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(54) METHOD FOR CONTROLLING KNOCKING IN A PISTON COMPRESSOR

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(57) ABSTRACT

A method is disclosed for controlling knocking in a piston compressor and for a piston compressor (1) that is designed to carry out the method. The method is characterized in that, if a knocking noise made by a piston of the piston compressor hitting a cylinder head is detected by means of a structure-borne noise sensor provided on the piston compressor, the piston stroke of the piston compressor is decreased or, if no knocking noise is detected over a predefinable period of time, the piston stroke is increased.

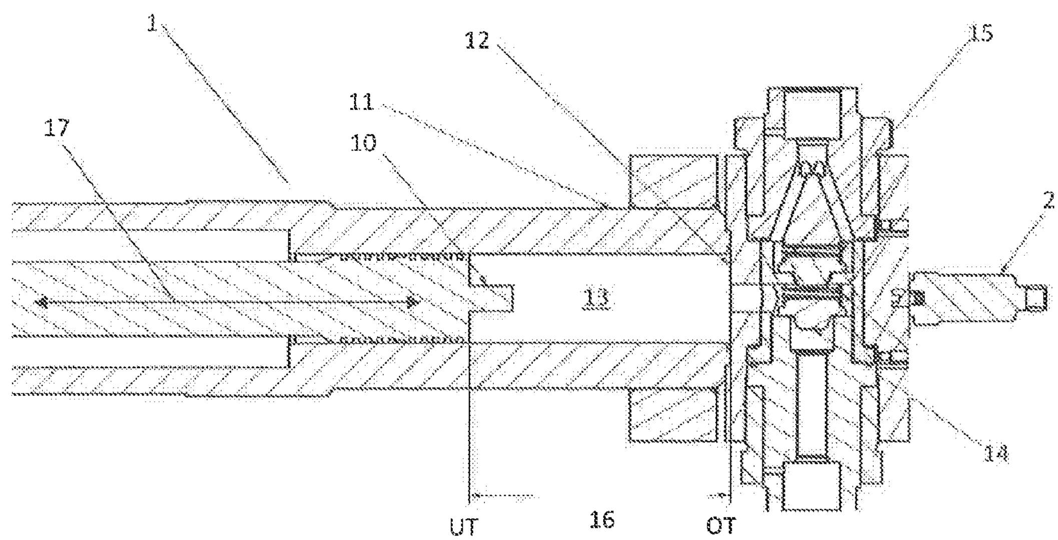


Figure 1

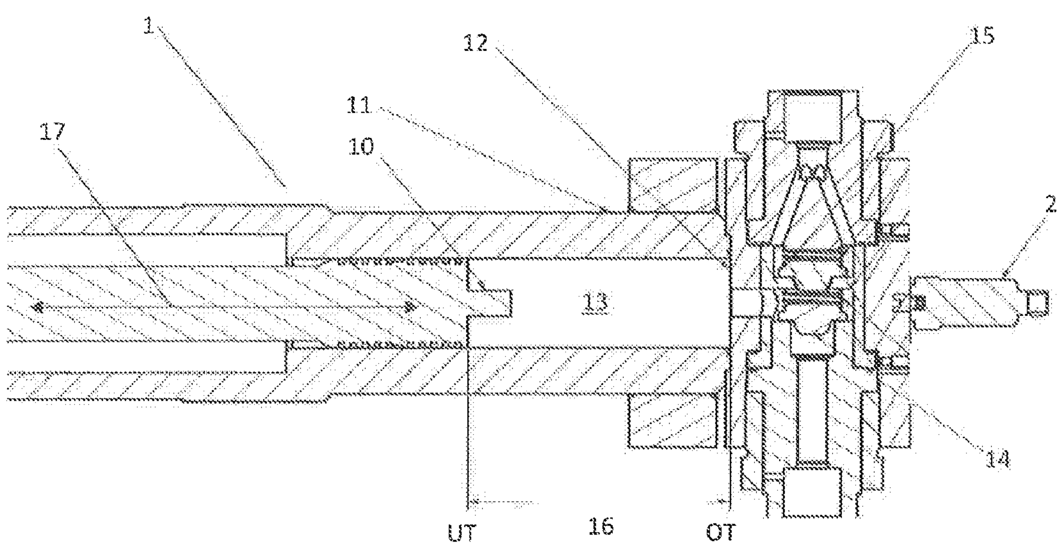
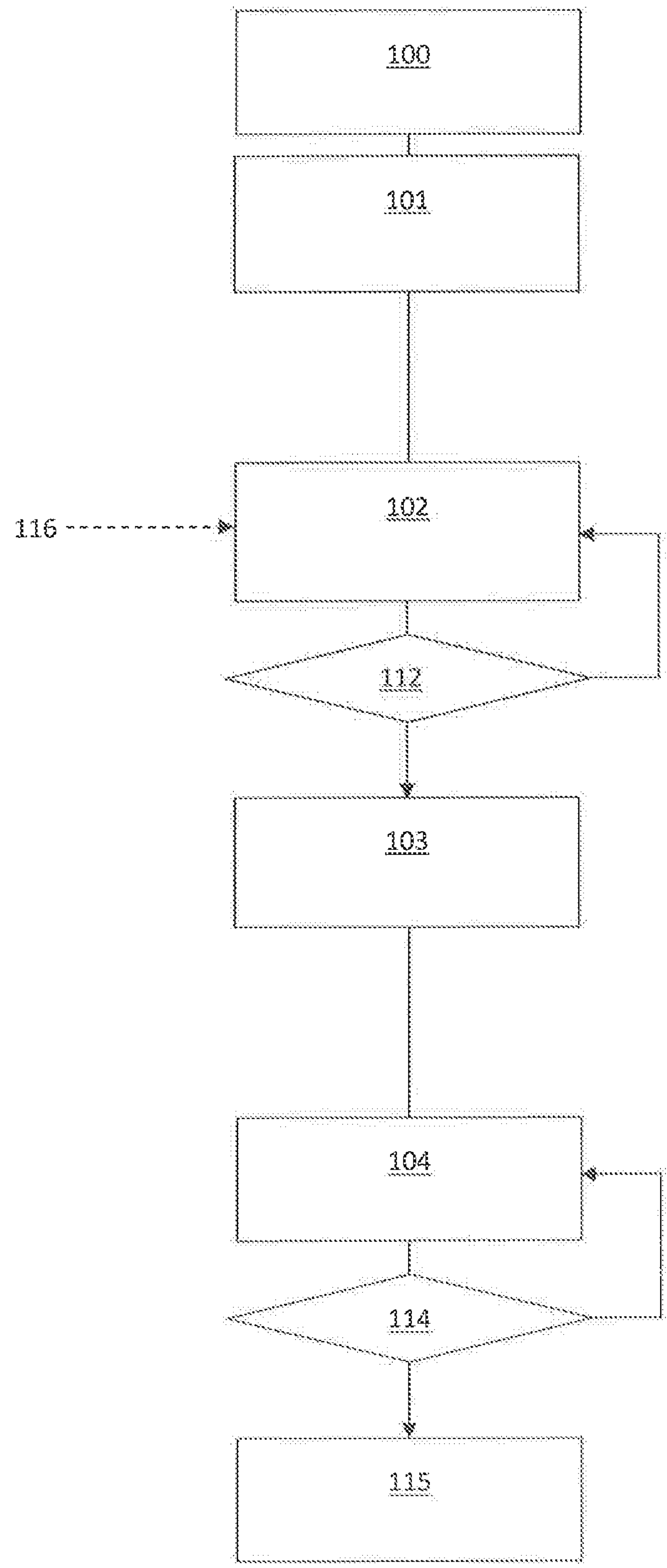


Figure 2



METHOD FOR CONTROLLING KNOCKING IN A PISTON COMPRESSOR

[0001] The invention relates to a method for controlling knocking in a piston compressor according to claim **1** and claim **9**, as well as to a piston compressor according to claim **10**.

[0002] Known from prior art are a plurality of methods for compressing and conveying fluids, to include piston compressors, with which a fluid can be compressed and again dispensed in a compressed state.

[0003] In such a piston compressor, a piston oscillates in a cylinder between a first and second reversal point along the cylinder axis, wherein the distance between the first and second reversal point represents the piston stroke. In addition, a cylinder head is situated at one end of the cylinder, wherein the first reversal point lies closer to the cylinder head than the second reversal point. The reversal points of the piston are also referred to as dead centers.

[0004] The cylinder head usually exhibits a pressure valve and a suction valve. A cycle or period or the piston compressor begins when the piston is at the first reversal point. If the piston in the cylinder now moves toward the second reversal point, the pressure valve is closed, and the suction valve siphons the fluid to be compressed into the compression chamber, which is comprised of the volume between the cylinder head and piston. If the piston then moves from the second reversal point toward the first reversal point again, the suction valve closes, and the fluid previously siphoned into the compression chamber is compressed in the compression chamber, wherein the pressure valve opens at a predefinable pressure in the compression chamber, and the compressed fluid flows out of the compression chamber through the pressure valve, specifically until such time that the piston has arrived at the first reversal point, and the cycle starts all over again.

[0005] When designing a piston compressor, the dimensions and tolerances must, if at all possible, be selected so as to prevent the piston from hitting the cylinder head. This is done predominately by taking structural measures, which are most often accompanied by a diminished output.

[0006] For example, the temperature differences encountered in compressors make it necessary from a structural standpoint in piston compressors to provide length tolerances that are accompanied by an increased dead space. Dead space here denotes the volume included by the cylinder head and the piston when it is located at the first reversal point. The elevated gas re-expansion caused by the dead space here translates into a diminished output.

[0007] In compressors having a variable stroke, and hence no fixed reversal points, additional problems arise. Ignoring a length tolerance between the reversal point and cylinder head may cause the piston to hit the cylinder head given too late a change in the direction of movement.

[0008] Therefore, the technical challenge for compressors lies in particular in selecting the geometry and used materials so as not to exceed the permissible surface pressure in the event a piston hits the cylinder head. It is often impossible not to exceed the permissible surface pressure, for example because the piston rests on the cylinder head at a minimal inclination. The components undergo plastic deformation in this instance. This deformation is frequently accompanied by a constant beading of the impacting or impacted parts. In serious cases, this leads to a defect in individual or several relevant components, and quite often ends in machine failure.

[0009] A constant banging of components further leads to significant noise exposure. This noise exposure is problematic above all for systems slated for installation in proximity to residential neighborhoods. Special requirements are in place here that can sometimes only be satisfied by a separate sound insulation.

[0010] There are known devices and methods suitable for knock detection in internal combustion engines, e.g., "Method for Knock Detection in Internal Combustion Engines", EP 1184651 B1, as well as EP 1208364 B1. "Knocking" in an internal combustion engine generally denotes the knocking noise that results from a premature or incomplete combustion of the fuel in the engine cylinder, for example. A knocking noise arising from the piston hitting the cylinder head cannot be equated with these noises caused by ignition and combustion processes in the internal combustion engines.

[0011] Therefore, the object of the present invention proceeding from the above is to provide a piston compressor along with a control method that are improved with respect to the aforementioned problem.

[0012] This problem is resolved with a method for controlling knocking in a piston compressor according to claim **1** and claim **11**. Advantageous embodiments of the invention are indicated in the subclaims, among other places.

[0013] Claim **1** provides that the piston stroke be reduced when a knocking noise made by the piston hitting the cylinder head is detected by means of a structure-borne noise sensor arranged on the piston compressor, and enlarged when no knocking noise is detected over a predefinable period of time.

[0014] Recognizing when the piston hits the cylinder head, in particular in the startup phase of the piston compressor, during which major temperature changes take place within short time intervals, and then controlling the latter advantageously makes it possible to diminish the failure probability of the compressor, which elevates the service life while simultaneously reducing the service outlay. Such a knocking recognition and control system represents an additional safety device for compressors operated without a position sensor, for example as can be imagined for reciprocating compressors driven by synchronous linear motors.

[0015] In addition, the lower noise emission resulting from the prevention of knocking noises enables the installation in particular of hydrogen filling stations in proximity to residential neighborhoods. Furthermore, the absence of knocking noises permits the better detection of untypical operating noises and inference of potential system errors. Specifically, preventing the constant impact on the compressor components makes it possible to significantly improve the acoustic fault detection owing to the absence of sound masking.

[0016] A reduction in the piston stroke is usually achieved by shifting the first and second reversal points toward each other, wherein the reversal points can in particular be shifted toward each other by the same length. Correspondingly, the piston stroke is enlarged by shifting the first and second reversal points away from each other (in particular also by the same length), for example. In this form of control, then, only the deflection of the piston in both oscillation directions is reduced/enlarged.

[0017] However, it is also conceivable that an "asymmetrical" reduction/decrease in the piston stroke be achieved by only shifting the first reversal point toward the second reversal point. Correspondingly, it is of course also possible for enlarging the piston stroke that only the first reversal point be shifted in the direction of the cylinder head, and the second reversal point be left unchanged. Therefore, the deflection here is only changed along one direction, specifically toward the cylinder head. Likewise, the two reversal points can be shifted toward or away from each other by differing amounts.

[0018] For example, the piston stroke is controlled in such a way that the distance between the first reversal point and the cylinder head measures a fraction of the piston stroke, wherein this fraction in particular measures less than one thousandth or less than one two thousandth.

[0019] A preferred variant of the invention provides that the piston stroke be reduced at least once by a first length when the knocking noise is detected, wherein in particular the piston stroke is reduced by the first length as many times as it takes until the knocking noise is no longer detected. For example, the first length here measures 0.5 mm.

[0020] Another embodiment of the invention is characterized in that the piston stroke is enlarged by a second length when the piston stroke was reduced at least once by the first length, wherein the second length in particular is smaller than the first length, and wherein the piston stroke in particular is enlarged by aforesaid second length as many times as it takes until a knocking noise is again detected.

[0021] In another preferred variant, the piston stroke is enlarged, in particular by the second length, when a knocking noise is not detected over the predefinable period of time, wherein the second length in particular is smaller than the first length, and wherein the piston stroke in particular is enlarged as many times as it takes or by the aforesaid second length until a knocking noise is again detected.

[0022] For example, the predefinable period of time measures 30-300 s, and depends in particular on the piston frequency and the expected temperature changes of the piston compressor. The lower the piston frequency, the longer the predefinable period of time can be. For example, the second length measures 20% of the first length, i.e., in particular 0.1 mm.

[0023] In an advantageous variant of the invention, the piston stroke is further reduced at least once by a third length after the knocking noise is detected again, wherein in particular the piston stroke is reduced by a third length as many times as it takes until the knocking noise is no longer detected. It must here be considered that this variant of the invention can in particular also be implemented when the piston stroke was increased by the second length beforehand, even if no knocking noise was detected, because a control intervention was performed, for example in response to the expiration of the predefinable period of time.

[0024] Let it be noted here that the third length is preferably both smaller than the second length and smaller than the first length. The third length preferably measures 20% of the first length, i.e., in particular 0.1 mm.

[0025] A preferred embodiment of the invention provides that the piston stroke be enlarged by a fourth length if the piston stroke was reduced at least once by the third length, wherein the fourth length in particular is smaller than the third length, and wherein the piston stroke in particular is enlarged by the aforesaid fourth length as many times as it takes until a knocking noise is detected again.

[0026] Another preferred embodiment of the invention provides that the piston stroke be reduced once by the fourth length after the aforesaid knocking noise was detected. For example, the fourth length here measures 50% of the third length, i.e., in particular 0.05 mm.

[0027] In an advantageous embodiment of the invention, the time it takes to reduce and/or enlarge the piston stroke is less than the period duration of the oscillating piston.

[0028] The problem according to the invention is further resolved with the features in claim **9**.

[0029] In particular the use of the method according to the invention in an existing piston compressor is here paramount.

[0030] The method according to the invention or the device according to the invention enables a more precise modeling of the dead space between the piston and cylinder head. As a result, for example, the distance between the piston and cylinder head can be incrementally diminished in an existing piston compressor under operating conditions until a knocking noise is perceived by manually reducing the dead space (i.e., in particular not by changing the piston stroke). For example, this is accomplished by attaching thrust washers. The knocking indicates that the stroke path is too small, so that the thrust washer must be replaced by a minimally thinner one. This process is repeated for as long as it takes for a knock-free compression to set in. Taking into account ail operating points, there no longer exists any need for knocking detection following the adjustment according to the invention with the thrust washers.

[0031] In addition, the problem according to the invention is resolved by a piston compressor having the features in claim **10**, wherein the piston compressor is designed in particular for implementing the method according to the invention.

[0032] Provided according to the above is a structure-borne noise sensor arranged on the piston compressor, which is designed to detect structure-borne noises or knocking noises generated by the piston of the piston compressor hitting the cylinder head of the piston compressor, wherein the structure-borne noise sensor is designed to generate an output signal upon detecting such knocking noises, wherein a control unit designed to control the piston stroke as a function of the output signal is provided, wherein in particular the control unit is designed to reduce the piston stroke toward the output signal, and wherein in particular the control unit is designed to enlarge the piston stroke if no knocking noise is detected over a predefinable period of time.

[0033] The piston compressor or its control unit is preferably designed to implement the individual procedural steps according to the invention.

[0034] The used structure-borne noise sensor is preferably especially sensitive to sound frequencies, frequency patterns and/or frequency progressions/sequences, which preferably arise as the piston hits the cylinder head.

[0035] In addition, a time measuring means can be provided for determining an expiration of the predefined period of time explained above, which works together with the control unit. The control unit can here be designed to receive corresponding signals from the time measuring means, or to read out, start, stop and/or reset the time measuring means.

[0036] In another preferred variant of the invention, the piston compressor exhibits a drive for driving the piston, wherein the drive is designed in particular as a linear motor, wherein the drive drives the piston in such a way as to move the piston in the cylinder back and forth between the first and second reversal points.

[0037] In addition, a position sensor can be provided (e.g., the drive can exhibit a position sensor), which indicates the current position of the piston or a drive element connected with the piston, in particular the reversal points. The control unit can then use these position data to adjust the piston stroke, i.e., reduce or enlarge the latter.

[0038] In a preferred variant of the invention, the structure-borne noise sensor is arranged on the cylinder head, and in particular constitutes an integral constituent of the cylinder head.

[0039] However, it is also possible for the structure-borne noise sensor to be arranged on the cylinder or on some other location of the piston compressor, wherein particular attention should be focused on positioning the structure-borne noise sensor as close as possible to where the (knocking) noise originated, and in particular on ensuring a good structure-borne noise transmission from the piston compressor to the structure-borne noise sensor, e.g., by securing the structure-borne noise sensor to smooth surfaces of the piston compressor.

[0040] A preferred embodiment of the invention provides that the structure-borne noise sensor be a piezoelectric sensor, which converts the pressure change on the sensor surface into electrical signals based on the piezoelectric effect. Of course, other noise sensors can also be used.

[0041] The invention advantageously enables an optimization of compression capacity relative to the usable piston path, since the reduced dead space increases the output. The diminished mechanical load further permits the use of materials with a lower permissible surface pressure. This reduces the procurement and manufacturing costs of the individual components. Using the piston compressor according to the invention or the method according to the invention further eliminates the need for an operational reference drive of a compressor with a variable piston stroke. For example, such a reference drive is used to find the zero point of the piston, or to compensate for changes in length caused by a varying thermal expansion in non-stationary operating states.

[0042] Further details and advantages of the invention will be explained based on the figures by the following descriptions to the figures of exemplary embodiments.

[0043] FIG. **1** is a side view of a piston compressor according to the invention

[0044] FIG. **2** is a flowchart of the method according to the invention.

[0045] FIG. **1** shows a piston compressor **1** according to the invention that is driven by a drive, which preferably involves a servotube linear motor with a frequency of 10 Hz, i.e., twenty piston strokes or a respective ten suction and pressure cycles per pressure stage per second. The piston stroke **16** here measures 120 mm, but is variably adjustable.

[0046] The reciprocating piston compressor **1** exhibits a structure-borne noise sensor **2** that is situated on a cylinder head **12** of the piston compressor **1**. The structure-borne noise sensor **2** is here joined with the cylinder head **12** over its entire surface, i.e., without air gaps, thereby enabling the most optimal structure-borne noise transmission from the cylinder head to the sensor **2**.

[0047] In the piston compressor **1**, a piston **10** oscillates in a cylinder **11** of the piston compressor **1** between a first or upper reversal point OT and a second or lower reversal point UT (in particular with a maximum stroke of 120 mm). The movement of the piston **10** from the first reversal point OT to the second reversal point UT reduces the pressure in a compression chamber **13** formed between, the piston **10** and cylinder head **12**. As soon as the value here drops below the opening pressure of a suction valve **14** provided on the cylinder head **12**, this suction valve **14** is opened, and fluid to be compressed is siphoned into the compression chamber **13**. Once the second reversal point UT has been reached, the piston **10** changes its direction of movement toward the first reversal point OT, as a result of which the pressure in the compression chamber **13** rises. The suction valve **14** closes as soon as the pressure in the compression chamber **13** is greater than the suction pressure. If the pressure in the compression chamber **13** then exceeds the opening pressure of a pressure valve **15** provided on the cylinder head **14**, the pressure valve **15** opens, and the compressed fluid flows out of the compression chamber **13** and exits the piston compressor **1**. upon reaching the first reversal point OT, the piston **10** again changes its direction of movement toward the second reversal point UT. Such a complete compression cycle yields the period duration.

[0048] If the piston **10** now hits the cylinder head **12** in the compression phase, this collision is detected by the structure-borne noise sensor **2** based on an accompanying knocking noise. In order to detect this structure-borne noise as close as possible to its origin, the structure-borne noise sensor **2** is here fixed in the midpoint of a cylinder head surface facing away from the piston. The contact surfaces of the structure-borne noise sensor **2** and cylinder head **12** here have the smoothest possible design.

[0049] As soon as a frequency range, frequency pattern and/or volumes typical for the knocking noise are recorded, a corresponding control unit initiates a control intervention.

[0050] In the piston compressor **1** according to the invention, the cylinder head **12** and piston **10** are preferably made out of austenitic stainless steel, wherein the sound velocity there lies within a range of 5100 m/s. The structure-borne noise sensor **2** is here preferably a piezoelectric element, for example one exhibiting a measuring range of +/−60 g, and covers a frequency range of 0.13-11000 Hz. The sensitivity of the structure-borne noise sensor **2** here preferably measures approx. 100 mV/g.

[0051] FIG. **2** shows a flowchart of the method according to the invention. In response to the detection of a knocking noise **100** caused by the piston **10** hitting the cylinder head **12**, the piston stroke **16** is in a first step **101** diminished by L**1** in the ensuing period, specifically as many times as it fakes until the knocking noise **100** stops. A preferred value for L**1** is here 0.5 mm.

[0052] In an ensuing second step **102**, the piston stroke **16** is elevated in particular in several steps (incrementally) by a respective length L**2**, until a knocking noise **112** caused by the piston hitting the cylinder head is again detected. Incrementally here means that such a step **102** is carried out per period. This process serves to minimize the dead space. A preferred value for L**2** is 0.1 mm per stroke movement (period).

[0053] In an ensuing third step **103**, the piston stroke **16** is reduced by a length L**3**, which is preferably smaller than L**1** by a factor of 5 (L**3**=0.1 mm).

[0054] In a fourth step **104** f the piston stroke is enlarged by a fourth length L**4** wherein L**4** here preferably measures 0.05 mm. The piston stroke **16** continues to be enlarged (incrementally) by L**4** as many times as it takes until a knocking noise **114** is again detected. As soon as a knocking noise **114** has again been detected, the piston stroke **16** is again reduced **115** by L**4**, i.e., by 0.05 mm.

[0055] If a knocking noise **100** is again detected later, e.g., resulting from a thermal shortening of the cylinder **11**, the control process takes place once more, starting with the first step **101**. Causes for another knocking nose **100** can include changes in length owing to varying temperature expansions of the individual compressor components. Knocking detection makes it possible to compensate for these changes in length. In order to compensate for the dead space (volume present between the piston **10** and cylinder head **12** when the piston is at the first reversal point OT) resulting from thermal expansion, the method according to the invention is initiated **116** beginning with the second step **102** (increasing the stroke by L**2**=0.1 mm) upon expiration of a predefinable period of time. Typical, values for aforesaid period of time are here 30-300 s.

[0056] The used factors and dimensions depend primarily on the positioning accuracy of the overall system. The expected value for the time interval between the individual knocking noises corresponds to the frequency of the compression process (stroke frequency). In the exemplary application, for example, the latter measures 10 Hz. Therefore, the controlled system with which the structure-borne noise sensor interacts preferably exhibits a correspondingly high processing speed, so that the control interventions can preferably already be taken into account during the next piston stroke **13** (in the next period). A piston **10** can hit the cylinder head **12** at very high accelerations, so that the structure-borne noise sensor **2** is preferably rated for these high accelerations.

[0057] Precisely adjusting the permissible length tolerance results in an elevated output by comparison to a system according to prior art owing to the diminished dead space. Measuring the structure-borne noise at the cylinder head further makes it possible to more precisely determine the behavior of the suction and pressure valves in the compressor. Placing the valve in the end positions produces a structure-borne sound wave in the cylinder head that can be detected. Numerous options are available for influencing the behavior of the valve while opening, closing or in the open state. The objective of the adjustments is here to quickly open the available suction valve annular gap, followed by a gentle placement in the upper end position. A gentle placement of the valve causes it to spring back to less of an extent, which would diminish the annular gap. In like manner, the pressure valve must be closed as quickly as possible to minimize a backflow of the medium that has already been compressed.

What we claim is:

1. A method for controlling knocking in a piston compressor, wherein a piston oscillates in a cylinder between a first reversal point and a second reversal point along the cylinder axis, wherein the distance between the first reversal point and the second reversal point defines the piston stroke, and wherein a cylinder head is arranged at one end of the cylinder, and wherein the first reversal point lies closer to the cylinder head than the second reversal point,

characterized in that

the piston stroke is reduced when a knocking noise made by the piston hitting the cylinder head is detected by means of a structure-borne noise sensor arranged on the piston compressor, or that the piston stroke is enlarged when no knocking noise is detected over a predefinable period of time.

2. The method according to claim **1**, characterized in that the piston stroke is reduced at least once by a first length when the knocking noise is detected, wherein the piston stroke is reduced by the first length as many times as it takes until the knocking noise is no longer detected.

3. The method according to claim **2**, characterized in that the piston stroke is enlarged by a second length when the piston stroke was reduced at least once by the first length wherein the second length is smaller than the first length, and wherein the piston stroke is enlarged by aforesaid second length as many times as it takes until a knocking noise is again detected.

4. The method according to claim **1**, characterized in that the piston stroke is enlarged, by the second length, when the knocking noise is not detected over the predefinable period of time, wherein the second length is smaller than the first length, and wherein the piston stroke is enlarged as many times as it takes, by the aforesaid second length, until a knocking noise is detected.

5. The method according to claim **3**, characterized in that the piston stroke is further reduced at least once by a third length after the knocking noise is detected again, wherein the piston stroke is reduced by a third length as many times as it takes until the knocking noise is no longer detected.

6. The method according to claim **5**, characterized in that the piston stroke is enlarged by a fourth length if the piston stroke was reduced at least once by the third length, wherein the fourth length is smaller than the third length, and wherein the piston stroke is enlarged by the aforesaid fourth length as many times as it takes until a knocking noise is detected again.

7. The method according to claim **6**, characterized in that the piston stroke is reduced once by the fourth length after the aforesaid knocking noise was detected.

8. The method according to claim **1**, characterized in that the time it takes to reduce and/or enlarge the piston stroke is less than the period duration of the oscillating piston.

9. A method for adjusting a dead space between a piston and a cylinder head in a piston compressor, characterized in that, in order to adjust a dead space between a piston and a cylinder head in a piston compressor the dead space between the piston and cylinder head is diminished by adding a suitable body as many times as it takes until a knocking noise is detected, wherein, when a knocking noise is detected, the distance between the piston and cylinder head is enlarged as many times as it takes until no more knocking noise is detected.

10. A piston compressor designed to compress a fluid and dispense it in a compressed state, with

a cylinder,

a piston arranged in the cylinder that is designed to oscillate in the cylinder between a first reversal point and a second reversal point along the cylinder axis, wherein the distance between the first reversal point and the second reversal point defines a piston stroke, and

a cylinder head arranged at the end of the cylinder, and wherein the first reversal point lies closer to the cylinder head than the second reversal point,

characterized in that

a structure-borne noise sensor arranged on the piston compressor is provided, and designed to detect knocking noises generated by the piston of the piston compressor hitting the cylinder head of the piston compressor, wherein the structure-borne noise sensor is designed to generate a first output signal upon detecting such a knocking noise, wherein a control unit designed to control the piston stroke as a function of the first output signal is provided.

11. The piston compressor according to claim **10**, characterized in that the structure-borne noise sensor is arranged on the cylinder head), and constitutes an integral constituent of the cylinder head.

12. The method according to claim **9**, characterized in that the suitable body is in the form of a thrust washer.

13. The method according to claim **9**, characterized in that the distance between the piston and cylinder head is enlarged by replacing an added thrust washer or an added body with a thinner thrust washer or a thinner body.

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