March 17, 1964 H. JÄNICKE 3,125,282

FREE-PISTON COMPRESSOR

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Fig. 1

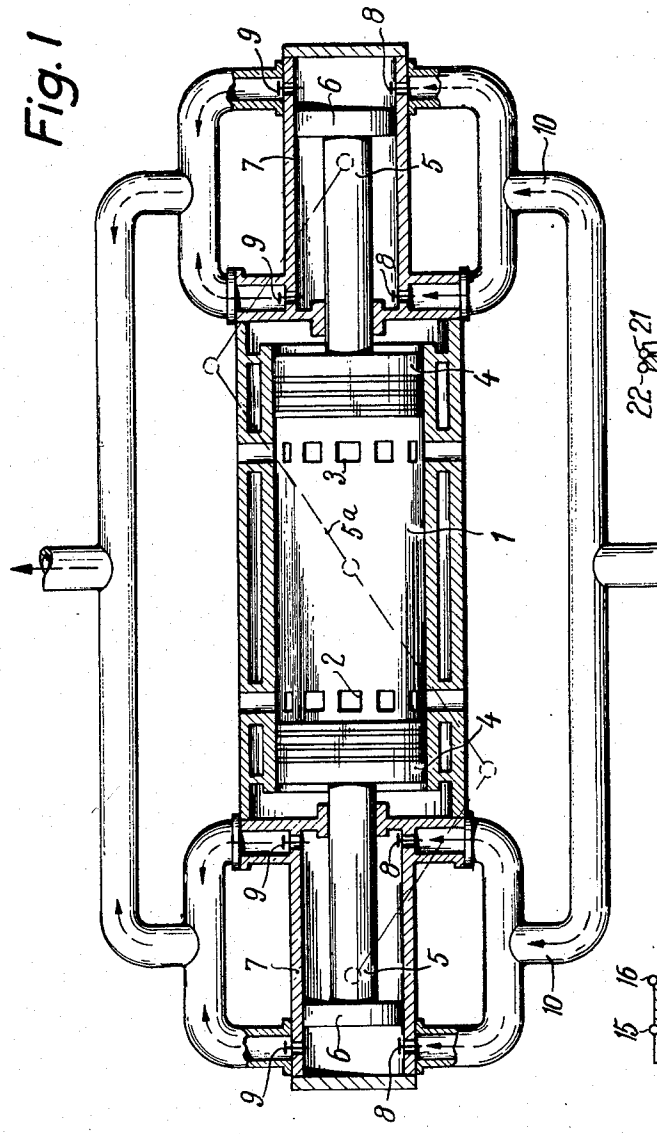


Fig. 3

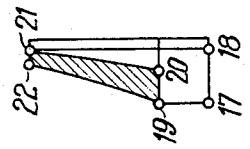
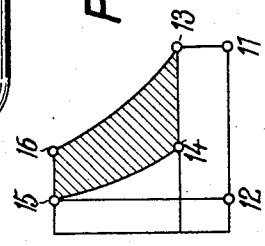


Fig. 2



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Fig. 4

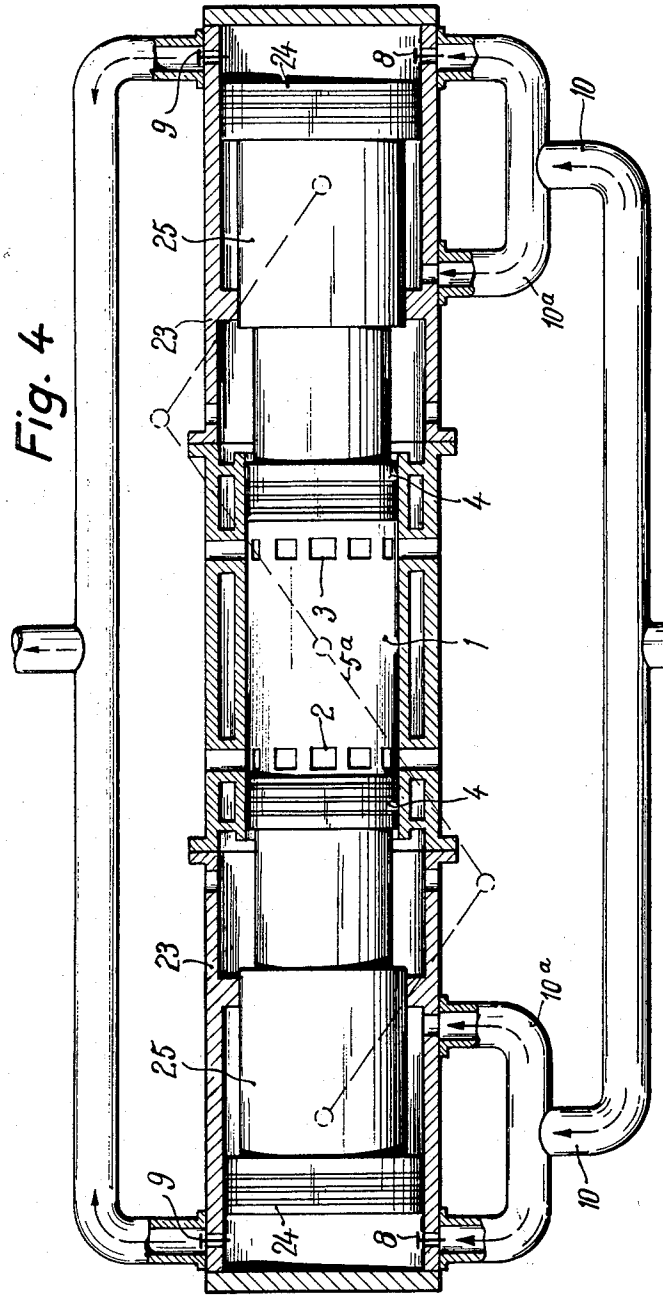


Fig. 6

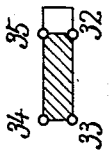
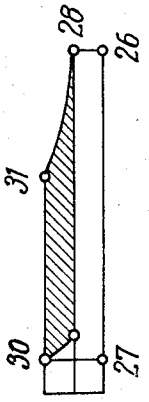


Fig. 5



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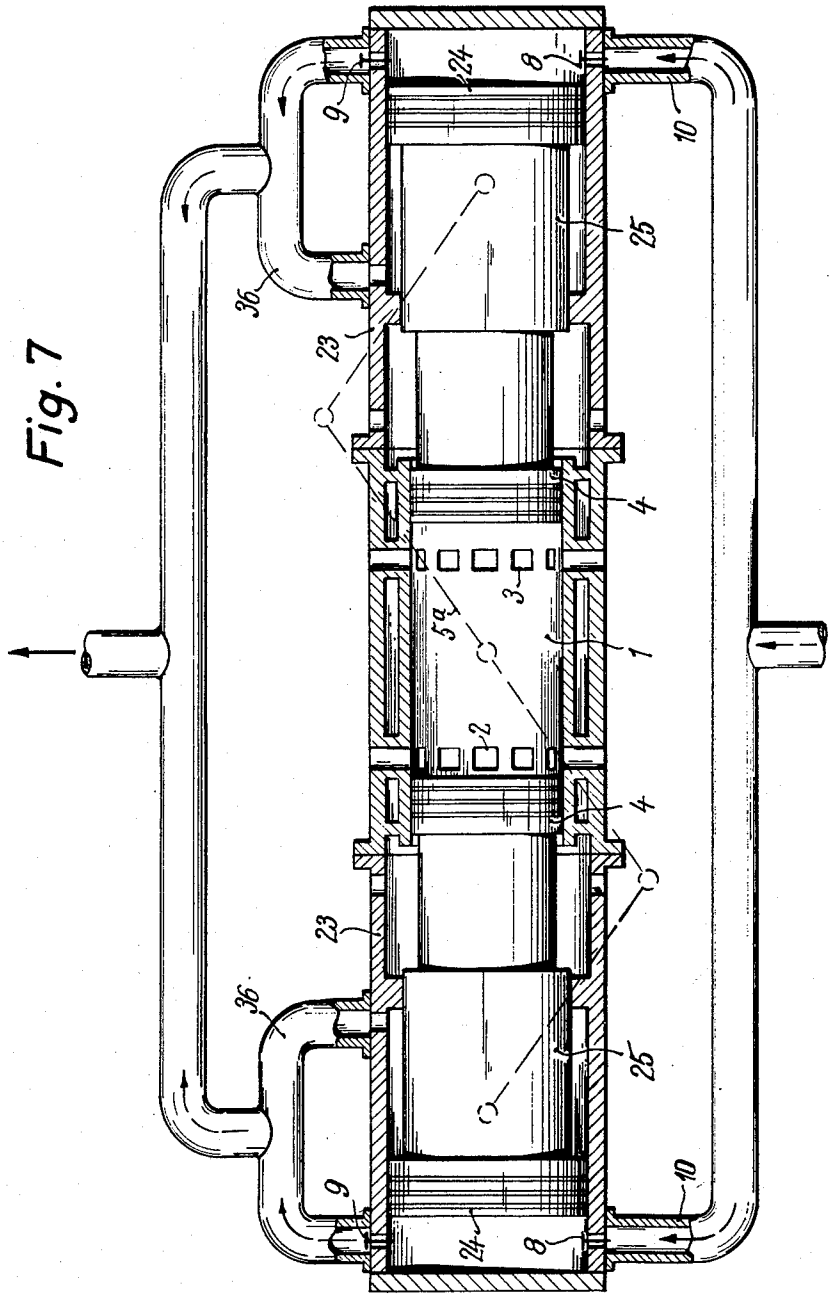
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Fig. 7



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3,125,282

FREE-PISTON COMPRESSOR

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In a free piston compressor, the energy required to compress the mixture in the engine cylinder is derived either from separate return cylinders, i.e., so-called buffer cylinders, or from the compressor cylinder itself. The amount of energy derived from the compressor cylinder during the inward stroke of the pistons is the sum of the work done by expansion in the dead space and the work done by the gas being drawn in. In this connection, the capacity of the compressor cylinder is not primarily determined by the work to be performed in compressing the mixture in the engine cylinder, but by the gas volume to be drawn in and to be compressed. The capacity of the cylinder will be the larger, the smaller the amount of external work to be done, the cylinder capacity thus depending on the volume of gas drawn in, the pressure at which the gas is drawn in, and the desired compression ratio. In the case of a compressor that is supplied with precompressed gas rather than with atmospheric air it may happen, even with the cylinder capacity being kept as small as possible, that the sum of the work done by expansion in the dead space and of the work performed by the thrust of the gas being drawn in considerably exceeds the amount of work required to effect compression in the engine, it thus being impossible to keep the degree of compression in the engine within the permissible limits.

Conditions may also require to supply the free piston compressor with a gas to be compressed which is supplied under variable pressure, or the free piston compressor may be required to compress the gas against a variable back pressure.

All of the aforementioned pressure variations produce changes in the amount of energy derived from the compressor cylinder to effect compression in the engine, thus, in most cases, resulting in an undesirable increase or decrease in the compression pressure produced in the engine.

It has been known in the case of non-symmetrical machines to provide special piston areas loaded by predetermined pressures to equalize the forces and amounts of work between the two non-symmetrical sides of the machine. It is the purpose of these provisions to relieve the coupling means connecting the two sides of the machine of the differential forces and amounts of work. The application of the said provisions is restricted to the purpose indicated and is of importance only in the case of multi-stage non-symmetrical machines.

It is one object of the present invention to provide a free piston compressor which is adapted to keep within the permissible limits the amount of work made available to effect compression in the engine, even though, in operation, the admission pressure and/or the back pressure may be subject to variations.

To achieve this object, the invention provides a free piston engine and compressor whose compressor cylinders are supplied with a gas under superatmospheric pressure, in which the suitably dimensioned rear surfaces of the compressor pistons perform work during their inward stroke and absorb work during their outward stroke.

In a specific embodiment of the invention, there is provided, between the engine and compressor pistons, a piston rod of special design serving to provide on the rear side of the compressor piston a working area which acts

in opposition to the front side of the compressor piston, and which is independent of the difference between the diameters of the engine piston and the compressor piston, the said working area, depending on requirements, either operating as a compressor with the same admission and discharge pressures or being constantly loaded by the admission or discharge pressure of the compressor so as to keep within the permissible limits the amount of work available to effect compression in the engine.

Thus, when the gas to be admitted into the compressor is under a pressure such that this pressure, in conjunction with the swept volume of the compressor cylinder, would produce an amount of work exceeding the requirements of compression in the engine, the suitably dimensioned active rear surface of the compressor piston will be used in the same manner as the front surface of the compressor piston in compressing and discharging the gas under pressure introduced into the compressor.

In cases in which it is to be expected that the pressure under which the gas is supplied to the compressor will be subject to considerable variations, it is proposed according to the invention constantly to load the effective rear surface of the compressor piston with the admission pressure of the gas to be compressed. This serves to compensate for the fact that the amount of work performed by the front side of the compressor piston during the inward stroke thereof is increased as the admission pressure rises and is reduced as the admission pressure is lowered.

In such other cases in which it is desired to compress and discharge the gas at differing pressure levels, provisions are made according to the invention constantly to load the suitably dimensioned rear surface of the compressor piston with the respective discharge pressure.

There may also be cases in which it is necessary to operate the free piston compressor under conditions of varying admission pressure and varying discharge or back pressure. Whether these conditions result in the amount of work performed by the front side of the compressor piston during its inward stroke being increased or reduced or maintained constant, the energy available for effecting compression in the engine can then be kept within the desired limits by causing the suitably dimensioned rear surface of the compressor piston to operate in the same manner as the front side thereof. Since under these conditions the amounts of work produced will vary in the same sense, any increase or decrease in the amount of work performed by the front side of the compressor piston will be accompanied by a similar increase or decrease in the amount of work performed by the rear side of the piston, so that the difference which is available to effect compression in the engine can be maintained approximately constant.

It is also possible, by suitably dimensioning the effective area of the rear side of the compressor piston, to provide for a compensation for the substantial reduction in the amount of work performed during the inward stroke which is known to occur upon the length of compressor stroke being reduced, in such a manner that the degree of compression in the engine will remain almost constant, in cases in which the pressure ratios are lower than

$$n^{\frac{n}{n-1}}$$

where n is the polytropic exponent.

Where the effective rear area of the compressor piston operates as a compressor in the same manner as the front surface, the use of a specific ratio between the gas volumes respectively drawn in on the front surface and the effective rear surface may additionally contribute to the amount of work available to effect compression in the engine being maintained constant.

Other objects and features of the invention will become apparent as the description proceeds, especially when taken in conjunction with the accompanying drawing, illustrating several preferred embodiments of the invention, wherein:

FIG. 1 is a longitudinal sectional view of a single-stage free piston compressor according to the invention, having double-acting compressor pistons and designed for a high admission pressure and a high compression ratio;

FIGS. 2 and 3 are diagrams showing the work respectively performed by the two ends of the compressor pistons;

FIG. 4 is a longitudinal sectional view of a single-stage free piston compressor according to the invention, having single-acting compressor pistons and designed for a low variable admission pressure and a low compression ratio;

FIGS. 5 and 6 are diagrams showing the work respectively performed by the two ends of the compressor pistons;

FIG. 7 illustrates a free piston compressor constructed in accordance with FIG. 4 and designed to produce a variable delivery pressure.

The embodiment shown in FIG. 1 is a single-stage machine designed for operation with a high admission pressure and a relatively high compression ratio. In view of these design features, the diameter of the compressor piston is smaller than that of the associated engine piston. Both ends of each compressor piston operate in a similar manner to compress the gas admitted thereto.

Arranged for operation within the engine cylinder **1** having scavenging ports **2** and exhaust ports **3** are the two engine pistons **4**, **4** which are connected to the compressor pistons **6**, **6** by means of piston rods **5**, **5** whose diameter differs from the diameter of the engine cylinders and the diameter of the compressor cylinders. The piston rod **5** leaves a predetermined effective area on the rear end of its associated compressor piston **6**. The compressor pistons operate in a double-acting manner in the compressor cylinders **7** which are provided with admission valves **8** and delivery valves **9**. The gas, which is under pressure, is supplied to the admission valves **8** through lines or conduits **10**.

The diagrams represented in FIGS. 2 and 3 indicate the manner in which the two ends of each compressor piston operate, the pressure being plotted against the volume, the two diagrams thus showing the ratio and the amounts of the work respectively performed by the two ends of the compressor pistons. The area enclosed by the lines **13—14—15—16—13** in FIG. 2 applies for the front side of the compressor piston, the area enclosed by the lines **19—20—21—22—19** in FIG. 3 applying for the rear side of the compressor piston. The diameter of the piston rod **5** is selected to give an effective area of the rear side of the compressor piston such that the work performed by the front end of the piston during the inward stroke, which work is represented by the lines **11—12—15—14—13—11**, covers not only the compression and thrust work represented by the lines **17—19—22—21—18—17** in FIG. 3 but also the compression in the engine and other losses resulting from friction and the like, so that the energy available to effect compression in the engine is limited to the necessary amount.

FIG. 4 illustrates another embodiment in the form of a single-stage compressor in which, in view of the low admission pressure and a relatively low compression ratio, the diameter of the compressor piston **24** operating in the cylinder **23** is larger than that of the engine piston. The effective rear area of the compressor piston is constantly loaded with the admission pressure prevailing in the branched off conduit **10***a*. In order to reduce the effective area of the rear end of the compressor piston to a sufficient extent, the diameter of the piston rod **25** is larger than that of the engine piston. The conventional coupling means serving to synchronize the operation of the two halves of the compressor has been diagrammatically indicated at **5***a*.

FIGS. 5 and 6 represent the digarams of the front end and the effective area of the rear end, respectively, of the compressor piston. In these diagrams, the pressure is again plotted against the cylinder volume. The lines **28—29—30—31—28** apply for the front side of the compressor piston, the lines **32—33—34—35—32** representing the energy absorbed by the rear side of the piston during its inward stroke and delivered during the outward stroke. Also in this case, the amount of work or energy is selected in such a manner that the energy represented in FIG. 5 by the lines **26—27—30—29—28—26** covers not only the amount of energy shown in FIG. 6 but also the energy required to effect compression in the engine cylinder and to cover any losses that may occur during operation.

In the embodiment shown in FIG. 7, which is intended to provide a variable delivery pressure, the effective area of the rear side of the compressor piston is constantly exposed, by means of the branched pipe **36**, to the pressure prevailing in the delivery line.

It will be understood that the invention, while having been described for single-stage compressors, is also applicable with multi-stage compressors.

What I claim is:

1. A free piston engine including an engine cylinder having disposed therein two oppositely reciprocating engine pistons defining between them an inner combustion chamber, a pair of piston rods and a pair of compressor pistons, each of which is rigidly connected by one of said piston rods to the outer side of one of said engine pistons, a pair of compressor cylinders aligned with said engine cylinder and slidably mounting said compressor pistons, the compressor pistons defining inner and outer compression chambers within the compressor cylinders arranged symmetrically with respect to said engine cylinder, the compression in said engine cylinder being effected by energy taken from the outer compression chambers of said compressor cylinders, supply conduits for supplying gas under super-atmospheric pressure to said compressor cylinders, the pressure of the gas in said supply conduits varying under operating conditions, delivery conduits for delivering the compressed gas from said compressor cylinders, and first branch conduits connecting said supply conduits to the inner compression chambers of each of the associated compressor cylinders, through which chambers the piston rods connected to the engine pistons extend, in order to continuously expose the inner sides of the associated compressor pistons to the supply pressure of the gas; second branch conduits connecting said supply conduits to the outer compression chambers of each of the associated compression cylinders; valve means in each of said second branch conduits for intermittently exposing the outer sides of the associated compressor pistons to the supply pressure of the gas.

2. A free piston engine including an engine cylinder having disposed therein two oppositely reciprocating engine pistons defining between them an inner combustion chamber, a pair of piston rods and a pair of compressor pistons, each of which is rigidly connected by one of said piston rods to the outer side of one of said engine pistons, a pair of compressor cylinders aligned with said engine cylinder and slidably mounting said compressor pistons, the compressor pistons defining inner and outer compression chambers within the compressor cylinders arranged symmetrically with respect to said engine cylinder, the compression in said engine cylinder being effected by energy taken from the outer compression chambers of said compressor cylinders, supply conduits for supplying gas under super-atmospheric pressure to said compressor cylinders, delivery conduits for delivering the compressed gas from said compressor cylinders, the pressure of the gas in said delivery conduits varying under operating conditions, and first branch conduits

connecting said delivery conduits to the inner compression chambers of the associated compressor cylinders, through which chambers the piston rods connected to the engine pistons extend, in order to continuously expose the inner sides of the associated compressor pistons to the delivery pressure of the gas; second branch conduits connecting said delivery conduits to the outer compression chambers of each of the associated compression cylinders; valve means in each of said second branch conduits for intermittently exposing the outer sides of the associated compressor pistons to the delivery pressure of the gas.

3. A free piston engine including an engine cylinder having disposed therein two oppositely reciprocating engine pistons defining between them an inner combustion chamber, a pair of piston rods and a pair of compressor pistons, each of which is rigidly connected by one of said piston rods to the outer side of one of said engine pistons, a pair of compressor cylinders aligned with said engine cylinder and slidably mounting said compressor pistons, the compressor pistons defining inner and outer compression chambers within the compressor cylinders, the compression in said engine cylinder being effected by energy taken from the outer compression chambers of said compressor cylinders and said inner and outer compression chambers having effective inner and outer areas, respectively, abutting said compressor pistons so dimensioned as to maintain the amount of work available to effect compression in said engine cylinder within permissible limits, supply conduits for supplying gas under super-atmospheric pressure to said compressor cylinders, delivery conduits for delivering the compressed

gas from said compressor cylinders, the pressure of the gas in said supply conduits varying under operating conditions, and at least one first branch conduit connecting at least one of said supply and delivery conduits to the inner compression chambers of the compressor cylinders, through which chambers the piston rods connected to the engine pistons extend, in order to continuously expose the inner sides of said compressor pistons to the gas pressure prevailing in the conduit communicating with said inner compression chambers by means of said branch conduit; at least one second branch conduit connecting at least one of said supply and delivery conduits to the outer compression chambers of each of the associated compression cylinders; valve means in said second branch conduit for intermittently exposing the outer sides of the associated compressor pistons to the supply and delivery pressure of the gas.

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