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FREE PISTON MOTOR-COMPRESSORS

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Fig. 1.

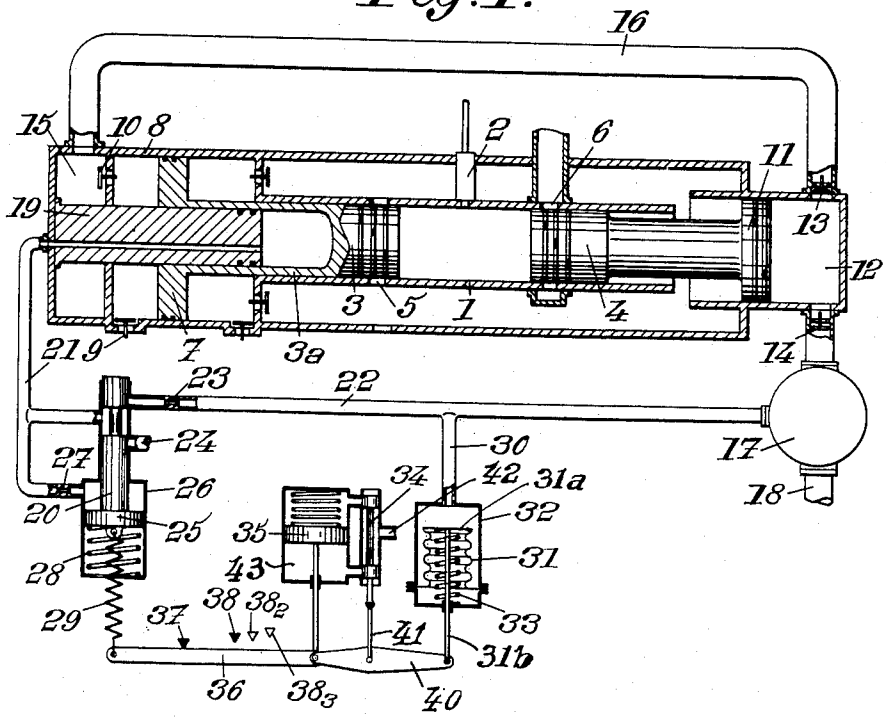


Fig. 2.

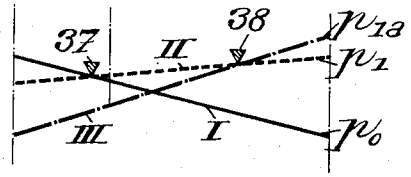
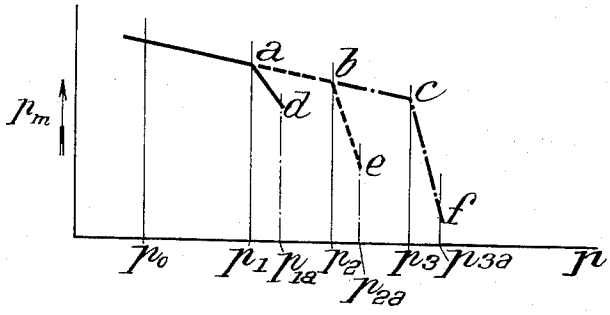


Fig. 3.



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FREE PISTON MOTOR-COMPRESSORS

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4 Claims. (Cl. 230—56)

The present invention relates to free piston motor compressors in which the movement of the movable system or systems in one direction (outward stroke) is produced by the combustion of fuel in the power cylinder of the motor compressor, whereas the movement in the opposed direction (inward stroke) is produced by the energy of a return energy accumulator which has stored up for this purpose a portion of the energy supplied by the combustion of fuel during the preceding outward stroke.

In the present specification, the term free piston motor compressor designates a machine the compressor portion of which discharges most of the air it compresses to the outside directly, that is to say without preliminary passage through the power cylinder of the machine.

The object of my invention is to provide a motor compressor of this kind which is better adapted to meet the requirements of practice than those existing up to the present time.

A preferred embodiment of my invention will be hereinafter described with reference to the accompanying drawing, given merely by way of example and in which:

Fig. 1 diagrammatically shows a free piston motor generator made according to my invention.

Fig. 2 diagrammatically shows different positions of a regulating device belonging to this motor-generator.

Fig. 3 is a diagram showing diagrammatically, in accordance with variations of the discharge pressure of the motor compressor, the mean pressures existing in the return energy accumulator.

The motor compressor proper may be of any suitable construction, such as that shown by Fig. 1. Such a motor compressor includes a power cylinder 1 provided, in the central part thereof, with at least one fuel injector 2 and in which operate, in opposed directions, two power pistons 3 and 4 which control respectively the inlet port 5 and the outlet port 6 of said power cylinder. The power portion of the motor compressor, constituted by said elements 1 to 6, works on the two stroke diesel cycle.

Power piston 3 is connected with a low pressure compressor piston 7 working in a low pressure compressor cylinder 8 provided with a suction valve 9 and a discharge valve 10.

On the other hand, power piston 4 is rigid with a high pressure compressor piston 11 which works in a high pressure compressor cylinder 12 provided with an inlet valve 13 and a delivery valve 14. The space 15 into which is delivered the air discharged from the low pressure compressor cylinder communicates with the inlet of the high pressure cylinder 12 through a conduit 16. The air discharged from the high pressure cylinder 12 is fed to a reservoir 17, from which it can flow through a conduit 18 to the place where it is to be used.

The two movable systems 3, 7 and 4, 11 are connected together by a synchronizing mechanism of a known type (not shown), constituted for instance by connecting rods and cranks, or by pinions and racks, and which is intended to give these systems, at any time, respective positions

symmetrical with reference to the center of the power cylinder 1.

In such a motor compressor, the outward stroke is produced by the combustion of fuel injected into the power cylinder in the space between the two power pistons 3 and 4, when they are close to their inner dead centers. During this outward stroke, the low pressure compressor piston 7 compresses and delivers through discharge valves 10 the air present in low pressure cylinder 8, while the high pressure cylinder subjects the air already compressed in the low pressure cylinder to a second stage of compression to discharge it into reservoir 17.

The return or inward strokes of free pistons 3, 7 and 4, 11 are ensured on the one hand by the compressed air cushions which, at the end of the outward stroke of these pistons, remain entrapped in the clearance spaces of compressor cylinders 8 and 12 and, on the other hand, by a return energy pneumatic accumulator constituted by the inside of a cylindrical chamber 3a formed in piston 3 and which cooperates with a stationary piston 19. The energy stored up in this accumulator depends, on the one hand, upon the length of the outward stroke of power piston 3 and, on the other hand, upon the mass of air which constitutes the cushion present in chamber 3a. The energy stored up in the accumulator increases, on the one hand, when the mass of air forming the cushion increases and, on the other hand, when the outward stroke of the movable systems increases, which compensates, at least partly, for the reduction undergone by the return energy of the air cushions of the dead spaces of the compressor cylinders when the outward stroke increases.

If the motor compressor worked always with exactly the same delivery pressure, it would not be necessary to provide a device for regulating the return energy of accumulator 3a, 19. However, even in a motor compressor which normally supplies air always at the same pressure (nominal pressure), some variations in the delivery pressure, due to variations in the load of the compressor are unavoidable. This is why the motor compressor must be fitted with a regulating device which varies the energy brought into play in the accumulator in accordance with the variations which may occur in the value of the delivery pressure of the compressor.

It should be noted here that the final pressure of compression in the power cylinder depends upon the amount of energy stored up in the accumulator and that this pressure, on the other hand, is one of the factors which determine the number of oscillations of the movable systems per unit of time, this number being higher as the final pressure of compression in the power cylinder is higher.

Furthermore, it should be noted that the final pressure of compression in the power cylinder can vary within rather wide limits.

As above stated when a motor compressor is arranged to work with a given delivery pressure called "nominal pressure," this does not mean that the delivery pressure is constantly equal to said nominal value and slight variations are unavoidable. This is due in particular to the fact that the obtainment of the desired delivery pressure (pressure in reservoir 17) is obtained by means of a regulating device, of conventional construction and not shown by the drawing, which controls the fuel injection (at 2) in accordance with the pressure in reservoir 17. When this pressure exceeds the desired value due to the fact that there is no load, the fuel injection is cut off and the motor compressor ceases feeding air to said reservoir 17. But it will be understood that since there is no load (i. e. since there is no outflow from reservoir 17) the slight excess of pressure which has caused the regulating device to cut off fuel injection remains, and the pressure in reservoir 17 is then slightly higher than when the motor compressor

is working on full load (i. e. reservoir **17** is delivering compressed air to receiver machines).

In other words, the "nominal pressure" which is to be achieved at the delivery of the motor compressor is not a fixed value, but a range of values, with an upper limit (corresponding to no load) and a lower limit (corresponding to full load), the interval between these limits (hereinafter called "regulation difference") being small, for instance some tenths of an atmosphere.

Starting from these considerations, I arrange, according to my invention, the regulating device of the return energy accumulator so that the final pressure of compression in the power cylinder is relatively high, for instance 60 atmospheres or more, as long as the delivery pressure is lower than or at most equal to the lower limit of the nominal delivery pressure, that is to say the value which corresponds to the maximum load of the motor compressor, and that the final pressure of compression in the power cylinder decreases quickly as soon as the delivery pressure exceeds said lower limit of its nominal value, to come to a minimum value when the delivery pressure reaches the upper limit of its nominal value.

In other words, according to my invention, the return energy regulating device is arranged in such manner as to work in accordance with two different laws one of which determines the operation of this device as long as the delivery pressure has not yet reached its minimum nominal value, whereas the other one determines its operation when the delivery pressure is within the limits of the above mentioned "regulation difference."

I thus obtain, in the period for which the motor compressor is working on a load lower than the maximum load thereof, a reduction of the number of oscillations per unit of time, which reduction is the greater as the load of the motor compressor gets nearer to its minimum value, and possibly to its zero value. This reduction of the number of oscillations per unit of time gives for the motor compressor the same effect as a reduction of the length of stroke of the movable systems. The reduction of the number of oscillations, for loads lower than the maximum load, makes it possible to reduce the differences between the maximum and minimum strokes of the movable units.

When the return energy accumulator is a pneumatic accumulator, the energy brought into play in this accumulator is regulated by varying the mass of air contained in the accumulator, which mass is, for a given length of stroke, proportional to the mean pressure in the accumulator.

It is clear that there are different ways, according to my invention as above set forth, of devising a motor compressor and the device for regulating its return energy.

A particularly advantageous embodiment of my invention is shown by the appended drawing. According to this construction, the device for regulating the mass of air in accumulator 3*a*, **19** includes a slide valve device **20** connected through conduit **21** with the inside of accumulator cylinder 3*a*. Slide valve **20** is adapted to connect, according to its position, conduit **21** either with the compressed air reservoir **17**, through a conduit **22** having a throttled portion **23**, or with the atmosphere through a tube **24**.

Slide valve **20** is made rigid with a piston **25** which cooperates with a cylinder **26** the upper chamber of which communicates through a throttled passage **27** with conduit **21**, whereby the mean pressure of the accumulator air cushion is transmitted to said chamber of cylinder **26** and acts upon the upper face of piston **25**. The other face of this piston is subjected on the one hand to the action of a compression spring **28** working in opposition to the accumulator mean pressure and on the other hand to the action of an adjustable pulling spring **29** exerting a force of the same direction as that of the accumulator mean pressure acting upon the upper face of piston **25**. Pulling spring **29** is adjusted in accordance with the delivery pressure existing in the reservoir **17** of the accumulator.

For this purpose, this delivery pressure is made to act through a conduit **30** upon a manometric box **31** placed in a casing **32** so that its top end **31***a* is subjected on the one hand to the action of said delivery pressure and on the other hand to that of a spring **33** which is given a preliminary compression. This manometric box is constituted by a kind of bellows **31** the lower edge of which is fixed in an airtight fashion to the cylindrical wall of cylinder **32** in which it is coaxially mounted. The flat top end **31***a* of said bellows carries, fixed thereto, a rod **31***b* hinged to the end of a lever **40** to an intermediate point of which is pivotally mounted the rod **41** of a slide valve **34** controlling the supply of a fluid under pressure fed through conduit **42** to a cylinder **43** containing a piston **35** the rod of which is pivotally connected to the end of a lever **36** to the other end of which pulling spring **29** is secured. In order to vary the tensioning of spring **29** in accordance with two different laws, this lever **36** bears successively upon two different fulcrum abutments **37** and **38** each analogous to the knife-edge of a balance. The effect of these two fulcrum abutments upon the operation of lever **36** is shown on a larger scale by Fig. 2. For all positions of the lever between position I, which corresponds to a delivery pressure p_0 lower than the lower limit p, of the nominal pressure of the motor compressor, and position II, which corresponds to this nominal pressure lower limit, lever **36** bears against fulcrum **37**, whereby the displacements of its right hand end are transmitted with a reduction to the left hand end, i. e. to spring **29**. Consequently, the variations of tension of spring **29** are relatively small as compared with the variations of the delivery pressure. When the delivery pressure exceeds value p_1, lever **36** ceases to bear against fulcrum **37** and comes to bear against fulcrum **38**. From this time on, the displacement of the right hand end of lever **36** is transmitted with an amplification to the left hand of this lever and therefore to spring **29**. Thus, the law according to which the tension of spring **29** varies as a function of the delivery pressure is different for the pressures lower than or equal to p_1 and for the pressures ranging from p_1 and p_{1a}. This last mentioned pressure, which is that corresponding to position III of lever **36** is the upper limit of the nominal delivery pressure of the motor compressor, which is reached when said compressor is working on no load.

The effect of this change in the law of variation of the energy brought into play in the accumulator is illustrated by Fig. 3, which shows the variation of the mean pressure p_m (in ordinates) of the accumulator air cushion as a function of the delivery pressure p in reservoir **17** (in abscissas). This diagram shows that p_m decreases slowly when the delivery pressure increases from p_0 to p_1. Preferably, the law of variation of p_m as a function of p is such that the reduction thereof balances the increase in the return energy which takes place in the air cushions of the clearance spaces of compressor cylinders **8** and **12** at the ends of the outward strokes. Thus, the sum of the return energies acting upon the moving systems remains substantially constant and has, for instance, a value which gives the final pressure of compression in the power cylinder a value approximating 60 atmospheres.

Now, when the delivery pressure exceeds value p_1, the change in the law of variation of the tension of spring **29** causes p_m to decrease much more quickly, as shown by line *a*—*d*, the value of p_m at point *d* of the curve being that existing in the accumulator air cushion when the delivery pressure is p_{1a}. This reduction of the mean pressure of the pneumatic accumulator air cushion causes a substantial reduction of the final pressure of compression in the power cylinder and consequently a reduction of the number of oscillations of the moving systems per unit of time. The reduction of this final pressure of compression may be such that for a delivery pressure equal to the upper limit of the nominal delivery pressure p_{1a}, said final pressure is only 30 atmospheres.

When the same motor compressor must be capable of giving at several different nominal pressures, the above described regulating device can easily be adapted to these different nominal pressures. It suffices, for this purpose, to provide for fulcrum abutment **38** several positions (by insertion thereof in different holes of the machine frame) each of which holes corresponds to a given nominal pressure. Fig. 1 shows a position 38_2 of said fulcrum abutment for a nominal delivery pressure lower limit p_2, with a nominal delivery pressure upper limit p_{2a}, and a position 38_3 for a nominal delivery pressure lower limit p_3, with a nominal pressure upper limit p_{3a}.

When fulcrum **38** is placed in position 38_2, fulcrum **37** remains operative for delivery pressures increasing up to pressure p_2 (point b of the curve) and lever **36** comes to cooperate with fulcrum 38_2 only when the delivery pressure exceeds p_2, a quick decrease of the mean pressure p_m then taking place along sloped curve b—e. Thus, the final pressure of compression in the power cylinder is substantially reduced, for instance from 60 to 30 atmospheres.

Finally, when fulcrum **38** is placed in position 38_3, fulcrum **37** remains operative for values of pressure p_m down to that corresponding to point c of the diagram of Fig. 3, for which the minimum nominal delivery pressure lower limit is p_3, and when the delivery pressure increases beyond this value p_3, up to p_{3a}, the mean pressure p_m decreases at a quicker rate, along line c—f of Fig. 3.

It will further be seen that the slopes of lines a—d, b—e, c—f are the steeper as the nominal delivery pressure is higher.

In all cases, the quick decrease of the accumulator energy as soon as the delivery pressure exceeds the nominal value lower limit corresponding to the maximum power causes a great reduction of the number of oscillations of the moving systems per unit of time.

In a general manner, while I have, in the above description, disclosed what I deem to be practical and efficient embodiments of my invention, it should be well understood that I do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

What I claim is:

1. In combination, a free piston motor compressor including at least one power cylinder and one compressor cylinder fixed with respect to each other, a movable system constituted by a power piston and a compressor piston rigid with each other and freely movable in said two cylinders, respectively, an energy accumulator having a portion thereof operatively connected with said movable system for accumulating energy from said movable system during the power stroke of said power piston and giving back said energy thereto during the return stroke thereof, a regulating device operatively connected to said accumulator operative in response to variations in the delivery pressure of said compressor for varying the energy stored up by said accumulator on every cycle of said movable system so as to reduce said energy when said delivery pressure increases, said device being adjustable to have two different laws of variation of said energy in response to variation of said delivery pressure, one for which the ratio of energy variation to delivery pressure variation is smaller than for the other, and means responsive to variations in the delivery pressure of the compressor for adjusting said regulating device to work according to the first of said two laws as long as said delivery pressure is below the lower limit of the motor compressor nominal delivery pressure and according to the second of said two laws when said delivery pressure is between the lower and upper limits of said nominal delivery pressure.

2. In combination, a free piston motor compressor including at least one power cylinder and one compressor cylinder fixed with respect to each other, a movable system constituted by a power piston and a compressor piston rigid with each other and freely movable in said two cylinders, respectively, a pneumatic energy accumulator having a portion thereof operatively connected with said movable system for accumulating energy from said movable system during the power stroke of said power piston and giving back said energy thereto during the return stroke thereof, a regulating device operatively connected to said accumulator operative in response to variations in the delivery pressure of said compressor for varying the mass of air present in said accumulator on every cycle of said movable system so as to reduce said mass of air when said delivery pressure increases, said device being adjustable to have two different laws of variation of said mass of air in response to variation of said delivery pressure, one for which the ratio of mass of air variation to delivery pressure variation is smaller than for the other, and means responsive to variations in the delivery pressure of the compressor for adjusting said regulating device to work according to the first of said two laws as long as said delivery pressure is below the lower limit of the motor compressor nominal delivery pressure and according to the second of said two laws when said delivery pressure is between the lower and upper limits of said nominal delivery pressure.

3. A combination according to claim 1 including a part movable in response to variations of the compressor delivery pressure, the means for operating said regulating device including a lever operatively connected at one end to said part and at the other end to said regulating device, and two fulcrum abutments for cooperating with said lever, said abutments being positioned to be both in contact with said lever when the delivery pressure is equal to the lower limit of the delivery pressure nominal value.

4. A combination according to claim 1 including a part movable in response to variations of the compressor delivery pressure, the means for operating said regulating device including a lever operatively connected at one end to said part and at the other end to said regulating device, and two fulcrum abutments for cooperating with said lever, said abutments being positioned to be both in contact with said lever when the delivery pressure is equal to the lower limit of the delivery pressure nominal value, one of said abutments being positioned to cause the lever to reduce the movements imparted thereto by said part when transmitting it to said regulating device and the other abutment being positioned to amplify these movements.

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