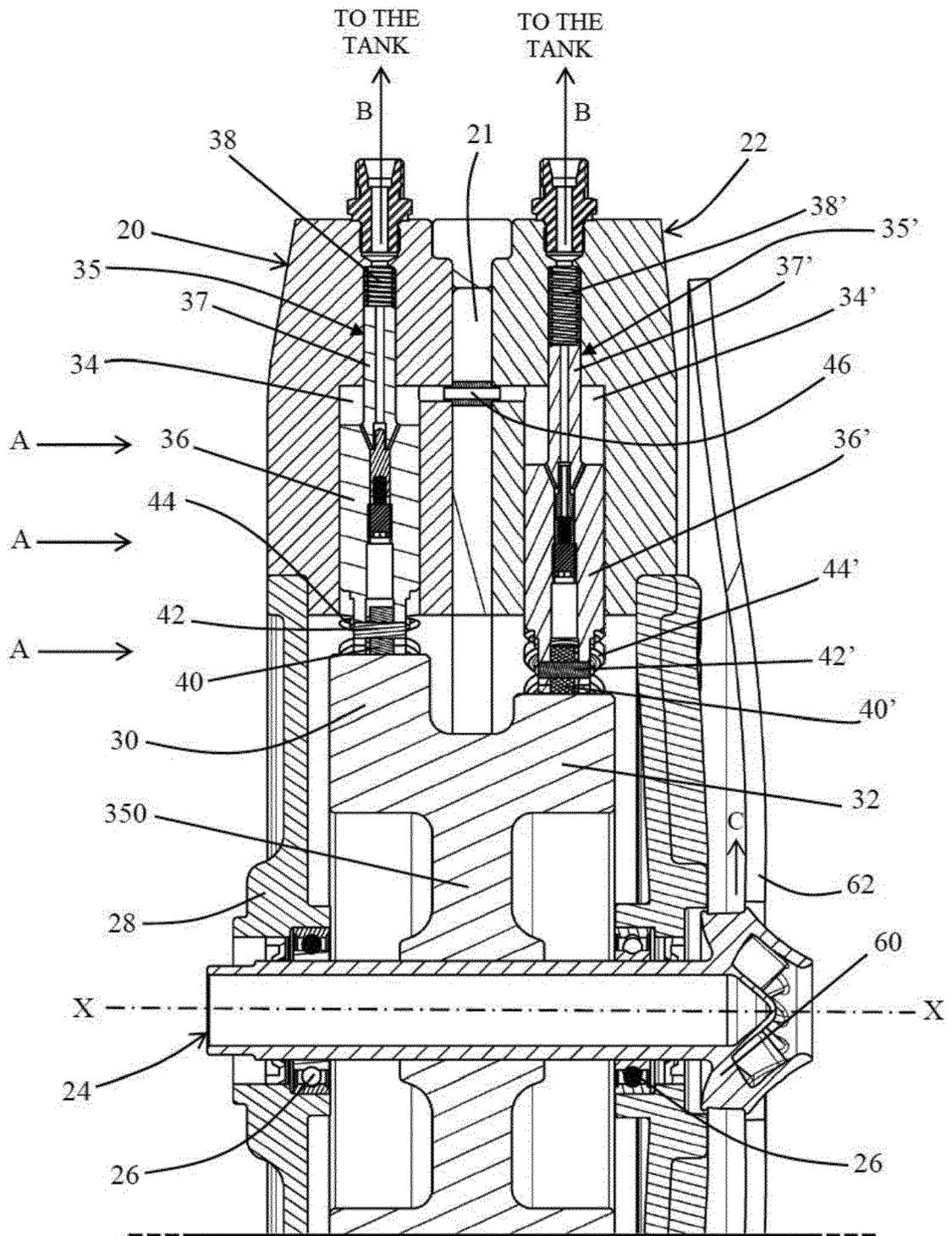


FIG. 3

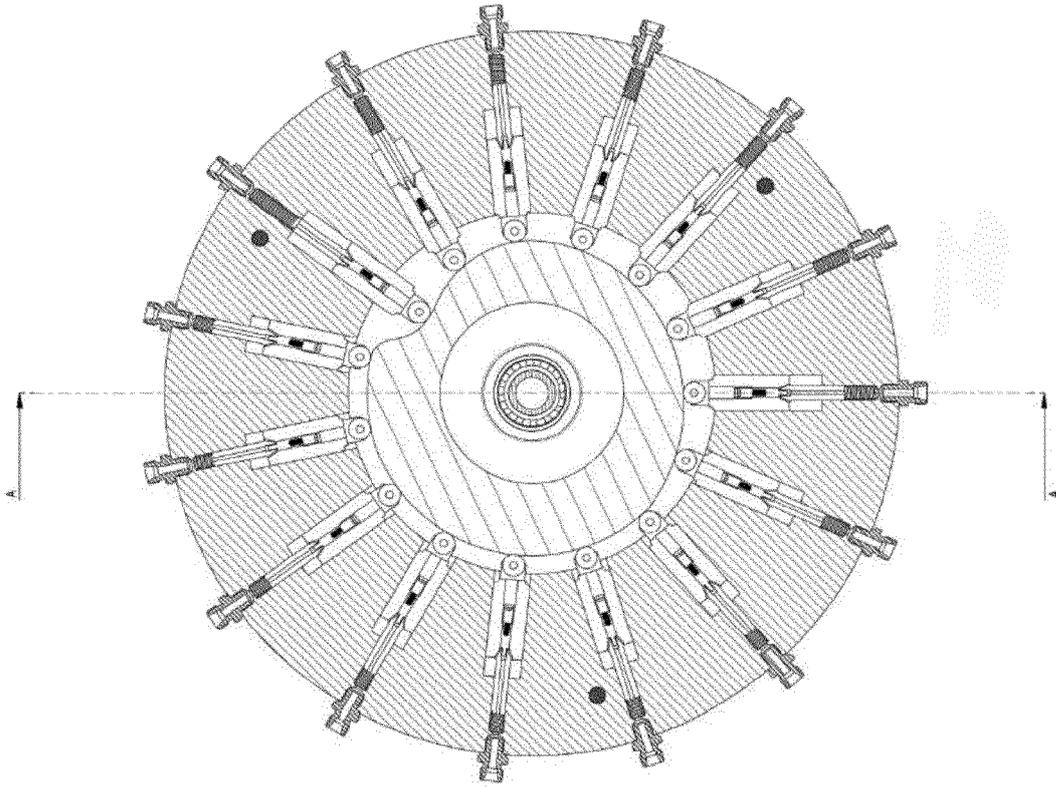


FIG. 4B

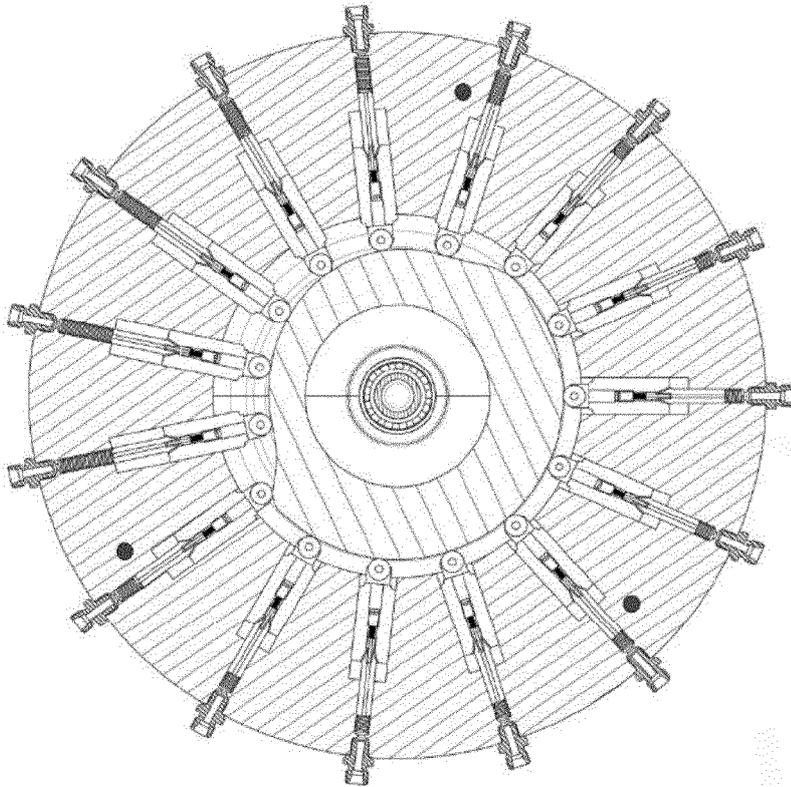


FIG. 4A

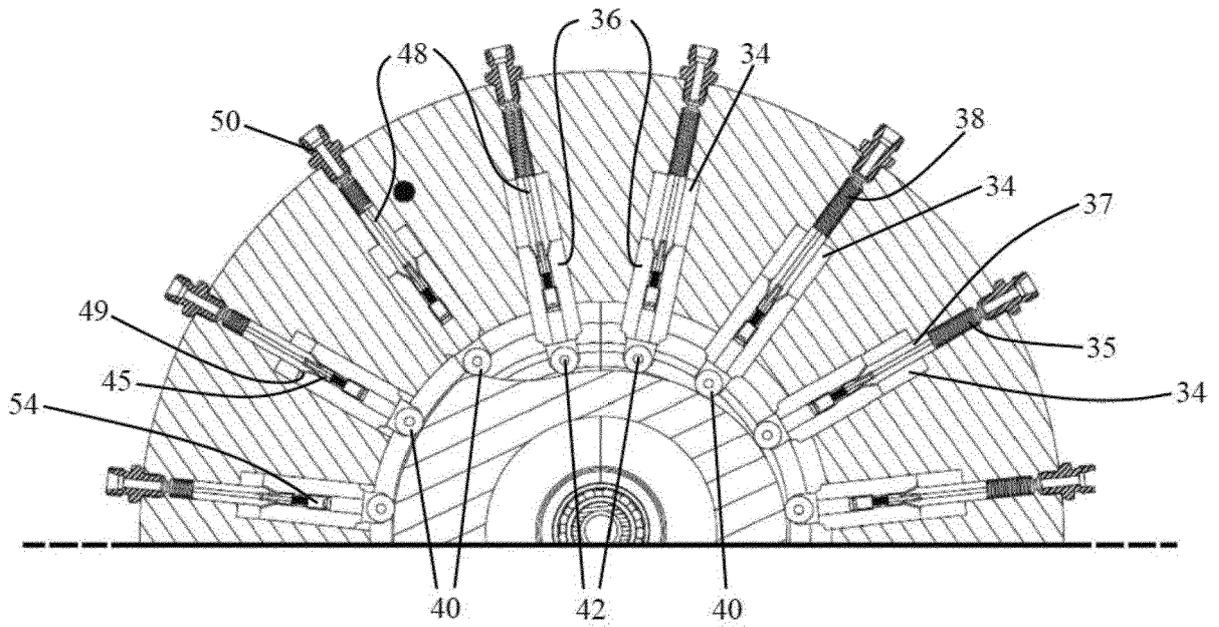


FIG. 5

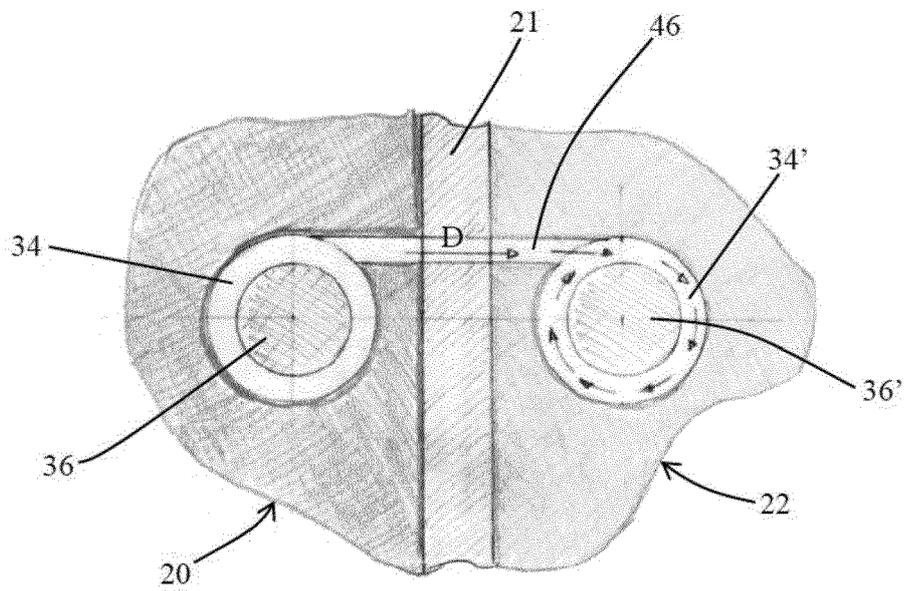


FIG. 6

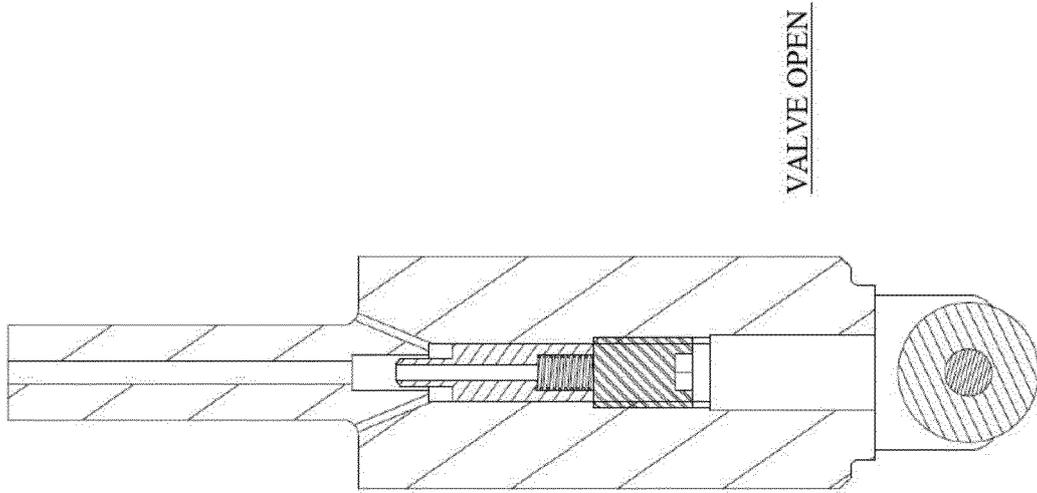


FIG. 8A

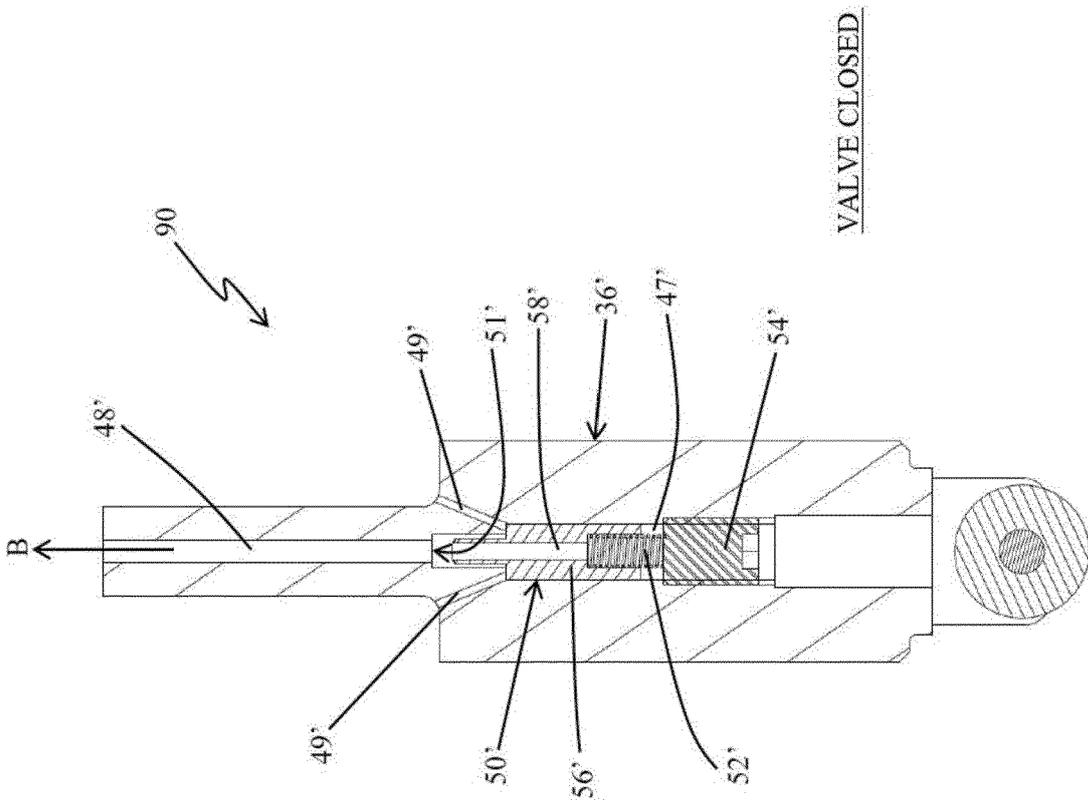


FIG. 8

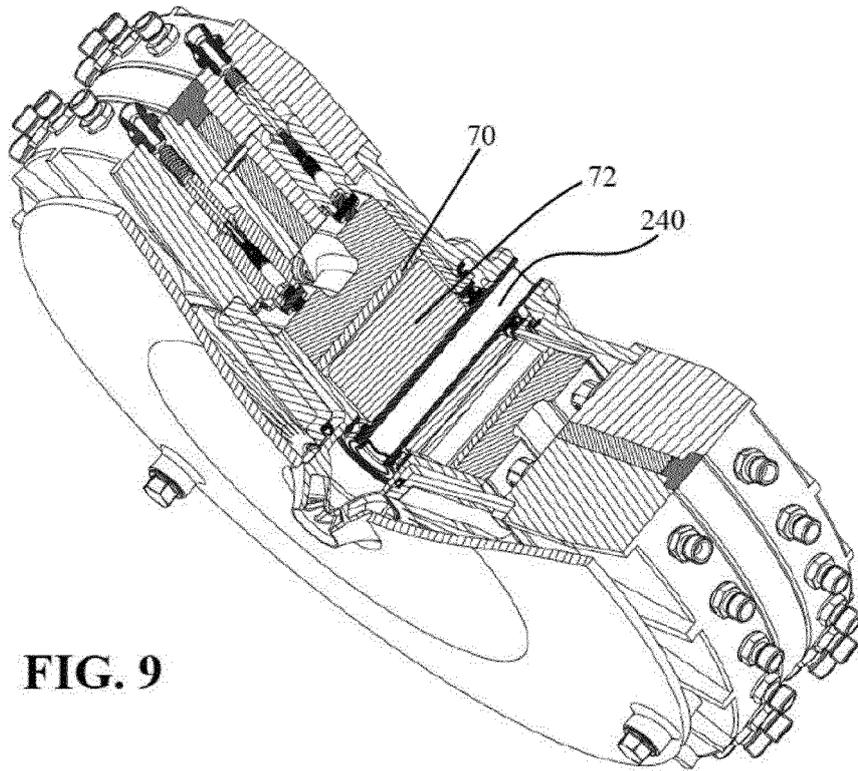


FIG. 9

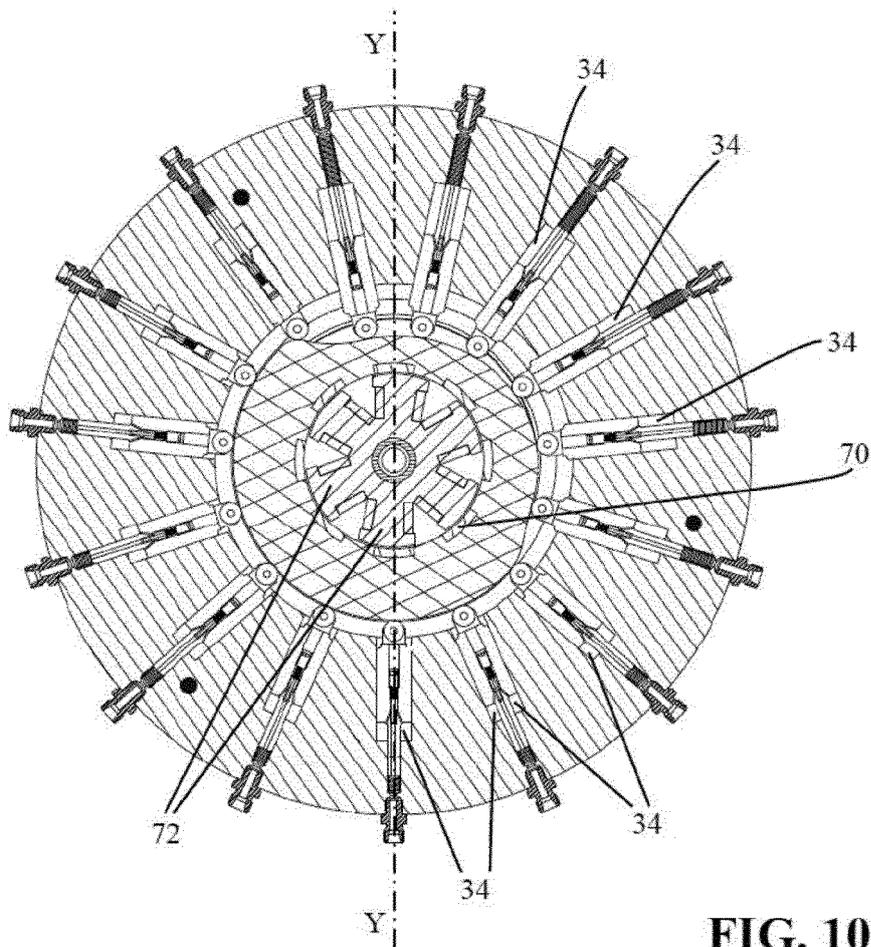


FIG. 10

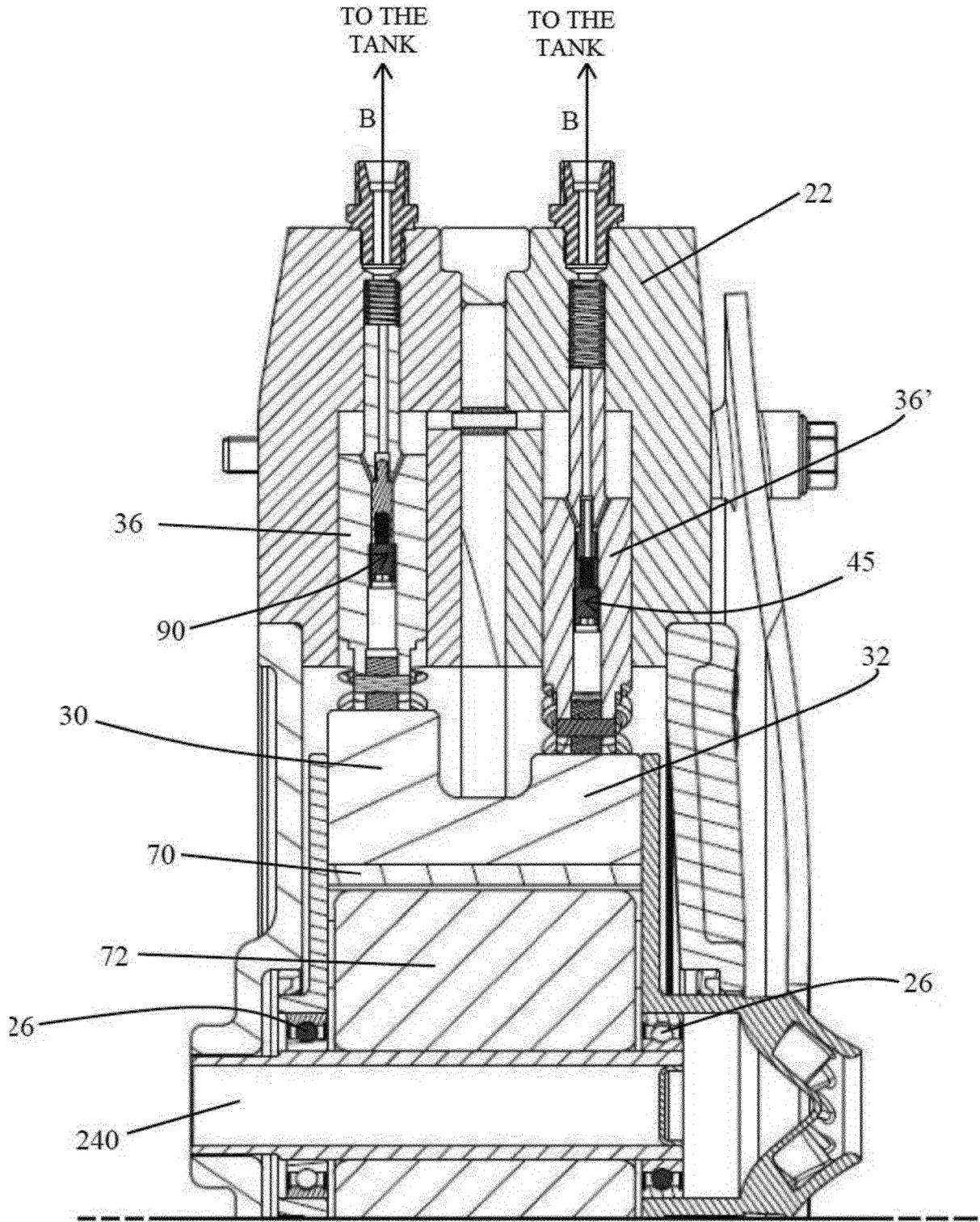


FIG. 11

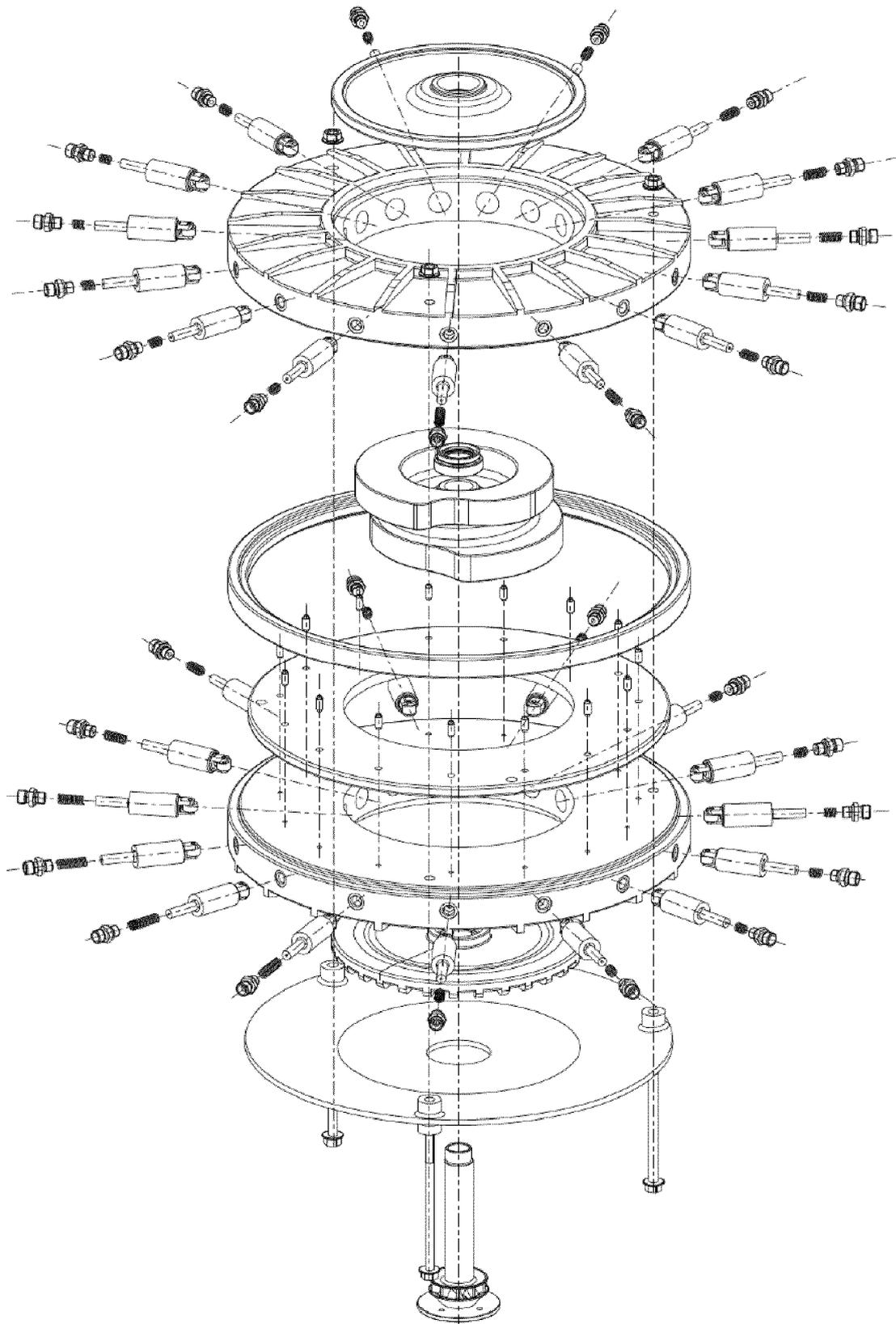


FIG. 12

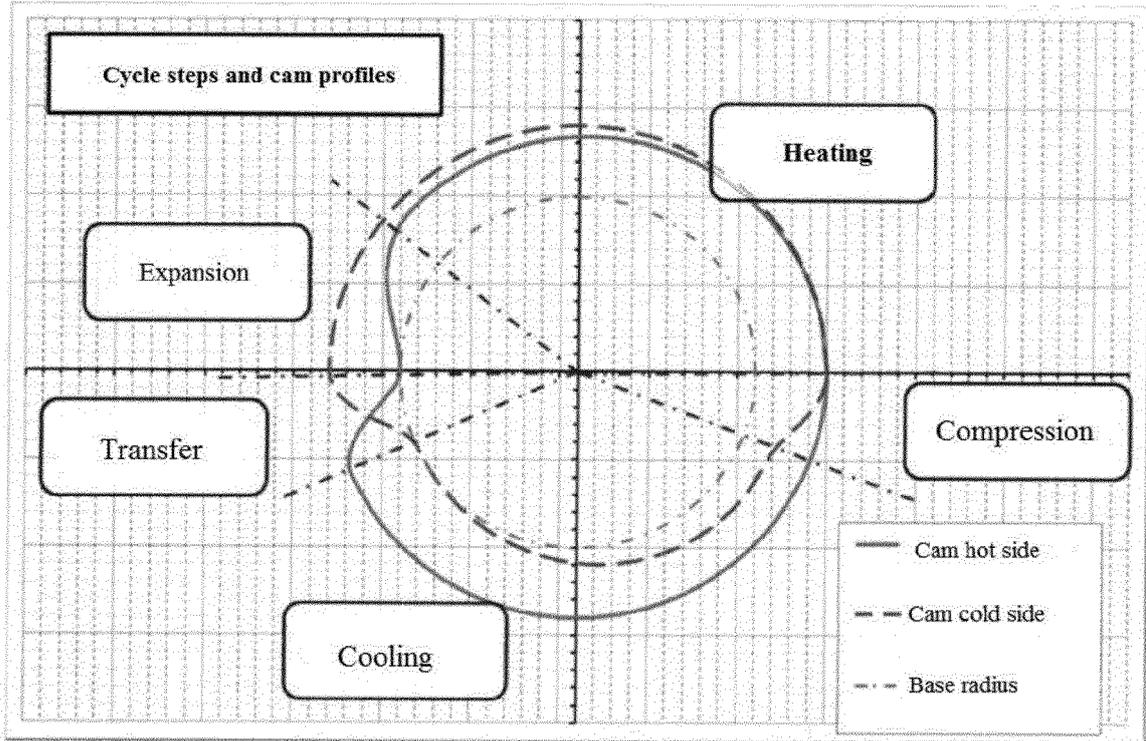


FIG. 13

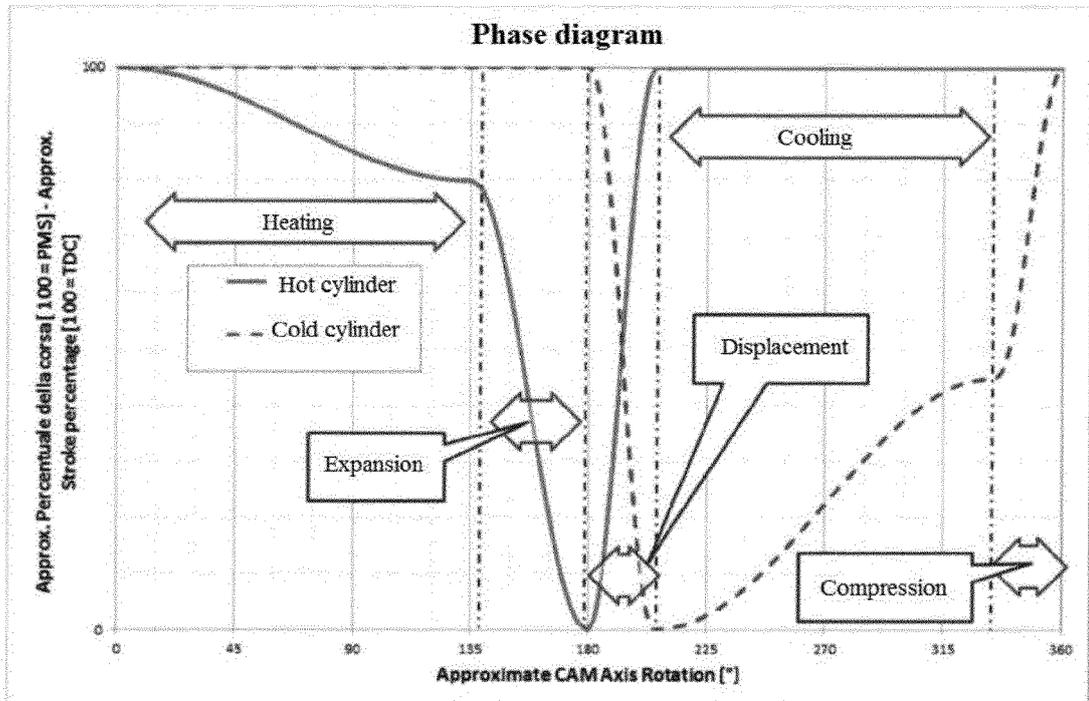


FIG. 14

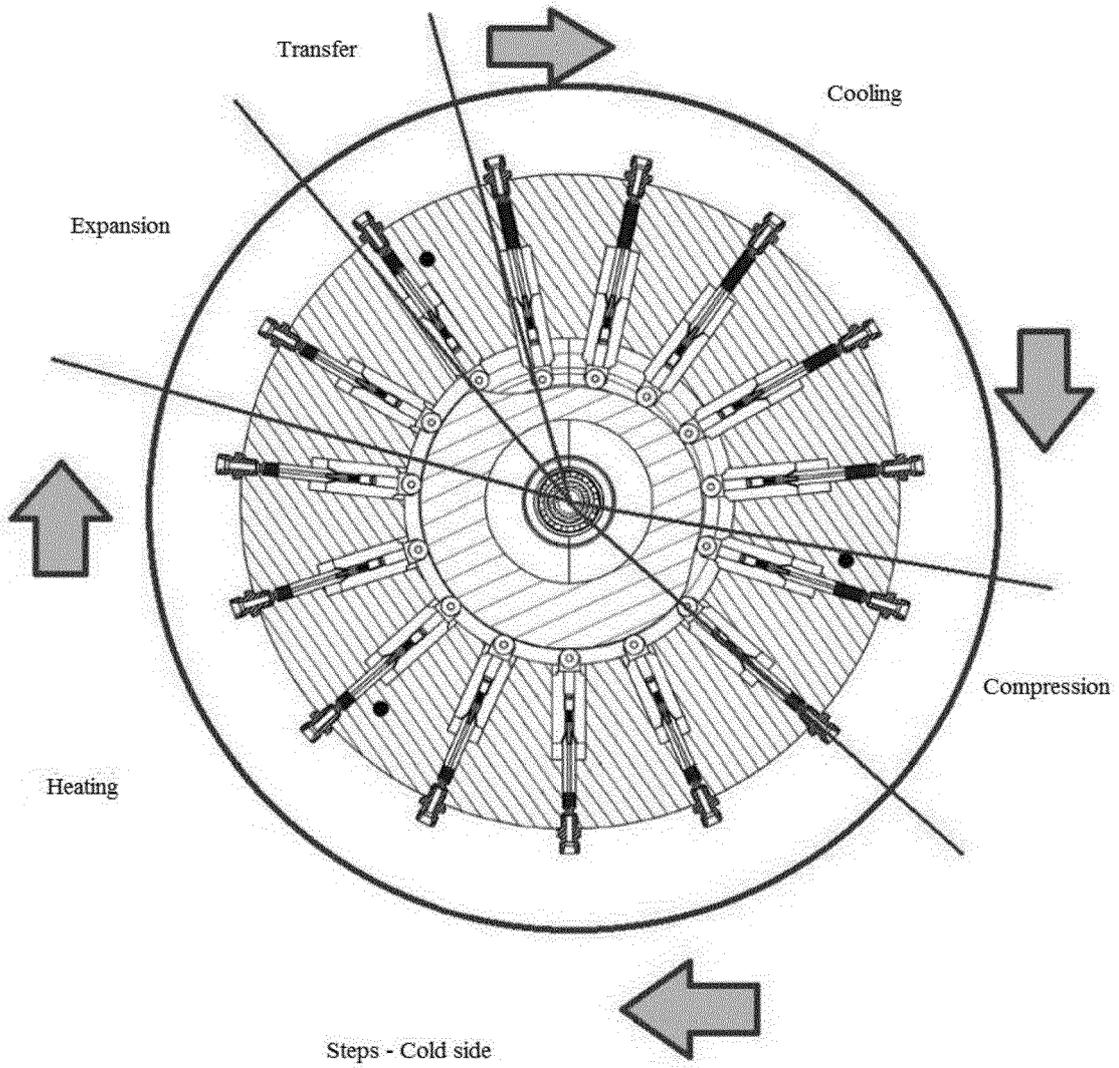


FIG. 15

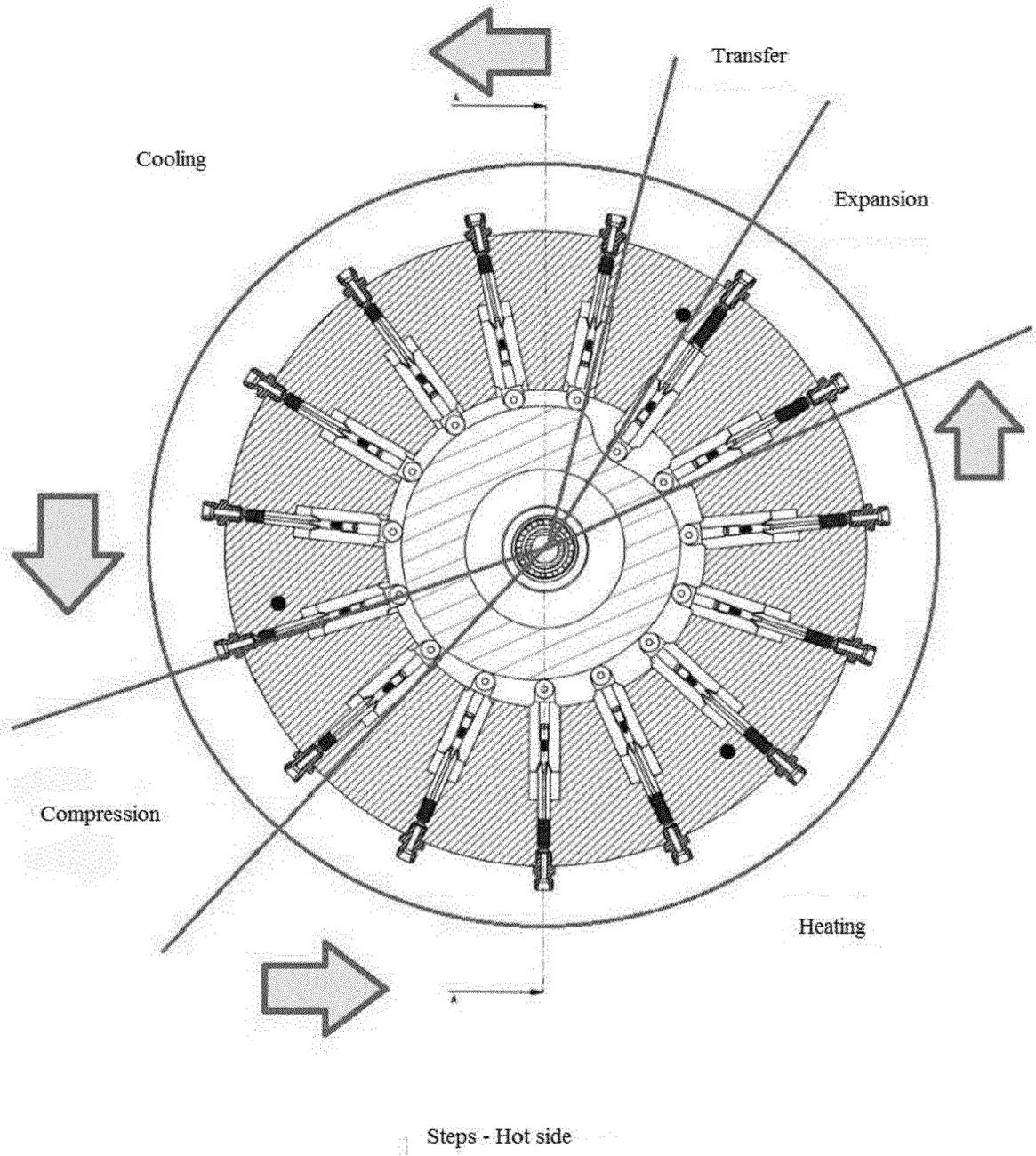


FIG. 16

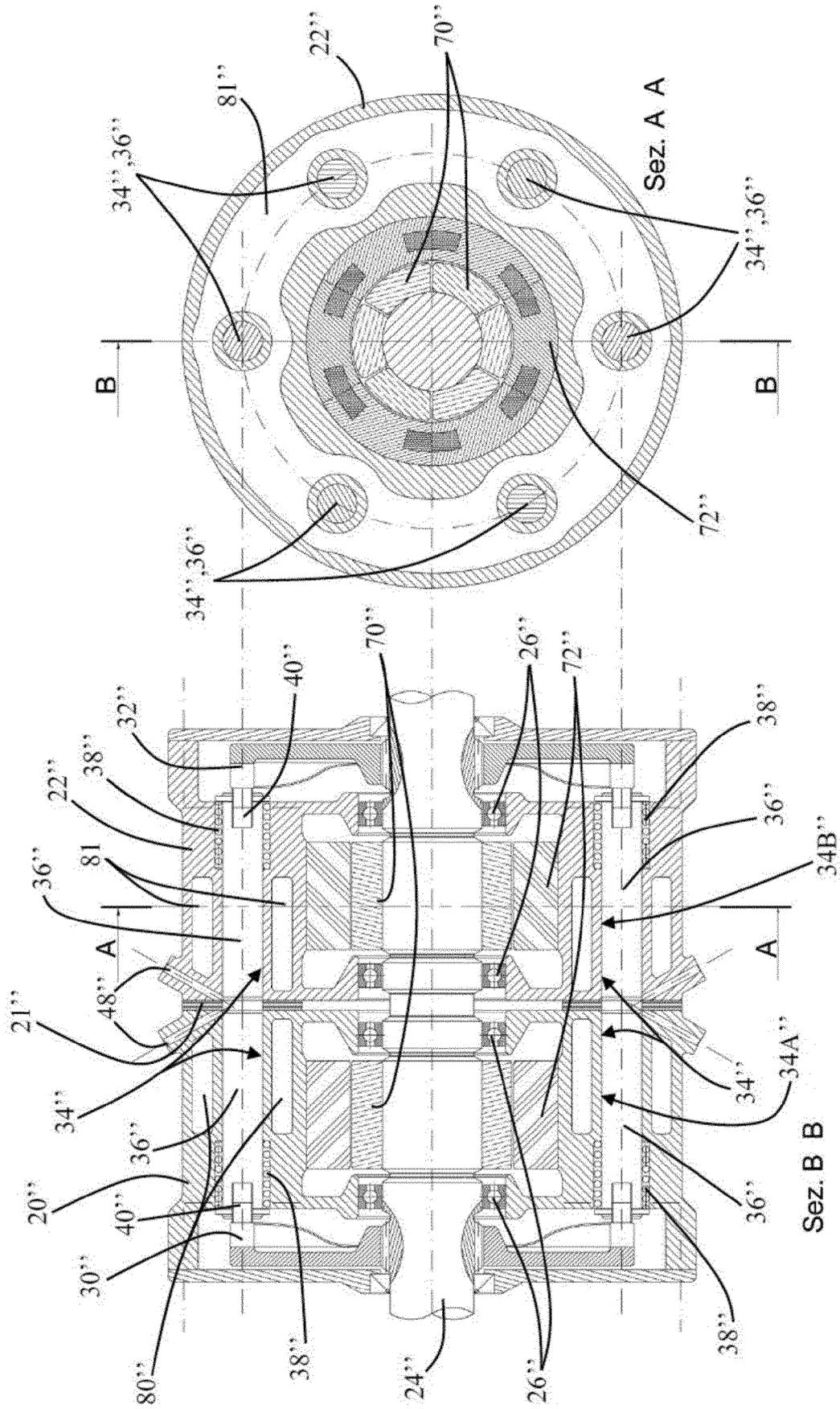


FIG. 17B

FIG. 17A



EUROPEAN SEARCH REPORT

Application Number
EP 18 17 1404

5

10

15

20

25

30

35

40

45

50

55

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	US 5 634 777 A (ALBERTIN MARC S [US] ET AL) 3 June 1997 (1997-06-03) * abstract; figures 1-6 * * column 4, line 45 - column 8, line 29 * -----	1-12	INV. F01B13/04
A	US 2012/073298 A1 (FREM NEEMAT [LB]) 29 March 2012 (2012-03-29) * abstract; figures 1, 2 * * paragraphs [0001], [0005] - [0013], [0018], [0028] - [0046] * -----	1-12	
A	US 2012/073296 A1 (COURSON MICHAEL W [US]) 29 March 2012 (2012-03-29) * abstract; figures 1-9, 17 * * paragraphs [0001], [0005] - [0013], [0018], [0028] - [0046] * * paragraphs [0011], [0089] - [0095] * -----	1-12	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
			F01B
Place of search		Date of completion of the search	Examiner
Munich		8 June 2018	Varelas, Dimitrios
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03.02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 18 17 1404

5 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
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

08-06-2018

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5634777 A	03-06-1997	US 5634777 A US 5944493 A	03-06-1997 31-08-1999
US 2012073298 A1	29-03-2012	EP 2434135 A1 US 2012073298 A1	28-03-2012 29-03-2012
US 2012073296 A1	29-03-2012	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 20060053793 A1 [0003]