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(54) **LOW COST HEAT ENGINE WHICH MAY BE POWERED BY HEAT FROM A PHASE CHANGE THERMAL STORAGE MATERIAL**

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(57) **ABSTRACT**

This invention is an engine where the working fluid may be in either a closed circuit or an open circuit. The engine may be powered by heat stored in an easily rechargeable high temperature phase change system or by heat of combustion directly. Also disclosed is a portable device incorporating the engine optionally as a) an electrical generator b) a source of refrigeration in remote environments c) a source of rotating mechanical power in remote environments. Also disclosed is a stationary device incorporating the engine and phase change thermal storage system as a co-generating heating and refrigeration system for widespread application. Also disclosed is a vehicle catalytic converter pre-heater incorporating a phase change thermal storage system and engine.

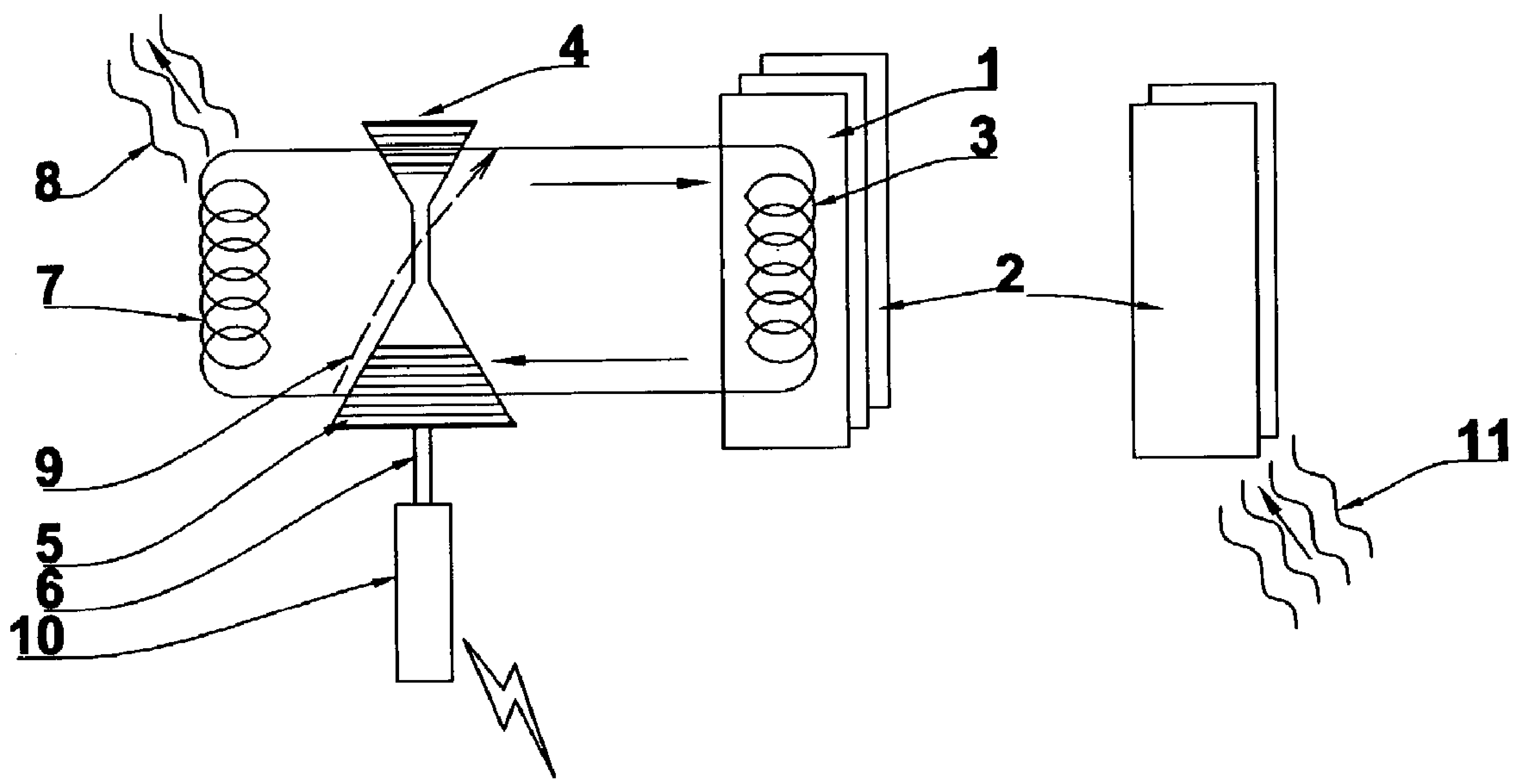

Fig 1

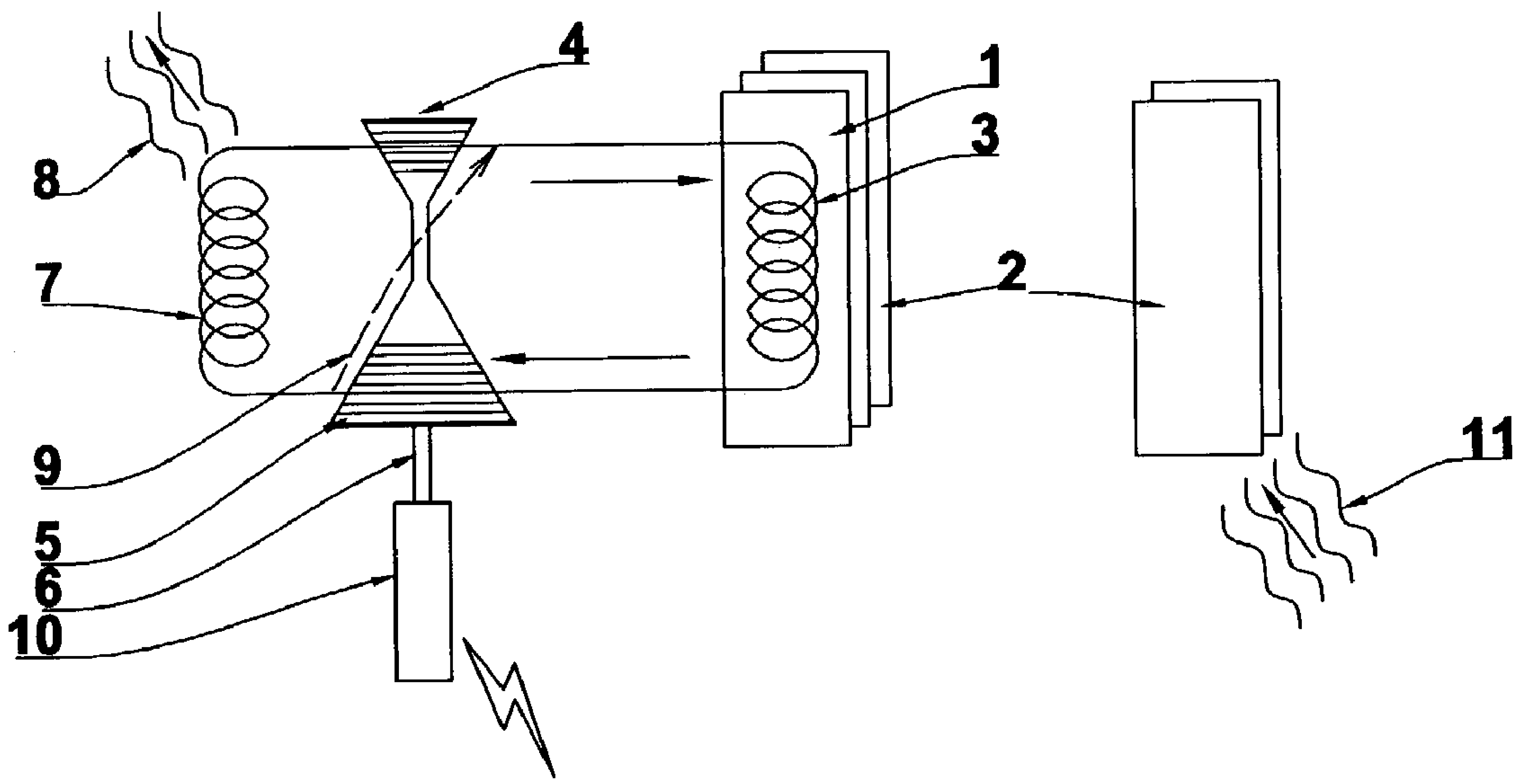

Fig 2

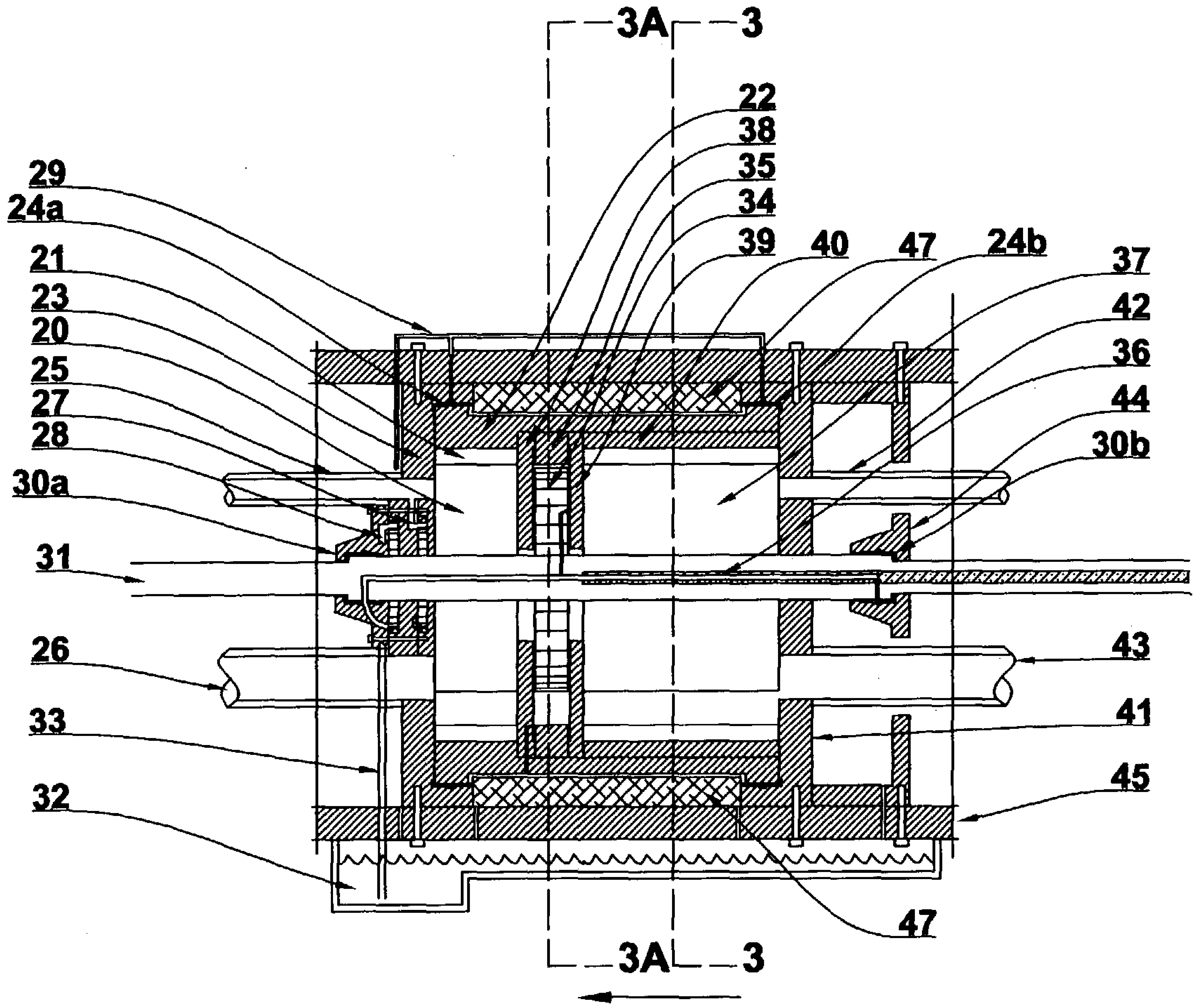
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Fig 3

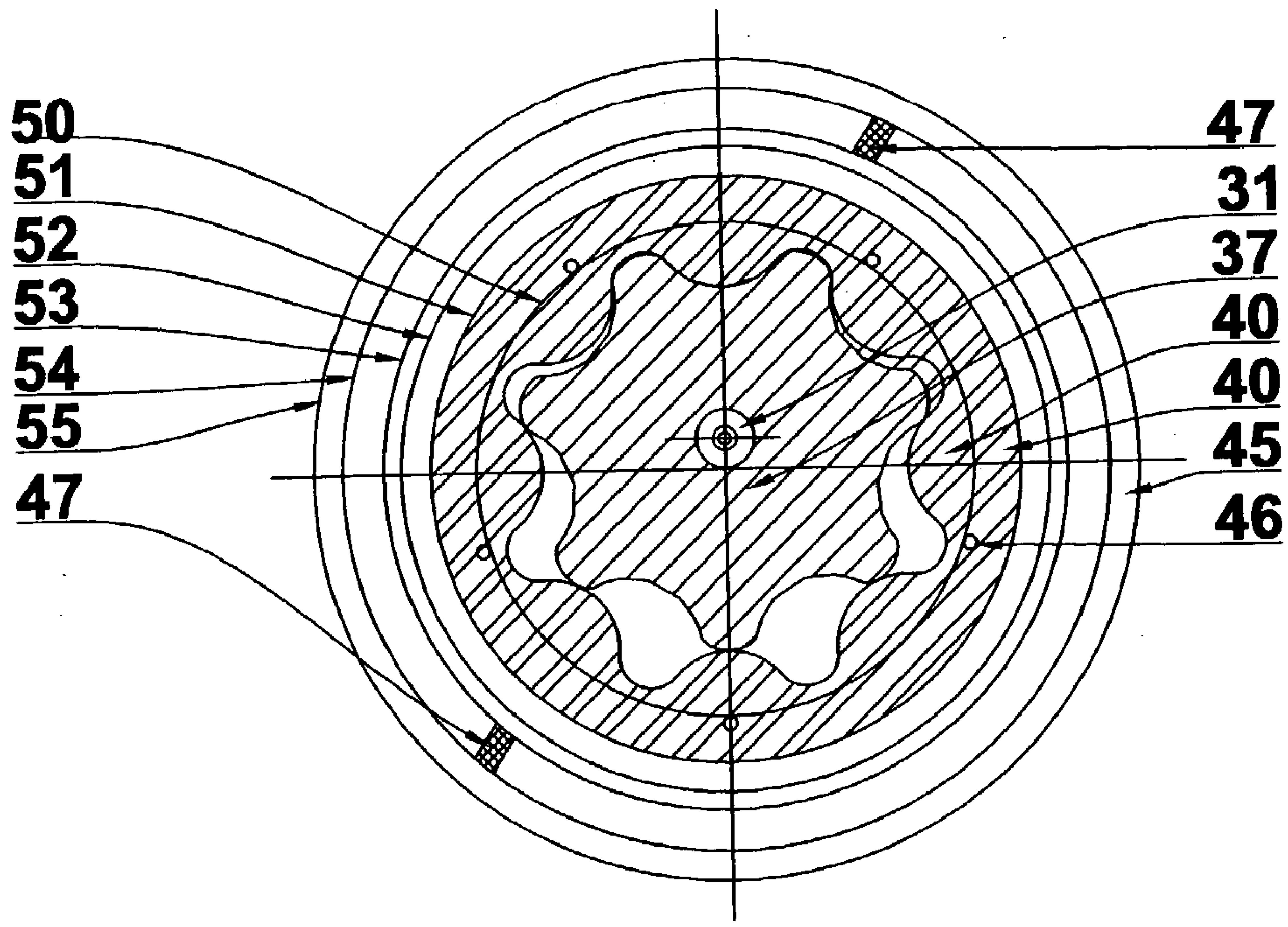

Fig 3a

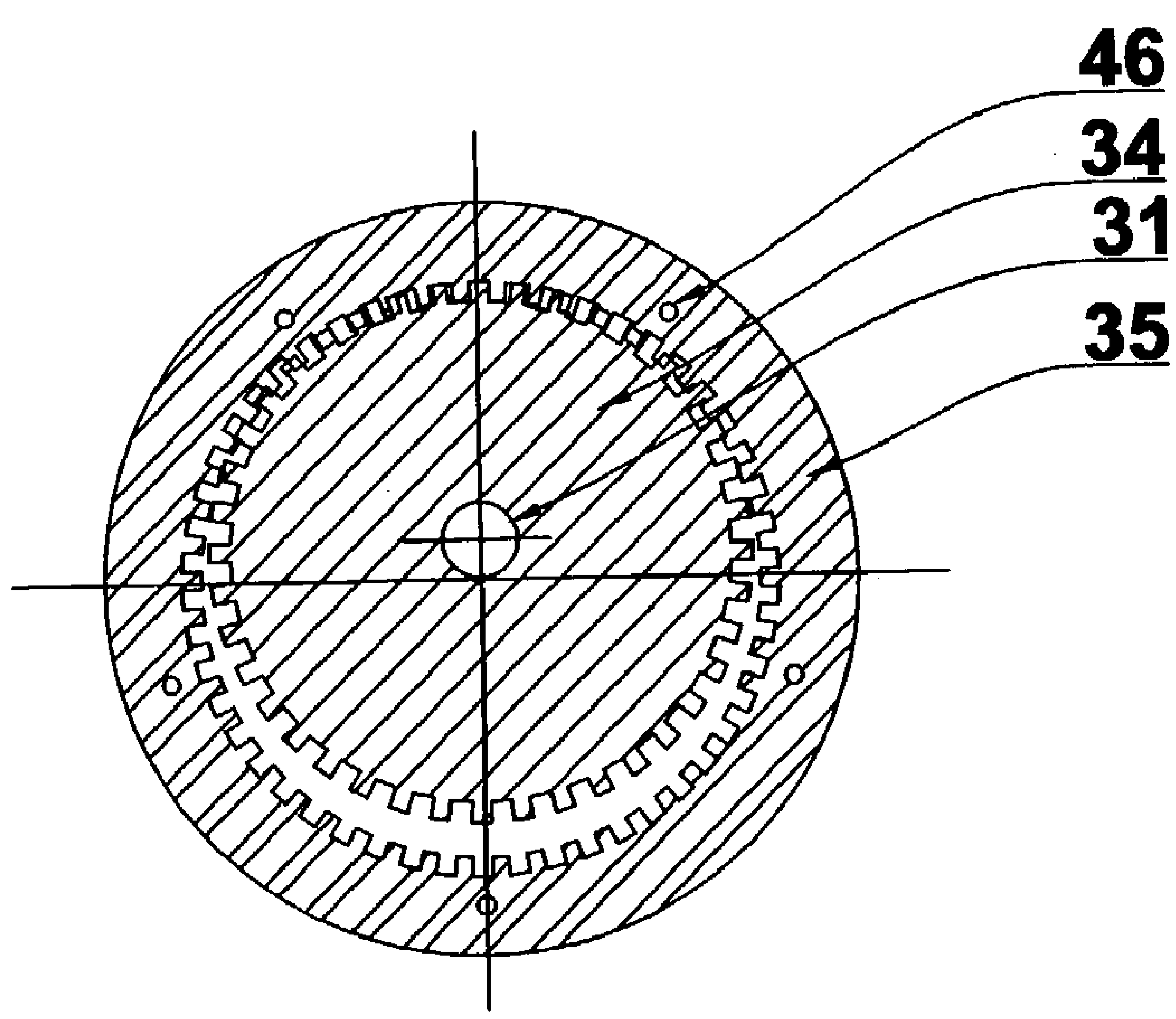

Fig 4

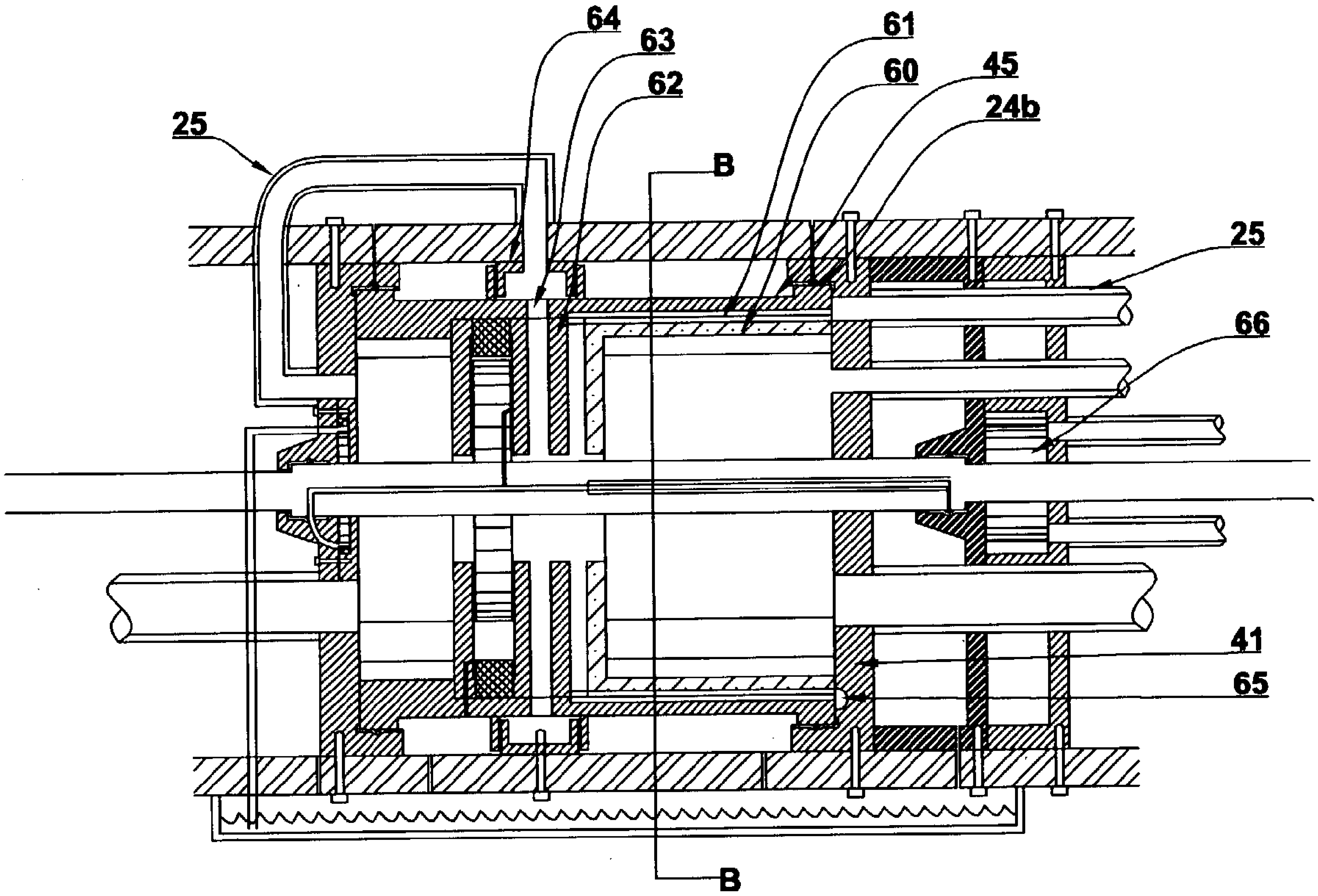

Fig 5

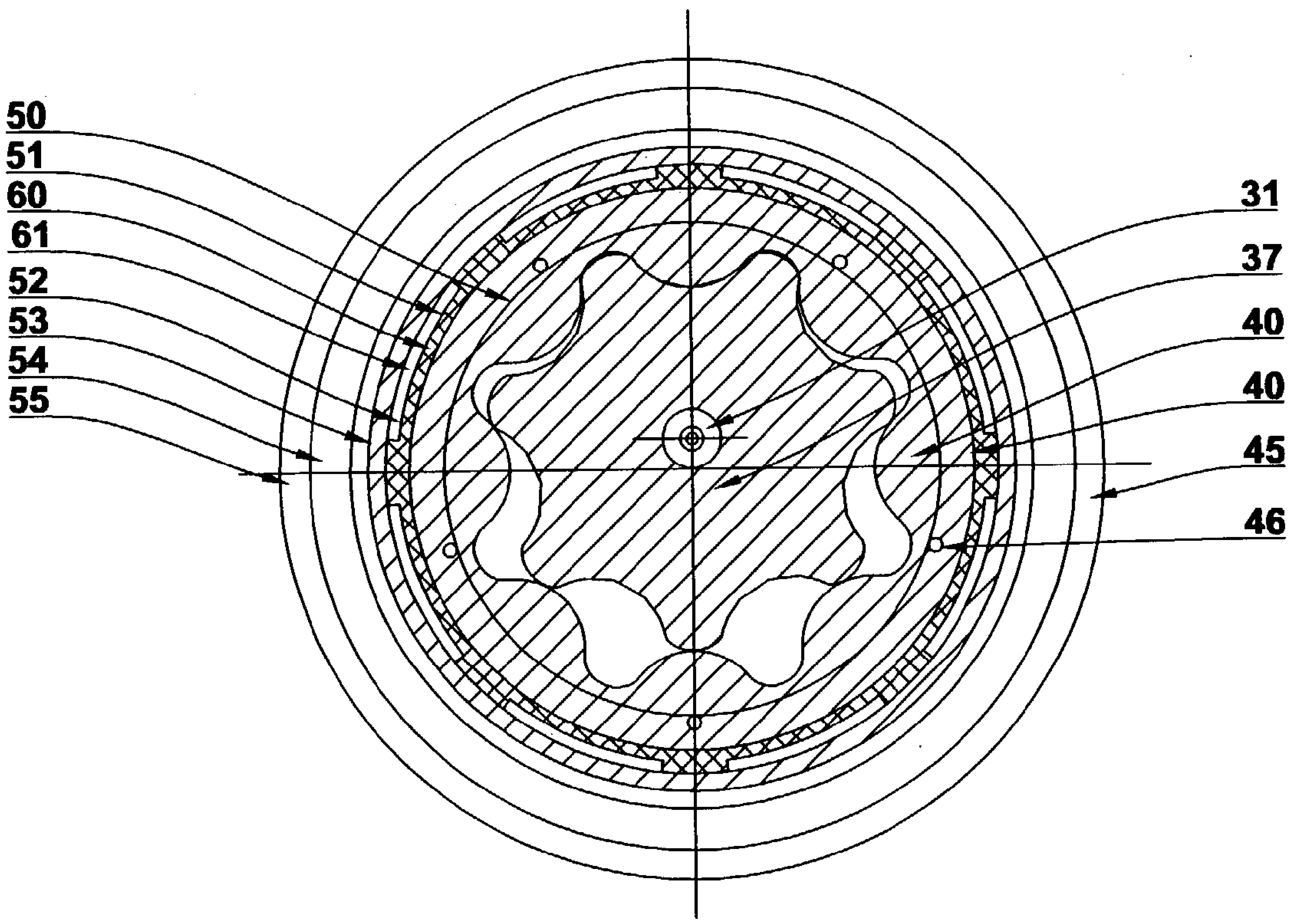

Fig 6

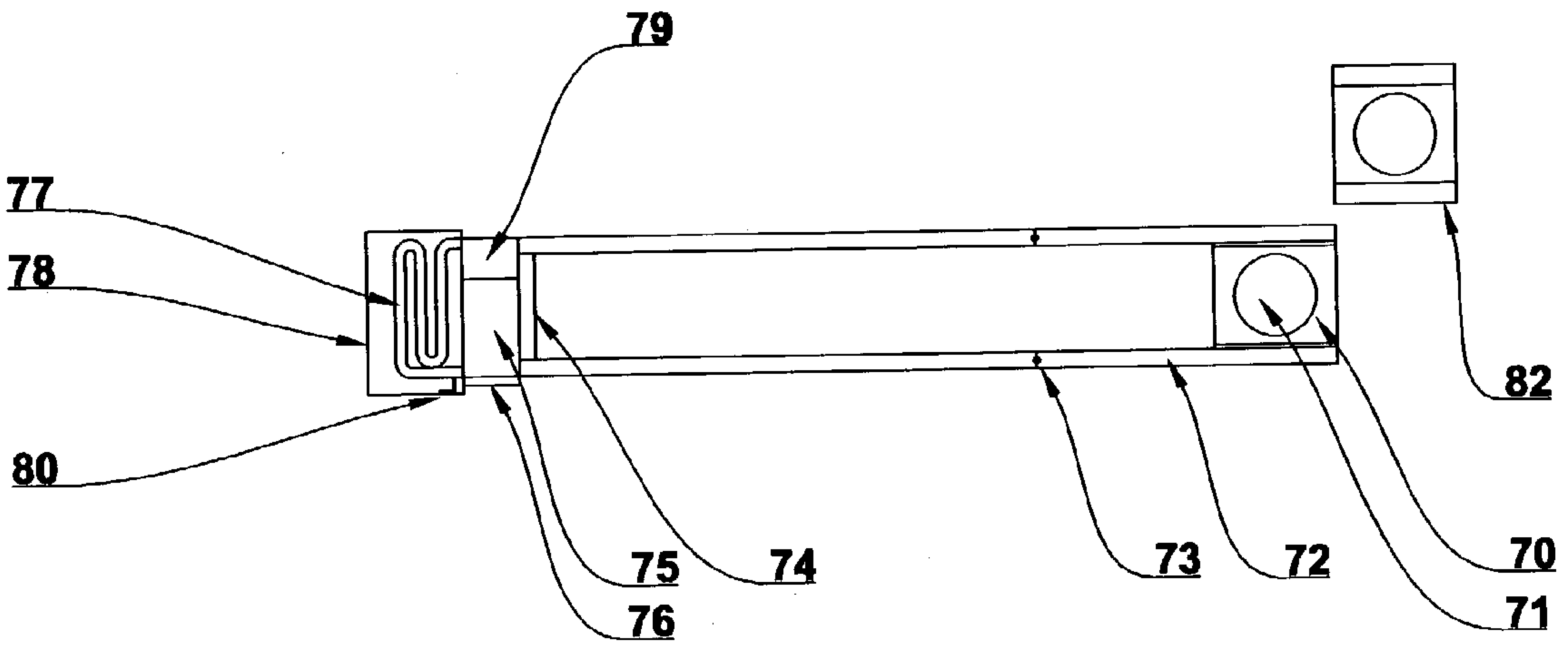

Fig 7

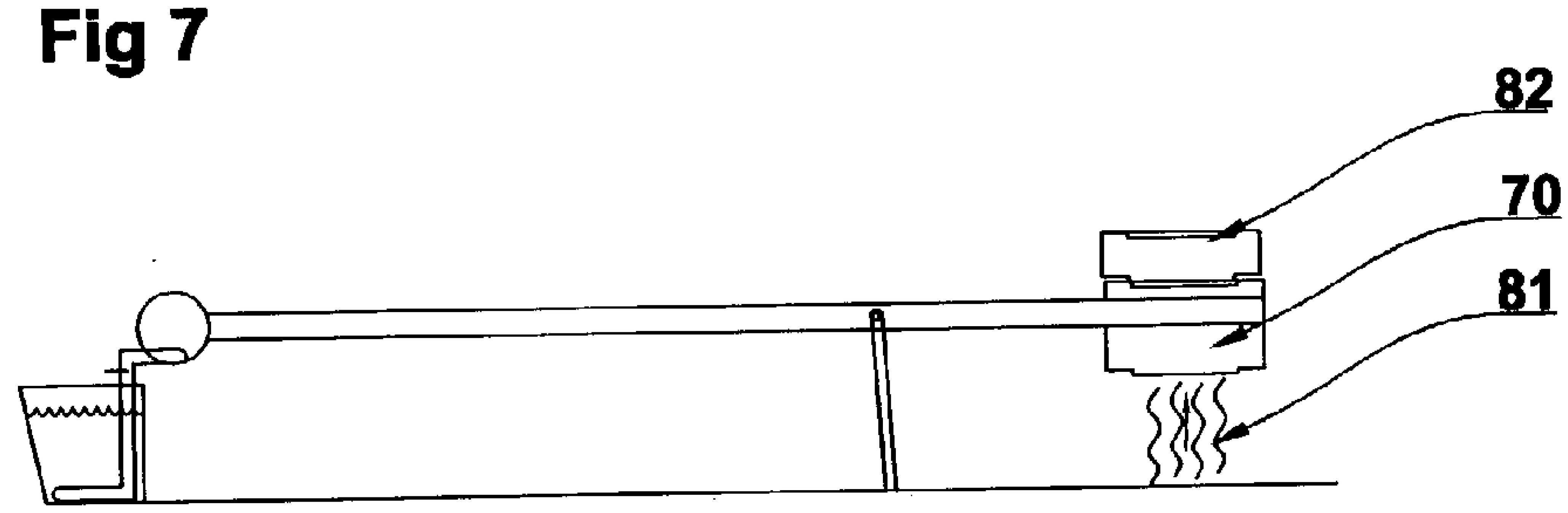

Fig 8

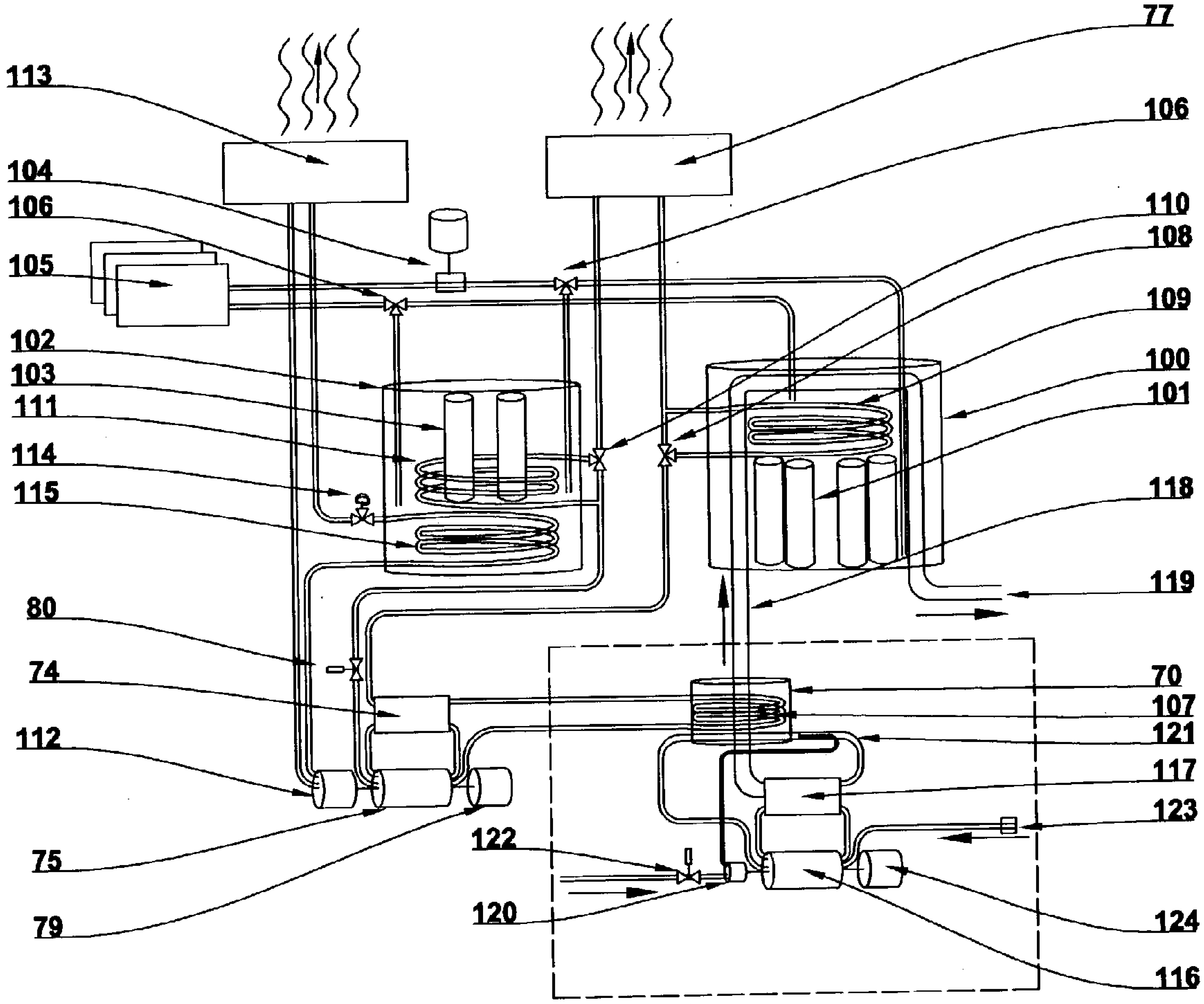

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Fig 9

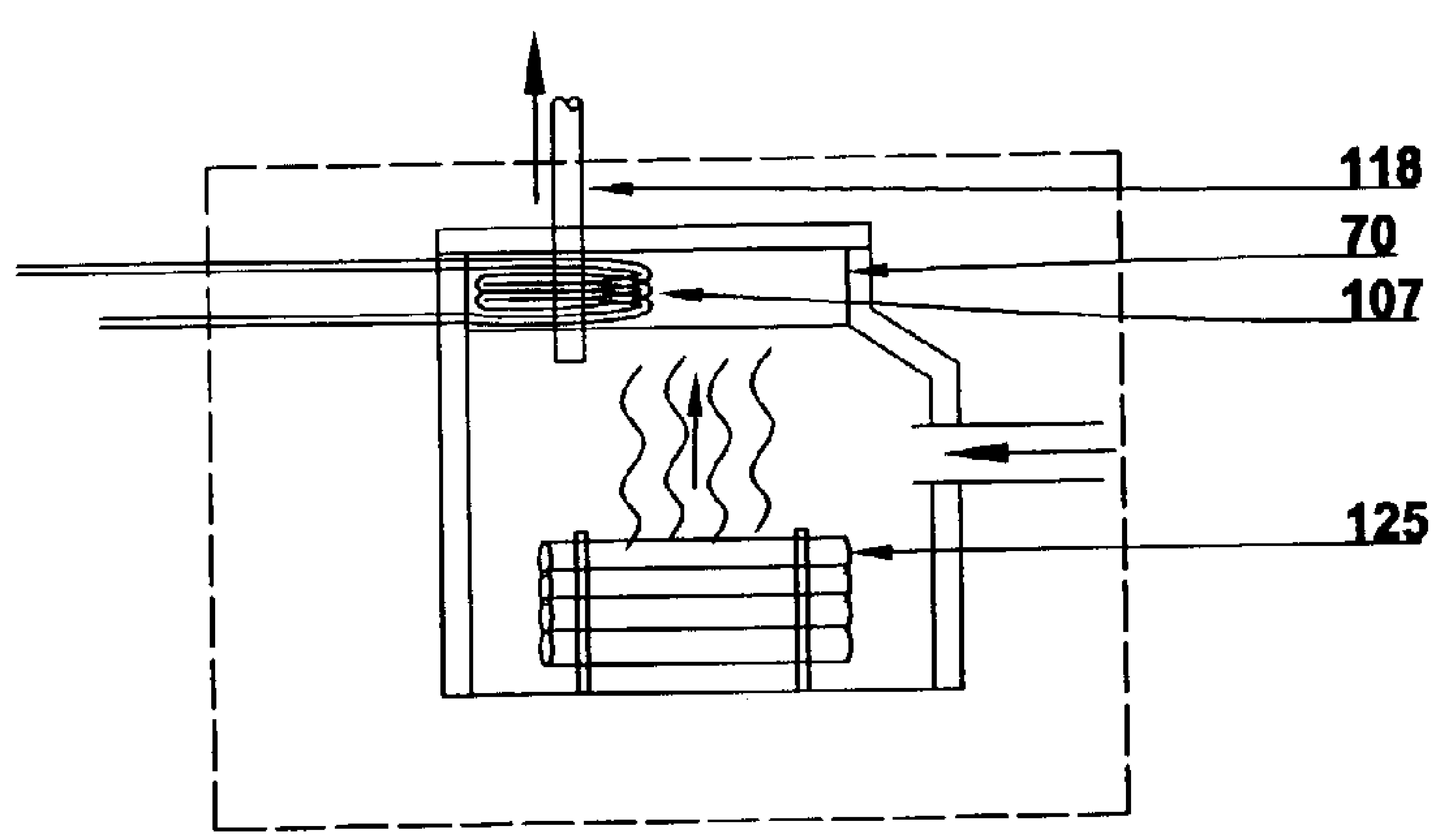

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Fig 10

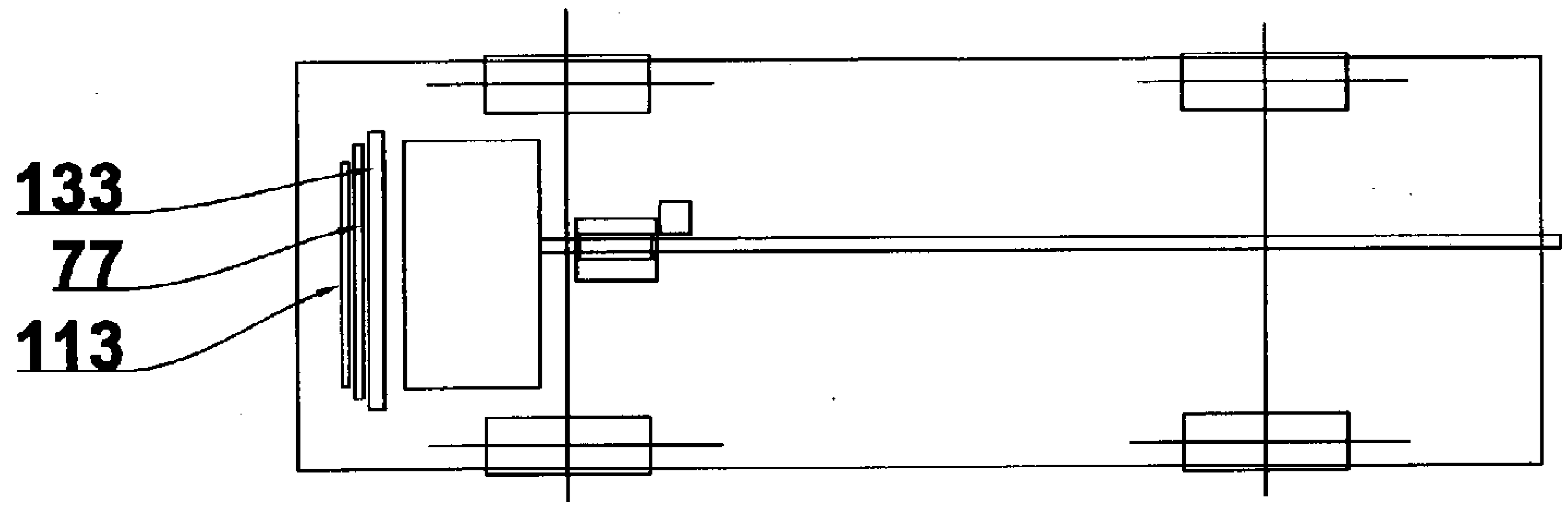
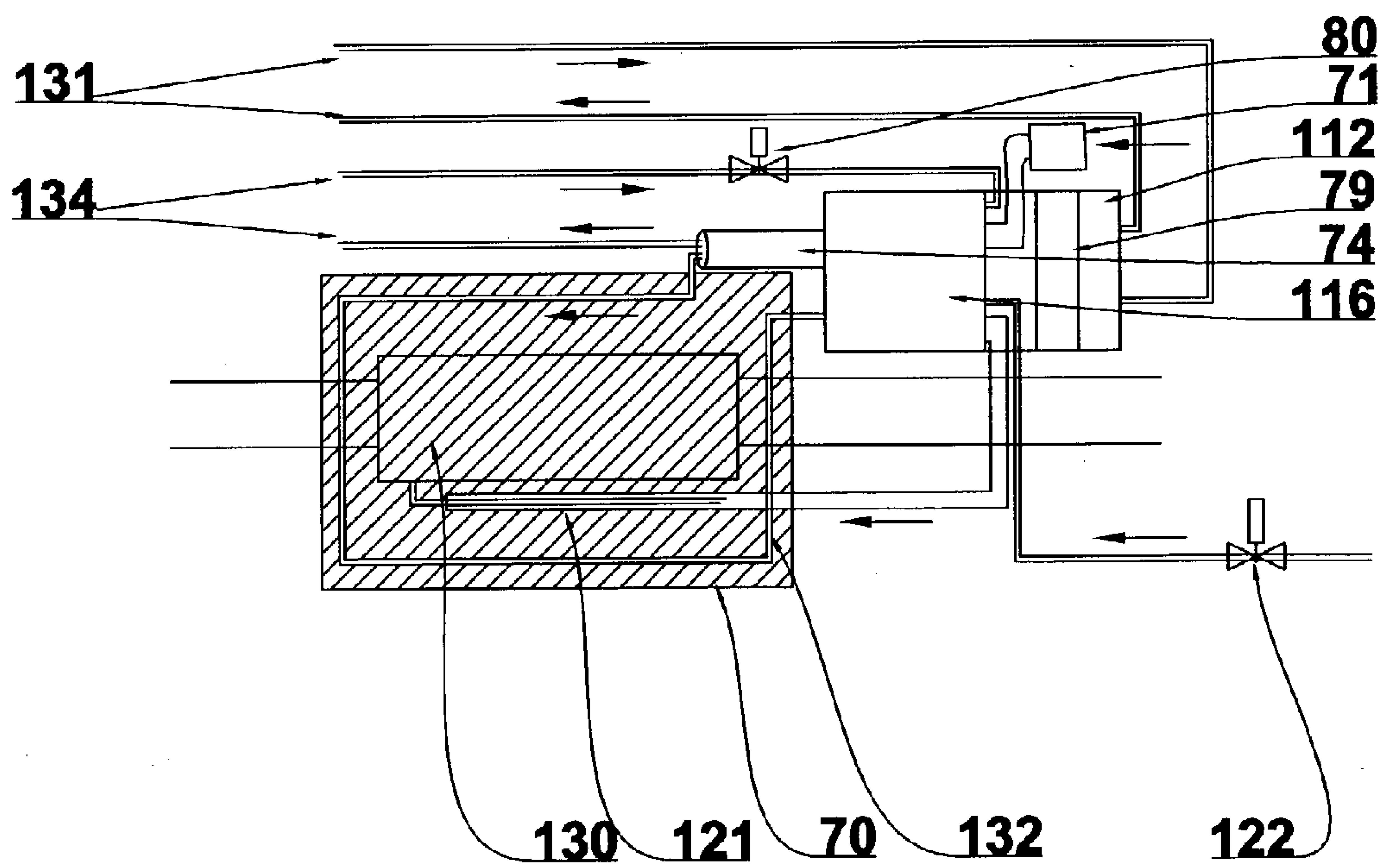


Fig 11



LOW COST HEAT ENGINE WHICH MAY BE POWERED BY HEAT FROM A PHASE CHANGE THERMAL STORAGE MATERIAL

FIELD OF THE INVENTION

[0001] This invention relates to heat engines and heat engines powered by heat stored in a phase change material.

BACKGROUND OF THE INVENTION

[0002] Designing an engine and generator machine for dedicated use in as a cogenerator to supply electrical needs to an off-grid single family dwelling or small commercial establishment presents some unique problems not commonly encountered in engine design. The first problem is that the generator must be very large to carry peak loads, yet operate efficiently at an average load of less than 10%. For example a home which can demand 20+ Kw at peak will likely consume only 1000 Kw hr per 720 hr month, meaning the 20 Kw generator is only required to produce 6.94% of its capability. A strategy of battery storage of electricity can work but batteries are expensive or short lived, and require costly inverters to re-convert their output for use, among other problems. Also the engine generator should be capable of producing a fairly broad range of output power at a fairly low fixed rpm, since current 50 or 60 hz systems require that even a two-pole alternator cannot synchronize above 3000 or 3600 rpm, and corrective electronics are very expensive. A further problem is the timing of the electrical load versus the thermal load. Thermal losses occur at a fairly even and continuous rate so the recovered waste heat from a cogeneration unit which experiences short daily peaks must be stored for later use.

[0003] There is thus a need for an engine which can be constructed at low cost and operate efficiently at low speed over a wide range of power outputs.

[0004] In current heat engines where the products of combustion are also the engine working fluid, much design effort and construction expense is devoted to allowing the fuel to be burned at high temperatures in order to gain maximum efficiency from the burning of the fuel. However this entails employing either exotic materials to survive the resulting temperatures, or external circuit cooling of operating parts which drains efficiency from the engine circuit In many applications where the balance of heat unused by the engine can be effectively employed for space heating purposes, notably small co-generating electrical systems or generating systems intended for use with solid fuels, the criterion of maximum efficiency should be secondary to the criterion of low cost. It is a benefit of the present invention to provide an engine which employs a novel combination strategy of "topping" of the fuel burner with a temperature mediating storage medium, combined with a compressor and expander incorporating a novel combination of bearing systems and optional regenerating cooling systems which can be constructed at low cost.

[0005] Burning a typical engine fuel such as gasoline, natural gas etc. at near stoiciometric ratios in a continuous flow will result in working fluid temperatures of 1400 C or above, at which temperatures standard steels loose strength or worse if continualy exposed uncooled. Ceramics can be created to withstand the higher temperatures, but costs are high, particularly when complex parts with additional materials or surface requirements above high temperature withstand are involved.

[0006] In U.S. Pat. No. 4,782,252, Meijer et al describe employing a phase change material to store heat for cabin heating of a vehicle, but do not contemplate then using the heat to power an engine.

[0007] In U.S. Pat. No. 4,586,334, Nilsson et al describe employing a phase change material to capture solar heat for operation of a stirling engine but no consideration is taken of the use of the storage to mediate the combustion temperature of hydrocarbon fuels, capture heat from fuels difficult to manage such as wood, or of constructing an affordable engine to employ the stored heat. Indeed Nilsson recommends converting part of the engine generator electrical output to hydrogen for storage and provision of heat when the sun doesnt shine. The costs of such a system are prohibitive.

[0008] In U.S. Pat. No. 5,871,041 among others is revealed a means of employing liquid to solid phase change materials to directly supply heat for environmental heating. No provision is made to then use the heat to operate an engine.

[0009] It is known to employ a gerotor machine as a heat engine. Holtzapple et al in U.S. Pat. No. 6,336,317 teach the use of a complex gerotor compressor and gerotor expander in a specifically open circuit brayton cycle engine. High temperatures in the combuster, heat exchanger and expander are still a source of materials problems in this design, and no consideration is given to thermal storage to mitigate the problem or to achieve load levelling or turndown rates.

[0010] It is known to construct heat engines to extract significant mechanical work from fairly low temperature differences. Many ingenious designs have been taught in patents to this purpose, among them many turbine engine and compressor combinations. Also U.S. Pat. No. 5,444,981 by Kakovitch. The key element to all of these designs is the minimizing of parasitic losses expecially into bearings, pumping losses and working fluid flow losses. However, turbine engines typically operate at very high speed, employ exotic materials and loose efficiency very rapidly with reductions in load.

[0011] It is known to employ the heat of fusion of a material to store large amounts of thermal energy in relatively small masses. The benefit to a small co-generation system of doing this is that it separates the timing dependence of the burning of the fuel from the generating of the electricity. The thermal storage system is essentially operating as a battery. It is easily shown that the amount of heating fuel such as natural gas normally burned at 70% efficiency to provide heat and hot water to an average home in a temperate climate, could also provide nearly all the home's electricity requirement if the higher quality part of the heat is used in an efficient engine-generator and the lower quality exhaust heat is recovered to 90+% and used to supply the heating requirement. The problem is that the heat load will not occur at the same time as the electrical load, which has meant that small systems require relatively large chemical battery storage of the electricity, the costs of which make such a system prohibitively expensive.

[0012] There is thus a need for a low-cost system to separate the timing of burning of the fuel from the generating of the electricity, and a means to convert the stored heat into useful mechanical energy when required.

SUMMARY OF THE INVENTION

[0013] It is therefore a primary object of the present invention to provide a means of powering any engine capable of operating on a relatively low temperature difference, from the heat stored in the heat of fusion phase change of a solid material which melts at the hot side temperature of such an engine.

[0014] It is a second object of the present invention to provide a new means of extracting useful rotating shaft work from a relatively low temperature difference heat source/sink using a novel compressor expander machine which may operate using a variety of working fluids from air and products of combustion in an open circuit; to a variety of gases, for example carbon dioxide, in a closed circuit; to a variety of fluids such as water or a refrigerant which themselves undergo a phase change through the engine cycle.

[0015] It is a further object of the present invention to provide a method of constructing a very compact, efficient and low cost compressor expander machine which can be used in such a thermal engine.

[0016] It is a further object of the present invention to show a method of constructing a very compact, efficient and low cost compressor expander machine which can be employed without damage to its materials or its lubricants in a fairly high temperature thermal engine such as one partly driven directly by the heat of combustion.

[0017] It is a further object of the present invention to show a method of constructing a novel heat engine, generator and phase change thermal storage machine which can be carried hot or cold to locations where electricity may not be available, and then also re-charged locally using simple heat sources.

[0018] It is a further object of the present invention to show a method of constructing a catalytic converter incorporating a novel heat engine, generator and phase change thermal storage machine which can provide hot or cold space conditioning and auxiliary electrical power to the vehicle in which it is installed. The thermal storage material ensures that the catalyst is more often at working temperature, even at vehicle startup, while significant mechanical energy is recovered from low value exhaust gases normally wasted.

[0019] In a first preferred embodiment of the present invention, the first object is met by providing a hollow container constructed of a material which can withstand fairly high temperatures. A loop of thermally conductive tubing of similarly high temperature material is placed within or in intimate thermal contact with the said container with both ends protruding to the container's exterior via sealed openings. The container is then filled with a material which has a high heat of fusion and a melting temperature at the design hot circuit operating temperature of a heat engine. The coefficients of thermal expansion of the container material and the phase change material should match as closely as possible. One good pair of materials are a T S20000 Series Stainless Steel from e.g. Carpenter Steels as the container, and pure Aluminum casting. The aluminum melts at 660 degrees C. absorbing 389,000 J/kg in the heat of fusion. For aluminum metal as the phase change material, the container needs to provide at least 9.25 kg of this phase change material per kilowatt hour thermal required of the storage system. Other useful materials include, but are not limited to, zinc, lead, copper, barium, boron oxide, lithium iodide, and a wide variety of alloys and/or chemical combinations of these and other elements. Selection is based on cost and operating temperature required, though alloys need to be carefully evaluated for likelihood of separation at melting, with a resulting change of operation.

[0020] If the system should be portable, then handling means are provided in order to enable one to place the said container in way of a heat source, e.g. a camp stove or even a good wood campfire possibly within a portable ceramic or other container also provided. Alternatively a designed burner may be provided for any of a variety of fuels which can supply heat to the storage container at at least the melting temperature of the phase change material chosen. Obviously precautions must be taken such as thermal containment covers etc. for protection of any person who may inadvertently contact a hot surface.

[0021] The further objects of the present invention are met by providing an expander and working fluid compressor or pump which can operate on either a closed or open working fluid circuit, said engine comprising a single housing containing gerotor compressor or pump and expander means with a mechanical gear mechanism disposed between the compressor or pump and the expander within the housing. The said housing is supported externally on 2 lubricant film bearings which provide close tolerance, e.g. clearances of 0.05 mm, radial and axial alignment of the housing relative to a stationary container. Said gear mechanism is designed to enforce precisely synchronized rotation of the inner gerotor member with the outer gerotor member of both the compressor if present and the expander, eliminating any sliding contact between the rotating members. The gear housing is separated from each working chamber by a solid seal plate pierced for passage of the shaft. Said stationary container supports at each end of the rotating members valve plates containing inlet and outlet ports for the expander and, if provided, the compressor. Also supported at each end are bearings which support the shaft through the inner rotating gerotor member. The shaft also may drive a small lubricant pump for bearing lubricant, a fuel pump for a burner, a working fluid pump if the working fluid undergoes a liquid phase, and any loads driven by the engine. The pressurized lubricant which may be a hydrocarbon or synthetic fluid, or a gas, is supplied by tubing or by drilled passages to each bearing, and possibly by a passage drilled into the center of the shaft to the central gear mechanism. If a liquid lubricant is used, a collection sump or other means is provided to collect spent lubricant from all points and recirculate it possibly through a cooler to the lubricant pump inlet.

[0022] In one preferred embodiment of the present invention the engine working fluid is carbon dioxide (CO_2) which operates in a closed circuit at normal compression pressure of 851 kpa. A small secondary gerotor compressor driven by the common shaft is then used to further compress a small amount of the compressed CO_2 above 7395 kpa, the critical point pressure of CO_2, at which point it becomes a supercritical fluid particularly suitable for use as a bearing lubricant. This lubricant is supplied by tube to the outer rotor bearings, thus providing lubrication and seal pressure to the interface between the outer rotors of both gerotors and the stationary end plates. The bearing leak-down simply re-joins the high pressure compressor output flow as it enters the expander cooling circuit or is re-collected to the main compressor outlet. The extent to which high pressure leak-down from the bearings is maintained for re-collection, is controlled by two fixed longitudinal sealing members attached to the stationary outer housing. The two internal spaces created by these seals, the stationary outer housing, and the rotating outer gerotor element allow for maintaining an unbalanced fluid pressure within these two chamber sufficient to counteract the unbalanced fluid pressures within the gerotor machine itself, or the unbalanced forces created by the synchronizing gear mechanism. In this way the load on the outer rotor bearings can be reduced to the point where the size and cost of the gas bearings which support them can be greatly reduced.

[0023] In the first, second and third preferred embodiments of the invention a heat exchanger is provided to transfer thermal energy from the expander exhaust flow to the compressor output flow. The compressor output flow is then connected to the the engine heat source. If operating conditions warrant, the flow is then connected to the tube which was disposed in the phase change container described previously and then optionally to a fuel burner. The outflow of the heat source is further connected by tube to the expander inlet port, thence to the regenerater hot exhaust inlet port. If a closed circuit is used then the exhaust flow from the heat exchanger is connected by tubing to a cold side heat exchanger, possibly a length of tubing disposed within a container designed to hold water or ice. The cold flow from this heat exchanger is then connected by tubing to the compressor inlet. Two valves in the high pressure circuit provide to shut the engine off while trapping high pressure working fluid for re-starting the engine. A third valve may be provided at the compressor inlet as a throttle which provides a simple though inefficient means to manually or automatically regulate the engine power. For a closed circuit, a more efficient regulation means can be provided by employing a storage container connected by two valves between the compressor outlet and inlet. Valving high pressure working fluid into the storage container reduces the total mass of working fluid in the engine circuit and thus the power of the engine. Valving working fluid from the tank into the compressor inlet will increase the said total mass of working fluid in circuit and thus the power of the engine.

[0024] The complete engine assembly may be semi-hermetically sealed within a container defined by the stationary container or fully hermetically sealed within a further container which may also contain the load machine. If a closed circuit is used, a working fluid can be selected according to requirements from many stable liquid or gaseous material, such as water, a standard refrigerant, carbon dioxide, air, helium, argon etc.

[0025] The invention as described needs little or no exotic materials or fabrication methods. A portable machine with separable phase change thermal storage containers may be designed to be carried on camping trips with the containers re-heated on hot campfires. A stationary system of similar design incorporated into a home or commercial heating system could provide significant electrical or refrigeration output from just topping the fuel normally used for space heating or hot water heating, as well as providing economically a means of storing energy for load leveling and emergency use without the need for expensive short-lived batteries.

[0026] A mobile closed circuit engine designed to provide heating and air conditioning for a vehicle cabin may have its phase change storage container with an auxiliary burner deployed to substantially surround the catalytic converter of the main vehicle engine exhaust system, in order to bring the catalyst temperature into working range prior to engine start and then to collect heat from the engine exhaust.

DESCRIPTION OF THE DRAWINGS

[0027] In drawings which illustrate embodiments of the invention:

[0028] **FIG. 1** is a schematic circuit of the simplest embodiment of the invention.

[0029] **FIG. 2** is a cross section view of a basic compressor and expander which form part of the engine.

[0030] **FIG. 3** is a section view axially at **3-3** through the expander of **FIG. 2** further illustrating a basic compressor expander which form part of the engine.

[0031] **FIG. 3A** is a plan view of the gear elements at **3A-3A** of **FIG. 2** which synchronize the compressor and expander rotors.

[0032] **FIG. 4** is a cross section view of a compressor and expander which might form part of the engine where the expander is provided with forced cooling by the compressed working fluid.

[0033] **FIG. 5** is a section view axially at **5-5** through the expander of **FIG. 4** illustrating the bearing cooling passages and thermal barrier which may be formed into the expander, as well as the bearing unloading seals.

[0034] **FIG. 6** is a plan view of an embodiment of the invention illustrating one possible physical relationship of the parts used for the portable version.

[0035] **FIG. 7** is a side view of **FIG. 6**.

[0036] **FIG. 8** is a schematic circuit of the dual engine embodiment of the invention as is used in a stationary cogeneration installation using a closed circuit engine powered by the heat stored in a thermal store where the thermal store is heated by the exhaust of an open circuit engine employing the compressor and expander of the invention fueled by a gaseous or liquid fuel.

[0037] **FIG. 9** illustrates an alternative heat source for the cogeneration installation of **FIG. 8** where the thermal store heat source is a simple burner rather than an open circuit engine, said burner fueled by wood or any other fuel.

[0038] **FIG. 10** is a plan layout of a motor vehicle where the invention is used partly to pre-heat the catalyst of the catalytic converter.

[0039] **FIG. 11** is a detail of **FIG. 10**

DETAILED DESCRIPTION OF THE DRAWINGS

[0040] In the preferred embodiments of the invention shown in Figures similar parts are referred to on all drawings by the same numbers.

[0041] In FIG. 1 is the simplest schematic of the engine incorporating the thermal storage system. A primary thermal storage container 1 and secondary thermal storage containers 2 are filled with the selected phase change material. Heat collection tube coils 3 are deployed within or in close thermal contact to the primary thermal storage container. The said tubes are connected to a compressor 4 and an expander 5 which are connected by a shaft 6 or similar means. The exhaust from the expander is led by tubes to a waste heat exchanger 7 and then back to the compressor intake. Provision is made to remove waste heat from the exhaust flow, as indicated at 8. A regenerative heat exchanger may be deployed to conduct heat from the expander exhaust gas flow into the compressor output flow, as indicated by dashed arrow 9. A means of employing the excess rotational energy of the expander is deployed, such as an oversized compressor to produce compressed working fluid or a machine such as a generator 10 connected by a shaft to the expander.

[0042] Heat is applied to the primary and possibly also the secondary thermal storage units as indicated at 11 either prior to or during the operation of the engine. Part or all of the applied heat is stored in the heat of fusion of the phase change material contained within the containers. The thermal storage units may then be insulated for efficiency and safety and left for later use or transported to a location where creating the required heat is not convenient, at which time the stored heat may be employed to drive the engine expander. The heat stored in the primary container may be used directly, while that stored in the secondary containers is accessed by physically moving said secondary containers into close thermal contact with the primary container as required.

[0043] In FIG. 2 is illustrated one preferred embodiment of a compressor and expander machine for use in an engine as described. The compressor is formed of an inner gerotor element 20 and outer gerotor element 21. The outer gerotor element is machined into the outer rotating housing 22 or formed separately and keyed into outer rotating housing 22. The compressor gerotor valve plate 23 carries the stationary side of gas bearing 24 which mounts one end of the outer rotating housing, providing both radial and axial location of the rotating housing. Valve plate 23 also carries the compressor outlet port and supply tube 25 and the compressor inlet port and supply tube 26. At the center of valve plate 23 are machined openings for 2 additional complete gerotor machines which are possibly fabricated from a self-lubricating ceramic material such as boron/silicon nitride etc, labeled items 27 and 28. Inboard machine 27 is supplied at it's inlet port from the outlet of the main compressor. It is designed to draw a small proportion of the output gas flow from the main compressor and to further boost the pressure until it is sufficient to support gas bearings 24*a* and 24*b*. Supply to these bearings is carried by tube 29 from the outlet of gerotor 27 to the bearing inlets. If the shaft bearings are sealed ball or roller bearings and the gears 33 and 34 are machined or moulded from a self-lubricating ceramic, then the problem of temperatures being too high for any fluid lubricant to withstand are resolved. Alternatively, as shown in FIG. 2, gerotor machine 28 may be provided at the outboard position as an oil pump sized to provide lubricant to bearings 30*a* and 30*b* which support shaft 31 radially and axially, and to gears 33 and 34. Fluid lubricant is drawn from sump 32 by tube 33 into gerotor machine 28 which pumps it at bearing pressure into bearing 30a via a short passage. Part of the lubricant flow then enters a passage to the centre of shaft 20 and exits through gear 34 to lubricate the gear pair. A further part of the lubricant fluid continues along the passage in the centre of shaft 20 through a section which may be lined with a ceramic thermal barrier material 36 to isolate the lubricant from the heat within expander 37, and exits to lubricate bearing 30*b*. Alternatively a separate tube may follw an external path from lubricant pump 28 to bearing 30*b*, reducing the complexity and thermal gain of the centre shaft passage. Passages are provided to return bearing lubricant to sump 32 which operates normally in contact with the engine working fluid and at or near compressor inlet pressure. In closed circuit engines it may be advantageous to remove sump 32 and lubricant inlet tube 33 to the lowest and coolest point in the exhaust waste heat exchanger where temperatures may provide improved oil separation from the working fluid. The gas bearing pressure flow would be sufficient to transport all lubricant to that point, at which the two could be readily separated and re-used. The gear case is separated from the compressor and expander by solid plates 38 and 39 which are round and keyed to rotate with the rotating outer rotor housing 45. Plate 39 may be formed partly or entirely from a thermally non-conducting material in order to isolate the gear case from the expander temperatures. The expander is comprised of an outer gerotor gear 40 and an inner gerotor gear 37 having one less radial projection than outer gear 40. Both are formed from any suitable material which can withstand the engine design temperatures and mechanical loads and working fluid corrosion characteristics. Valve plate 41 mounts expander inlet port and tube 42, and expander exhaust port and tube 43. Bearing mounting plate 44 is provided to separate and isolate bearing 30*b* from the high temperatures within the expander. Enlarged holes for tubes 42 and 43 are provided in plate 44 to the same purpose. The majority of the assembly is contained within casing 45 which can be semi-hermetically sealed using standard shaft seals and end plates not shown.

[0044] Fixed chamber separation seal plates 47 are provided to maintain a pressure differential on the outer surface of outer rotor housing 45, the pressure differential being designed to partially balance the load from pressures within the outer rotor on the bearings 24*a* and 24*b*. The pressure differentail may be maintained by trapping the leak-down gas pressure from the bearings at regulated outlets not shown, or any other convenient means. When the high pressure side of the external rotor is maintained at or near compressor outlet pressure and the opposite side is maintained at or near compressor inlet pressure, the widths of bearings 24*a* and 24*b* can be reduced to arbitrarily small dimensions making them very low-cost to manufacture.

[0045] It is to be understood that persons skilled in the art could propose modifications to this embodiment without altering the essential concept. For example if this compressor and expander were deployed in an open circuit, a designer might consider eliminating the gas bearings in favor of simply burning any evaporated lubricant supplied to the hottest points, in a manner similar to current two-cycle otto cycle engines. Several fuels, e.g. diesel oil might also serve to lubricate the bearings and/or the gears prior to being burned. The gears might be formed from a self-lubricating ceramic. The choice of bearing types for each location can be altered depending on operating conditions, design life, construction costs or available maintenance inter alia. All wall thicknesses shown are for illustrative purposes only and whould be evaluated for volume production.

[0046] In **FIG. 3** is illustrated a cross section through the expander of **FIG. 2** at **3-3**. The several bolt holes used to assemble all outer rotor parts are showed as **46**. These through bolts connect together all rotating elements of the outer rotor of the expander and compressor during assembly, which progresses from left to right in **FIG. 2**. The line labels **50** to **55** mark significant radii of the expander. Line **50** is only a construction line used to locate holes **46**. Line **51** is the outer radius of the expander outer rotor insert and of the outer gear and the gear case separator plates. Line **52** is the outer radius of the rotating outer rotor housing. Line **53** is the line separating the rotating bearing face from the fixed bearing face. Line **54** is the radius of the inner wall of the fixed casing. Line **55** is the radius of the outer wall of the fixed casing. The linear seals used for bearing load balancing are showed at **47**.

[0047] **FIG. 3***a* is a sketch drawing of the inner and outer gears at 3A-3A of **FIG. 2**, which gears synchronize the rotation of the inner and outer rotors.

[0048] **FIG. 4** illustrates a second preferred embodiment of a compressor and expander for use in this invention. In order to reduce the temperature of the bearing supporting the expander, the said expander outer rotor is either comprised of or surrounded by a material of low thermal conductivity and which is constructed having longitudinal ridges on its outer surface. These ridges form a series of passages **61** surrounding the said expander outer rotor when it is assembled into the rotating outer rotor housing **45**. An additional separator plate **62** is placed between the expander and the gear case and a series of drilled holes **63** are provided in the outer case **45** If the outer bearings are not gas bearings then a simple labyrinth seal **64** is provided to separate the lubricant flow from the compressor flow supplied by tube **25** which conducts all or part of the flow from the compressor into the newly formed chamber between the gear casing and the expander. If the bearing load balancing system described in **FIG. 3** is used here, then the seal plate will need to be pierced to enable rotation of this labyrinth seal mechanism, and its sealing clearances reduced. From there the compressor flow travels along the passages **61** surrounding the expander to be collected again into channel **65** which is machined in the entire circumference of valve plate **41** and from there to compressor flow tube **25**. Using the compressor output flow for cooling in this manner, bearing temperatures may be reduced suffiently to allow standard lubricants to be used in bearing **24***b* while the heat lost to cooling may be carried by the working fluid back into the engine circuit, thus reducing the negative impact on efficiency.

[0049] Also illustrated in **FIG. 4** is the addition of gaseous fuel gerotor pump **66**, a valuable addition if the engine must operate in an open working fluid circuit on a low pressure fuel supply. Commercial pumps capable of raising natural gas pressure to the 7+ bar pressures required in an open circuit engine burner are extremely expensive. Using a simple fuel throttle valve and/or dedicated regulator and a backflow preventer on the inlet of pump **66** will provide for an accurate and consistent fuel/air ratio throughout the entire rpm range of the compressor, while the tube path from the fuel pump to the burner can be very short, improving the system safety.

[0050] In **FIG. 5** is illustrated a cross section through the expander of **FIG. 4** at **5-5**. All is the same as **FIG. 3** except for the addition of the thermal barrier layer **60** and the longitudinal ridges which form cooling passages **61** for working fluid.

[0051] **FIG. 6** is a plan view of one embodiment of the present invention as a portable engine which can be powered by a variety of heat sources. A container **70** which is filled with a thermal storage phase change material is suspended by thermally insulated structural tubes **72** and vertical supports **73** over thermal source **81**. The shape of container **70** is modified by indentations such as at **71** to improve heat collection from both the primary thermal source and additional auxiliary thermal storage containers of similar shape as at **82**. Persons skilled in the art may see additional modifications which may be made to the container shape for a variety of purposes without altering the essential design. Primary container **70** contains within it a heat exchanger means for transferring the thermal energy of the phase change material into a working fluid which is supplied from and returned to compressor/expander **75** by tubes thermally isolated within structural tubes **72**. A regenerative heat exchanger is provided at **74**. Waste heat exchanger **77** is deployed within a container **78** which is designed to hold cooling water poured into container **78**. A throttle valve means is provided at **80**. A mechanical load such as a generator or mechanical drive means may be provided at **79**. A variety of starting means may be provided to bring the hot side tubes up to pressure, some of which are a recoil rope starter such as at **76**, or one or more valves designed to supply pressurized working fluid from a storage container, or an electrical source which could drive a generator at **79** as a motor for starting purposes. An automatic control system may be included employing any of a variety of feedback mechanisms to automatically modulate the output of the engine either by throttling, by varying the working fluid pressure within the engine circuit, by varying the efficiency of any of the heat exchangers provided, or by varying the compression and expansion ratios of compressor/expander **75** using port position adjustment means not shown.

[0052] If the working fluid is a material such as water which undergoes a phase change in the waste heat exchanger **77**, then the compressor is replaced by a working fluid liquid pump, and the configuration is slightly modified so that container **78** is at a greater height than the expander. An appropriate means of power control such as a working fluid liquid container which is sealed to the circuit, capable of containing all the engine working fluid in the liquid phase and connected by a branch fitting and a rotatable elbow to the lowest point between said waste heat exchanger **77** and said working fluid pump may be provided. Power control is then provided by the degree of rotation of this container. If it is positioned so that the condensate preferrably flows into it than into the pump inlet, then the amount of working fluid in the engine circuit is reduced or the engine is shut off. Alternatively, if the container is positioned so that the condensate preferrably flows into the pump inlet rather than the container, then the amount of working fluid in the engine circuit is increased, increasing the engine output. Other possible means of power control, such as a manual or automatic flow bypass valve conecting the pump outlet back to its inlet, are also apparent to those skilled in the art.

[0053] For further clarification, **FIG. 7** is a side view of the portable engine embodiment shown in **FIG. 6**, all reference numbers the same.

[0054] An alternate preferred embodiment of the present invention is shown schematically if **FIG. 8**. In this embodiment three separate phase change thermal storage containers are deployed. At **70** is a hot thermal storage container constructed of steel or a ceramic material capable of safely containing a material such as zinc, lead, copper, barium, boron oxide, lithium iodide, or one of a wide variety of alloys and/or chemical combinations of these and other elements. The key criteria in the selection of the material are the temperature of the input heat source, and the desired temperature input to the next heat consumer in the hot circuit. At **100** is an intermediate temperature thermal storage container designed to store large amounts of low quality heat. This container may be designed to store thermal energy in the phase change of a material which melts at a temperature just below the boiling point of water at atmospheric pressure. Many useful materials to this purpose are well known in the art, including glaubers salt, many other hydrated salts of lithium, sodium and potassium, tars, pitches, resins etc. This phase change material may be sealed into containers **101** deployed within the intermediate temperature thermal storage container. At **102** is a low temperature thermal storage container designed to store large amounts of refrigeration, in the chilled working fluid contained within tank **102** and possibly in the heat of fusion of a third phase change material such as water ice or a hydrate such as CO2: H2O sealed within containers **103** deployed within the low temperature thermal storage container. Pump **104** is installed to circulate a working fluid such as a water/glycol mix from either the intermediate temperature thermal storage container or the low temperature thermal storage container into space conditioning units **105** depending on the settings of three-way valves **106**. A domestic hot water heating coil not shown may also be deployed within intermediate thermal storage container **100**. All three thermal storage containers are suitable insulated for efficiency.

[0055] A closed circuit engine, possibly using the compressor expander set illustrated in **FIG. 2** above, is then deployed at **75**. Its regenerative heat exchanger is showed at **74**. Heat collection tube coils **107** are deployed within hot storage container **70**, and the main waste heat rejection heat exchanger **77** is installed as convenient. If efficient and useful, a heat recovery indoor air heat exchanger, not showed, may be provided prior to outdoor heat exchanger **77**. Provision is made using three way valve **108** for the control system to optionally route the exhaust flow from this engine into a heat exchanger coil **109** installed within intermediate thermal storage container **100**. If it is installed, provision may also be made using three way valve **110** for the control system to optionally route the waste heat exchanger return flow from this engine into a heat exchanger coil **111** installed within cold thermal storage container **102** for the purpose of occasionally increasing the power output of the closed circuit engine for load leveling purposes etc. The loads on the closed circuit engine may be a generator **79** and/or an air conditioning circuit compressor **112**. If the air conditioning circuit is installed then secondary waste heat rejection heat exchanger **113** is installed as convenient to reject the heat. Thermal expansion valve **114** is then installed just before the return flow from this heat exchanger enters cooling circuit heat exchanger **115** installed within cold storage container **102**. The refrigerant is then routed back to air conditioning compressor **112**.

[0056] If the fuel for the system is to be one which can usefully operate an open circuit engine, such as natural gas, propane, hydrogen or any of the pumpable hydrocarbon fluids, then a second compressor expander set as illustrated in **FIG. 2** or **FIG. 4** above may be installed as showed at **116** in **FIG. 8**. A regenerative heat exchanger **117** may be installed in the expander exhaust flow depending on the efficiency required and the system materials and lubricants temperature withstand abilities. The exhaust flow is then further routed into hot thermal storage unit **70** where a large portion of the exhaust thermal energy above the melting temperature of the hot phase change material, e.g. 660 degrees C., is collected and stored. From there the exhaust flow is routed into the intermediate thermal storage container **100** via tube **118** where a large portion of the remaining exhaust thermal energy above the melting temperature of the intermediate phase change material, e.g. 80 degrees C., is collected and stored. The exhaust is then routed to atmosphere at a safe location by tube **119**. If efficient and desirable and the pressure drop on the engine is acceptable, a final indoor condensing air heat exchanger not shown may be provided in tube **119**, since this is a pressurized flow. In any case care must be taken to ensure that continuous or occasional condensation in the exhaust circuit does not cause problems for the system. A fuel supply pump **120**, possibly as illustrated in figures above and driven by engine **116**, is connected to burner **121** which also is supplied compressed air from inlet air filter **123** by the compressor. The heated output of burner **121** is tempered to a temperature which the expander can handle, e.g. 900 C to 1000 C, by transferring part of the heat of combustion into hot phase change thermal storage unit **70**. The burner output is then fed into the expander to drive mechanical loads such as a generator **124**. Fuel shutoff valve **122** controls fuel supply to the burner. A well known variety of other controls implementing a variety of control strategies and auxiliary functions such as burner ignition etc. are assumed but not showed in figures.

[0057] **FIG. 9** illustrates an alternative source of thermal energy for the system in **FIG. 8**. If the fuel source should be a solid fuel such as wood etc., then the open circuit engine within the dotted box in **FIG. 8** is replaced with the burner system of **FIG. 9**. Hot thermal storage container **70** contains closed circuit engine heat exchanger **107** which is heated by burning fuel **125**. Hot exhaust gas then enters tube **118** and proceeds as in the previous discussion. In the case of wood fuels or others where the exhaust may contain condensible and flammable materials, care must be taken to ensure the exhaust tube remains sufficiently hot to safely discharge them completely. It is also apparent that the burner showed in **FIG. 9** may be a decorative fireplace fueled by any fuel and deployed all or partly within a residential or commercial building in a fireplace insert or stove designed for the purpose.

[0058] **FIGS. 10 and 11** show schematically another alternate preferred embodiment of the present invention. In this embodiment a container **70** which is filled with a thermal storage phase change material is installed surrounding the catalytic converter **130** of a motor vehicle. The shape of container **70** is designed to optimize heat collection from both the primary thermal source, the vehicle engine exhaust, and additionally from an auxiliary fuel burner such as at **121** supplied air by a pump within a heat engine **116** of type as shown in figures above. A fuel supply pump not detailed, possibly as illustrated in figures above and driven by engine **116**, is connected to burner **121** which also is supplied compressed air from inlet air filter **123** by an auxiliary compressor. The output of burner **121** is simply used to pre-heat thermal storage container **70** if the vehicle exhaust is insufficient to do so. A starter motor/generator and/or air conditioning circuit compressor **112** is driven by engine **116**. If the air conditioning circuit is installed then secondary waste heat rejection heat exchanger **113** connected to supply tube **131** is installed as convenient to reject the heat. A thermal expansion valve not shown is then installed just before the return flow from this heat exchanger enters a cooling circuit heat exchanger installed within the vehicle cabin. The refrigerant is then routed by tube **131** back to air conditioning compressor **112**.

[**0059**] Fuel shutoff valve **122** controls fuel supply to the burner. A well known variety of other controls implementing a variety of control strategies and auxiliary functions such as burner ignition etc. are assumed but not showed in figures.

[**0060**] Container **70** contains within it a heat exchanger means for transferring the thermal energy of the phase change material into a working fluid which is supplied from and returned to compressor/expander **116** by tubes **132**. A regenerative heat exchanger is provided at **74**. Waste heat exchanger **77** is deployed at a convenient location in the vehicle for cooling, possibly adjacent the engine cooling water heat exchanger **133**. The waste heat exchanger is connected to the compressor/expander by tubes **134** A throttle valve means under automatic control is provided at **80**. A generator as an additional mechanical load is provided at **79**. Starting is provided to bring the hot side tubes up to pressure, preferably using the vehicle electric battery which can drive the generator at **79** as a motor for starting purposes. An automatic control system not shown is included employing any of a variety of feedback mechanisms to automatically modulate the output of the engine either by throttling, by varying the working fluid pressure within the engine circuit, by varying the efficiency of any of the heat exchangers provided, or by varying the compression and expansion ratios of compressor/expander **75** using port position adjustment means not shown.

[**0061**] It is understood that those skilled in the art may propose other variations and modifications of the preferred embodiments described above without departing from the scope of the invention.

I claim:

1) A gerotor machine having

the outer rotor supported by two journal bearings surrounding the outer rotor

2) A gerotor machine as in claim 1 where

lubricant to the journal bearings is oil pumped by a purpose-built additional gerotor pump which is driven from the common shaft of the main gerotor machine.

3) A gerotor machine as in claim 2 where

Coolant passages are provided between any lubricated element and any hot gas chambers of the gerotor machine for the purpose of cooling the lubricant.

4) A gerotor machine as in claim 1 where

lubricant to the journal bearings is an engine fuel pumped by a purpose-built additional gerotor pump which is driven from the common shaft of the main gerotor machine.

5) A gerotor machine as in claim 1 where

lubricant to the journal bearings is a gaseous working fluid pumped by a gerotor compressor which is driven from the common shaft of the gerotor machine.

6) A gerotor machine as in claim 5 where

lubricant to the journal bearings is further compressed by a purpose-built additional gerotor pump which is driven from the common shaft of the main gerotor machine.

the lubricant is compressed to a pressure above its critical point pressure to become a supercritical fluid.

7) A gerotor machine as in claim 1 where

the outer rotor is substantially surrounded be a sealable case

the sealable case is separated into two or more chambers by fixed seals

provision is made to pressurize the resulting several chambers to differing pressures to reduce unbalanced loads on the journal bearings

8) A gerotor machine as in claims 1 to 7 where

thermal energy to operate the gerotor machine as a heat engine derives substantially from a phase change Thermal Store.

the heat storage phase change material is one of aluminum, zinc, copper, lead, barium, tin, silver, silicon, boron oxide, lithium iodide or any alloy composed substantially of one or more of these.

9) A heat engine as in claim 8 where

the engine drives an electrical generator as its primary load

provision is made for the engine to drive other loads mechanically

the thermal storage container is attached to the engine by one or more insulated structural shafts said shafts are designed to house and protect the conduit tubes which transport the engine working fluid to and from the said thermal storage.

said shafts are designed to allow the thermal storage container to be suspended over a substantially open fire or other general purpose heat source for collection of heat.

the thermal storage container is shaped to provide for additional thermal storage containers to be placed in close thermal contact with it to provide additional thermal storage capacity.

10) A heat engine as in claim 9 where

the engine working fluid is air

the engine working fluid operates in an open cycle with additional heat energy supplied by a burner oxidizing part of the working fluid.

11) A heat engine as in claim 8 where

the engine working fluid operates in a closed cycle the thermal storage is part of a stationary space conditioning electrical co-generation system

12) A heat engine as in claim 8 where

heat is provided by a solid fuel burning system disposed to supply heat primarily to the thermal storage

13) A heat engine as in claim 8 where

heat is provided by a sollar collector system disposed to supply heat primarily to the thermal storage

14) A heat engine as in claim 8 where

heat is provided by the fuel burner of a second heat engine as in claim 8 with the working fluid operating in an open circuit

the fuel burner is disposed to supply heat primarily to the thermal storage

the exhaust of the fuel burner drives the second engine

15) A heat engine as in claim 13 where

heat is provided by a decorative fireplace

16) A heat engine as in claim 8 where

the thermal storage surrounds the catalytic converter of a motor vehicle

the thermal store is normally heated by the exhaust of the vehicle engine

the heat engine working fluid operates in a closed cycle

the heat engine drives an auxiliary compressor to operate a refrigeration circuit providing space cooling to the vehicle cabin

17) A heat engine as in claim 16 where

an auxiliary fuel burner is disposed to provide heat to the thermal store

18) A heat engine as in claim 17 where

the thermal store or engine exhaust is also used to provide space heating to the vehicle cabin

19) A heat engine as in claim 17 where

the thermal store or engine exhaust is also used to provide heating to the engine prior to startup of the vehicle engine

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