Jan. 22, 1963 S. F. MALAKER ETAL 3,074,244

MINIATURE CRYOGENIC ENGINE

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Fig. 1

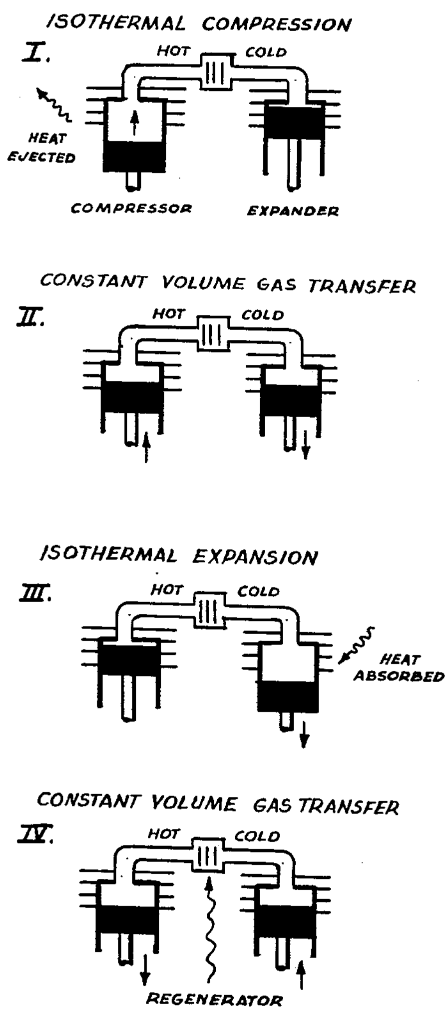

Fig. 2

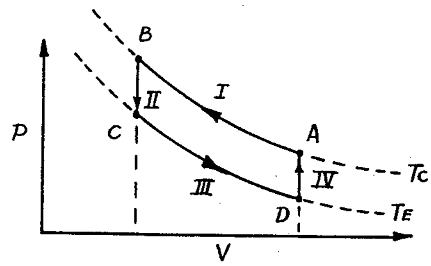

Fig. 3

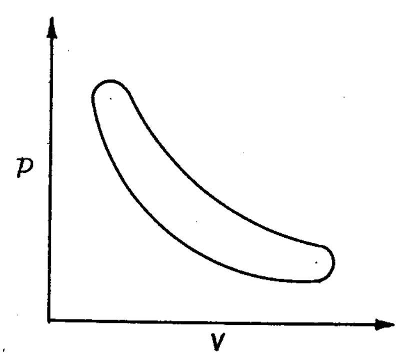

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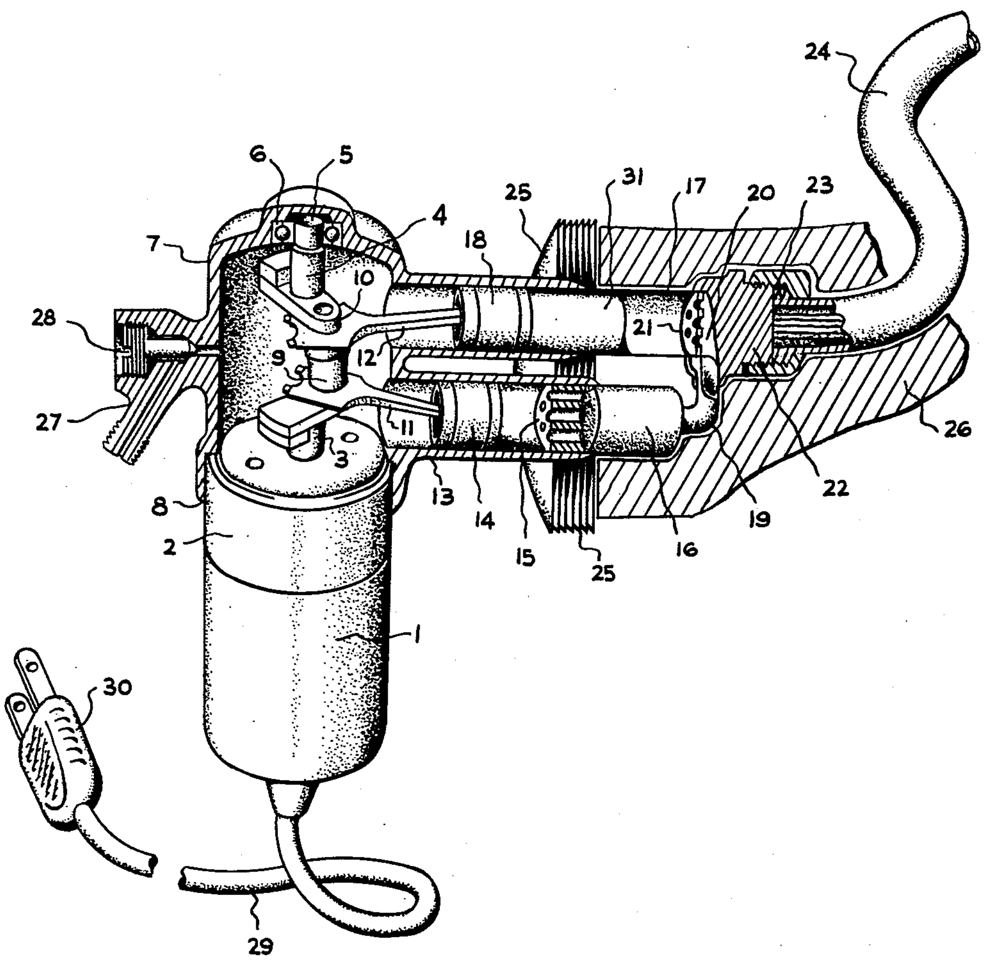
Fig. 4



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MINIATURE CRYOGENIC ENGINE

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This invention deals with a miniature engine for providing cooling to a temperature of 100° K., or even lower. More specifically, it relates to a two-cylinder small size, motor-driven engine for providing refrigeration in electronic and similar applications.

There is a need, particularly in the fields of electronics and air space technology, for a refrigerating machine of very small size which will provide temperatures in the neighborhood of 100° K., or even lower. At the present time, at least five general systems can be considered for supplying miniaturized units for such deep refrigeration applications (J. G. Daunt, "Handbuch der Physik," vol. 14, 1957). A detailed study of each of these has led to the conclusion that cascaded evaporation systems, for example, are unsuitable because they greatly increase the complexity of the equipment. Likewise, the Linde system, which is based on the Joule-Thomson effect, precludes adequate miniaturization due to the high gas inlet pressures required. Moreover, systems involving isentropic expansion, such as the Claude system, do not have a long period of reliability due to the low temperature needed for the operation of the inlet and exhaust valves in the expansion engines. Also, the Taconis system, using a displacement expander, is considerably handicapped in that it requires a source of pressurized gas, or an external compressor, if the system is to be operated as a closed cycle.

Research on this subject has led to the further conclusion that the Stirling cycle (described by A. G. Kirk in Min. Proc. Inst. Civ. Eng. 37, 244, 1873–4) offers the greatest promise for miniaturized low temperature production, provided a suitable engine employing such a cycle, could be developed. The engine of the present invention operates on a modified Stirling cycle.

In the accompanying drawings, supplied herein to clarify further the present invention, FIGURE 1 illustrates the four principal stages involved in the operation of the modified Stirling cycle, while FIGURE 2 presents a theoretical indicator diagram thereof. The actual indicator diagram obtained more nearly resembles that depicted in FIGURE 3. A side view, partly cut away and in cross-section, of a preferred embodiment of an engine of the present invention, is illustrated in FIGURE 4.

This modified Stirling cycle, as illustrated by the schematic step-by-step outline depicted in FIGURE 1, has an indicator diagram such as that shown in FIGURES 2 and 3. The ideal cycle involves the following steps (In the subsequent discussions, symbol "V" stands for volume, "P" for pressure, and "T" for temperature. Subscript "C" stands for compression space and "E" for expansion space):

(1) Isothermal compression of the gas in V_C while V_E is zero. The heat of compression is emitted at the head of the compressor at temperature T_C and, ideally, the process can be considered isothermal. On the indicator diagram of FIGURE 2, this step follows the isothermal curve at temperature T_C from point A to B.

(2) Constant volume gas transfer from V_C to V_E. In this step, illustrated by the path B to C along the isochoric path on the indicator diagram, there is no work done by simultaneous and equal increase in V_E and decrease in V_C. During this process, the gas, in passing through a regenerator, gives up heat so as to emerge into V_E at temperature T_E.

(3) Isothermal expansion of the gas in V_E, with V_C as zero. The refrigeration produced by the expansion results in heat being absorbed at the expander at temperature T_E so that, ideally, the process can be considered isothermal. On the indicator diagram, this step follows the isothermal curve at temperature T_E from point C to D.

(4) Constant volume gas transfer from V_E to V_C. In this step, illustrated in the diagram by the isochoric path D to A, no work is done, and this is achieved by simultaneous and equal decrease in V_E and increase in V_C. During this process, the gas, in passing through the regenerator, picks up the heat stored there during Step 2 and emerges in V_C at temperature T_C. Ideally, this cycle, being one between two operational temperatures, is as efficient as a Carnot cycle.

By using this Stirling cycle in suitably modified form, there has been developed a closed-cycle refrigeration engine of extremely small size, weighing only a few pounds, and one which is self-contained, requiring only a suitable electrical supply. No external gas supply or compressor is needed. This engine employs no valves, expansion nozzles, or constrictions, so that blocking and other operational problems are avoided. As a single unit, it is capable of maintaining temperatures down to −180° C.

In recent months, an engine employing the Stirling cycle has been described by the Philips Laboratories (Space/Aeronautics, January 1961, page 63). However, such unit described therein has an in-line rhombic piston drive design which entails considerable maintenance problems and which exhibits efficiency losses due to unavoidable stage heat transfer.

The engine of the present invention employs a hollow crankshaft housing from the side of which project, at right angles thereto, two parallel air-cooled cylinders, disposed one above the other. The motor-driven crankshaft has two cranks to which are attached piston rods terminating with pistons, moving approximately harmonically with a phase difference of about 90°. At the end of the compressor cylinder, there is provided a regenerator for absorbing the compression heat from the compressed gas, as the latter passes therethrough, via a tube, on its way into the cylinder space of the expander piston. The phase angle is such that the expansion volume leads with respect to the compressor volume.

As shown in FIGURE 4, the engine of the present invention includes an electric motor **1**, the shaft of which is connected to a reduction gear box **2**. The reduced speed shaft **3** from this box is connected to one end of crankshaft **4**, the other end **5** being mounted in a bearing **6** set in cylindrical airtight housing **7**, the bottom **8** of which is fixed to gear box **2**. Cranks **9** and **10** on shaft **4** are disposed so that piston rods **11** and **12** (riding on bearings on cranks **9** and **10**, respectively) reciprocate approximately harmonically at a phase angle of about 90°.

Projecting at right angles from the side wall of housing **7** is compressor cylinder **13**, in which rides compressor piston **14** attached to the end of piston rod **11**. The gas compressed by piston **14** passes through perforated head **15** and regenerator **16** disposed on the end of cylinder **13**. Regenerator **16** is filled with a metallic network such as a metal wool of high heat capacity serving to absorb compression heat from the gas leaving compression cylinder **13**.

Also projecting at right angles from the side wall of housing **7**, and disposed immediately above and parallel to cylinder **13**, is expander cylinder **17** in which reciprocates expander piston **18** attached to the end of connecting rod **12**. Gas leaving regenerator **16** passes through tube **19** which leads to end **20** of expander cylinder **17**. The gas then passes through perforated head **21** on its way into the cylinder **17**. The end of cylinder **17** comprises a mass **22** of highly heat-conducting metal to which is attached, by threaded cap **23**, a flexible metal conductor **24** which is led to the item or apparatus to be cooled. Both cylinders **13** and **17** are provided with cooling fins **25**, and the cold end **22** of cylinder **17** and the cooled cable **24**, as well as regenerator **16**, are insulated by means of insulation **26**.

Housing **7** is provided with filling nipple **27** for introducing the working gas into the system. Needle valve **28** serves as a shut-off for nipple **27**. Cord **29** and plug **30** connect motor **1** to a source of electrical power (not shown).

When in operation, the system is filled with working gas, such as hydrogen or helium at a pressure up to about 30 atmospheres, through nipple **27** and valve **28**. Then, plug **30** is connected to a suitable source of power for rotation of motor **1** which, through reduction gears in box **2**, rotates crankshaft **3**. This, in turn, reciprocates pistons **14** and **18** in cylinders **13** and **17**, respctively. Both cylinders are of approximately equal volume and the main body of each piston is at crankcase temperature. Each piston incorporates piston rings and oil-sealing rings. The outermost portion **31** of expansion **18** is a thermally-insulated extension having a slight clearance between it and cylinder wall **17**.

As compression piston **14** begins to move outwardly to compress the gas in cylinder **13**, expander piston **18** is stationary at the outermost part of its stroke (Step I in FIG. 1, and path A to B on the diagram in FIG. 2). Then, as compressor piston **14** continues to move outwardly, expander piston **18** begins to move inwardly, so that compressed gas from cylinder **13** passes through the multiple gas passages in perforated head **15**, whereby maximum heat transfer is obtained with minimum pressure drop and minimum dead volume. The heated gas, in passing through regenerator **16**, gives up its heat to the metal wool and then passes through tube **19** past cool end **20** and perforated head **21** and into cylinder **17** wherein expander piston **18** already is on its inward stroke. Thus, the gas is transferred at approximately constant volume between the two cylinders (Step II in FIG. 1, and path B to C in FIG. 2).

As compressor piston **14** remains stationary at the end of its stroke, expander piston **18** begins to move inwardly, whereby heat is taken in by the expander and end **20** is cooled (Step III in FIG. 1 and path C to D in FIG. 2). Thereafter, as compressor piston **14** moves inwardly, expander piston **18** moves outwardly, and gas from cylinder **17** passes through tube **19** and regenerator **16** where it picks up heat as it enters cylinder head **21** and cylinder **17**. Expander piston **18** already is on its inward stroke and the gas is transferred between cylinders at approximately constant volume (Step IV in FIG. 1, and path D to A in FIG.2).

As this cycle is repeated, head **20** and conductor **24** become cooled. The latter may be placed in the immediate vicinity of the equipment to be refrigerated. The motor **1** may be of variable speed to allow adjustment of the refrigeration temperature.

With compression and expansion cylinder of equal volumes and a bore of ½″ and ½″ stroke, the maximum shaft power required by the engine would be about 75 watts. Such a refrigerator, using the design of the present invention, would operate at a cooling head temperature of between 30° C. and −180° C. At −180° C., the refrigerative capacity of the engine would be 1 watt. With this design, the effective dead volume would be less than 0.25 times the effective volume of the hotter cylinder, while the regenerator efficiency would be 93%, or even greater, provided the expander cylinder head, gas ports and passages, regenerator, and the upper

part of the expander cylinder are adequately insulated.

The housing and cylinders may be made of thin stainless steel, while the cool end **20** and flexible cable **24** may be of copper. The packing in regenerator **16** is of lead-plated copper wool. The use of light alloys such as aluminum magnesium and/or beryllium, or alloys thereof, however, is not precluded.

The engine of the present invention possesses many valuable advantages over other disclosed in the art, including relatively higher efficiency, more reliable and simpler construction, freedom from contamination by dirt, dust or chemical impurities, and adaptability for cascade operation. The whole system is self-contained, requiring no gas supply. There are no constrictive passages thereby avoiding blocking problems, and the engine can very readily be made in a variety of sizes, based on a single design.

We claim:

1. A miniature cryogenic engine of the character described and designed to operate according to a modified Stirling cycle wherein a motor and its shaft drive a compressor piston and an expander piston operating on a working gas, comprising a housing having a wall attached in gas-sealing relation to a motor, a crankshaft having one end mounted within and at the end of said housing and the other end affixed to the motor shaft, two adjacently-disposed cranks arranged on said crankshaft in about a 90° phase relationship, connecting rods connecting said cranks, a compressor piston connected to one of said rods, an expander piston connected to the other of said rods, a finned compression cylinder projecting at a right angle from said housing wall and designed to accommodate said compression piston, conduction means for conducting compression heat from said compressor cylinder to its cylinder wall, a finned expander cylinder also projecting from said housing wall in vertically parallel relation to said compression cylinder and designed to accommodate said expander piston, conduction means for thermal transfer of low temperature from said expander cylinder to its cylinder wall, a regenerator attached to the head of said compression cylinder and designed to permit flow of compressed gas therethrough and to absorb heat therefrom, a conduit connecting the regenerator with the head of the expander cylinder and designed to permit gas flow into said expander cylinder, flexible cold-conducting means for conducting low temperature from the head of the expander cylinder to any desired location to be cooled, and insulation means insulating said regenerator, conduit, expander cylinder end and flexible cold conducting means.

2. A miniature cryogenic engine according to claim 1 in which the conduction means for conducting compression heat from the compression cylinder comprises a foramenous plate through which the compressed gas is passed.

3. A miniature cryogenic engine according to claim 1 in which the conduction means for thermal transfer of low temperature from said expander cylinder comprises a foramenous plate, and means forming a space between said latter plate and said cold conducting means serving as a discharge space for said conduit.

4. A miniature cryogenic engine of the character described and designed to operate according to a modified Stirling cycle wherein a driving means and its shaft drive a compressor piston and an expander piston operating on a working gas, comprising a gas-sealed housing having a wall, a crankshaft having one end mounted within and at the end of said housing and the other end affixed to the driving means shaft, two adjacently-disposed cranks arranged on said crankshaft in about a 90° phase relationship, connecting rods connecting said crank, a compression piston connected to one of said rods, an expander piston connected to the other of said rods, a cooled compression cylinder projecting at a right angle from said housing wall and designed to accommodate said compression piston, conduction means for conducting

compression heat from said compression cylinder to its cylinder wall, a cooled expander cylinder also projecting from said housing wall in vertically parallel relation to said compression cylinder and designed to accommodate said expander piston, conduction means for thermal transfer of low temperature from said expander cylinder to its cylinder wall, a regenerator attached to the head of said compression cylinder and designed to permit flow of compressed gas therethrough and to absorb heat therefrom, a conduit connecting the regenerator with the head of the expander cylinder and designed to permit gas flow into said expander cylinder, conduction means attachable to the head of said expander cylinder for conducting cold away therefrom, and insulation means insulating said regenerator, conduit, expander cylinder and attachable conducting means.

5. A miniature cryogenic engine of the character described and designed to operate according to a modified Stirling cycle wherein a driving means and its shaft drive a compressor piston and an expander piston operating on a working gas and designed to cool an object by transfer thereto of cold from its cylinder head, comprising a gas-sealed housing having a wall, a crankshaft having one end mounted within and at the end of said housing and the other end affixed to the driving means shaft, two

adjacently-disposed cranks arranged on said crankshaft in about a 90° phase relationship, connecting rods connecting said cranks, a compressor piston connected to one of said rods, an expander piston connected to the other of said rods, a cooled compression cylinder projecting at a right angle from said housing wall and designed to accommodate said compression piston, conduction means for conducting compression heat from said compression cylinder to its cylinder wall, a cooled expander cylinder also projecting from said housing wall in vertically parallel relation to said compression cylinder and designed to accommodate said expander piston, conduction means for thermal transfer of low temperature from said expander cylinder to its cylinder wall, a regenerator attached to the head of said compression cylinder and designed to permit flow of compressed gas therethrough and to absorb heat therefrom, a conduit connecting the regenerator with the head of the expander cylinder and designed to permit gas flow into said expander cylinder, and insulation means insulating said regenerator, conduit, and expander cylinder.

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