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(54) STARTING METHOD FOR A PISTON COMPRESSOR AND PISTON COMPRESSOR

(75) Inventor: Stefan Zeh, Wangen (DE)

Correspondence Address:
LERNER GREENBERG STEMER LLP
P O BOX 2480
HOLLYWOOD, FL 33022-2480 (US)

(73) Assignee: Diehl AKO Stiftung & Co. KG

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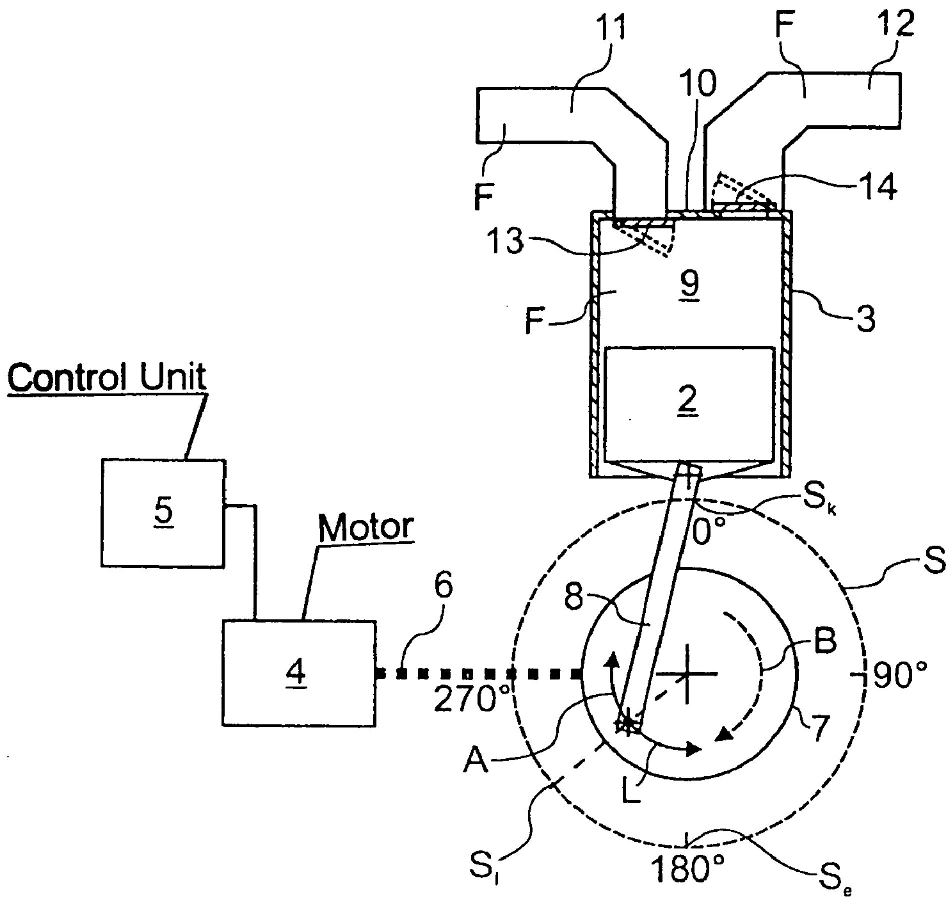
(57) ABSTRACT

In an effective method for starting a piston compressor which is easy to implement, and a piston compressor suitable for carrying out the method, there is provision, in a resetting phase, for driving a piston of the piston compressor in the direction of a compression point of the piston position by the application of a resetting drive moment. The resetting drive moment being maintained until the piston has reached a starting position by overstepping a steady-state point as a result of displacement of fluid out of the compression space, formed between the piston and a corresponding pressure cylinder, through at least one leakage point. In a subsequent acceleration phase, the piston is then accelerated out of the starting position into an operational direction of rotation with a starting drive moment.



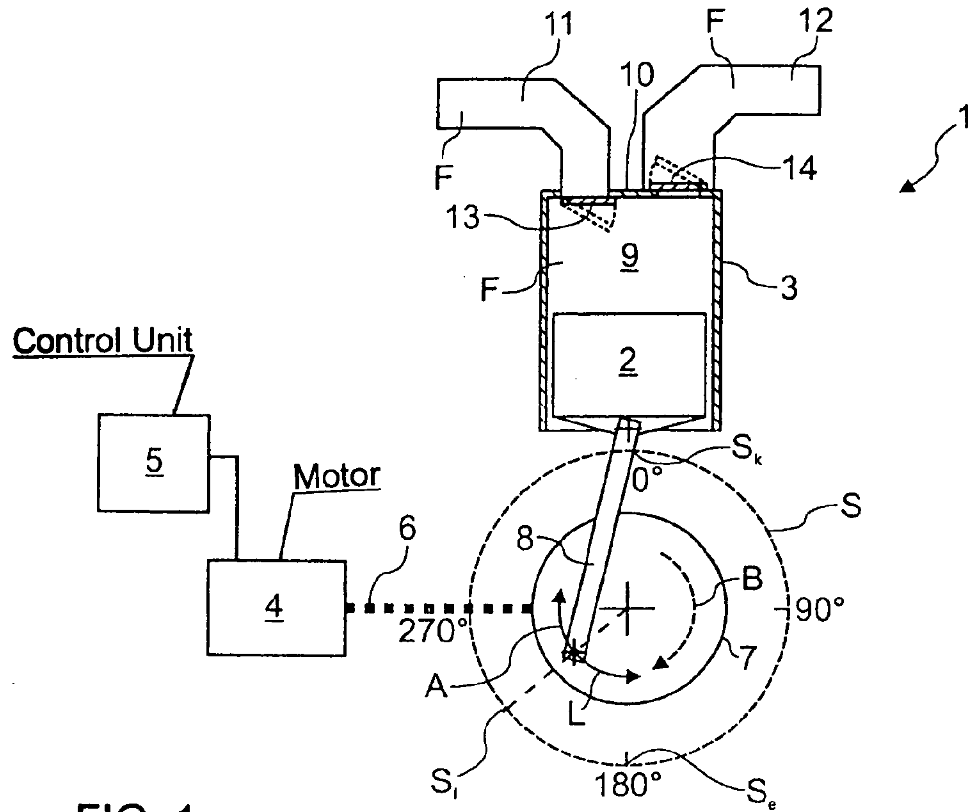

11
F
12
10
1
F
14
13
9
F
3
Control Unit
2
5
Motor
S_k
0°
S
6
8
B
4
90°
270°
7
A
L
S_i
180°
S_e

FIG. 1

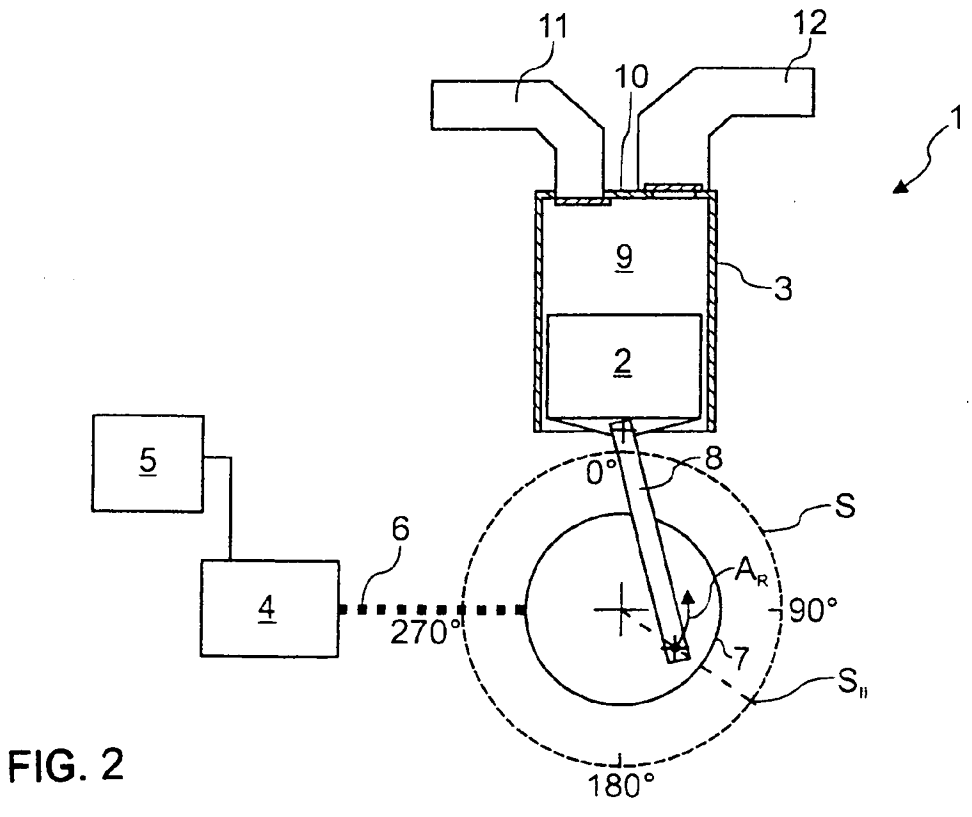
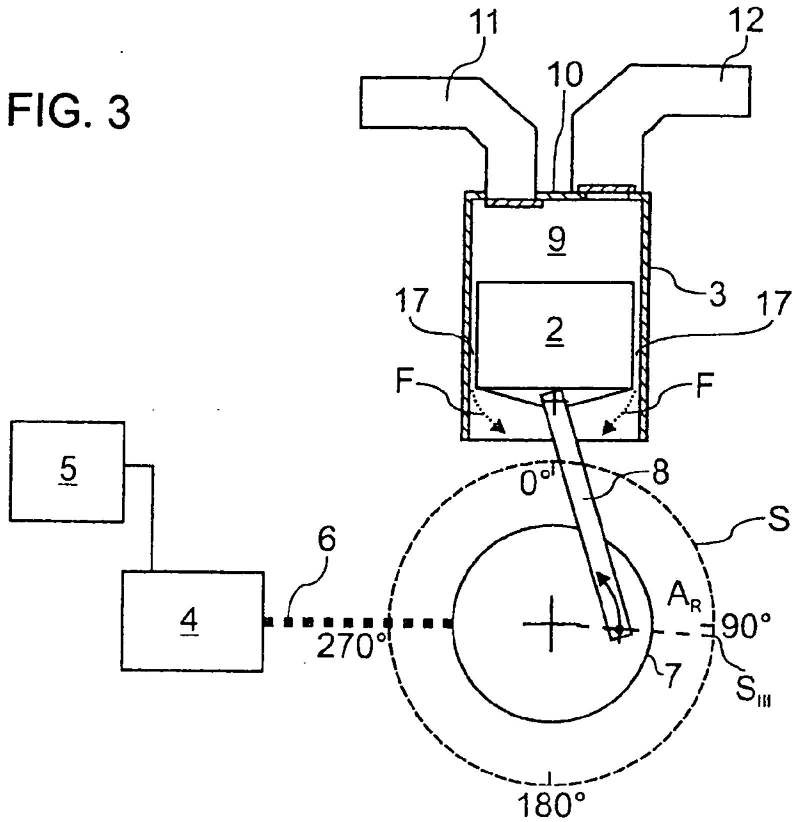

11
12
10
1
9
3
2
5
0°
8
S
6
A_R
4
90°
270°
7
S_{II}
180°

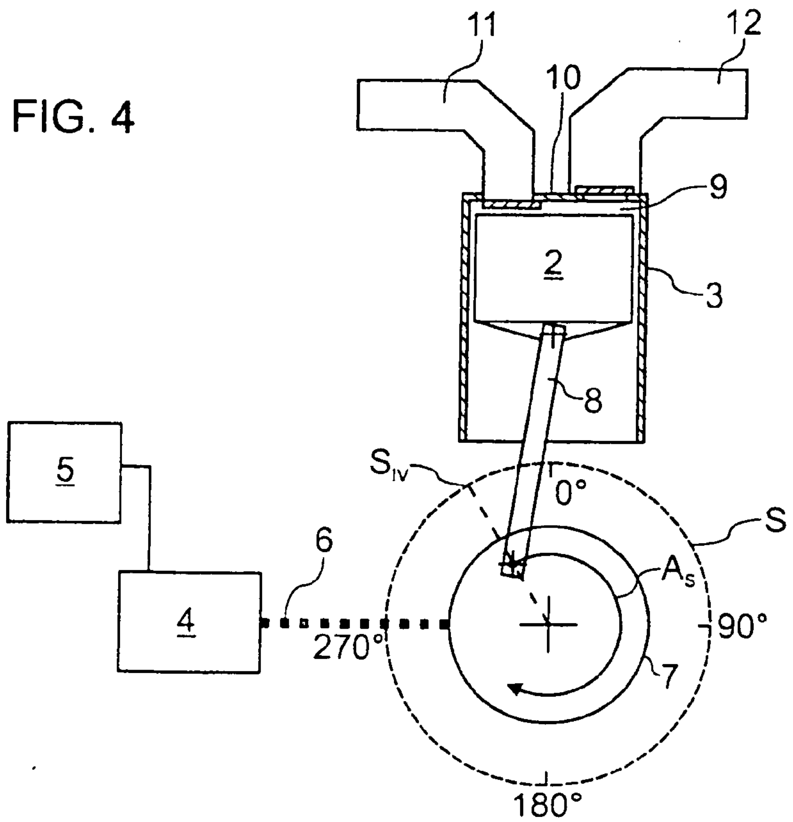
FIG. 2

FIG. 3



11
12
10
1
9
3
17
2
17
F
F
5
0°
8
S
6
4
A_R
270°
90°
7
S_III
180°

FIG. 4



11
12
10
1
9
2
3
8
5
S_IV
0°
S
6
A_S
4
270°
90°
7
180°

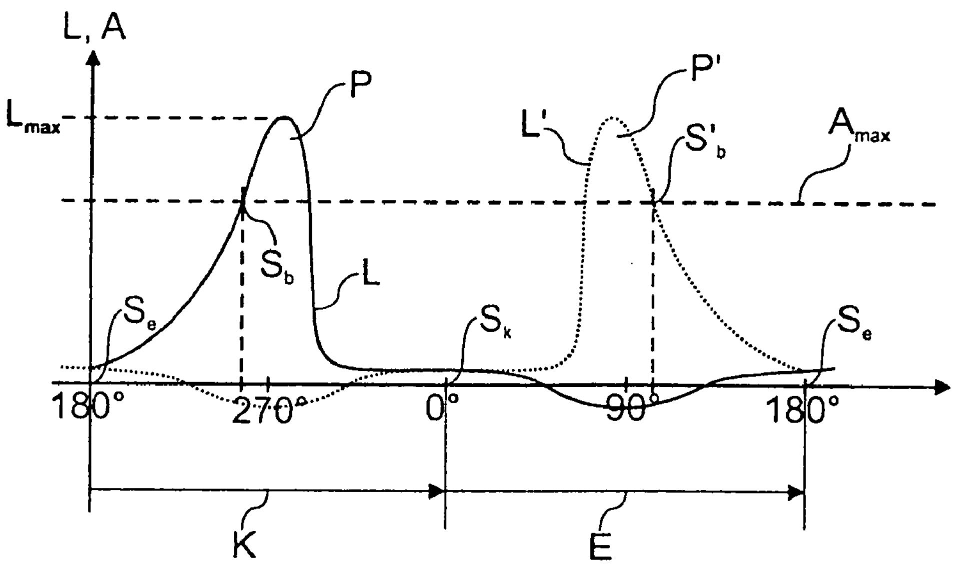

L, A
L_{max}
P
L'
P'
S'_b
A_{max}
S_b
L
S_e
S_k
S_e
180°
270°
0°
90°
180°
K
E

FIG. 5

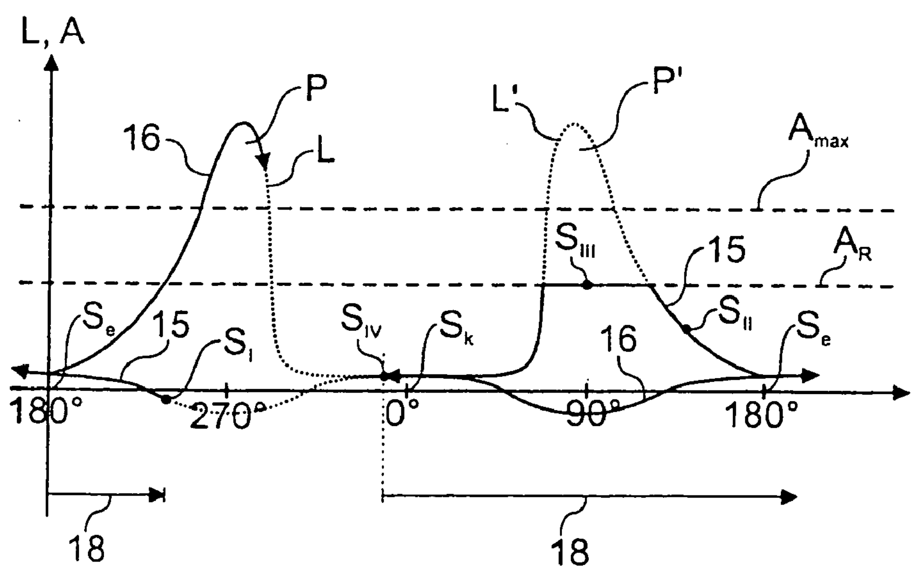

L, A
P
16
L
L'
P'
A_{max}
S_{III}
15
A_R
S_e
15
S_I
S_{IV}
S_k
16
S_{II}
S_e
180°
270°
0°
90°
180°
18
18

FIG. 6

STARTING METHOD FOR A PISTON COMPRESSOR AND PISTON COMPRESSOR

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The invention relates to a method for starting a piston compressor. The invention relates, furthermore, to a piston compressor operating according to the method.

[0002] A piston compressor conventionally has at least one piston which can be moved in a pressure cylinder by a motor in such a way that the volume of a compression space formed between the pressure cylinder and the piston is periodically expanded and compressed in the course of the piston movement. During the expansion phase, in this case a compressible fluid, in particular a refrigerant such as R600a, for example, is sucked into the compression space through an inlet valve provided in the pressure cylinder. During the subsequent compression phase, the sucked-in fluid is compressed and expelled under increased pressure through an outlet valve of the pressure cylinder. The piston position which identifies the transition from a compression phase into a subsequent expansion phase is designated below as the compression point. In a similar way to this, that piston position which identifies the transition between an expansion phase and a subsequent compression phase is designated as the expansion point.

[0003] The designation "piston compressor" relates both to a reciprocating-piston compressor and to a rotary-piston or rolling-piston compressor. Where a reciprocating-piston compressor is concerned, a piston is movable linearly in the pressure cylinder. The piston of such a reciprocating-piston compressor is conventionally driven by a rotating eccentric. Where a rotary-piston cylinder is concerned, the piston, by contrast, is driven in rotation directly via a drive shaft and rotates with respect to the pressure cylinder. Without restriction to one of these two forms of construction, the rotary position of the drive shaft or of the eccentric is adopted below as a measure of the piston position, so that reference to a specific piston position of a reciprocating-piston compressor is also in the form of a given angle value. The sequence of an expansion phase and of a subsequent compression phase, to which, as a rule, a full rotation of the drive shaft or of the eccentric through 360° corresponds, is designated as the work cycle of the piston compressor.

[0004] When a piston compressor is in operation, a load moment occurs which fluctuates periodically with the work cycle and which, as a rule, passes through a pronounced maximum (designated below as the load peak) in the course of the compression phase. It is customary to configure an electronically regulated piston compressor in such a way that the maximum drive moment of the motor undershoots the maximum value of the load moment occurring during the load peak. In operation, the load peak is overcome by the inertia of the piston compressor, that is to say by the kinetic energy stored in a flywheel mass.

[0005] When a piston compressor is started, the momentum required for this purpose is not available, so that a usual piston compressor often cannot be started by its inherent force, or at least not from every piston position. In order to increase the momentum travel and thus make self-starting easier, the piston of the piston compressor is sometimes rotated backwards, opposite to an operational direction of rotation, before the actual starting operation. In a conventional piston compressor, the backward rotation of the piston is terminated at the latest in a piston position in which the maximum drive torque of the motor corresponds to the load moment opposing a further compression.

SUMMARY OF THE INVENTION

[0006] It is accordingly an object of the invention to provide a starting method for a piston compressor and a piston compressor which overcomes the above-mentioned disadvantages of the prior art devices and methods of this general type, by which an improved starting behavior is achieved in a simple way in a piston compressor. The piston position is designated below as the steady-state point.

[0007] With the foregoing and other objects in view there is provided, in accordance with the invention, a method for starting a piston compressor, which includes during a resetting phase, driving a piston of the piston compressor in a direction of a compression point of a piston position by applying a resetting drive moment. Maintaining the resetting drive moment until the piston reaches a starting position by overstepping a steady-state point as a result of displacement of fluid out of a compression space, formed between the piston and a corresponding pressure cylinder, through at least one leakage point. During an acceleration phase, accelerating the piston out of the starting position into an operational direction of rotation with a starting drive moment.

[0008] Accordingly, there is provision, first, in a resetting phase, for driving the piston of the piston compressor in the direction of a compression point of the piston position by the application of a resetting drive moment, and for maintaining the resetting drive moment until, by overshooting a steady-state point, the piston has reached a starting position. In this case, use is made in a controlled way of at least one leakage point (outlet) of the piston compressor, through which the fluid compressed in the course of the resetting phase escapes from the compression space, so that the piston position successively approaches the starting position beyond the steady-state point. In an acceleration phase following the reaching of the starting position, the piston is then accelerated out of the starting position in an operational direction of rotation by a starting drive moment. The outlet point which is used is, in particular, the piston/cylinder play always present as a consequence of construction in a piston compressor.

[0009] By the method described above, a particularly long acceleration travel for absorbing the kinetic energy required for overcoming the load peak is achieved in a simple way in a piston compressor. The drive system of the piston compressor operating by the method according to the invention can thereby be configured for a comparatively low maximum drive torque. As a result, production costs are saved to a decisive extent.

[0010] The resetting drive moment is preferably directed opposite to the operational direction of rotation, so that, during the resetting phase, the piston compressor is rotated backwards opposite to the operational direction of rotation. This is expedient particularly when, as a result of the type of construction of the piston compressor, a lower load moment and/or a higher leakage rate occur(s) during backward rotation than during corresponding forward rotation. Particularly where a reciprocating-piston compressor is concerned, the output or leakage rate and the profile of the load moment behaves, as a rule, symmetrically with respect to a reversal in the direction of rotation. In this case, during the resetting phase, the piston may also be driven equivalently in the operational direction of rotation.

[0011] In order to achieve as long an acceleration travel as possible during the acceleration phase, the starting position is preferably selected such that it lies in the vicinity of the compression point or slightly precedes the latter, as seen in the operational direction of rotation. Expediently, the starting position lies, in particular, in an angular range of +/−30° about the compression point.

[0012] Accordingly, the piston compressor contains a piston movable in a pressure cylinder by a drive system. The drive system contains an electric motor active on the piston via a drive shaft and an electronic control unit activating the motor. The control unit is in this case configured for activating the motor according to the method described above. The control unit is in this case configured, in particular, for activating the motor during the resetting phase in such a way that the piston is driven in the direction of the compression point under the action of the resetting drive moment, and for maintaining the resetting drive moment until the piston has reached a starting position. The control unit is configured, furthermore, to activate the motor during the acceleration phase in such a way that the piston is accelerated out of the starting position into the operational direction of rotation under the action of the starting drive moment.

[0013] Other features which are considered as characteristic for the invention are set forth in the appended claims.

[0014] Although the invention is illustrated and described herein as embodied in a starting method for a piston compressor and a piston compressor, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalents of the claims.

[0015] The construction and method of operation of the invention, however, together with additional objects and advantages thereof will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIGS. **1** to **4** are diagrammatic, sectional views of a piston compressor in four successive piston positions during the starting operation of the piston compressor according to the invention;

[0017] **FIG. 5** is a graph of a characteristic profile of a load moment occurring during the operation of the piston compressor according to **FIG. 1**, as a function of the piston position; and

[0018] **FIG. 6** is a graph according to **FIG. 5** showing the profile of the load moment during the starting operation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] In all the figures of the drawing, sub-features and integral parts that correspond to one another bear the same reference symbol in each case. Referring now to the figures of the drawing in detail and first, particularly, to **FIGS. 1-4** thereof, there is shown a piston compressor **1** illustrated diagrammatically as a reciprocating-piston compressor. The piston compressor **1** contains a piston **2** which is displaceable linearly (in a vertical direction according to **FIG. 1**) in a pressure cylinder **3**. For driving the piston **2**, an electric motor **4** is provided, which, in particular, is configured as a permanent-magnet synchronous motor and is activated by an electronic control unit **5**. The motor **4** acts via a drive shaft **6**, merely indicated, on a drive eccentric **7** which, in turn, is connected in an articulated manner to the piston **2** via a connecting rod **8**, so that the rotational movement of the drive eccentric **7** is converted into a linear oscillating movement of the piston **2** in a known way.

[0020] The pressure cylinder **3** and the piston **2** delimit the compression space **9**, into which an inlet **11** and an outlet **12** for a fluid F to be compressed issue on a cylinder bottom **10**, facing away from the piston **2**, of the pressure cylinder **3**. The fluid F is preferably a refrigerant, for example R600a.

[0021] At the respective issue of the inlet **11** and outlet **12** into the compression space **9**, an inlet valve **13** and outlet valve **14** are provided, which respectively shut off in a fluid-tight manner or release the inlet **11** and the outlet **12**, depending on the valve position. Each valve **13** or **14** is configured as a flap which is prestressed into a closed position of rest by an elastic force, in particular a spring, or due to the elastic configuration of the flap itself. Each valve **13** or **14** opens and closes automatically, in the manner of a non-return valve, under the action of a corresponding pressure gradient of the fluid F. The inlet valve **13** in this case opens when a sufficient under pressure prevails in the compression space **9** with respect to the inlet **11**. Similarly, the outlet valve **14** opens when a sufficient over pressure prevails in the compression space **9** with respect to the outlet **12**.

[0022] The volume of the compression space **9** varies as a function of piston position S. In this case, the rotary or annular position of the drive shaft **6** and of the drive eccentric **7** connected fixedly in terms of rotation to the latter is adopted as a measure of the piston position S. In a piston position S=0°, the piston **2** is moved into the pressure cylinder **3** to a maximum extent, and the volume of the pressure space **9** is thus minimized. In a piston position S=180°, the piston **2** is correspondingly drawn out of the pressure cylinder **3** to a maximum extent, and the volume of the compression space **9** is thus maximized. Given rotation of the drive eccentric **7** in an operational direction of rotation B indicated in **FIG. 1**, a change in the piston position S from 0° to 180° corresponds to an expansion phase E (**FIG. 5**), in the course of which the compression space **9** expands, and therefore fluid is sucked in from the inlet **11**. A change in the piston position S from 180° to 360°=0° corresponds to a compression phase K (**FIG. 5**), during which the fluid F contained in the compression space **9** is compressed and is expelled through the outlet **12**. The commencement of the expansion phase E corresponding to a piston position S=0° is designated as the compression point S_k, and the commencement of the compression phase K corresponding to a piston position S=180° is designated as the expansion point S_e. A full rotation of the drive eccentric **7**, that is to say a change in the piston position S from 0° to 360°, is designated as the work cycle of the piston compressor **1**. The work cycle thus contains the expansion phase E and the subsequent compression phase K.

[0023] During the operation of the piston compressor **1**, there arises—essentially due to the variable fluid pressure in the compression space **9**—a load torque (designated below in brief as the load moment L) which is exerted on the drive eccentric **7** by the piston **2** and which counteracts a drive torque (designated below in brief as the drive moment A) which is exerted on the drive eccentric **7** by the motor **4**.

[0024] As illustrated by way of example in **FIG. 5**, the load moment L varies periodically as a function of the piston position S. Under usual operating conditions, the amount of the load moment L occurring during the expansion phase E is small, whereas, in the course of the compression phase K, the load moment L passes through a pronounced maximum which is designated below as the load peak P. A maximum load moment L_{max} is reached in the region of the load peak P, for example, in a piston position $S \approx 270°$.

[0025] The motor **4** is configured in such a way that a maximum drive moment A_{max} capable of being exerted on the drive eccentric **7** is lower than the maximum load moment L_{max}. Consequently, there is a piston position S, in which the load moment L just overshoots the maximum drive moment A_{max}, so that the motor power is no longer sufficient for further compression. The steady-state point S_b, as it may be referred to, occurs in the vicinity of the load peak P, that is to say, when the piston **2** is driven in the operational direction B, in a piston position S which slightly undershoots 270°.

[0026] When the piston **2** is driven opposite to the operational direction of rotation B, a load moment L' (indicated in **FIG. 3** as a dotted line) substantially mirror-symmetric with respect to the compression point S_k and having an associated load peak P' occurs in the piston compressor. During backward rotation, a corresponding steady-state point S'_b is reached in a piston position S slightly overshooting 90°.

[0027] When the piston compressor **1** is in operation, the steady-state point S_b and consequently the load peak P are overcome by the kinetic energy of the piston compressor **1** being utilized. However, the kinetic energy is not yet available during the starting of the piston compressor **1**, so that the piston compressor **1** cannot be started directly by its inherent force from an initial piston position S_I illustrated by way of example in **FIG. 1**. The method described in more detail below with reference to FIGS. 2 to 4 and 6 serves for improving the starting behavior of the piston compressor **1**.

[0028] The starting operation of the piston compressor **1** is accordingly divided into a resetting phase **15** (**FIG. 6**) and a subsequent acceleration phase **16** (**FIG. 6**). During the resetting phase **15**, the piston **2** is rotated backwards out of the initial piston position S_I, opposite to the operational direction of rotation B, with a low drive moment, until, with regard to the piston position S, a starting position S_{IV} (**FIG. 4**) is reached. The piston compressor **1** in this case passes through the piston positions S_{II} and S_{III} illustrated in **FIGS. 2 and 3**.

[0029] What is characteristic of the method according to the invention is that the starting position S_{IV} is selected in the vicinity of the compression point S_k and in this case, in particular, between the steady-state points S_b and S'_b, so that, during the resetting phase **15**, the steady-state point S'_b has to be overcome when the piston **2** is rotated backwards. Likewise, if the piston **2** were to be moved into the starting position S_{IV} by forward rotation, the steady-state point S_b would have to be overcome.

[0030] The steady-state point S'_b is overcome in that, during the resetting phase **15**, the motor **4** exerts a resetting drive moment A_R which is also maintained precisely when the steady-state point S'_b is reached or overshot. This is implemented in technical terms in that the stator field of the motor **4** is rotated backwards at a low angular speed for a predetermined time span.

[0031] In this case, output points of the compression space **9**, which, as a consequence of construction, are formed, in particular, by the piston/cylinder play always present to some extent, are utilized in a controlled way. With the resetting drive moment A_R being maintained, fluid F (**FIG. 3**) escapes through the output points **17** to an appreciable extent, contrary to the usual operating behavior of the piston compressor **1**, so that, under stationary load conditions, the volume of the compression space **9** is further reduced and the piston position S thereby approaches the compression point S_k beyond the steady-state point S'_b. The load peak P' is virtually "tunneled through" in this way.

[0032] Depending on the type of construction of the piston compressor **1**, a leakage point which, if appropriate, connects the compression space **9** to the inlet **11** may also be utilized additionally or alternatively to the leakage or output points **17** formed by the piston/cylinder play. Additionally or alternatively to leakage points **17** obtained as a consequence of construction, an artificial leakage point, for example in the form of a thin bypass line circumventing the inlet valve **13**, may also be provided. This is expedient particularly when an escape of the fluid F into the environment is to be avoided.

[0033] The exact site of the starting position S_{IV} depends slightly on the initial piston position S_I. Motor activation during the resetting phase **15** is in this case configured in such a way that the starting position S_{IV} always lies in an angular range of +/−30° about the compression point S_k and, in an initial piston position S_I of approximately 180°, coincides substantially with the compression point S_k. It has proved expedient, for the suitable dimensioning of the resetting drive moment A_R, to have a motor activation in which the stator field of the motor **4** is rotated backwards at an angular speed of between 1 and 10 revolutions per minute for a predetermined time span of between 3 and 30 seconds, in particular at approximately 4 revolutions per minute for approximately 20 seconds.

[0034] After the starting position S_{IV} is reached, in the course of the acceleration phase **16** a starting drive moment A_S is exerted on the drive eccentric **7**, and therefore on the piston **2**, the starting drive moment acting in the operational direction of rotation B and corresponding in terms of its amount to the maximum drive moment A_{max}.

[0035] As can be seen particularly from **FIG. 6**, during the acceleration phase **16** the piston position S passes through an acceleration range **18** of more than 240°, in the course of which no increased load moment L occurs, with the result that the piston compressor **1** can absorb sufficient momentum to overcome the load peak P. The long acceleration range **18** thus makes it possible for the motor **4** to be configured with a particularly low maximum drive moment A_{max}, without the starting behavior of the piston compressor **1** being impaired.

[**0036**] The resetting phase **15** and the acceleration phase **16** may be executed directly one after the other in time. However, the resetting phase **15** and the acceleration phase **16** may also be executed separately from one another in time. In particular, there is optionally provision for carrying out the resetting phase **15** at the end of an operating phase of the piston compressor **1**, so that, during a subsequent operating phase, the piston compressor **1** is already in the starting position S_{IV} from the outset and can be started immediately by the execution of the acceleration phase **16**. Alternatively to this, there is optionally provision for the method described above to be carried out only when a previously conducted attempt at immediate starting has failed because of an unfavorable initial piston position S_I.

[**0037**] Where the piston compressor illustration in FIGS. **1** to **4** is concerned, furthermore, in a variant of the starting method described, a resetting drive moment A_R acting in the operational direction of rotation B may also be exerted. Furthermore, the starting method described can also be applied equivalently to a rotary-piston compressor.

[**0038**] The method described can also be used equivalently in a piston compressor with a different type of electronically regulated motor, in particular a brushless direct-current motor (BLDC), an asynchronous motor, a reluctance motor, etc.

[**0039**] This application also claims the priority, under 35 U.S.C. §119, of German patent application No. 10 2004 057 467.7, filed Nov. 29, 2004; the entire disclosure of the prior application is herewith incorporated by reference.

I Claim:

1. A method for starting a piston compressor, which comprises the steps of:

during a resetting phase, driving a piston of the piston compressor in a direction of a compression point of a piston position by applying a resetting drive moment;

maintaining the resetting drive moment until the piston reaches a starting position by overstepping a steady-state point as a result of displacement of fluid out of a compression space, formed between the piston and a corresponding pressure cylinder, through at least one leakage point; and

during an acceleration phase, accelerating the piston out of the starting position into an operational direction of rotation with a starting drive moment.

2. The method according to claim 1, which further comprises directing the resetting drive moment opposite to the operational direction of rotation.

3. The method according to claim 1, which further comprises selecting the starting position in an angular range of the piston position of +/−30° with respect to the compression point.

4. The method according to claim 1, which further comprises exciting a stator field of a motor driving the piston compressor at a predetermined angular speed of between 1 and 10 revolutions per minute for a predetermined time span of between 3 and 30 seconds for generating the resetting drive moment.

5. The method according to claim 1, which further comprises setting said starting drive moment to correspond to a predetermined maximum drive moment.

6. A piston compressor, comprising:

a pressure cylinder;

a drive shaft;

a motor driving said drive shaft;

a piston being moved in said pressure cylinder by said drive shaft being driven by said motor; and

a control unit for activating said motor, said control unit being configured to:

in a resetting phase, predetermine a resetting drive moment, by which said piston being driven in a direction of a compression point of a piston position;

maintain the resetting drive moment until said piston reaches a starting position by overstepping a steady-state point as a result of displacement of fluid out of a compression space, formed between said piston and said pressure cylinder, through a leakage point; and

in an acceleration phase, predetermine a starting drive moment, by which said piston is accelerated out of the starting position into an operational direction of rotation.

* * * * *