PATENT SPECIFICATION

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COMPLETE SPECIFICATION

Improved Method of and Apparatus for Starting Free Piston Internal Combustion Engines for Operating Compressors

I, HUGO JUNKERS, a German Citizen, of 21 Hauptmann Loeper Platz, Dessau, Anhalt, Germany, do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

The invention relates to a method and apparatus for starting free-piston internal combustion engines for operating compressors.

It is known in such machines, to connect the moving masses with springs which store up, during the working stroke, the energy needed for compressing the engine charge, and transmit said energy to the charge during the return stroke after the direction of movement of the piston has been reversed. Machines of this kind are started by applying tension to the springs by an external force, and then releasing the moving masses. Such springs, permanently used as accumulators of energy, have the drawback of being disproportionately large and heavy, if they are to be sufficiently reliable in action in the long run.

It has also been proposed to employ an energy accumulator composed of springs, solely for starting purposes, said accumulator being automatically coupled with the moving masses when the said springs have been placed under tension and being detached therefrom after having transmitted its energy and during the first compression stroke of the engine.

It is also known to start free-piston machines for actuating gas compressors, by firstly retaining the moving mass in a suitable position in the cylinder, by means of a catch, then charging the compression chambers with gas under suitable pressure, and finally releasing the catch, so that the moving mass is accelerated by the expansion of the compressed gas and the work of compression on the engine side is performed.

A drawback of this latter method lies in the large amount of air necessary for filling the compression chambers which in the starting position have a relatively large capacity and, in addition, considerable losses of the starting compressed air are liable to occur through almost unavoidable leakages at the suction valves.

In these known methods of starting, a fundamental difficulty consists in that only a single impulse can be applied to the moving masses and consequently, in the second half of the oscillation, that is to say, in the first working stroke (outward stroke of the engine piston) it is necessary to provide such working conditions, both on the engine side and the energy-absorbing side of the free-piston machine that the engine will be certain to continue running satisfactorily. For example, with the known spring starters, it is quite impossible to attain at the first compression stroke, sufficient pressures in all the stages of a multi-stage free-piston compressor, to ensure that the requisite energy is available from the compressor side for the succeeding return stroke (compression of the engine charge) and that the machine will not simply stall. On the contrary, in the case of such a multi-stage compressor the possibility must always be afforded for it first to pump itself up, during a series of strokes, to its normal running condition, before the change over from starting to normal running can be carried out.

It is the object of the invention to obviate the defects attaching to the previously known methods referred to and to provide a method of starting that is economical in respect of energy consumption.

According to the present invention, energy is delivered by suitable means (for example an energy accumulator charged with the requisite starting energy) to the reciprocatable masses of the engine and compressor and absorbed by said means while the compressor is running under substantially no load (without absorbing and redelivering energy) the amount of energy delivered and absorbed by said means being gradually reduced, at approximately the same rate as the load on the engine and compressor is increased to normal working conditions. The gradual loading of the engine and compressor may be increased automatically as the amount of energy imparted to the means for delivering and absorbing energy is reduced or conversely the energy imparted to the means for delivering and absorbing energy may be automatically reduced as the load on the engine and compressor increases. When normal working conditions have been established the said means for delivering and absorbing energy may either continue to oscillate idly or be disconnected from the reciprocating masses.

The starting-energy accumulator may be designed as a mechanical accumulator, for example in the form of springs, rubber cords, falling or swinging weights, or also in the form of pistons acted upon by gas or liquid under pressure. During the loading of such accumulators, the moving masses are preferably restrained, in known manner by means of catches on the release of which the starting stroke begins.

Various means are applicable for the purpose of minimising the dimensions of said auxiliary starting-energy accumulator.

If starting gas of low pressure be present, the requisite amount of starting energy can be applied by allowing the inflow of compressed gas to continue during a portion of the starting stroke. On the other hand, the energy can be supplied to the accumulator in the form of gas under high pressure, suddenly admitted through a large intake aperture, or in the form of a gunpowder cartridge which may be inserted in the chamber 9 and detonated by a striker or other suitable means. No catch will then be needed for restraining the moving masses, since they receive instantaneously a high initial acceleration.

The delivery of compressed gas by the compressor to a point of consumption during the starting period would entail an increase in the amount of energy required for starting. The delivery of compressed gas, therefore, is controlled during the starting period by arranging valves in the delivery pipe, or between the individual stages of a multi-stage compressor, to permit the full delivery pressure being attained gradually, that is to say in the course of a number of strokes of the compressor.

With this object in view, valves may be arranged in the outlet of the compression chamber or chambers, the valves being initially loaded to a small extent and being subjected gradually to heavier loading as the compressor attains normal working conditions. Alternatively, the compressor may deliver compressed gas into a vessel of such capacity that its normal working pressure is only attained after several strokes of the compressor. In this case the outlet valve of the vessel is arranged to open to permit the supply of compressed gas to a point of consumption, only when normal working pressure is attained in the vessel.

The requirement in respect of starting energy and consequently the dimensions of the accumulator, can also be reduced by reducing the effort of resistance to the starting stroke, for example, in known manner by reducing the volume of gas to be compressed in the engine cylinder, by discharging a portion of the engine-cylinder charge again through control members. The control of these starting members is preferably dependent on the regulating of the change over of the transmission and supply of energy from the starting-energy accumulator to the compressor. This regulating can also be combined with an influencing of the supply of fuel, for example by arranging for the admission of fuel to be small in starting and then increasing it gradually during the changeover.

Several typical embodiments of the invention are illustrated in the accompanying drawing.

Fig. 1 shews a sectional view of a free-piston machine with a pneumatic starting-energy accumulator.

Fig. 2 shews a similar machine to that in Fig. 1 but with modified regulating devices.

Figs. 3 and 4 represent an embodiment of a mechanical energy-accumulator for starting.

The free-piston engine shewn in Fig. 1 has two moving masses, each composed of the engine piston 1, the compressor piston 2 and the accumulator piston 3, said masses moving in opposite directions in the corresponding cylinders; engine cylinder 11, compressor cylinder 12 and accumulator cylinder 13.

The engine cylinder 11 is provided with admission ports 4 and exhaust ports 5, controlled by the pistons 1, and the compressor cylinders 12 are provided with inlet valves 7 and delivery valves 8. The moving masses are connected together by a coupling device, for ensuring accurate relative movement and consisting of the racks 14, 14^1 and the intermediate pinion 15 mounted on the casing of the machine. The supply of fuel to the engine cylinder is effected through an injector nozzle 16. The device for retaining the moving masses in a desired position for starting consists of a nose 17 on one of the racks and a pawl 18 which coacts with said nose and can be moved out of engagement by means of a hand lever 19.

The special starting-energy accumulator formed by the cylinders 13 and pistons 3 is charged with the starting energy in the form of compressed air, through the pipe 21, admission valve 22 and intake passage 23. The said accumulator may also be provided on one side only in which case it acts upon the moving mass on the other side of the machine through the agency of the coupling gear.

In order to obtain, in the starting accumulator, a working diagram that is as complete as possible, and to reduce the size of the accumulator accordingly compressed air is also allowed to flow into the accumulator during a portion of the starting stroke. For automatically stopping the flow of compressed air the wall of the accumulator cylinder 13 is provided with an outlet 25 which is not uncovered by the piston 3 until the latter has traversed a considerable portion of the starting stroke. The air issuing through said outlet, when opened, impels an auxiliary piston 26 connected with a slide valve 27 controlling the admission of the compressed air into the accumulator cylinder 13. Said slide valve is provided with a through passage 28, through which the air can continue to flow to the cylinder 13, until the piston 26 is forced towards the left by the pressure of the air issuing through the outlet 25.

To enable the piston 2 of the compressor to move idly during the return stroke succeeding the starting stroke, whilst the contents of the working chamber 9 of the accumulator are further compressed—and the accumulator accordingly recharged—by the expansion of gas actuating the engine, the following arrangement is devised.

A pressure-regulating valve is provided in the pipe 30, 31 leading from the delivery valves 8 to the site of consumption. The plate 32 of said valve is loaded by a spring 33, in such a way that delivery from the working chamber 6 of the compressor cylinders begins only at a predetermined pressure that is favourable for the working of the machine. The valve plate 32 is also connected with a piston 35, adapted to travel in the valve casing 34 and to be acted upon through the pipe 36 by compressed air from the starting accumulator, in such a manner that the said pressure on the piston tends to open the valve. The pipe 36 connects with a small vessel 20 in permanent communication with the working chamber 9 of the starting accumulator by way of a small orifice 37. An outlet pipe 38, with regulating valve 39, is also provided in connection with said working chamber.

For starting, the moving masses are brought into the position shewn for example by turning the pinion 15 of the coupling by means of a disengageable crank handle, and are secured in that position by slipping the pawl 18 into engagement with the nose 17. The outlet valve 39 being closed, the compressed-air admission valve 22 is opened and the working chamber 9 of the starting accumulator, and the vessel 20 are consequently filled with compressed air, which acts on the piston 35 of the regulating valve 32 and opens the latter. If the catch 18 be then disengaged by turning the lever 19, the moving masses will perform the first starting stroke under the pressure of the air enclosed in the chamber 9 and continuing to enter the latter. This stroke compresses the charge in the engine cylinder, the ignition functions and the resulting gases of the combustion drive the moving masses back again, thereby compressing the air contained in the accumulator cylinders 13. The cycle of operations can then be recommenced. During these first starting strokes, the pressure in the vessel 20 falls to only a slight extent—owing to the smallness of the orifice 37—so that the regulating valve 32 remains open and, accordingly the compressors idle for the time being. To prevent undesirable loading of the compressor pistons during the starting operations it is arranged that only a slight pressure (approximately atmospheric pressure) prevails in the pipe 31 at the commencement of the starting operations and for this purpose a suitable valve (not shown) may be provided which is opened to relieve the pressure in the pipe 31 and then closed. The pressure in the pipe 31 is gradually increased during the starting strokes, in accordance with the delivery of gas from the compressor cylinders.

For gradually transmitting the reception and emission of energy from the starting accumulator to the compressor, the delivery valve 39 of the accumulator is opened slowly. The pressure of the starting air in the accumulator chamber 9 and also in the vessel 20, consequently falls, so that the pressure-regulating valve 32 also closes slowly. Accordingly, the compressor is increasingly loaded, in about the same proportion as the accumulator is progressively relieved by the discharged starting air, until finally, the compressor is running under the normal working load, and the starting accumulator merely idles.

On the attainment of normal working conditions the pressure on the piston 35 ceases and the valve 32 then opens in accordance with the pressure on the valve head against the pressure of the spring 33 to allow air to be delivered to the pipe 31 leading to the site of consumption.

In the example shown, an outlet 41, controlled by a valve 40, is also provided on the engine cylinder 11. The plate of said valve is closed by a spring 42, whilst a piston 44, acting under the pressure of air coming from the vessel 20 by way of the pipe 43 tends to open the valve 40. During the starting operation, the piston effort predominates at first, so that the valve 40 opens and a portion of the air charge can escape from the engine cylinder into the exhaust pipe 46 by way of the opening 41 and the attached pipe 45. As the working chamber 9 of the accumulator is gradually relieved by the opening of the valve 39, the pressure in the vessel 20 also sinks, and consequently the force acting on the piston 44, so that the valve 40 gradually closes, allowing a continually diminishing escape of charge air.

Fig. 2—in which parts coinciding with those in Fig. 1 are indicated by the same reference numerals—shews a modified arrangement for the change-over of the transmission and absorption of energy from the starting accumulator to the compressor. In the pipe between the delivery valves 8 of the compressor and the pressure-regulating valve 32 which, at first, is held in the closed position by the spring 33, is disposed a vessel 50 of such capacity that it becomes charged to the normal final compression pressure during a certain number of working cycles after the machine is started. On that pressure being attained, the valve 32 opens against the pressure of the spring 33 and now allows the delivered air to pass to the site of application. In order that the working chamber 9 of the starting accumulator may be relieved to the same extent as the working chamber 6 of the compressor is gradually placed under load, a valve 47, with a passage 48, is provided in the outlet 38 of the starting accumulator, and, by means of an auxiliary piston 49 loaded by the pressure (transmitted through the pipe 51) from the vessel 50, is displaced, against the action of an adjustable spring device 52 in such a way that, as the pressure in the vessel 50 increases, a progressively increasing aperture is presented for the passage of the air issuing from the outlet conduit 38.

A device for automatically varying the quantity of fuel during the starting operation is also provided. The fuel pump piston 54, which is actuated by a rocking cam 55, is attached to a two-armed lever 56, the one end of which bears against the cam whilst the other end is acted upon (in opposite directions) by a spring 57 and a piston 58 subjected to the pressure from the chamber 50. As the pressure in the chamber 50 increases the lever 56 is turned in such a manner that the piston 54 on its pressure stroke progressively passes over the mouth of the induction pipe 59 thus supplying an increasing amount of fuel to the injector nozzle 16.

Figs. 3 and 4 represent an example of a mechanical energy accumulator which is connected with the coupling gear which ensures the oppositely directed movement of the two moving masses, said gear being composed—for example as shewn in Figs. 1 and 2—of the racks 14 and 14^1 attached to the pistons 2 and of a pinion 15 supported in an undisplaceable bearing and gearing with said racks. According to Fig. 4, this pinion 15 is detachably connected through a shaft 60 and dog clutch 61 with a pinion 62 which in turn gears with a pinion 63. The shaft 64 of the pinion 63 carries a cam plate 65 having a plurality of cams 66 uniformly distributed over its periphery. The transmission ratio of the pinions 62 and 63 and the design of the cams are such that the angle of rotation of the pinion 63 or of the cam plate 65 corresponding to a complete stroke of the moving masses is about equal to the angle covered by the oblique surface 67 of the cams, cylindrical surfaces 68, covering at least the same angle being provided between the cams on the plate 65

A casing 70 adapted to be rotated about the shaft 64 of the cam-plate 65. accommodates springs 71, the tension of which is transmitted, through sliding shoes 72 and rollers 73 to the cams 66 in such a manner that said springs tend to turn the cam plate 65 in the direction of the arrow *a*. The casing 70 is turned by means of a hand lever 74, provided with a pawl 77 engaging in notches 75 and 76 in a fixed arm 78, thus enabling the casing 70 to be secured in two different positions, the one (notch 75) corresponding to starting conditions and the other (notch 76) to running conditions. The casing also carries a stud 80, the rocking movement of which is transmitted through rods and levers 81, 82, 83 to the spring 33 loading the pressure-regulating valve 32 in the delivery pipe 31 of the compressor in such a manner that the tension of said spring is low when the casing 70 is in position for starting, and that it increases to a degree balancing the normal final compression pressure, when the casing is turned into the position for running.

For starting, the casing 70 is first turned into the position shown in Fig. 3 (pawl 77 in notch 75) and the clutch 61 is thrown in. The moving masses are then brought into position for starting, for example by turning a hand crank slipped over the squared end 69 of the gear shaft 60, whilst, at the same time, the cam plate 65 is also turned in the direction of the arrow *b* and the springs 66, forming the starting-energy accumulator, are compressed. On the moving masses being then released, for example by releasing the catch 18 shewn in Fig. 1 the springs in expanding, perform the task of starting, that is to say, the moving masses are caused to converge and thereby compress the engine charge, whereupon ignition follows. In the now succeeding working stroke the springs are again compressed, whilst the compressor idles, since the spring 33 of the regulating valve 32 is relaxed. The casing 70 is now turned gradually, by means of the lever 74 in the direction of the arrow *b* thereby progressively diminishing the pressure applied to the springs, that is to say they are no longer so powerfully compressed as previously per working cycle. At the same time the tension of the spring 33 of the pressure-regulating valve is progressively increased, and the compressor accordingly subjected to heavier load, until finally, when the casing 70 reaches its end position (notch 76) the change over from starting to running is complete, and the starting-energy accumulator merely idles, the rollers 73 running entirely on the cylindrical portions 68 of the cam plate 65. After the change, the clutch 61 is thrown out and the starting accumulator is thus put entirely out of action.

Instead of gradually loading the compressor by hand in accordance with the relief of the starting accumulator the casing 70 may be arranged to be turned by a piston influenced by the increasing final pressure of the compressor.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The method of starting free piston internal combustion engines for operating compressors characterised in that energy is delivered by suitable means to the reciprocatable masses of the engine and compressor and absorbed by said means while the compressor is running under substantially no load (without absorbing and redelivering energy) the amount of energy delivered and absorbed by said means being gradually reduced at approximately the same rate as the load on the engine and compressor is increased to normal working conditions.

2. The method of starting according to claim 1 characterised in that the load on the engine and compressor is increased automatically as the amount of energy imparted to the means for delivering and absorbing starting energy is reduced.

3. The method of starting according to claim 1 characterised in that the energy imparted to the means for delivering and absorbing starting energy is automatically reduced as the load on the engine and compressor increases.

4. The method of starting according to any one of the preceding claims characterised in that the fuel supply to the engine is automatically increased as the engine attains normal working conditions.

5. The method of starting according to claim 4 characterised in that the fuel supply is increased automatically as the load of the compressor is increased to the normal working conditions.

6. The method of starting according to any one of the preceding claims characterised in that the means for delivering and absorbing starting energy is disconnected from the reciprocatable masses of the engine and compressor when normal working conditions are attained.

7. The method according to any one of the preceding claims characterised in that energy is rapidly supplied to the means for delivering and absorbing starting energy for the purpose of imparting a high initial acceleration to the reciprocatable masses of the engine and compressors.

8. Apparatus for starting a free piston internal combustion engine according to the method of any of the preceding claims characterised in that the means for delivering and absorbing starting energy comprises a member, such as a piston adapted to be loaded by pressure and operatively connected with the reciprocatable masses of the engine and compressor.

9. Apparatus according to claim 8 characterised in that means are provided for supplying pressure to the piston before and during a part of its stroke.

10. Apparatus for starting free piston internal combustion engines by the method according to any one of claims 1 to 7 characterised in that the means for

delivering and absorbing starting energy comprises a mechanical accumulator of energy (such as springs, rubber cords, weights or the equivalent) which is adapted to be loaded and coupled to the reciprocatable masses of the engine and compressor.

11. Apparatus according to claim 10 characterised in that the mechanical accumulator of energy comprises springs acting on cams of a cam-plate to rock it and transmit motion through a suitable coupling to the reciprocatable masses of the engine and compressor; said springs and cam-plate being independently mounted in such a manner as to permit the relative positions of the cams and springs being adjusted to vary the amount of energy imparted by said springs.

12. Apparatus according to claim 11 characterised in that the springs are accommodated in a casing which is adapted to be rocked relatively to the cam, said casing being positively coupled with means for gradually increasing the load on the compressor in such a manner that the rocking of the casing to vary the energy imparted by the springs varies the degree of loading of the compressor.

13. The method of starting according to claim 1 characterised in that the delivery of compressed gas or the like from a vessel (supplied with compressed gas by the compressor) is prevented when starting and permitted as the normal working conditions of the compressor are attained.

14. The method of starting according to claim 1 characterised in that for the purpose of reducing the starting energy to be accumulated, means are provided for lessening the resistance to be overcome in the starting strokes, for example by lessening in known manner the amount of the charge that is to be compressed to ignition pressure in the engine cylinder.

15. The method of starting according to claim 1 or claim 14 characterised in that the actuation of the control devices for varying the amount of the charge for the engine cylinder is effected at the same time and in the same sense as the actuation of the regulating devices for the transition from the starting operation to normal running conditions, for example by actuating the said control devices and regulating devices by means of the same adjusting medium so that the attainment of full normal running conditions is accompanied by the establishment of the greatest possible useful engine charge.

Dated this 23rd day of May, 1934.

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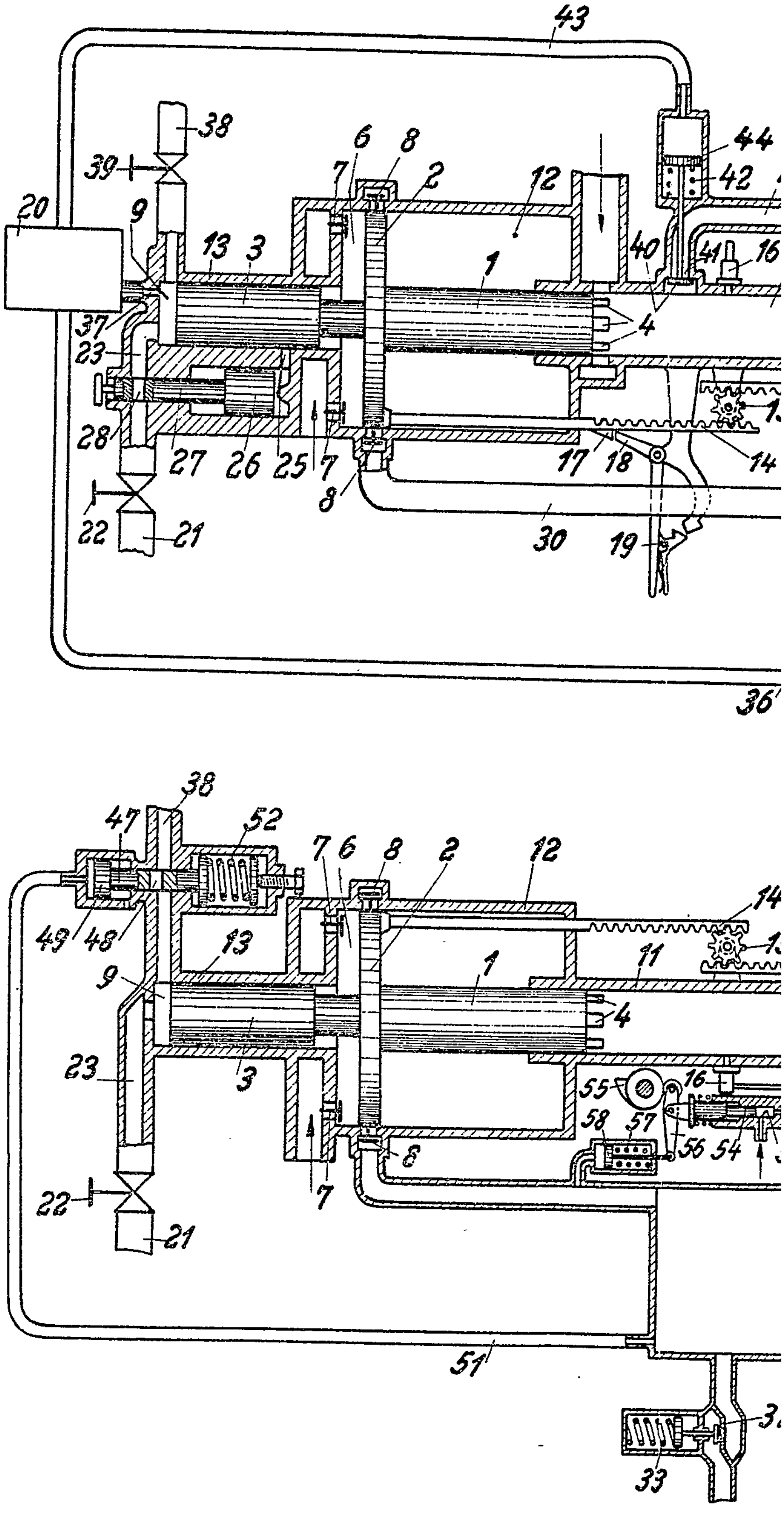
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Fig. 1

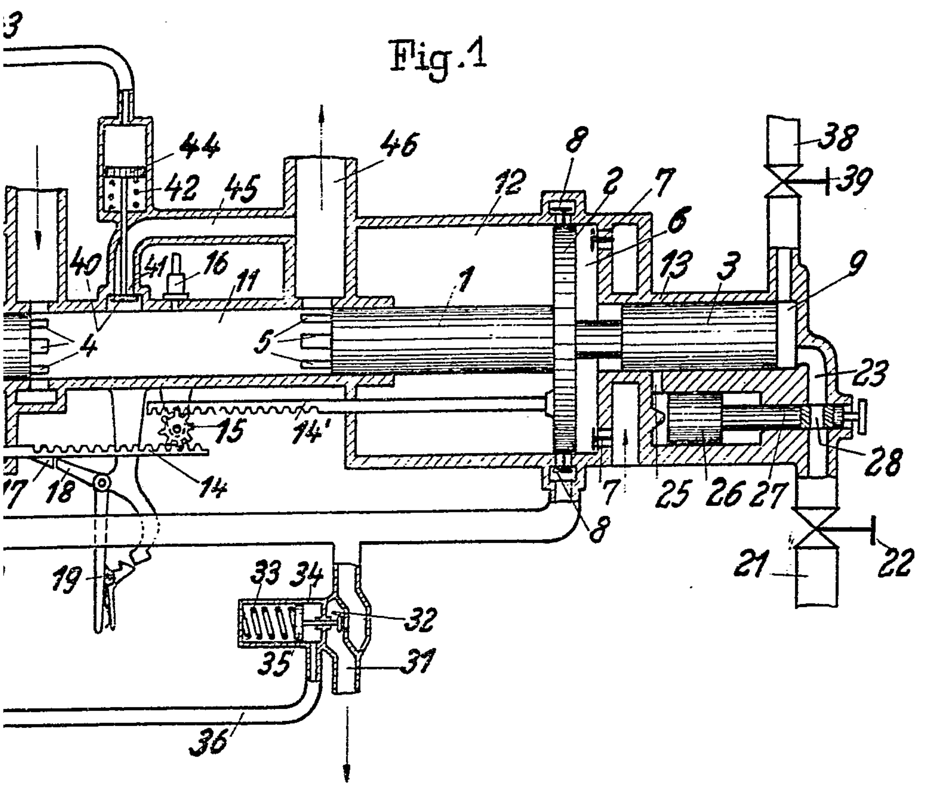
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Fig. 2

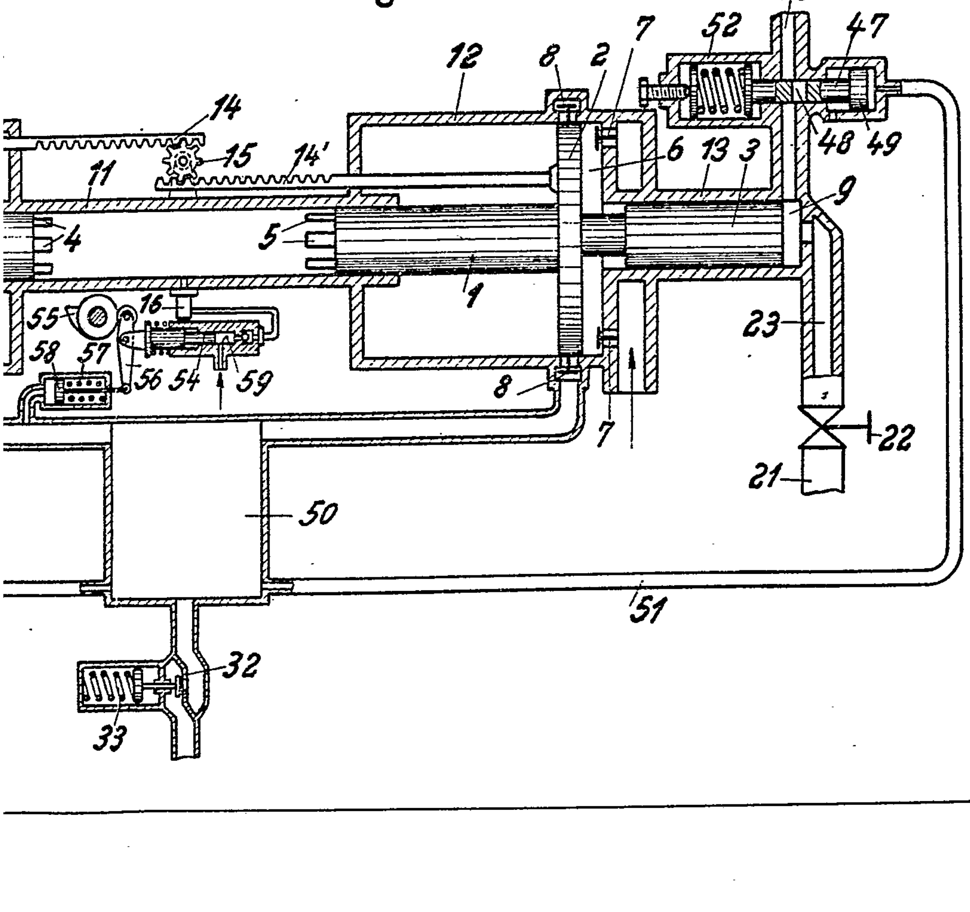
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Fig. 1

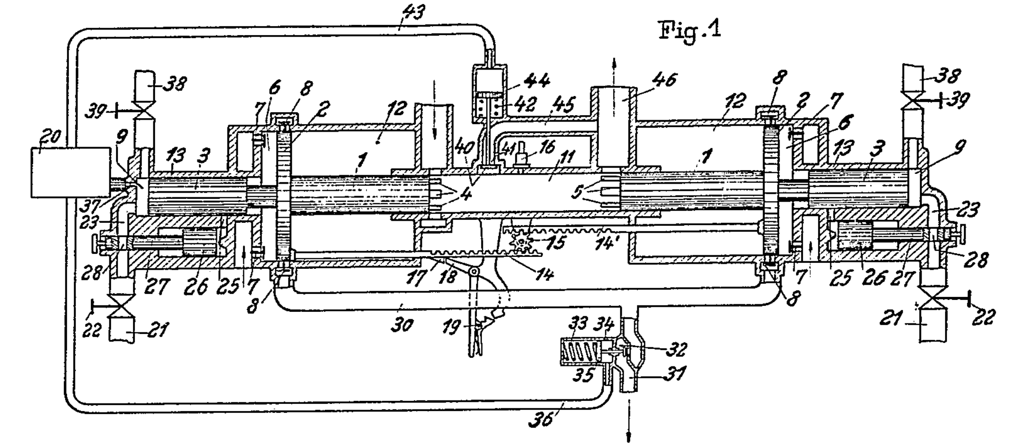

Fig. 2

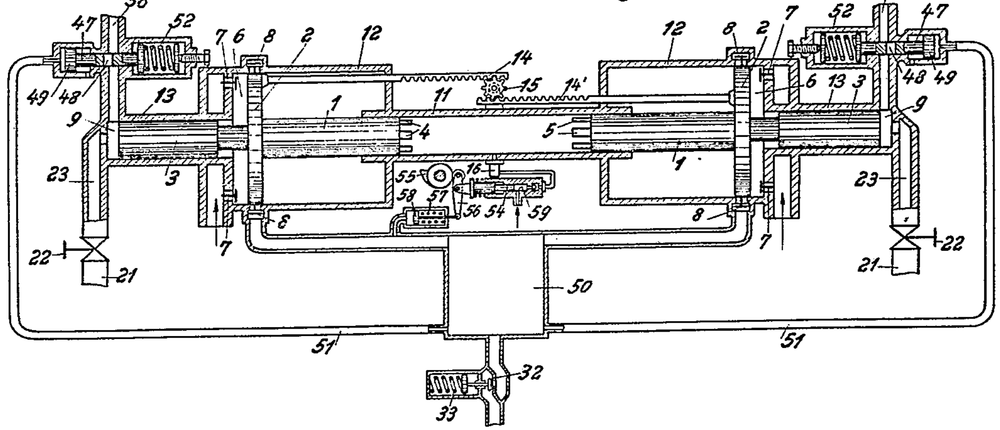

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Fig.3

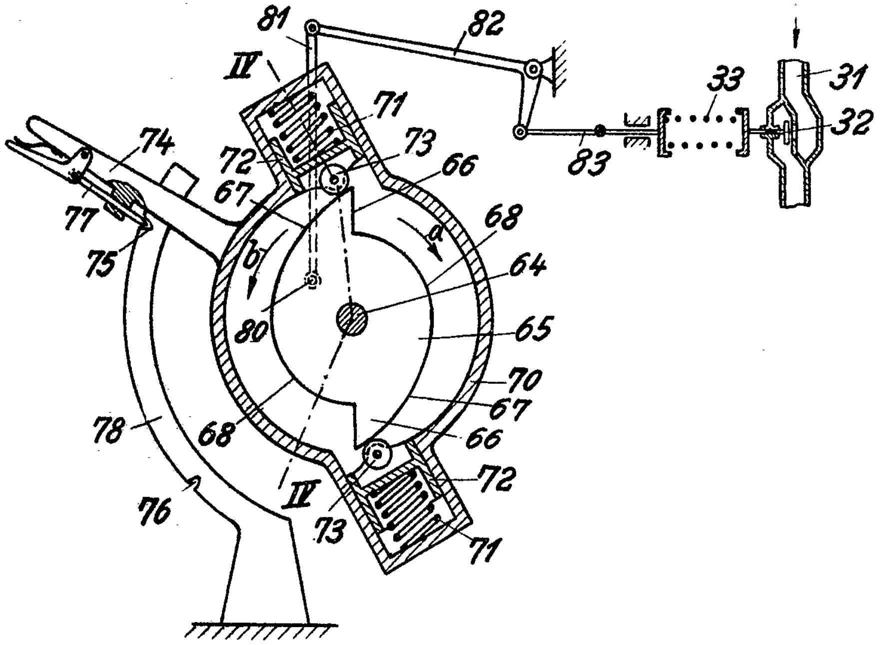
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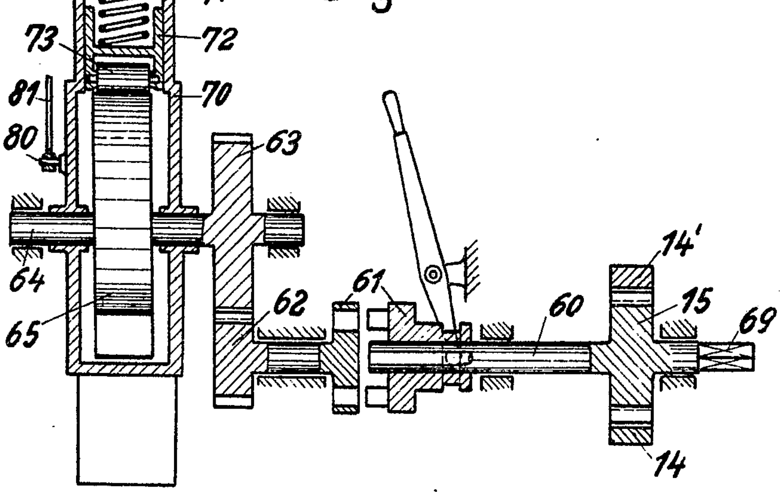
Fig.4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