July 7, 1936. H. JANICKE 2,046,631

MULTISTAGE FREE PISTON MOTOR COMPRESSOR

Filed May 15, 1934 2 Sheets-Sheet 1

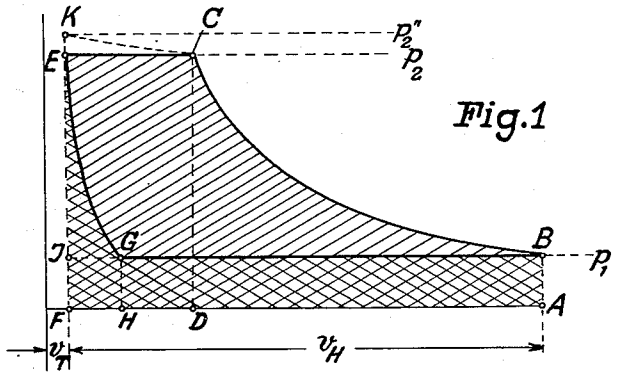


Fig.1

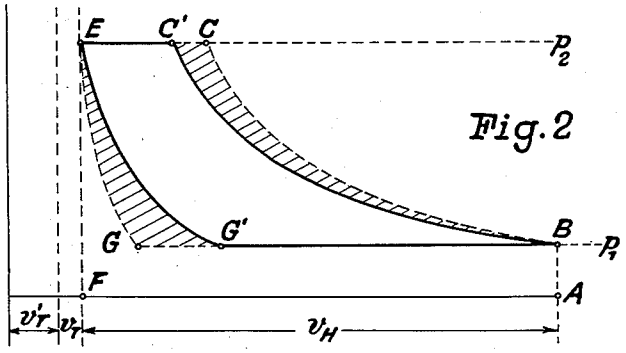


Fig.2

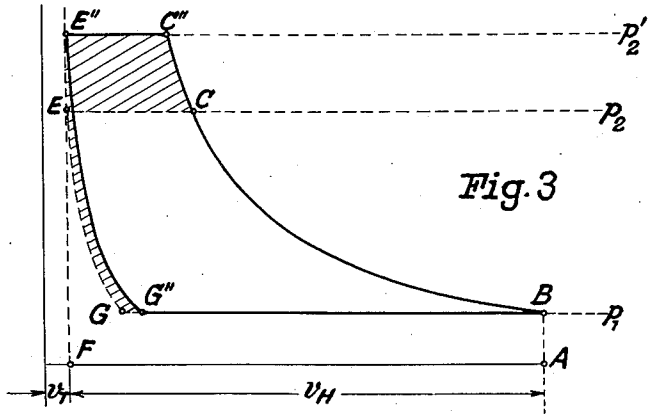


Fig.3

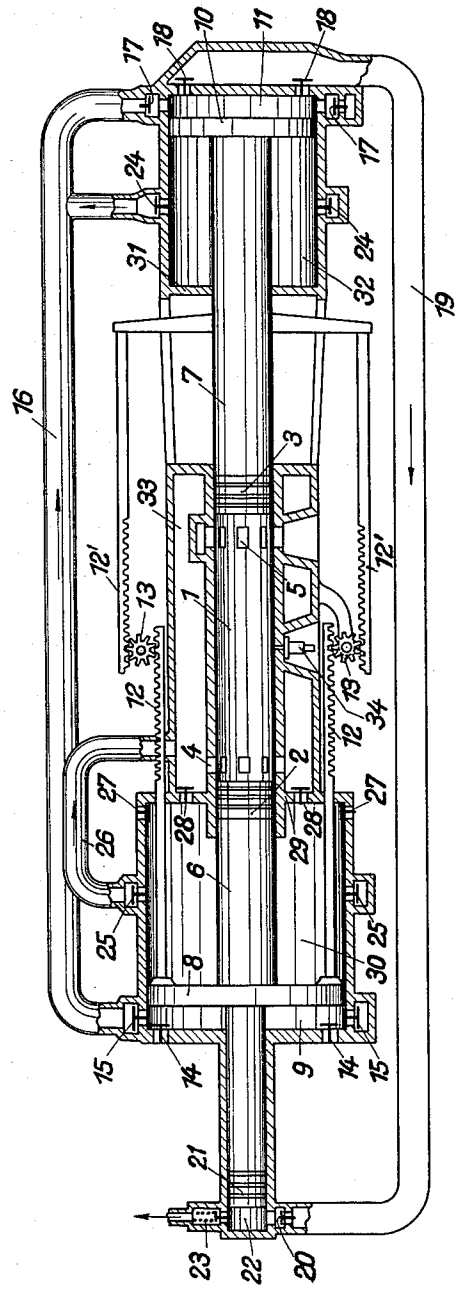
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Filed May 15, 1934 2 Sheets-Sheet 2

Fig. 4



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Patented July 7, 1936 2,046,631

UNITED STATES PATENT OFFICE

2,046,631

MULTISTAGE FREE PISTON MOTOR COMPRESSOR

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Application May 15, 1934, Serial No. 725,749
In Germany May 20, 1933

11 Claims. (Cl. 230—56)

My invention relates to free piston motor-compressors and more particularly to apparatus comprising two pistons arranged in a cylinder for simultaneous reciprocation in opposite directions, in which the freely moving bodies, for instance the pistons, are coupled with each other by means of a coupling gear in order to secure an exact synchronous reciprocation of the pistons.

In apparatus of this type, in order to reduce the dimensions of the coupling gear care must be taken to avoid a transfer of mechanical energy by means of the coupling gear from one side of the apparatus to the other. To this end in free piston multi-stage compressors the two halves have been designed symmetrically to each other, for instance by providing on each side a three-stage compressor, so that the apparatus comprises six stages. Such a device, however, has a very large overall length and is composed of a large number of parts. Even the scavenging pump must be made in two parts, one on each side, in order to avoid a unilateral load on the engine. If on the other hand the structure is designed unsymmetrically, for instance by arranging the scavenging pump at one side, or by providing different numbers of compressor stages on the two sides, the coupling gear will transfer mechanical energy from one side to the other during the working stroke and the return stroke, so that the members of the gear must be made relatively strong and heavy. Hereby the weight of the reciprocating masses is increased, the building cost is high and owing to the increased friction losses occurring in the coupling gear the efficiency is reduced.

It is an object of my invention to provide an unsymmetrical multistage free piston motor-compressor of the kind referred to, in which the coupling gear is substantially relieved from transferring mechanical energy from one side of the structure to the other. A device according to my invention involves the advantage that the overall length is considerably smaller than in symmetrically designed devices, while the coupling gear may consist of light members. In order to accomplish this I choose the pressure ratios or the volume ratios or both in the single compressor chambers in a suitable manner. In the multistage free piston motor-compressors hitherto known the ratios were so chosen that the amount of energy fed to the compressor chambers during the working stroke or fed back to the free pistons during the return stroke is uniformly distributed over the single stages. In contradistinction thereto in a structure according to my invention these energies are distributed over the stages in a non-uniform manner, the sum of the energies, however, on one side being equal to the sum of the energies on the other side during the working stroke as well as during the return stroke.

Other objects of my invention will appear from the following description.

In the drawings affixed to this specification and forming part thereof some diagrams illustrating the operation of a motor-compressor according to my invention and an embodiment of such apparatus are shown diagrammatically by way of example.

In the drawings:

Figs. 1 to 3 are pressure-volume diagrams in which the abscissae designate the volume v and the ordinates the pressure p of the gas in a compressor stage.

Fig. 4 is an axial section of an apparatus according to my invention.

Referring first to Fig. 1, in which the curve B—C—E—G illustrates an operating cycle of a compressor stage, the point B corresponds to the inner dead centre position of the piston of the stage. During the initial portion of the working stroke, indicated by the curve B—C, the gas is compressed from the pressure p_1 to the pressure p_2. During the last portion of the working stroke, indicated by the horizontal straight line C—E, the compressed gas is discharged. The energy fed to the compressor stage during the working stroke may be calculated from the area of the surface A—B—C—E—F—A. At the end of the working stroke a gas body remains in the dead space v_T at the pressure p_2, in which is stored a portion of the energy fed to the stage during the working stroke, this energy being re-fed to the piston of the stage during the return stroke in order to return the piston to its inner dead centre position and to compress the charge of fuel in the motor cylinder of the engine. The return stroke is indicated in the diagram by the curve E—G—B. During the initial portion E—G of the return stroke the gas body is expanded from the pressure p_2 to the pressure p_1. During the second portion G—B gas is sucked into the cylinder of the stage. The total amount of energy fed back to the pistons during the return stroke may be calculated from the area of the surface A—B—G—E—F—A. The energy delivered by the stage together with the discharged gas is rendered by the area of the surface enclosed by the cycle B—C—E—G—B.

The energy fed to the stage during the working

stroke and the feed-back energy fed back to the pistons during the return stroke, which are rendered by the surfaces A—B—C—E—F—A and A—B—G—E—F—A, respectively, are functions of the pressure ratio

$$\frac{p_2}{p_1}$$

and of the volume ratio

$$\frac{v_T}{v_H+v_T}$$

v_H being the stroke volume.

Fig. 2 illustrates the diagram of a stage operating at the same pressure ratio and the same stroke volume, the volume ratio being however increased by increasing the dead space from v_T to $v_T+v'_T$. The cycle of this stage is illustrated by the curve B—C'—E—G'. The energy fed to this stage during the working stroke is reduced with respect to the corresponding value of Fig. 1 by the area of the surface B—C—C'—B, while the feed-back energy is increased by the area of the surface E—G—G'—E. The energy fed by the stage together with the discharged gas is indicated by the area of the cycle B—C'—E—G' and is reduced with respect to the corresponding value of the diagram shown in Fig. 1 by the sum of the areas of the surfaces B—C—C'—B and E—G'—G—E.

Fig. 3 shows a diagram of a stage operating at a higher ratio

$$\frac{p_2'}{p_1}$$

and at the same volume ratio and the same stroke volume as the cycle shown in Fig. 1. The energy fed to the stage during the working stroke is increased by the area of the surface C—C''—E''—E and the feed-back energy is increased by the surface of the area E''—G''—G—E''.

As will be seen from the diagrams shown in Figs. 1 to 3, the energies fed to the compressor stage during the working stroke and fed back by it during the return stroke and the difference of these energies may be varied within wide limits by suitably choosing the pressure ratio and the volume ratio. Now in an unsymmetrically designed motor-compressor according to my invention the pressure ratios and the volume ratios of the single stages are so chosen as to obtain equal sums of energies on each side during the working stroke as well as during the return stroke, so that the coupling gear securing synchronous reciprocation of the pistons in opposite senses is relieved from transfer of energy excepting the energy required for driving auxiliary devices such as fuel pumps or cooling water pumps.

This shall be still further explained by discussing a three stage free piston compressor comprising three compressor chambers, two of which are arranged on the same side of the structutre. If the load is uniformly distributed over the stages by providing equal pressure ratios and volume ratios therein, the side of the apparatus comprising two stages would operate at two thirds, the other side at one third of the total load, so that the coupling gearing must transfer one sixth of the total load from one side to the other. If however, according to my invention the pressure ratios on the side of the engine comprising two stages i. e. in the embodiment shown in Fig. 4 on the left hand side of the motor cylinder f are made smaller than the pressure ratio on the other side comprising only one stage, the energy can be uniformly distributed over both sides. In consequence thereof a simple construction comprising the minimum number of cylinders is obtained with a coupling gear relieved of transfer of energy and which may be constructed with low weight members, the efficiency of the apparatus being increased by avoiding friction losses in the coupling gear. Instead of or besides varying the pressure ratios, the volume ratios of the single stages may be varied in a similar sense as discussed above in connection with the pressure ratio. By varying the volume ratio the suction stroke G—B is reduced to G'—B (see Fig. 2), thus reducing the amount of gas sucked in during the sucking stroke. This, however, may be easily compensated for by correspondingly increasing the diameter of the piston, which involves the further advantage that the difference between the forces exerted by or on the pistons, which is a maximum at the end of the working stroke, is reduced, because this force is equal to the product of the specific pressure (p_1 or p_2) and the area of the piston surface. In order to reduce this difference, the diameter of the pistons of the stages arranged on the side comprising the smaller number of stages should be enlarged as far as possible, and this can be done by choosing the volume ratio in these stages higher than in the stages on the other side.

The amount of the forces exerted by the pistons at the end of the working stroke may be further controlled within certain limits by changing the discharge pressure p_2. p_2 has a constant value only, if the chamber into which the gas is discharged, has an infinite volume, so that the pressure existing therein is not increased by discharging the gas into the chamber. If, however, the chamber into which the gas is discharged from the stage, is suitably dimensioned, the discharge pressure p_2 will increase during the discharge stroke, so that the corresponding portion of the diagram will be indicated by a more or less inclined curve, as shown by C—K in Fig. 1, in which the discharge pressure increases from p_2 to p''_2.

In some cases it may be desirable to increase the working surface of the piston of a stage beyond the limit corresponding to the increase of the volume ratio. In order to avoid in such cases an undesirable increase of the stroke volume and the input and output of the stage, whereby the uniform distribution of energy would be disturbed, a portion of the gas sucked in may be discharged during the initial portion of the working stroke, so that the point B indicating the beginning of the compression is shifted to the left along the line B—G shown in Fig. 1.

In an air compressor air discharged from a low pressure stage during the initial portion of the working stroke in the manner described may be added to the scavenging air conveyed by a scavenging pump. The pump may be formed by the rear faces of one or a plurality of compressor pistons. If a separate scavenging pump is provided, it should be arranged in such manner that the input of the pump may be used for equalizing the sums of the energy amounts occurring on the two sides of the structure.

If the diameters of some compressor stages are larger than the diameter of the motor piston at the rear of the compressor pistons, a surface equal to the difference between the areas of the compressor piston and of the motor piston is available which may be used as an operating piston surface, for instance as a scavenging pump

piston or as a piston of a compressor stage or of a storage container for storing energy during the working stroke and discharging same during the return stroke. The pressure ratios and the volume ratios of such pump chambers, compressor stages or energy storage chambers should be so chosen that the energy amounts fed to, and refed by, such chambers in addition to the energy amounts of the other compressor stages amount to equal sums on the two sides of the structure.

My invention may be used in connection with any free piston engine comprising a multistage energy consumer, for instance a compressor, in which the stages are non-uniformly distributed over the sides of the apparatus. An example of such an apparatus is a three stage compressor, in which two stages are arranged on one side and one stage on the other side. The invention may however be advantageously used also in connection with compressors with an even number of stages, since in devices of this kind the areas of the diagram curves of the single stages need not be equal, so that a compensation according to my invention may involve considerable advantages in connection with these devices.

Referring now to Fig. 4 showing a three stage free piston motor-compressor, 1 is the motor cylinder and 2 and 3 are the motor pistons arranged in the cylinder 1 for synchronous reciprocation in opposite directions. 4 and 5 are scavenging and exhaust ports arranged in the wall of the cylinder and controlled by the pistons 2 and 3, respectively. The rod 6 of piston 2 is connected to the piston 8 of the first compressor stage, piston 8 being connected to the piston 21 of the third stage. 9 and 22 are the cylinders, in which the pistons 8 and 21 reciprocate, respectively. Piston 3 is connected by means of rod 7 to the piston 10 of the second compressor stage, which reciprocates in the cylinder 11. The freely moving bodies of the two sides of the apparatus are coupled with each other by means of a coupling gear comprising racks 12 and 12' and a pinion 13 rotatably secured to the casing of the motor cylinder by means of suitable bearings (not shown) or the like. 14 are the suction valves of the first compressor stage, from which compressed gas is discharged through exhaust valves 15 into a connecting pipe 16, from which it is sucked by the second compressor stage through suction valves 17. The air compressed in the second stage is discharged through valves 18 into a connecting pipe 19, from which it is sucked through valve 20 into the third stage. The air compressed in the third stage is discharged through a pressure valve 23.

In order to equalize the energy amounts occurring on the two sides of the structure during the working stroke and during the return stroke, the pressure ratio and the volume ratio are chosen higher in the second stage 11, than in the other stages, in the manner discussed above. The forces exerted by the pistons, particularly at the end of the working stroke, are equalized by making the diameter of piston 10 relatively large. In order to avoid an undesirably large input of energy at the second stage, a portion of the gas sucked in is discharged again during the initial portion of the working stroke as described above, pressure valves 24 being provided in the wall of the cylinders 11, through which during the initial portion of the working stroke a portion of the gas sucked in through the valves 17 is re-fed into the pipe 16, until the piston 10 has passed the valves 24. Similar valves 25 may be provided in the first compressor stage. The air discharged through valves 25 is used as additional scavenging air by providing a pipe 26 connecting the valves 25 to the interior of the motor casing 33 used as a scavenging air container. The scavenging pump is formed by the rear side of the piston 8 and by the portion 30 of the cylinder 9 closed by an end wall 29 provided with pressure valves 28. During the working stroke the scavenging pump sucks in air and discharges it during the return stroke into the scavenging air container 33. The energy input and output of the scavenging pump is balanced on the opposite side of the engine by a storage chamber connected with the second compressor stage and formed by the left-hand portion 32 of the cylinder 11, which is closed by an end wall 31. During the return stroke of the pistons the air present in the chamber 32 is compressed and the energy amount therefor required may be so chosen as to balance the energy demand of the scavenging pump. A partial balancing may be obtained, if the wall 31 is omitted or is provided with openings so that the chamber 32 is connected to the atmosphere and the piston 10, during its return stroke, must overcome the pressure of the atmosphere. In any event the pressure ratios and the volume ratios in the compressor stages 9, 11 and 22 and in the rear chambers 30 and 32 are so chosen that during the working stroke as well as during the return stroke the sums of the energies are substantially equal on both sides of the engine, so that the coupling gear 12, 12', 13 is relieved from transfer of energy.

The operation of the device shown in Fig. 4 is substantially the same as that of known free piston devices. Fuel mixture is periodically delivered to the cylinder 1 through a fuel inlet 34 and burnt therein so that the motor pistons 2 and 3 excute a working stroke, during which the air in the compressor chambers is compressed and partly discharged in the manner above described. The pistons are returned to their inner dead centre positions by the energy stored in the gas or air bodies remaining over in the dead spaces of the compressor chambers, scavenging being effected in the manner above described. It should, however, be understood, that in an apparatus according to my invention the pressure ratios and the volume ratios are chosen in the manner described above so as to relieve the coupling gear from any substantial transfer of energy in spite of the fact, that the structure is not symmetrically designed.

I wish it to be understood that I do not desire to be limited to the exact details of construction shown and described for obvious modifications will occur to a person skilled in the art.

I claim:—

1. A free piston multi-stage motor compressor comprising in combination a motor cylinder, a pair of pistons arranged in said cylinder and adapted to reciprocate therein in opposite directions, a coupling gear substantially free from transmitting mechanical energy connecting said pistons for synchronizing the movements thereof, a plurality of compression cylinders, asymmetrically arranged on both sides of said motor cylinder, a compressor piston in each compression cylinder, each compressor piston and each compression cylinder so determining the ratios of the volumes and pressures prevailing in each compression cylinder at the outer and inner dead

center positions of said compressor piston that, for the working stroke as well as for the return stroke, the sum of the work yielded in all compression cylinders on one side of said motor cylinder is substantially equal to the sum of the work yielded in all compression cylinders on the other side of said motor cylinder.

2. A free piston multi-stage motor compressor comprising in combination a motor cylinder, a pair of pistons arranged in said cylinder and adapted to reciprocate therein in opposite directions, a coupling gear substantially free from transmitting mechanical energy connecting said pistons for synchronizing the movements thereof, a plurality of compression cylinders arranged asymmetrically on both sides of said motor cylinder, a compressor piston in each compression cylinder, rigid connections connecting each motor piston with the compressor pistons on its side of the motor cylinder, each compressor piston and each compression cylinder so determining the ratios of the volumes available in each compression cylinder at the outer and inner dead center positions of said compressor piston that, for the working stroke as well as for the return stroke, the sum of the work yielded in all compression cylinders on one side of said motor cylinder is substantially equal to the sum of the work yielded in all compression cylinders on the other side of said motor cylinder.

3. A free piston multi-stage motor compressor comprising in combination a motor cylinder, a pair of pistons arranged in said cylinder and adapted to reciprocate therein in opposite directions, a coupling gear substantially free from transmitting mechanical energy connecting said pistons for synchronizing the movements thereof, a plurality of compression cylinders arranged asymmetrically on both sides of said motor cylinder, a compressor piston in each compression cylinder, means connecting each motor piston with the compressor pistons on its side of the motor cylinder, said compressor piston and said compression cylinder so determining the ratios of the pressures prevailing in each compression cylinder at the outer and inner dead center positions of said compressor piston that, for the working stroke as well as for the return stroke, the sum of the work yielded in all compression cylinders on one side of said motor cylinder is substantially equal to the sum of the work yielded in all compression cylinders on the other side of said motor cylinder.

4. A free piston multi-stage motor compressor according to claim 2, in which the ratios of the initial and end pressures prevailing in said compression cylinder at the outer and inner dead center positions of said compressor piston are substantially higher on the side of the motor cylinder comprising the smaller number of stages than on the other side.

5. A free piston multi-stage motor compressor according to claim 2, in which the ratios of the initial and end volumes available in said compression cylinder at the outer and inner dead center positions of said compressor piston are substantially higher on the side of the motor cylinder comprising the smaller number of stages than on the other side.

6. A free piston multi-stage motor compressor comprising in combination a motor cylinder, a pair of pistons arranged in said cylinder and adapted to reciprocate therein in opposite directions, means substantially free from transmitting mechanical energy connecting said pistons for synchronizing the movements thereof, a plurality of compression cylinders arranged asymmetrically on both sides of said motor cylinder, a compressor piston in each compression cylinder, valve means associated with at least one of said compression cylinders for discharging, during the initial portion of the compression stroke, a portion of the gas contained in said compression cylinder, rigid connections connecting each motor piston with the compressor pistons on its side of the motor cylinder, each compressor piston and each compression cylinder so determining the ratios of the volumes and pressures prevailing in each compressor cylinder at the outer and inner dead center positions of said compressor piston that, for the working stroke as well as for the return stroke, the sum of the work yielded in all compression cylinders on one side of said motor cylinder is substantially equal to the sum of the work yielded in all compression cylinders on the other side of said motor cylinder.

7. A free piston multi-stage motor compressor comprising in combination a motor cylinder, a pair of pistons arranged in said cylinder and adapted to reciprocate therein in opposite directions, a coupling gear substantially free from transmitting mechanical energy connecting said pistons for synchronizing the movements thereof, a plurality of compression cylinders arranged asymmetrically on both sides of said motor cylinder, a compressor piston in each compression cylinder, said compression cylinders comprising high pressures and low pressures stages, means in at least one low pressure cylinder for discharging, during the initial portion of the compression stroke, a portion of the gas contained in said cylinder and for delivering said portion to said motor cylinder for scavenging purposes, rigid connections connecting each motor piston with the compressor pistons on its side of the motor cylinder, each compressor piston and each compression cylinder so determining the ratios of the volumes and pressures prevailing in each compressor cylinder at the outer and inner dead center positions of said compressor piston that, for the working stroke as well as for the return stroke, the sum of the work yielded in all compression cylinders on one side of said motor cylinder is substantially equal to the sum of the work yielded in all compression cylinders on the other side of said motor cylinder.

8. A free piston multi-stage motor compressor according to claim 1 which comprises in combination a motor cylinder, a plurality of compression cylinders and pistons provided therein, at least one of said cylinders being adapted to be used, on one side of the piston reciprocating therein, as a compressor chamber and on the other side as a scavenging pump, and valves connecting said pump with said motor cylinder.

9. In a free piston multi-stage motor compressor according to claim 1, comprising a motor cylinder and a plurality of compression cylinders, the improvement which comprises means for adapting a compression cylinder on one side of said motor cylinder to act as a scavenging pump, and means for adapting a compression cylinder on the other side thereof to act as an energy storage chamber.

10. In a free piston multi-stage motor compressor according to claim 1 comprising a plurality of compression cylinders, the improvement which comprises a discharging chamber, valves

connecting at least one of said compression cylinders to said chamber for discharging gas thereto during the compression stroke, said chamber being adapted to gradually increase the pressure of the gas contained in said compression cylinder during the discharge.

11. In a free piston multi-stage motor compressor according to claim 1, comprising a motor cylinder and a plurality of compression cylinders, the improvement which comprises means for adapting a compression cylinder on one side of said motor cylinder to act as an energy storage chamber.

HERMANN JÄNICKE.