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(54) **Title:** EXTERNAL HEAT ENGINE OF THE ROTARY VANE TYPE

(57) **Abstract:** A heat engine of the rotary vane type and thermodynamic cycle is disclosed. The engine converts thermal energy contained within relatively low temperature hot gasses into mechanical energy. The engine operates by expanding a hot gas to a lower pressure than its starting pressure, cooling the gas briefly at a approximately constant volume and then cooling the gas further while compressing it back to its original pressure. Possible sources of hot gasses for powering the engine include exhaust gasses from other engines and air heated by solar collectors.

Description

EXTERNAL HEAT ENGINE OF THE ROTARY VANE TYPE

Technical Field

[1] The present invention is an external heat engine of the rotary vane type that converts thermal energy into mechanical energy.

Background Art

[2] Heat engines that convert thermal energy into mechanical energy by cycling a working fluid through a suitable thermodynamic cycle have been around for a very long time and come in countless varieties. To maximize efficiency heat engines are typically designed to heat their working fluid to a high temperature. The higher the temperature reached by the working fluid the more efficient the engine can become.

[3] Unfortunately however, heat engines that are designed to operate at high temperatures and efficiencies typically cannot effectively or economically convert thermal energy contained within relatively low temperature heat sources such as exhaust gasses from other engines into other usable forms of energy.

[4] Given the rising cost of fuel and a relative abundance of low cost and environmentally friendly low temperature heat sources, the economic viability of an engine that can effectively harness the energy of low temperature heat sources is greater than ever.

[5] The Rankine Vapor Compression cycle if often used to harness power from low temperature heat sources. Unfortunately however, the Rankine cycle does not efficiently harness thermal energy from exhaust gasses when the gasses are at temperatures significantly above or below the boiling point of its working fluid.

[6] Additionally, gas turbines that follow the Inverted Brayton cycle have been proposed to harness waste heat from low temperature exhaust gasses. However, the adiabatic inefficiency of gas turbine compressors and expanders as well as the need for multiple intercooling phases to approximate isothermal compression has made the cycle impractical for low temperature applications.

Disclosure of Invention

[7] Accordingly, it is an object of this invention to provide an engine capable of effectively converting relatively low temperature thermal energy into mechanical energy at the lowest possible cost. The invention can be used in addition to or as a replacement for the ranking vapor compression cycle commonly used for such purposes.

[8] Briefly described in a preferred embodiment, the invention is a heat engine of the rotary vane type that can utilize an open cycle or a closed cycle. The thermodynamic cycle of the engine begins as the working gas of the engine is heated by a heat source.

Sources of thermal energy to power the engine include exhaust gasses from gas turbine, diesel or gasoline engines as well as air heated by solar collectors.

[9] After the working gas is heated it enters the engine through the inlet port into the spaces between the engines vanes, rotor and housing. As the gas moves past the inlet port it enters the expansion section of the engine wherein the gas expands adiabatically to a lower pressure and temperature. Just before the gas reached the end of the expansion section a liquid coolant is injected into the gas through holes in the walls of the engine housing further reducing its temperature and pressure.

[10] After the gas leaves the expansion section of the engine it enters the compression section. Here more liquid coolant is injected into the gas, which absorbs heat generated by the compression process and as a result the gas is compressed in a generally isothermal fashion. This reduces the amount of work required to compress the gas back to its original pressure. Finally, the working gas and the liquid coolant are expelled from the engine through the outlet port near the bottom of the engine.

[11] Because the expansion process occurs at a higher temperature than the compression process, more work is created by expansion process than is consumed by the compression process. This creates pressure differentials across the sliding vanes that force the engine rotor and shaft to spin about their axis and create a net work output.

[12] Finally the working gas leaving the engine is either expelled to the atmosphere if the engine is utilizing an open cycle, or the working gas is reheated and recirculated back to the inlet port of the engine if the engine is utilizing a closed cycle. Additionally, the liquid coolant is cooled in a heat exchanger before it is pumped back into the engine.

Brief Description of Drawings

[13] The present invention will be better understood by reading the Detailed Description of the Preferred and Alternate Embodiments with reference to the accompanying drawing figures, in which like reference numerals denote similar structure and refer to like elements throughout, and in which:

[14] FIG. 1 is a side cross section view of the present engine operating according to an open cycle;

[15] FIG. 2 is a side view of the present engine operating according to an open cycle;

[16] FIG. 3 is a schematic illustration of two of the engines sliding vanes having four support rails attached to each one;

[17] FIG. 4 is a side view schematic illustration of the tip of an engine vane;

[18] FIG. 5 is a pressure-volume diagram of the thermodynamic cycle of the present engine;

[19] FIG. 6 is a side cross section view of another embodiment of the engine operating according to a closed cycle.

Detailed Description of Best Modes

[20] In describing the preferred and alternate embodiments of the present invention, as illustrated in FIGS. 1-6, specific terminology is employed for the sake of clarity. The invention, however, is not intended to be limited to the specific terminology so selected, and it is to be understood that each specific element includes all technical equivalents that operate in a similar manner to accomplish similar functions.

[21] Referring now to FIG. 1, illustrated therein is the preferred embodiment of the heat engine 1 operating according to an open cycle, having a housing 2 that encloses a cavity and a rotor 3 that rotates within the cavity of the housing 2. Disposed within the rotor 3 are a plurality of vane slots 4 and a plurality of sliding vanes 5 residing within the vane slots 4. When the engine 1 is in operation the sliding vanes 5 are forced outwards by centrifugal force to make contact with the inner wall of the housing 2. A rotor shaft 16 extends though the rotor's axis of rotation.

[22] Each sliding vane 5 has a plurality of support rails 6 attached to their inner end. The support rails 6 provide structural support to the sliding vanes 5 when they slide outwards a significant distance from the edge of the rotor 3. The support rails 6 are horizontally offset through a distance parallel to the rotors axis of rotation from the supports rails attached to the adjacent sliding vanes 5, which allows them to slide past each other without colliding. These support rails 6 are not necessary for the engine to operate however they enable an engine of a given size to move more working fluid through it on a single rotation.

[23] A plurality of support rail slots 7 extend beyond the inner end of each vane slot 4. The support rails 6 slide into the support rail slots 7 when the sliding vanes 5 are positioned close to the center of the rotor 3. Like the support rails 6 the support rail vane slots 7 are also horizontally offset from the supports rail vane slots 7 attached to the adjacent vane slots 4. This allows them to be positioned next to each other without interfering with each other.

[24] The space between the sliding vanes 5, the rotor 3 and the housing 2 define variable volume gas chambers. The volume of these gas chambers change as the rotor 3 rotates within the housing 2 and the distance between the rotor 3 and the inner wall of the housing 2 changes.

[25] A heat source external to the engine 1 heats a gas, which is supplied to the engine 1. This hot gas is both the energy source and working fluid of the engine. The thermodynamic cycle begins as the working gas is heated and expanded outside of the engine 1. The engine 1 then draws in the hot gas through the inlet port 8 into the space between the sliding vanes 5. A guide rail 9 traverses the inlet port 8 keeping the vanes 5 in the proper position as they move past the inlet port 8 while allowing the hot gas to flow into the engine 1.

[26] As the sliding vanes 5 and the gas chambers surrounded by the vanes 5 move past the inlet port 8 they enter the expansion section of the engine, which is downstream from the inlet port relative to the flow of the working gas. In this section the vanes 5 slide outwards from the rotor 3 and the volume of the gas chambers surrounded by the vanes 5 increase. The expansion section of the engine extends from the point where a trailing vane 5 of a gas chamber passes the inlet port until the gas chamber reaches a point where it is no longer expanding. This expansion process lowers the pressure and temperature of the working gas. A layer of insulation 11 covers the inlet port 8 as well as the outside of the housing 2 on top of the expansion section to prevent unwanted loss of thermal energy from the working gas.

[27] Just before a gas chamber reaches the end of the expansion section a liquid coolant is injected into the gas chamber through a plurality of liquid passageways 10 in the walls of the housing 2. This further reduces the temperature and pressure of the working gas within the chamber.

[28] After a gas chamber leaves the expansion section of the engine 1 it enters the compression section which is downstream from the compression section relative to the flow of the working gas. In the compression section the vanes 5 slide inward towards the rotor 3 and the volume of the gas chambers surrounded by the vanes 5 decrease. In the compression section more liquid coolant is continuously injected into the gas chambers through liquid passageways 10 in the walls of the housing 2.

[29] Choices of liquid coolants usable by the engine include water as well as coolants with a higher boiling point than water such as oil. Lubricants could also be injected into the engine along with the coolant to lubricate the engine. Additionally chemicals capable of absorbing pollutants within the working gas, and corrosion inhibitors could be mixed with the liquid coolant.

[30] When the leading vane 5 of a gas chamber reaches the outlet port 12 the compression process is complete and the working gas and liquid coolant are expelled from the engine through the outlet port 12. The outlet port 12 is positioned downstream from the compression section and near the bottom of the engine 1 which allows gravity to assist in expelling the liquid coolant from the engine 1.

[31] A catch basin 13 is positioned beneath the outlet port 12 to collect the liquid coolant expelled from the engine 1. A metal grate 14 covers the catch basin. A pump 15 pumps the liquid coolant captured in the catch basin through a pipe 18 to a heat exchanger 19 and then back to the engine 1 through the liquid passageways 10 in the housing 2. The heat exchanger 19 expels heat absorbed by the liquid coolant while it was in the engine 1 before it returns to the engine 1.

[32] Referring now to FIG. 2 illustrated therein is a side view of the engine 1 showing the housing sidewall 25. A bearing 17 is mounted to the housing sidewall 25. The rotor

shaft 16 extends outward from the engine through the housing sidewall 25 and bearing 17. A generator can be coupled to the rotor shaft 16 to produce electricity when the engine is in operation.

[33] Referring now to FIG. 3 illustrated therein is a pair of sliding vanes 5 with four support rails 6 attached to each vane. The support rails 6 attached to the upper sliding vane are horizontally offset from the support rails 6 attached to the lower sliding vane. This allows for these two sliding vanes to be positioned in slots that are positioned next to each other within the rotor.

[34] Referring now to FIG. 4 illustrated therein is a side view of the tip of a preferred sliding vane 5. Attached to the tip of the vane 5 is a rolling element 30. This rolling element 30 reduces friction as the vane moves along the inner surface of the housing 2. A floating seal 31 is housed within the tip of the vane. A spring 32 exerts a force on the floating seal 31 keeping it on contact with the inner wall of the housing 2. The floating seal 31 is designed to minimize gas leakage from one gas chamber to another.

[35] Referring now to FIG. 5 illustrated therein is a pressure-volume diagram of the thermodynamic cycle of the present engine 1. The pressure of the working gas is plotted on the vertical axis and the volume is plotted on the horizontal axis. Line a-b is a constant pressure heat addition line representing the working gas of the engine being heated and expanded by some process external to the engine. Line b-c is an adiabatic expansion line representing the working gas being expanded adiabatically in the expansion section of the engine. Line c-d is a constant volume heat rejection line representing the working gas being cooled at a roughly constant volume while liquid coolant is being injected into the working gas as the working gas begins to leave the expansion section and enter the compression section. Line d-a is an isothermal compression line representing the working gas being simultaneously compressed and cooled in the compression section of the engine.

[36] Referring now to FIG. 6 illustrated therein is alternate embodiment of the heat engine 1 operating according to a closed cycle. In this embodiment the working gas leaving the outlet port 12 of the engine 1 circulates through the upper passageway 21 of a high temperature heat exchanger 20 where it is heated. A high temperature fluid passes through the lower passageway 22 of the heat exchanger 20 to provide the thermal energy necessary to heat the working gas within the upper passageway 21. After the working gas leaves the high temperature heat exchanger 20 it reenters the engine 1 though the inlet port 8. The working gas is then cooled within the engine by the liquid coolant before it is expelled from the engine and the cycle is repeated.

[37] In this embodiment the working gas within the system can be at pressures significantly greater than atmospheric pressure. Increasing the operating pressures can significantly increase the power output for the engine of a given size and speed.

[38] This embodiment also has an additional heat exchanger or boiler 26 which is used to boil a small amount of the liquid coolant for use as working fluid within the engine. This boiler 26 is not necessary for this embodiment of the engine to operate, however it can be used to increase the power output from the engine if two separate heat sources at different temperatures are available to power the engine. For example, if waste heat from a diesel engine is to be used to power the engine, heat from both the relatively low temperature engine block and the relatively high temperature exhaust gas can be used to power the engine at the same time. In this arrangement a liquid such as water is used as the liquid coolant and a gas such as air is used as the primary working gas. Heat from the engine block is used by the boiler 26 to vaporize some of the water that is captured in the liquid coolant catch basin 13. The water vapor is then mixed with the air in the high temperature heat exchanger 20 where it is superheated. The working gas then consists of a mixture of hot air and water vapor before it exits the high temperature heat exchanger 20 and enters the expansion section of the engine 1. In the compression section the working gas is cooled and the water vapor that was produced by the boiler 26 condenses back into liquid water, which is again collected in the catch basin 13.

[39] Many alternative embodiments of the present invention also exist. For example a constant volume section could be added to the engine in between the expansion section and the compression sections wherein the volume of the gas chambers moving through that section does not change for a more significant period of time.

[40] Additionally the expansion section of the engine could be eliminated entirely simply by making the inlet port larger. This embodiment could be useful if the heat source powering the engine was at a very low temperature.

[41] In other embodiments the pump for pumping liquid coolant into the engine could be eliminated. This is possible because the pressure difference between the working gas and liquid coolant leaving the engine is higher than the pressure of the working gas within the engine where the liquid coolant is injected. This pressure differential could be used to suck the liquid coolant up from the catch basin and into the engine. Alternatively, a smaller pump could be used only to pump the coolant into the lower part of the compression section where the pressure is higher.

[42] In another embodiment the heat exchanger for cooling the liquid coolant could be eliminated if the engine was near an abundant source of liquid coolant such as a river. In this embodiment water from the river could be sucked into the engine for use as its liquid coolant and the coolant leaving the engine could be returned into the river without cooling it first.

[43] In another embodiment a filter could be added to filter the coolant before it is injected into the engine.

[44] Having thus described exemplary embodiments of the present invention, it should be noted by those skilled in the art that the within disclosures are exemplary only, and that various other alternatives, adaptations, and modifications may be made within the scope of the present invention. Accordingly, the present invention is not limited to the specific embodiments illustrated herein, but is limited only by the following claims.

Claims

[1] A heat engine comprising:
a housing enclosing a cavity, the housing having an inner and an outer wall surface;
a rotatable rotor mounted within the cavity of the housing;
a plurality of slots contained within the rotor;
a plurality of sliding vanes mounted within the slots that can slide outwards towards the inner surface of the housing;
a plurality of variable volume gas chambers defined by the regions between the rotor, the housing and the sliding vanes;
an inlet port wherein a high temperature working gas enters the variable volume gas chambers moving past the inlet port;
an expansion section downstream from the inlet port relative to the flow of the working gas wherein the sliding vanes moving through the expansion section slide outwards away from the rotor increasing the volume and decreasing the pressure of the gas within the section;
a compression section downstream from the expansion section relative to the flow of the working gas wherein the vanes moving through the compression section slide inwards toward the rotor decreasing the volume and increasing the pressure of the gas within the section;
a means for injecting a liquid coolant into the working gas moving through the compression section of the heat engine;
an outlet port downstream from the compression section relative to the flow of the working gas wherein the working gas and the liquid coolant injected into the working gas are expelled from the heat engine;
a means for transferring power from the spinning rotor to an apparatus.

[2] A heat engine according to claim 1 operating according to a closed cycle wherein the working gas leaving the outlet port of the heat engine is reheated and then re-circulated back into the heat engine through the inlet port.

[3] A heat engine according to claim 1 having a plurality of support rails attached to the inner ends of the sliding vanes wherein the support rails are horizontally offset through a distance parallel to the rotor's axis of rotation from the support rails on the adjacent sliding vanes.

[4] A heat engine according to claim 1 having a catch basin for the collection of the liquid coolant being expelled from the heat engine positioned beneath the outlet port of the heat engine.

[5] A heat engine according to claim 1 having a means to cool the liquid coolant

before it is injected into the heat engine.

[6] A heat engine according to claim 2 having a pump means to pump liquid coolant into the heat engine.

[7] A heat engine according to claim one having a boiler wherein a liquid is converted into a vapor and then mixed with additional working gas for use as working fluid within the heat engine.

[8] A heat engine according to claim 1 having holes in the walls of the housing wherein liquid coolant is injected into the latter part of the expansion section of the heat engine.

[9] A heat engine according to claim 1 wherein a lubricant is injected into the heat engine along with the liquid coolant.

[10] A heat engine according to claim 1 wherein a chemical capable of absorbing pollutants contained within the working gas are injected into the heat engine along with the liquid coolant.

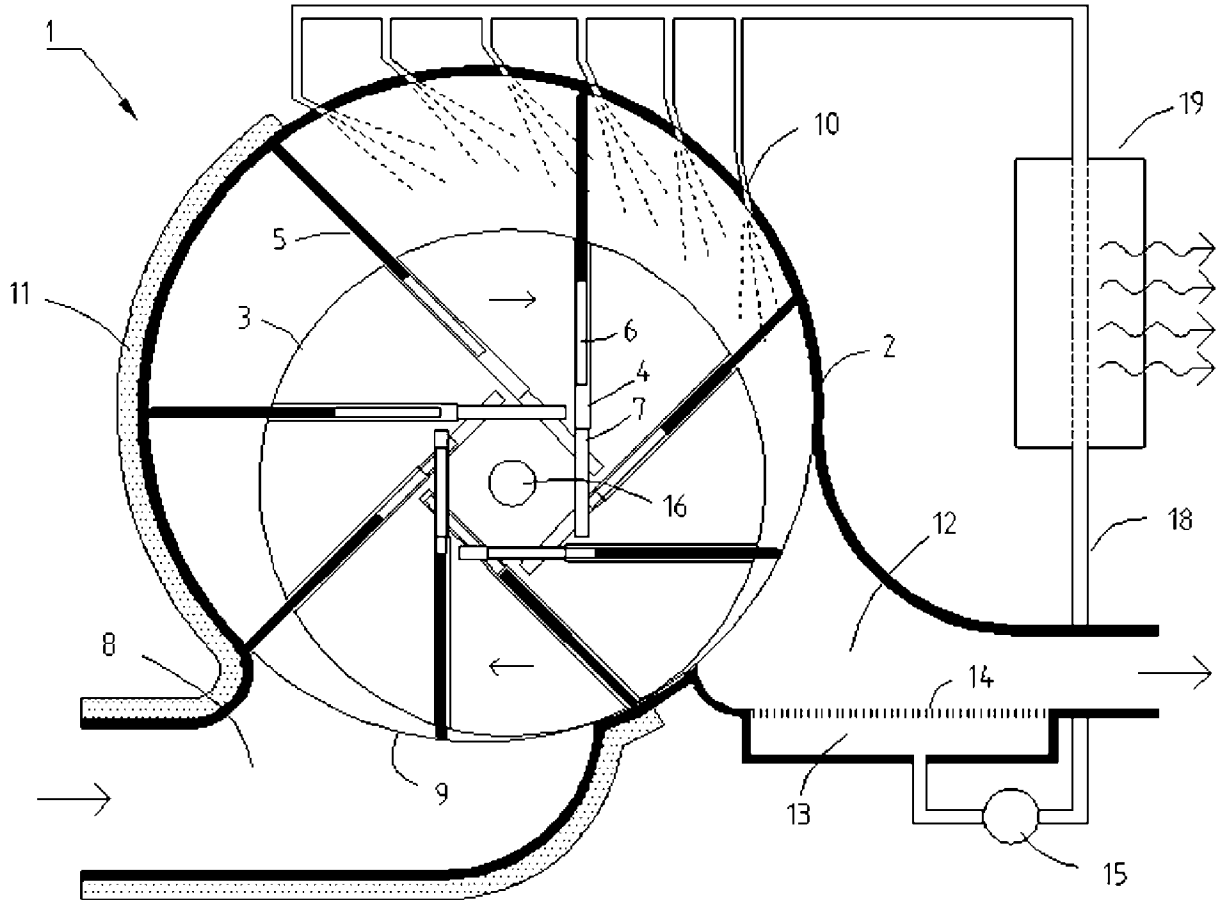
[11] A heat engine according to claim 1 wherein contains corrosion inhibitors are injected into the heat engine along with the liquid coolant.

[12] A heat engine according to claim 1 having a section in between the expansion section and the compression section wherein the variable volume gas chambers moving through it maintain a generally constant volume.

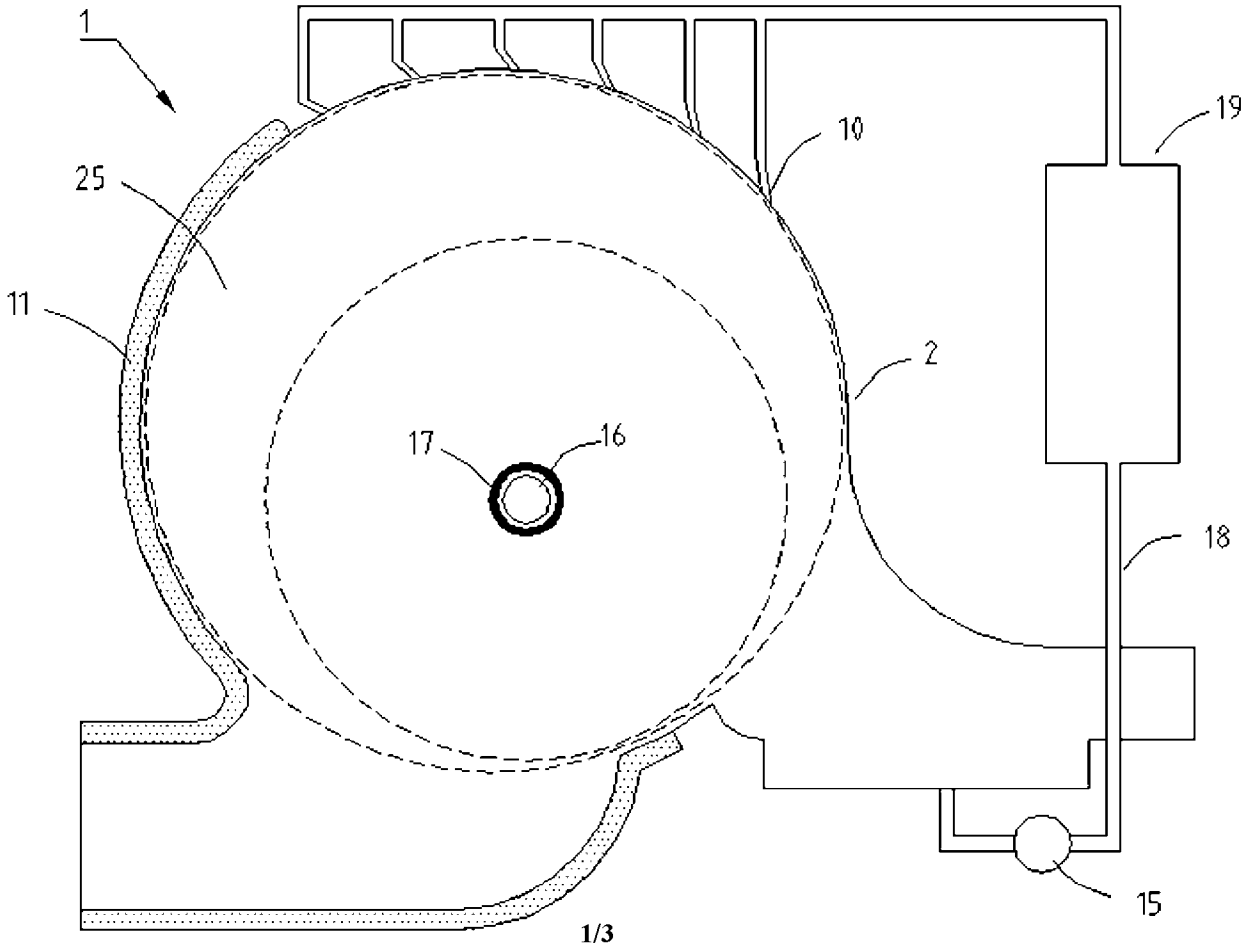
[13] A heat engine according to claim 1 having a plurality of roller means at the tips of the sliding vanes in contact with the inner wall of the housing.

[14] A heat engine according to claim 1 having a plurality of floating seals at the tips of the sliding vanes making contact with the inner wall of said housing.

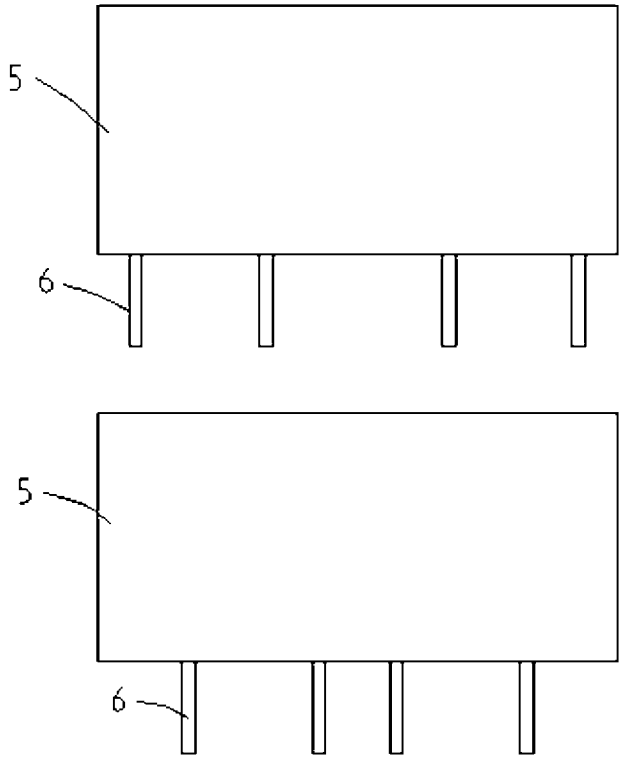
[Fig. 1]



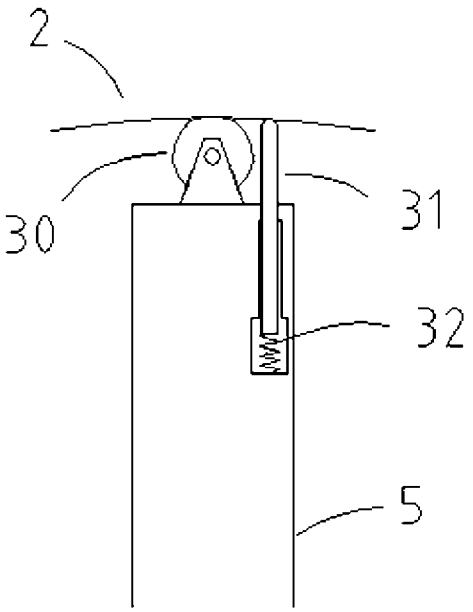
[Fig. 2]



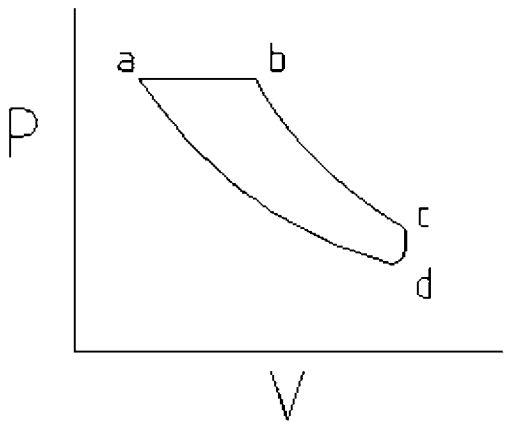
[Fig. 3]



[Fig. 4]



[Fig. 5]



[Fig. 6]

