MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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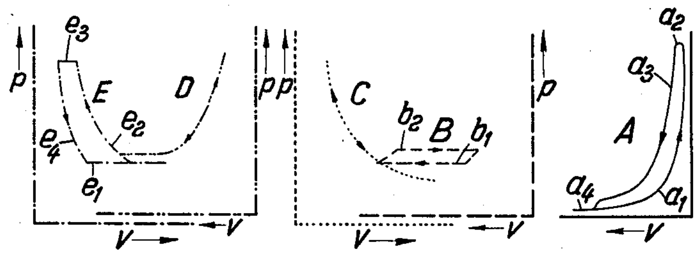

Fig. 1c Fig. 1b Fig. 1a

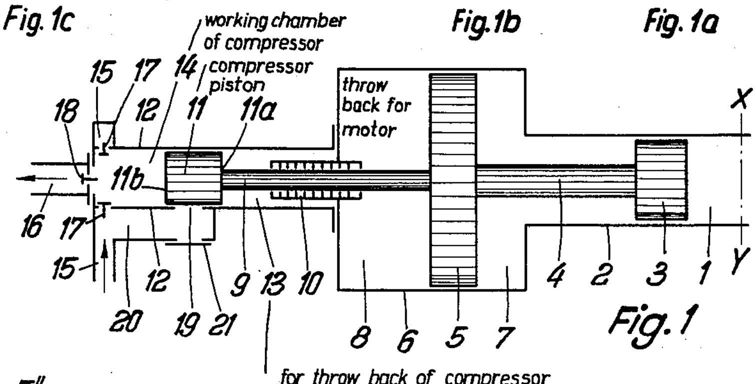

Fig. 1

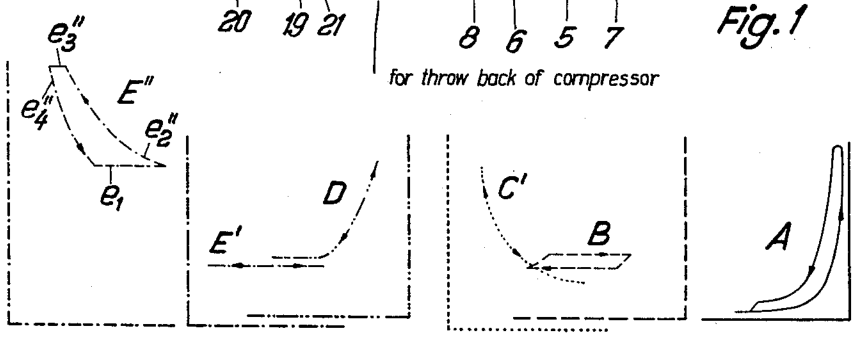

Fig. 2d Fig. 2c Fig. 2b Fig. 2a

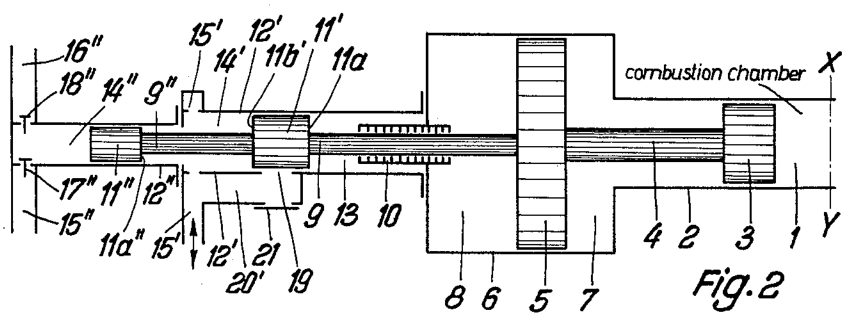

Fig. 2

Inventor:
Heinz Boldt
By [signature]

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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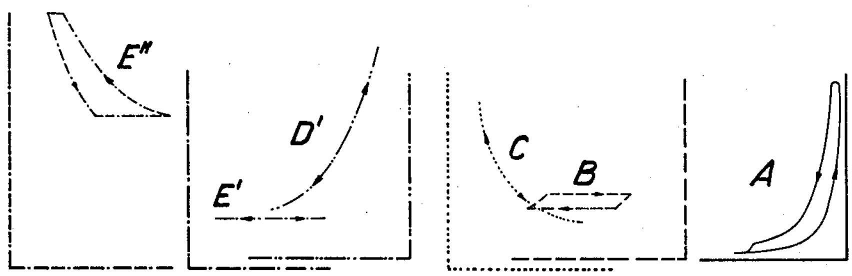

Fig. 3d Fig. 3c Fig. 3b Fig 3a

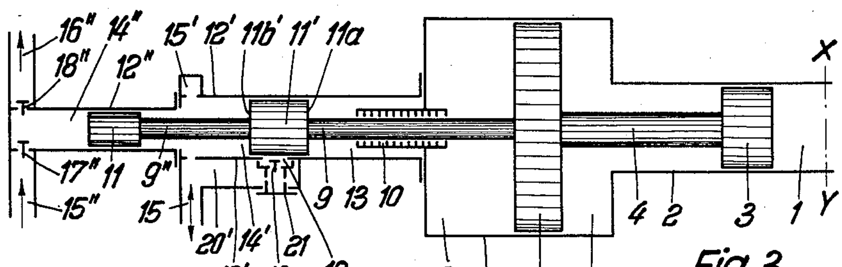

Fig. 3

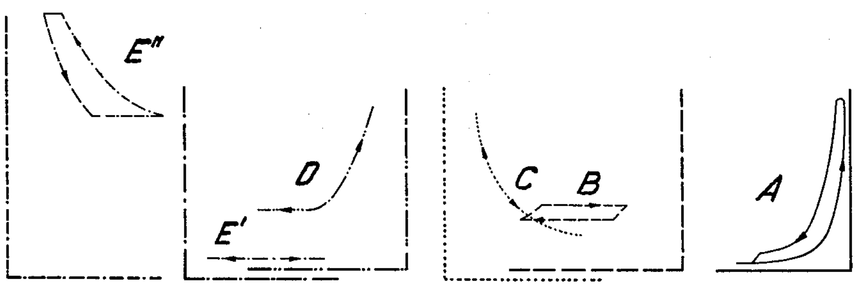

Fig. 4d Fig. 4c Fig. 4b Fig. 4a

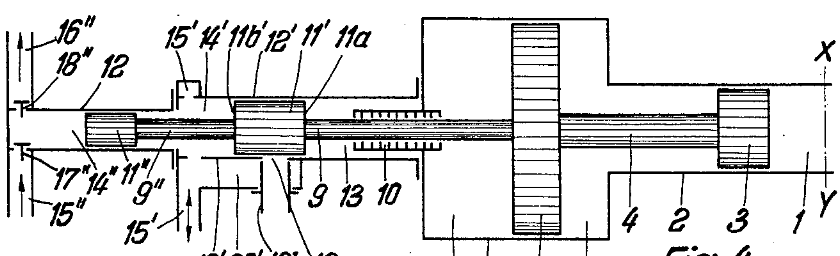

Fig. 4

Inventor:
Heinz Boldt
By

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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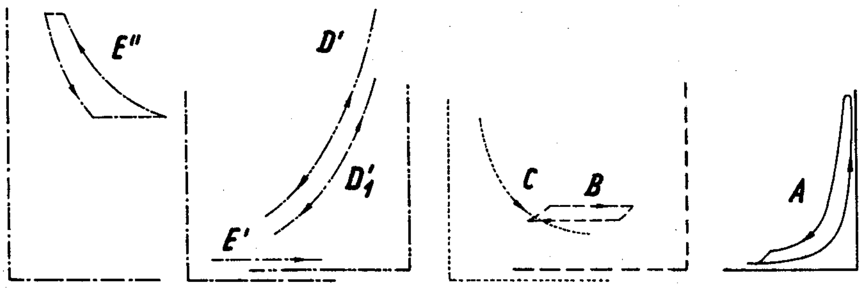

Fig. 5d Fig. 5c Fig. 5b Fig. 5a

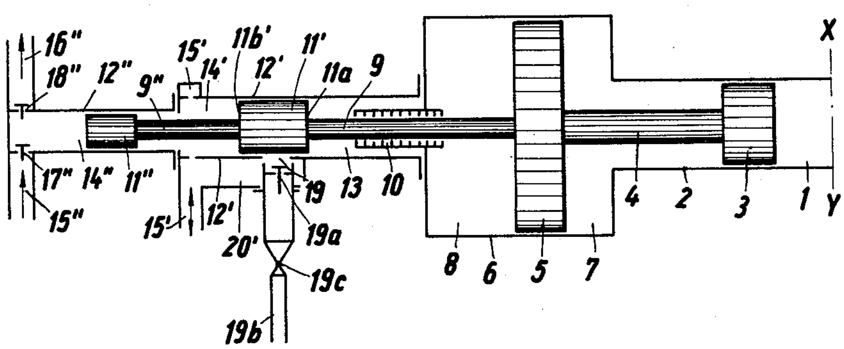

Fig. 5

Inventors:
Heinz Boldt
Arno Krause
Heinz Nink
By Walter Becker

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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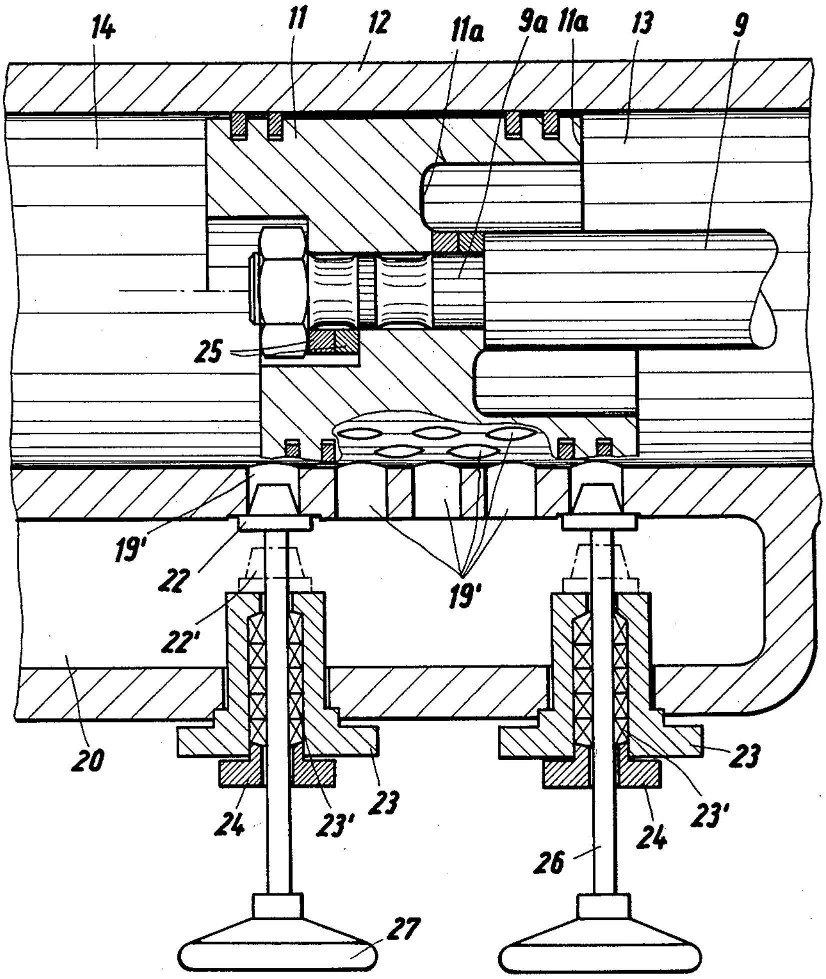
Fig. 6



Inventors:
Heinz Boldt
Arno Krause
Heinz Nink
By

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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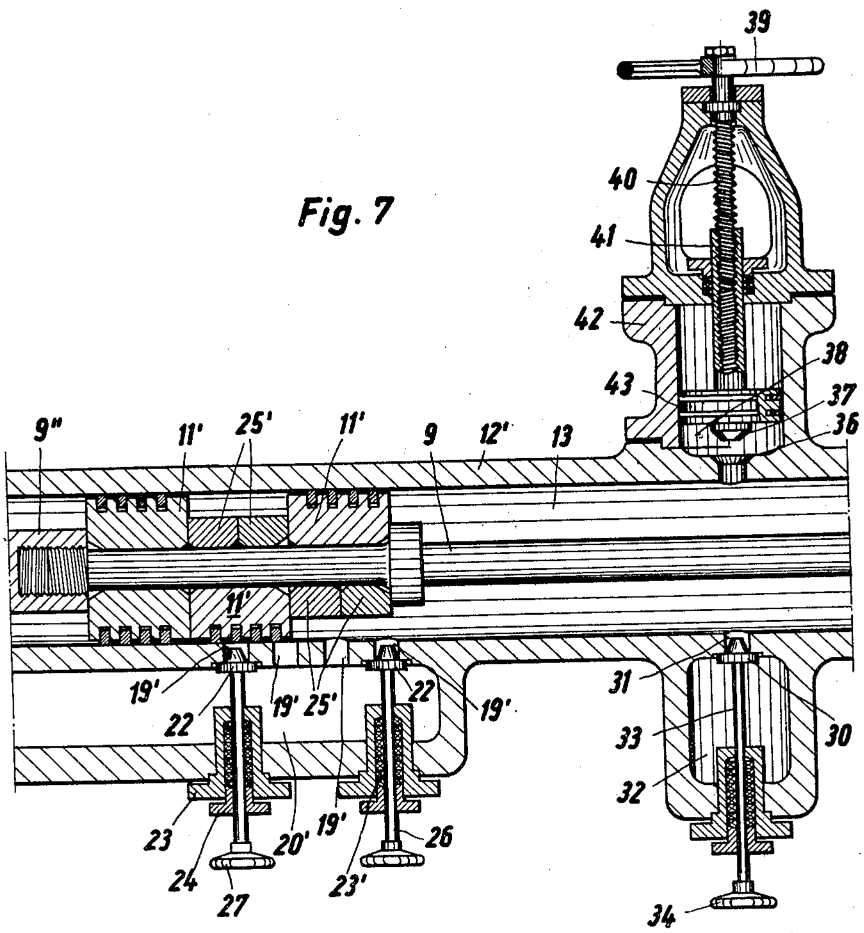
Fig. 7



Inventors:
Heinz Boldt
Arno Krause
Heinz Nink
By Walter Becker

Dec. 1, 1964 H. BOLDT ETAL 3,159,331

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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Fig. 8

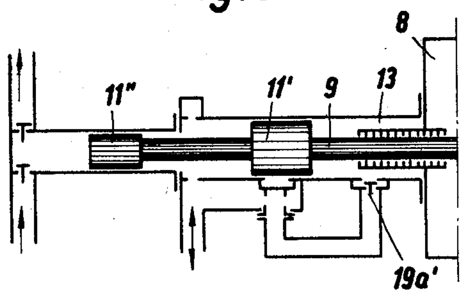
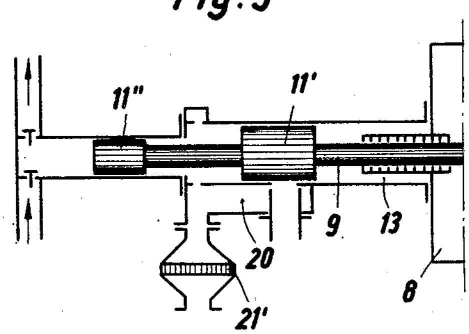


Fig. 9



Inventors:
Heinz Boldt
Arno Krause
Heinz Nink

By [signature]

MULTI-STAGE FREE PISTON TYPE COMPRESSOR

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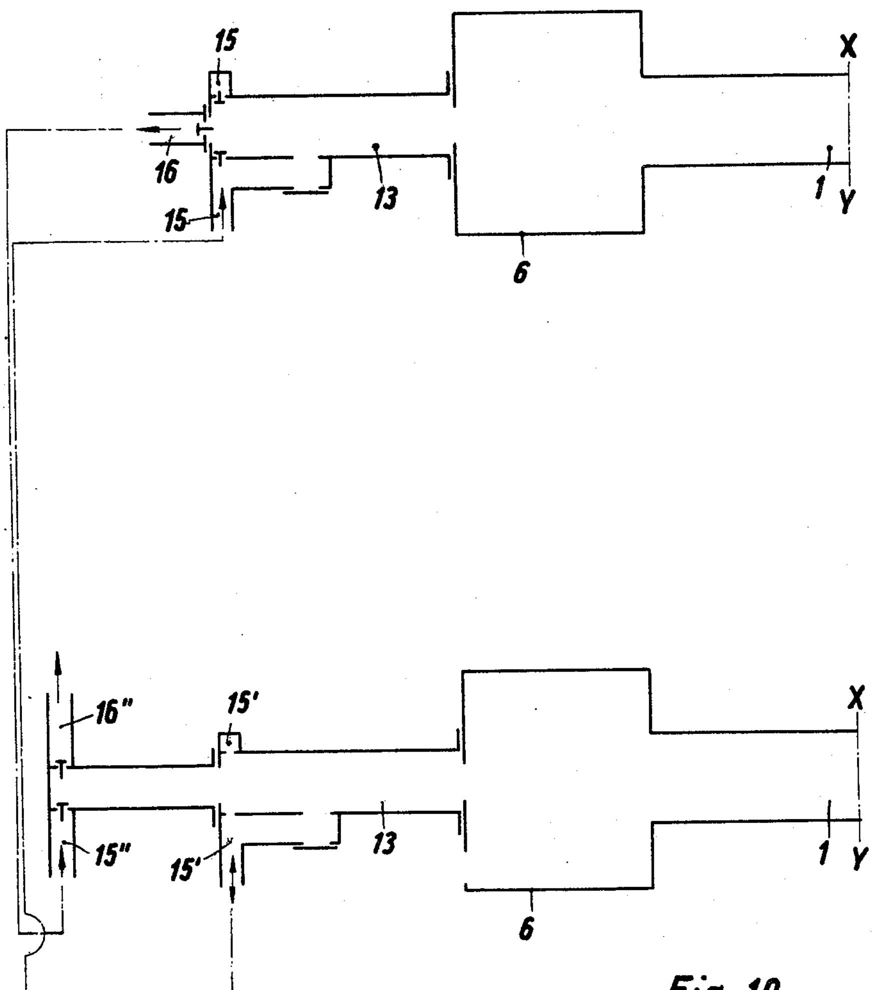

Fig. 10

Inventors:
Heinz Boldt
Arno Krause
Heinz Nink
By [signature]

United States Patent Office

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MULTI-STAGE FREE PISTON TYPE COMPRESSOR

Heinz Boldt, Berlin-Charlottenburg, Arno Krause, Berlin, and Heinz Nink, Berlin-Reinickendorf, Germany, assignors to Borsig Aktiengesellschaft, Berlin-Tegel, Germany

Filed July 18, 1963, Ser. No. 297,178
Claims priority, application Germany July 20, 1962
23 Claims. (Cl. 230—56)

The present invention relates to a multi-stage free piston type compressor.

In assignee's copending patent applications Ser. No. 290,145, filed June 24, 1963 (based on German patent application Ser. No. B 67 862 Ia/46a4, filed June 29, 1962), and Ser. No. 292,501, filed July 2, 1963 (based on German patent application Ser. No. B 67 945 Ia/46a4, filed July 6, 1962), there have been described free piston compressor systems the motor part of which primarily comprises a free piston compressed gas generator while each of the two parts of said system which are arranged as an image to each other and on opposite sides of a transverse plane of symmetry, comprises a prime mover piston, a throw-back or return piston, and a compressor piston. Each one of the said two parts has its pistons interconnected by a piston rod so that each part forms a rigid system. The motor part which is balanced in itself may represent a diesel engine or a gas diesel engine.

In order, after the attachment of compressor parts, to obtain the same number of strokes per minute, it is necessary that also the compressor parts are balanced. This has been realized, according to the structures of the above-mentioned copending applications, by employing one side of the compressor piston as working side, whereas the chamber on the back side of the respective compressor piston is employed for storing the work for the return or throw-back stroke. In this way, not only a balancing of the compressor parts is obtained but also the additional advantage that a compressed gas generator known per se, can, in conformity with the building block principle, be changed and converted into a compressor.

The above-mentioned constructions and advantages inherent thereto can, in most instances, no longer be employed when with a multi-stage free piston type compressor it is desired to realize a second, or third, etc. further higher compression stage, in other words if, for instance a second or third compression stage is involved which operates at pressures from 60 to 500 atmospheres. With such multi-stage compressors, the diameter of the compressor piston for the second and any higher compression stage would necessarily become relatively small so that it would be no longer possible, in the chambers on the back side of the compressor pistons, to store or accumulate sufficient work for the throw-back or return stroke of the compressor parts when the pressure increase in said chambers becomes relatively high. Such high increase in pressure brings about that the packing intended to effect the seal between each of these chambers and the respective adjacent chambers in which the return work is stored for the motor part of the respective compression stage, will no longer be able to carry out the intended function to the required extent, particularly since with such units very high piston speeds are involved which generally exceed 7 meters per second. Actual tests have proved that at present no packing material is available on the market which, while showing sufficient strength for this type of operation, will assure a proper seal.

In addition thereto, it is also to be borne in mind that the mentioned packing is to seal on one side against air and on the other side against the gas to be compressed. As a result thereof, it is easily possible that dangerous,

and above all, corroding or explosive mixtures of the gases are formed which have to be prevented under all circumstances in order to avoid endangering the lives of servicing and operating personnel.

It is, therefore, an object of the present invention to provide a multi-stage free piston type compressor which will be free from the above-mentioned drawbacks while making use of the above-mentioned construction, which has proved advantageous for the first compression stage.

It is a further object of this invention to provide a multi-stage free piston type compressor as set forth in the preceding paragraph, which will assure that also with the second and any further higher compressor stage, a sufficient compensating work for the compressor parts will be obtained within a relatively low pressure range, preferably within the corresponding pressure range of the first compression stage, so that the above-mentioned packings will have to seal at a relatively low pressure drop only.

It is still another object of this invention to provide a compressor of the above-mentioned type which is simple in construction and highly reliable in operation.

These and other objects and advantages of the invention will appear more clearly from the following specification in connection with the accompanying drawings, in which:

FIGURE 1 diagrammatically illustrates the basic form of the first compression stage of a compressor according to the present invention;

FIGURES 1*a*, 1*b*, and 1*c* by way of diagrams illustrate the operation of the first compression stage of FIGURE 1;

FIGURE 2 is a diagrammatic illustration of an embodiment of a two-stage compressor developed from the first compression stage of FIGURE 1;

FIGURES 2*a*, 2*b*, 2*c* and 2*d* illustrate by way of diagrams the operation of the two-stage free piston compressor system of FIGURE 2;

FIGURE 3 is a modified two-stage compressor developed from the first compression stage of FIGURE 1;

FIGURES 3*a*, 3*b*, 3*c* and 3*d* illustrate the operation of the two-stage compressor system of FIGURE 3;

FIGURE 4 represents a further modification of a two-stage compressor according to the present invention;

FIGURES 4*a*, 4*b*, 4*c* and 4*d* illustrate by way of diagrams the operation of the two-stroke free piston compressor system of FIGURE 4;

FIGURE 5 is still another embodiment of a two-stage free piston compressor system according to the invention as developed from the first compression stage;

FIGURES 5*a*, 5*b*, 5*c* and 5*d* illustrate by way of diagrams the operation of the two-stage free piston compressor system according to FIGURE 5;

FIGURE 6 illustrates a slight modification of a portion of the arrangement according to the invention, according to which the compressor piston is axially displaceable on the piston rod;

FIGURE 7 shows a further modification of the arrangement according to the invention, according to which a control slot is displaceable in axial direction or variable as to its effective length;

FIGURE 8 diagrammatically illustrates a modification according to the invention in which in contrast to the arrangement of FIGURE 2 the control slot is closed and the suction valve is arranged at a portion of the cylinder over which the piston pertaining thereto does not sweep;

FIGURE 9 shows an arrangement similar to that of FIGURE 8 but in addition thereto is provided with a suction filter;

FIGURE 10 diagrammatically illustrates an interconnection of FIGURES 1 and 2 and, more specifically, the interconnection of certain conduits thereof.

As mentioned above, the present invention is directed to a multi-stage free piston type compressor system the first compression stage of which is so designed that its motor part comprises a free piston compressed gas generator, while each of the two parts forming an image to each other and arranged on opposite sides of a transverse plane of symmetry comprises a prime mover piston, a return piston and a compressor piston with the pistons of each part interconnected by a piston rod so as to form a rigid system. The compressor piston has its respective outer end face perform the compressing work, while the inner balance in the compressor parts, as is necessary for the free piston system, is obtained by means of the inner end faces of the compressor piston through the intervention of control slots or suction valves, said inner end face being adapted through control slots and gas conduits to communicate with the suction lines of the compressor parts. The invention consists primarily in that the second and any further higher compression stage primarily designed corresponding to the first compression stage, for the compression of the working gas, and the storage of the work for the throw-back or return stroke for the compressor parts on each side of said transverse plane of symmetry, have respectively associated therewith separate pistons.

More specifically, according to the present invention, advantageously each second or higher compression stage of each of the two parts on each side of said transverse plane of symmetry comprises a prime mover piston, a return piston for the motor part, a compensator piston for the compressor part and a compressor piston, while the pistons on each side of said transverse plane of symmetry are interconnected to a rigid system. Preferably, the four pistons on each side of the said transverse plane of symmetry are, by piston rods, interconnected to a rigid system and with the second and any higher compression stage are, when viewed from said transverse plane of symmetry toward the outside in axial direction of the piston, arranged in the following sequence: prime mover piston—return piston for the motor part—compensator piston for the compressor part—compressor piston. In view of the present invention to allot the compression work proper and the storage of work for the return stroke of each compressor part to different pistons, the above-mentioned difficulties encountered heretofore for the second and any higher compression stage, will be properly avoided.

For purposes of starting the second and any further higher compression stage of the compressor system, preferably both compressor sides of each compression stage will have associated therewith a common pressure accumulator, or each of the compressor sides may have a separate pressure accumulator associated therewith. Such pressure accumulator may, if desired, be fed through a check valve with working gas of the compressor from a chamber or a conduit in which a sufficient pressure prevails. If desired, such pressure accumulator or accumulators may through conduits with a starting valve be connected to the compression chambers of compressor cylinders provided with plungers and arranged on both sides of said transverse plane of symmetry and pertaining to the respective compression stage.

The two-or-more-stage compressor according to the present invention is advantageously further designed so that in conformity with the building block principle, important parts of the first or other lower compression stage may, under slight changes, be made useful for the second or any other higher compression stage. Accordingly, the invention provides that the arrangements provided in pairs and each comprising the respective rigidly interconnected prime mover piston, return piston and compressor piston, and the respective cylinders pertaining thereto of a lower compression stage, may be employed for one or more higher compression stages. To this end the compressor pistons of the lower compression stage will, with one of the higher compression stages, take over the function of compensator pistons which, in the outward direction with regard to the transverse plane of symmetry, are followed by the corresponding compressor pistons and cylinders pertaining to the higher compression stage or stages.

Referring now to the drawings in detail, the free piston system according to FIG. 1 comprises a combustion chamber **1** of a prime mover, preferably a diesel engine or a gas diesel engine. The combustion chamber **1** is formed by a prime mover cylinder **2** having reciprocably mounted therein a prime mover piston **3** which latter is connected by a piston rod **4** to a return piston **5** acting as scavenging pump piston. Piston **5** is reciprocably mounted in a cylinder **6** which together with piston **5** confines a chamber **7** for the compression of scavenging air and a chamber **8** for storing the throw-back or return work for the motor part. Chamber **8** acts in the manner of a gas spring, its spring medium generally consisting of air.

A piston rod **9** passing through a seal or packing **10** connects the return piston **5** to a compressor piston **11** reciprocable in a compressor cylinder **12**. If desired, compressor piston **11** may be axially displaceably mounted on piston rod **9**. Such an arrangement is shown for instance in FIGURE 6 of the drawings. More specifically, with regard to FIGURE 6, the arrangement shown therein comprises a piston rod **9** the offset end **9***a* of which has connected thereto piston **11** and for instance two spacer members **23** clamped in by means of a hexagon nut. By inserting the said parts in different sequence, in the illustrated example, three different positions of the compressor piston **11** will be obtainable.

The change in the axial location and/or length of the control opening may, for instance, in conformity with FIGURE 6 be obtained by providing a plurality of control bores **19'** instead of the control slot **19**. The two outer control bores **19'** may be closed by valves. Each valve comprises in a manner known per se a valve core **22**, a spindle **26**, a handwheel **27**, a stuffing box **23** with packing **23'**, and a gland **24**.

If, for instance, the left-hand valve is opened (position **22'**), the compression of the gas volume in chamber **14** will commence only when the front piston ring has passed over the left-hand bore **19'**. By closing this valve, the compression chamber **14** is extended by a corresponding section. In a similar way it is possible by closing or opening the right-hand valve to increase or lower the accumulator pressure in chamber **13**. The chamber **13** adjacent the back face end **11***a* of compressor piston **11** serves for storing the throw-back or return work for the compressor part. Also this chamber **13** acts in the manner of a gas spring. Its spring medium is the gas which is to be compressed in the compressor and may, for instance, consist of air. That portion of compressor cylinder **12** which is adjacent the front end face **11***b* of compressor piston **11** forms the working chamber **14** of the compressor. The compressor compartment comprises a suction conduit **15** for the gas to be compressed, a pressure conduit **16** for the compressed gas, and suction valve **17** and a pressure valve **18**. The reference numeral **19** designates a control slot which may be so designed as to be displaceable in axial direction. If desired, it may also be variable as to its length as shown for instance in FIGURE 6. Both possibilities of variation may be provided at the same time. The arrangement furthermore comprises a gas conduit **20** leading from the suction conduit **15** through the control slot **19** to the chamber **13** of the gas spring of the compressor part.

The operation and thereby the respectively obtained effects will be evident from the diagrams of FIGS. 1*a*, 1*b* and 1*c* which, however, are presented merely for purposes of example. Of these diagrams, "A" represents the working diagram for the combustion chamber **1** of the prime mover (diesel engine) with the essential portions a_1 indicating the compressing stage, a_2 indicating the heat supply by combustion, a_3 indicating the expansion, and a_4 indicating the scavenging (FIG. 1*a*).

"B" represents the scavenging air diagram for the scavenging air compression chamber 7 with the two essential diagram sections b_1=intake, b_2=discharge (FIG. 1*b*).

FIG. 1*b*, "C" represents the diagram of the gas spring in chamber 8 which has no delivery but merely shows a pressure going upwardly and downwardly in conformity with the stroke.

FIG. 1*c*, "D" is the diagram of the gas spring in chamber 13 which has no delivery but shows a rising and falling pressure in conformity with the stroke.

"E" is the working diagram of the compressor which, for instance compresses from an intake pressure of about 20 atmospheres to a compression pressure of approximately 60 atmospheres. The essential portions of the said diagram are e_1=intake, e_2=compression, e_3=discharge of the compressed gas, and e_4=expansion.

If the second compression stage were adapted to the fundamental structure of the first compression stage according to FIG. 1, it will be appreciated that at a reduced diameter of the compressor piston 11, the pressures in chambers 14 and 13 would be considerably higher, which would entail all difficulties that result for the packing of the seal 10 from a great pressure drop between chambers 13 and 8.

According to the arrangement of FIG. 2, these difficulties with the second compression stage have been overcome by the fact that the compressor piston 11 of the first compression stage, at the same dimensions, does in the second compressing stage, take over the function of a compensator piston 11'. The exclusive purpose of the compensator piston consists in storing a compensating work.

Those parts of the second compressor stage according to FIG. 2 which have been designated with the reference numerals 1 to 10 correspond to those respective parts of the first compressing stage according to FIG. 1 which carry the same reference numerals and correspond to the same not only with regard to the structural dimensions but also with regard to their functions. The structural dimensions of parts 11' and 12' in FIG. 2 likewise precisely correspond to those of similar parts in FIG. 1. However, the parts 11' and 12' have a new function insofar as 11' now acts only as a compensator piston, whereas part 12' only acts as compensator cylinder. Connected to the compensator piston 11' by means of a piston rod 9'' is the compressor piston 11'' of the second compressing stage, said compressor piston 11'' being reciprocable in the compressor cylinder 12''. The arrangement shown in FIG. 2 furthermore comprises a suction conduit 15'', a pressure conduit 16'', a suction valve 17'', a pressure valve 18'' and the working chamber 14'' of the compressor of the second compressing stage.

In structural respect, the elements of the first compressing stage, when employed as second compressing stage, have undergone only minor changes. More specifically, the suction valves 17 and pressure conduit 16 with the lid pertaining to cylinder 12 and containing the pressure valve 18 have been eliminated, and instead of the said lid, the compressor piston 11'' has been connected to the piston 11' now forming the compensator piston. This makes it possible to make use of the building block principle when converting the first compressing stage into the second compressing stage, and thus also reduces the keeping of stock.

The functions of the chambers 1, 7, 8 and 13 with the second compressing stage according to FIG. 2 are precisely the time as they were with the first compressing stage according to FIG. 1. Also the pressure range in chamber 13 for storing work for the throwback or return stroke of the compressor part has been retained with the second compressing stage. Since chamber 13 communicates through control slot 19 and overflow conduit 20' with conduit 15', which latter is advantageously connected to the suction line of the first compressing stage (as shown in FIGURE 10), the following diagrams are obtained with regard to FIG. 2 (see FIGS. 2*a*, 2*b*, 2*c*, 2*d*).

The diagrams A, B, C and D are, with the embodiment of the second compressing stage according to FIG. 2, the same as with the first compressing stage according to FIG. 1. The outer end face 11*b'* of the compensator piston 11' and the back side 11*a''* of the compressor piston 11'' which back side faces the outer end face 11*b'* merely bring about a moving back and forth of the working gas in conduit 15' without any performance of work. This is clearly evident from the diagram E' of FIG. 2*c*. With the embodiment according to FIG. 2, the entire stroke volume is drawn in on the outer end face 11*b'* and is discharged, and on the inner end face 11*a*, that quantity of gas is taken in and discharged which corresponds to the stroke volume up to the movement over the control slot 19. The quantities of gas moved back and forth correspond to the horizontal diagram portions in the diagram D and E' of FIG. 2*c*. The work stored in chamber 13 corresponds to the difference in the surfaces below the curves D and E'. In conformity with the character of the second compressing stage, the working diagram E'' (FIG. 2*d*) of the compressor of FIG. 2 is located within a higher pressure range than the working diagram E of the first compressing stage of FIG. 1.

The pressure ranges in the individual working chambers of the embodiment of FIG. 2 are as follows. In chamber 1, approximately from 1 to 80 atmospheres, in chamber 7, approximately from 1 to 1.4 atmospheres, in chamber 8, approximately from 1 to 4.2 atmospheres, in chamber 13, approximately from 20 to 60 atmospheres, in chamber 14' approximately 20 atmospheres, and in chamber 14'' approximately from 60 to 180 atmospheres.

If the arrangement of FIG. 2 would run as third compressing stage, it would be necessary, as far as the structure of the elements to be added is concerned, merely to adapt the diameters of the compressor piston 11'' and the compressor cylinder 12'' to these pressure conditions, whereas in functional respect, merely the pressure range in chamber 14'' would be approximately from 180 to 500 atmospheres. In a corresponding manner, analogous changes would be necessary when a further higher pressure stage were desired.

The above listed pressures including the assumed initial pressure of the working gas in the suction conduit of the first compressing stage, i.e. 20 atmospheres, are, of course, to be understood as by example only. They vary according to the respective starting conditions and in conformity with the desired conditions of operation.

The invention yields the advantage that the load on the packing of seal 10 will be independent of the peak pressure in the working chamber 14'' of the compressor. The pressure in chamber 13 is, with all stages of the multistage compressor, always the same and can, without difficulty, be held within such limits that the packings of the seals 10 will also over a long period of operation, seal in a completely proper manner.

Referring now to the embodiment of FIG. 3, fundamentally the same remarks apply thereto as have been set forth in connection with FIG. 2. The particular feature of FIG. 3 is to be seen in the fact that the function of the control slot 19, according to FIGS. 1 and 2, has been eliminated by a suction valve 19*a* in such a way that throughout the entire piston stroke, gas is being compressed in chamber 13 so that also the work stored in this chamber 13 is greater than that stored with the embodiment of FIGS. 1 and 2. This is evident from the difference in the diagram D' according to FIG. 3*c* in comparison to the diagram D of FIGS. 1 and 2. The diagrams E' and E'' of FIGS. 3*c* and 3*d* do not show any difference over the corresponding diagrams in FIG. 2. However, in distinction from the embodiment of FIG. 3 also the control slot 19 may be closed and the suction valve may be located at such a portion of the cylinder 12' that piston 11' does not move thereover (FIGURES 8 and 9).

The pressure ranges in chambers 1, 7, 8, 13, 14' and

14″, according to the embodiment of FIG. 3, may be the same as indicated with the embodiment of FIG. 2.

According to the particularly simple embodiment of FIG. 4, the structural adaptations to FIG. 1 are substantially the same as those of FIGS. 2 and 3. With FIG. 4, however, there exists the difference that the suction conduit **19b** which advantageously communicates with the suction side of the first pressing stage (in the assumed examples approximately 20 atmospheres) is directly connected to the control slot **19**, whereas the chambers **14′** and **20′** communicate through the normal suction connection of conduit **15′** with a gas chamber having a considerably reduced pressure, for instance, a pressure of from 0.5 to 1.5 atmospheres. The slight overpressure above atmospheric pressure in chamber **14′** as well as in the connecting chambers pertaining thereto is required only when the air surrounding the unit could, when entering the working chambers of the entire installation, develop explosive or other dangerous gas mixtures. When suitable compressor gases are available, the suction conduit **19b** may also be connected to a foreign pressure source. The advantage of the embodiment of FIG. 4 consists in that it is able to store a higher compensating work for the throw-back of the compressor part. It will be appreciated that the magnitude of this compensating work corresponds, as is the case with all embodiments, to the difference in the surfaces below the curves of the diagrams D, E′ and D′ and E′. Since with FIGS. 2 and 3 the curves E′ are located in a pressure range of approximately 20 atmospheres, whereas with the embodiment of FIG. 4 they are located in a pressure range of approximately 1 atmosphere, it will be evident that with the arrangement of FIG. 4, the stored compensating work increases to the extent of the lower location of the diagram curve E′ in the lower pressure range. This is a result of the structural arrangement of FIG. 4.

A particular advantage of the FIG. 4 arrangement is to be seen in the fact that on the outer side **11b′** of the compensator piston **11′**, a gas of lower density corresponding to the lower pressure (approximately 1 atmosphere instead of 20 atmospheres) is moved back and forth whereby the lost work is reduced. If desired, merely atmospheric air may be drawn in and discharged through a suction filter. If gas to be compresesd is involved which, together with air, would form corrosive or explosive mixtures, care is to be taken that the respective stroke volume is greater than the total of the gas guiding chambers up to the filter. With the embodiment according to FIG. 4, piston **11′** must have a sufficient length in order to be able to prevent a short-circuit between the conduits **15′** and **19b**.

The embodiment of FIG. 5 insofar reflects a certain combination of the embodiments according to FIGS. 3 and 4 as each of these two embodiments has furnished some features. The arrangement of FIG. 5 has in common with FIGS. 3 and 4 the feature that the second as well as any further higher compressing compensator cylinders **12′** are arranged between the cylinder **6** for the throw-back piston **5** of the motor parts on one hand, and the compressor cylinders **12″** on the other hand. In these compressor cylinders **12′** there are reciprocably arranged compensator pistons **11′**.

The arrangement of FIG. 5 has taken over from the embodiment of FIG. 4 that the chambers **14′** between the pistons **11′** and **11″** are connected through conduits **15′** with pressureless chambers or with the atmosphere or are connected to pressure containers at a slight over-pressure of approximately from 0.5 to 1.5 atmospheres. On the other hand, FIG. 5 has embodied from the arrangement of FIG. 3 the feature that the inner compensation in the compressor parts necessary for the free piston principle, is obtained by the back sides **11a** of the compressor piston **11′** through suction valves **19a** inserted into the control slots **19**. The compensator pistons **11′** are connected through suction valves **19a** and gas conduits **19b** with the suction pressure of the first compressing stage, for instance at approximately 20 atmospheres, or communicate with another pressure level of the working gas. The pressure in conduit **19b** may be adjustable. In addition thereto, FIG. 5 may be varied in such a way that the control slot **19** is closed and the suction valve **19a** is connected to a portion of the compensator cylinder **12′** over which the compensator piston **11′** does not move.

The advantage of this combined embodiment consists in that above all embodiments it is able to store the greatest amount of throw-back work. This is evident from the curves D′ and E′ in FIG. 5c. The pressure level in conduit **19b**, which may be variable by means of a reducing valve inserted in said conduit **19b**, makes it possible to vary the stored throw-back work inasmuch as the diagram curve D′, according to FIG. 5, would then be transformed to D_1' (see FIG. 5c). This represents one of the various possible means for correcting errors occurring when designing the machine or for adapting the arrangement to different conditions of operation as caused by different gases to be compressed.

An advantage of the embodiment of FIG. 2 consists in that the compressor cylinder of the first compressing stage may be employed without the slightest changes for the second and any further higher compressing stage. The embodiment according to FIG. 3 requires the addition of a suction valve **19a** but brings about the additional advantage that the work stored in chamber **13** is greater than that with the embodiment of FIG. 2 which, however, due to the higher compression pressure with the curve *d′* results in a somewhat higher load on the stuffing-box packing of seal **10**. With the embodiment of FIG. 4, a particular advantage is obtained inasmuch as the end pressure of the compressing course of the diagram curve D precisely corresponds to the end pressure obtained with the embodiment of FIGS. 1 and 2, whereas the work stored in chamber **13** is higher. The maximum possible stored work for the throw-back stroke of the compressor parts is obtained with the embodiment of FIG. 5.

With the embodiments of FIGS. 2, 3, 4 and 5, it was assumed that a second compressing stage was involved. In an analogous manner the same advantages are obtained when, with the embodiments of FIGS. 2, 3, 4 and 5, a further higher compressing stage was involved.

With all compressing stages, the two halves arranged as an image to each other on opposite sides of the transverse plane of symmetry X–Y of the entire unit of each stage, may be coupled to each other by any standard structural elements for purposes of obtaining a synchronous movement in opposite direction of their two movable systems consisting of the rigidly interconnected parts **3–4–5–9–11′–9″–11″**.

With each second or higher pressure stage, the work stored in chamber **13** for the throw-back stroke of the compressor part may be varied by certain additional structural features whereby structural errors made during the designing of the machine may be compensated for and by means of which it is possible to adapt the arrangement to different gases to be compressed with different polytrope exponents. Such possibilities of adaptation consist, for instance, in changing the structural dimensions, especially the length of the compensator piston **11′**, in the displaceable arrangement of the compensator piston **11′** on its piston rod, in the change of the axial position and/or the length of the control slot **19**, and in the change of the dead space with regard to chamber **13** by connecting chamber **13** with one or more additional chambers which may be added individually or by groups to said chamber **13**, and of which one or more may be varied as to their size. This may be effected by forming the additional chamber or chambers by a cylinder or cylinders whose piston may be adjustable. The variation of the length and/or the axial location of the compressor piston **11′** may, in conformity with the arrangement of FIGURE

7, be obtained by composing the piston of two sections. These two sections may, in different arrangement with the two spacing members 25′ be arranged on piston rod 9. There will then be obtained the arrangement shown for instance on the lower side of the piston rod according to which the two piston sections are located on the left-hand side and the two reduction members are located on the right-hand side or according to the upper side of the piston rod, the two piston sections may be located on the outside and the two reduction members may be located in the center. It will be obvious that similar further variations are easily possible.

The variation in the length and the axial arrangement of the control opening 19′ is, as has been described in connection with FIGURE 6, obtainable by opening or closing one of the two valves 22 so that either all four control openings 19′ or only the two central ones or only the three right-hand ones or the three left-hand ones may be open. The variations in the dead chamber with regard to chamber 13 may be effected steplessly or in steps. When a stepless variation is desired, piston 43 is, by means of handwheel 39 adjusted in housing 42. In this way, the additional chamber 38 communicating through bore 36 with chamber 13 is changed in a stepless manner. By opening or closing valve 30, chamber 32 may through bore 31 be brought into communication with chamber 13 or may be disconnected therefrom so that chamber 13 may be varied by the volume of chamber 32.

All of the above-mentioned various possibilities are adapted to serve primarily two purposes. As has been mentioned above, these means are adapted to compensate for errors in dimensions which occurred when the machine unit was designed. Furthermore, these possibilities represent advantageous means by which the compressor can be adapted to different gases to be compressed. It will be appreciated that with the operation of compressors with different gases, i.e. with gases of different polytrope exponents, the course of the compression and expansion in the working chambers of the compressor varies, which fact makes necessary special means by which the compressor of the driving machine can be modified inasmuch as the work stored for the return of each compressor piston will be so controlled that also the compressor parts of the entire unit will have the character of a balanced machine. Such conditions prevail when earth-gases of different earth-gas fields are to be compressed by means of a free piston type compressor. The adapting means of the gas chambers which may be connected additionally to the plunger piston cylinder for increasing the dead chamber thereof, yield the particular advantage that by means thereof the machine can be varied in its condition of operation. If it is desired to employ the machine in a universal manner, the said possibilities of adaptation to the respective conditions of operation are necessary.

When starting the second and each following higher compression stage of the compressor installation, it is advantageous to add to both compressor sides of each compressing stage a common pressure accumulator or to add to each compressor side an individual pressure accumulator. Such common or additional pressure accumulator may be fed through a check valve with working gas of the compressor from a chamber or a conduit of sufficient pressure height of the entire installation and may through conduits with starting valves, be connected to the compressing chambers of the compressor cylinders which are equipped with plunger pistons and are arranged on both sides of the transverse central plane and pertaining to the respective compressing sides.

It is, of course, to be understood that the present invention is, by no means, limited to the particular constructions shown in the drawings, but also comprises any modifications within the scope of the appended claims.

What we claim is:

1. A free piston type compressor structure having two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axis of said units, in which each of said cylinder piston units comprises: prime mover cylinder piston means, return cylinder piston means for storing the work for the return stroke of the piston means of said prime mover cylinder piston means, compressor cylinder piston means for compressing a medium to be compressed, said compressor cylinder piston means including first inlet and discharge means for conveying the medium to be compressed into and discharging the compressed medium from the cylinder means of said compressor cylinder piston means, additional cylinder piston means for storing the work for the return stroke of the compressor piston of said compression cylinder piston means, and piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder unit.

2. A free piston type compressor structure having two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units includes: a prime mover piston reciprocable in said prime mover cylinder, a return piston reciprocable in said return piston cylinder, a compensator cylinder, a compensator piston reciprocable in said compensator cylinder and having a front end face and a rear end face, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit, first inlet means communicating with said compensator piston at said front and rear end faces thereof and adapted to be connected to the inlet means of a compressor chamber of a lower stage compressor, second inlet means leading to that end face of said compressor piston which faces away from said compensator piston, and discharge means for discharging the medium compressed by that side of said compressor piston which faces away from the adjacent compensator piston.

3. A free piston type compressor structure having two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment and in the following succession: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return piston cylinder, a return piston reciprocable in said return piston cylinder, a compensator cylinder, a compensator piston reciprocable in said compensator cylinder and having a front end face and a rear end face, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit, first inlet means communicating with said compensator piston at said front and rear end faces thereof and adapted to be connected to the inlet means of a compressor chamber of a lower stage compressor, second inlet means leading to that end face of said compressor piston which faces away from said compensator piston, and discharge means for discharging the medium compressed by that side of said compressor piston which faces away from the adjacent compensator piston.

4. A free piston type compressor structure having a first compression stage and at least a second compression stage, each of said compression stages comprising two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return cylinder, a return piston reciprocable in said return cylinder, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, and piston rod means rigidly interconnecting all of

the pistons of the respective one and the same cylinder piston unit; each cylinder piston unit of each compression stage higher than said first compression stage additionally including compensator cylinder piston means arranged in axial alignment with but interposed between the return cylinder of the respective cylinder piston unit and the compressor piston thereof; each of said compressor cylinders having intake and outlet conduit means for taking in the medium to be compressed and for discharging the compressed medium respectively; first connecting means establishing communication between the intake conduit means of said first compression stage on one hand and the cylinder chamber means between the compressor piston of said second stage compressor and the piston means of said compensator cylinder piston means thereof on the other hand, second conduit means for establishing communication between said outlet conduit means of said first compressor stage and said intake conduit means of said second compression stage, and third conduit means adapted to establish communication between said second conduit means and that side of said compensator piston means which faces away from the respective adjacent compressor piston.

5. A compressor structure according to claim 4, in which the cylinder means of the respective compensator cylinder piston means comprises suction valve means located beyond the stroke of said compensator piston means.

6. A compressor structure according to claim 4, which includes means for varying the effective dimensions of said compensator cylinder piston means.

7. A compressor structure according to claim 4, in which the piston means of said compensator cylinder piston means is adjustable on the piston rod means connected thereto.

8. A compressor structure according to claim 4, which includes at least one accumulator means for each compression stage higher than said first compression stage, said accumulator means being adapted to be connected to the respective compression cylinder for starting the respective higher compression stage.

9. A compressor structure according to claim 4, in which the cylinder means of the respective compensator cylinder piston means comprises slot means controlled by the respective adjacent compensator piston means and communicating with said third conduit means.

10. A compressor structure according to claim 9, which includes suction valve means inserted in slot means.

11. A compressor structure according to claim 8, which includes means for permitting loading of said accumulator means by the respective compressor pertaining thereto.

12. A free piston type compressor structure having a first compression stage and at least a second compression stage, each of said compression stages comprising two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return cylinder, a return piston reciprocable in said return cylinder, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, and piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit; each cylinder piston unit of each compression stage higher than said first compression stage additionally including compensator cylinder piston means arranged in axial alignment with but interposed between the return cylinder of the respective cylinder piston unit and the compressor piston thereof; each of said compressor cylinders having intake and outlet conduit means for taking in the medium to be compressed and for discharging the compressed medium respectively; second conduit means leading to the cylinder space between the respective compressor pistons of said second compression stage and the respective adjacent compensator piston means of said compensator cylinder piston means, said second conduit means being adapted to be connected with a source of a gaseous medium; slot means respectively provided in the cylinder means of said compensator cylinder piston means of the said second compression stage, said slot means being controlled by the respective adjacent compensator piston means, and third conduit means communicating with said slot means for communication with the intake conduit means of said first compression stage.

13. A compressor structure according to claim 12 in which said second conduit means is connected to the atmosphere.

14. A compressor structure according to claim 12 in which said second conduit means is connected to a source of a gaseous medium having from 0.5 to 1.5 atmospheres above atmospheric pressure.

15. A compressor structure according to claim 12, which includes means for varying the gas pressure in said second conduit means.

16. A compressor structure according to claim 12, in which said slot means is variable as to its length.

17. A compressor structure according to claim 12, in which said slot means is variable as to its location.

18. A free piston type compressor structure having a first compression stage and at least a second compression stage, each of said compression stages comprising two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return cylinder, a return piston reciprocable in said return cylinder, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, and piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit; each cylinder piston unit of each compression stage higher than said first compression stage additionally including compensator cylinder piston means arranged in axial alignment with but interposed between the return cylinder of the respective cylinder piston unit and the compressor piston thereof; the respective compressor piston of each cylinder piston unit being rigidly connected to the respective adjacent compensator piston means of said compensator cylinder piston means by the respective adjacent piston rod means, the cylinder space between each compressor piston and the respective adjacent compensator piston means of each higher compression stage than said first compression stage communicating with a source of a gaseous medium; each of said compensator cylinder means of said compensator cylinder piston means being provided with a slot controllable by the respective adjacent compensator piston means, suction valve means inserted in said slot means, and conduit means for establishing communication between said suction valve means and a source of a gaseous medium.

19. A compressor structure according to claim 18, which includes reducing valve means for varying the pressure in said last-mentioned conduit means.

20. A free piston type compressor structure having a first compression stage and at least a second compression stage, each of said compression stages comprising two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return cylinder, a return piston reciprocable in said return cylinder, a compressor

cylinder, a compressor piston reciprocable in said compressor cylinder, and piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit; each cylinder piston unit of each compression stage higher than said first compression stage additionally including compensator cylinder piston means arranged in axial alignment with but interposed between the return cylinder of the respective cylinder piston unit and the compressor piston thereof; the respective compressor piston of each cylinder piston unit being rigidly connected to the respective adjacent compensator piston means of said compensator cylinder piston means by the respective adjacent piston rod means, the cylinder space between each compressor piston and the respective adjacent compensator piston means of each higher compression stage than said first compression stage communicating with a source of a gaseous medium; suction valve means respectively inserted in the cylinder means of said compensator cylinder piston means beyond the stroke of the compensator piston means thereof, and conduit means for establishing communication between said suction valve means and a source of a gaseous medium.

21. A compressor structure according to claim 20, which includes reducing valve means for varying the pressure of said last-mentioned conduit means.

22. A free piston type compressor structure having a first compression stage and at least a second compression stage, each of said compression stages comprising two axially aligned cylinder piston units arranged as an image to each other at opposite sides of a plane of

symmetry transverse to the axes of said units, in which each of said cylinder piston units when viewed from said plane of symmetry includes in axial alignment: a prime mover cylinder, a prime mover piston reciprocable in said prime mover cylinder, a return cylinder, a return piston reciprocable in said return cylinder, a compressor cylinder, a compressor piston reciprocable in said compressor cylinder, and piston rod means rigidly interconnecting all of the pistons of the respective one and the same cylinder piston unit; each cylinder piston unit of each compression stage higher than said first compression stage additionally including compensator cylinder piston means arranged in axial alignment with but interposed between the return cylinder of the respective cylinder piston unit and the compressor piston thereof; and means connectable to that portion of said compensating cylinder means of said compensator cylinder piston means which is located beyond the respective compensator piston means pertaining thereto and the adjacent return cylinder, each of said compressor cylinders having intake and outlet conduit means for taking in the medium to be compressed and for discharging the compressed medium respectively.

23. A compressor structure according to claim 22, in which said last-mentioned means is formed by cylinder piston means with adjustable piston means.

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