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(54) LINEAR COMPRESSOR AND CORRESPONDING DRIVE UNIT

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(57) **ABSTRACT**

A drive unit for a linear compressor comprising a frame and an oscillating body. The oscillating body is mounted in the frame via at least one diaphragm spring and can be moved back and forth in one direction. The diaphragm spring comprises a plurality of limbs, fastened with one end to the frame and with the other end to the oscillating body. Two limbs each have inversely curved sections between the two ends.

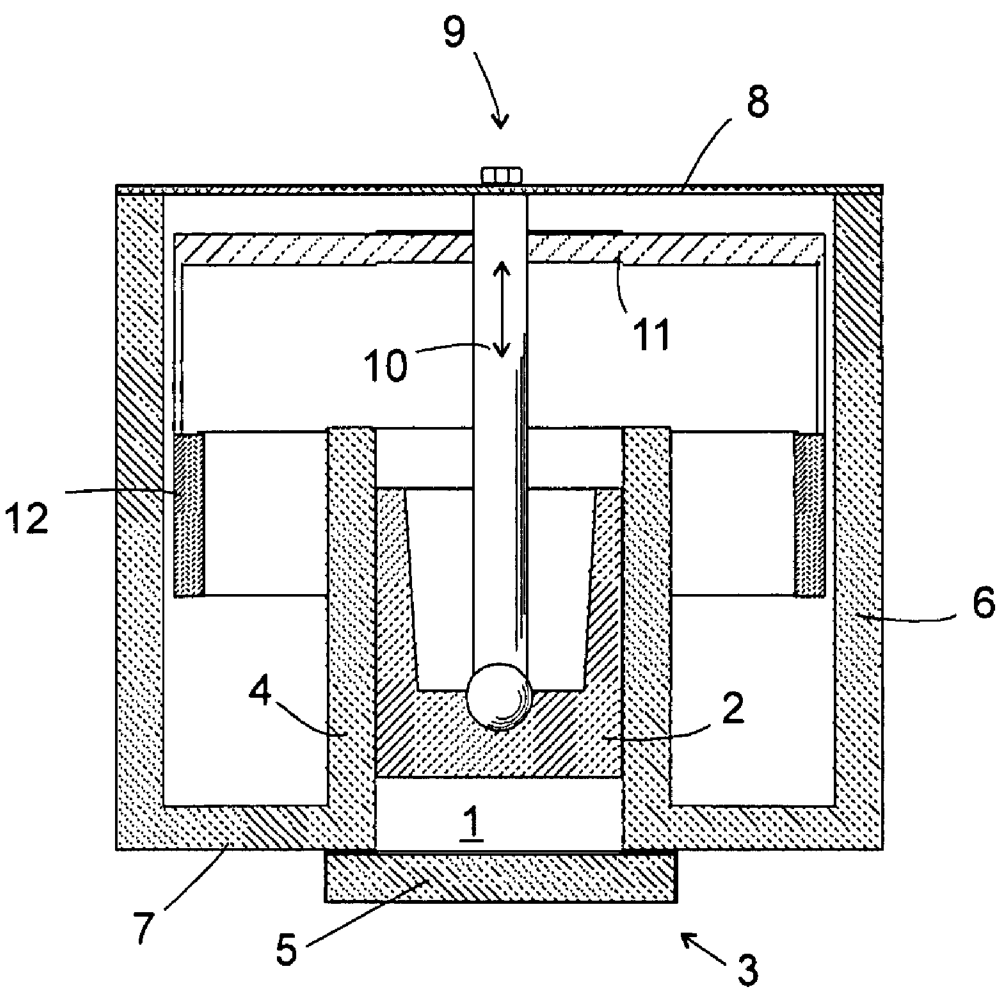

Fig. 1

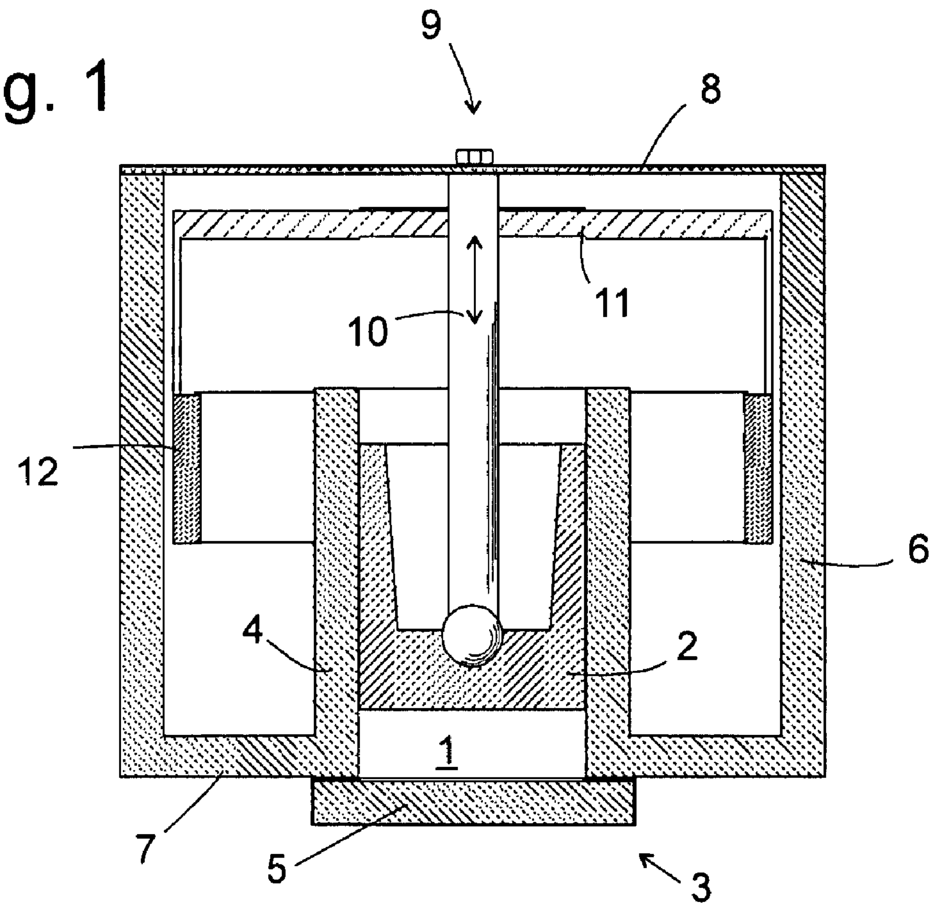

Fig. 2

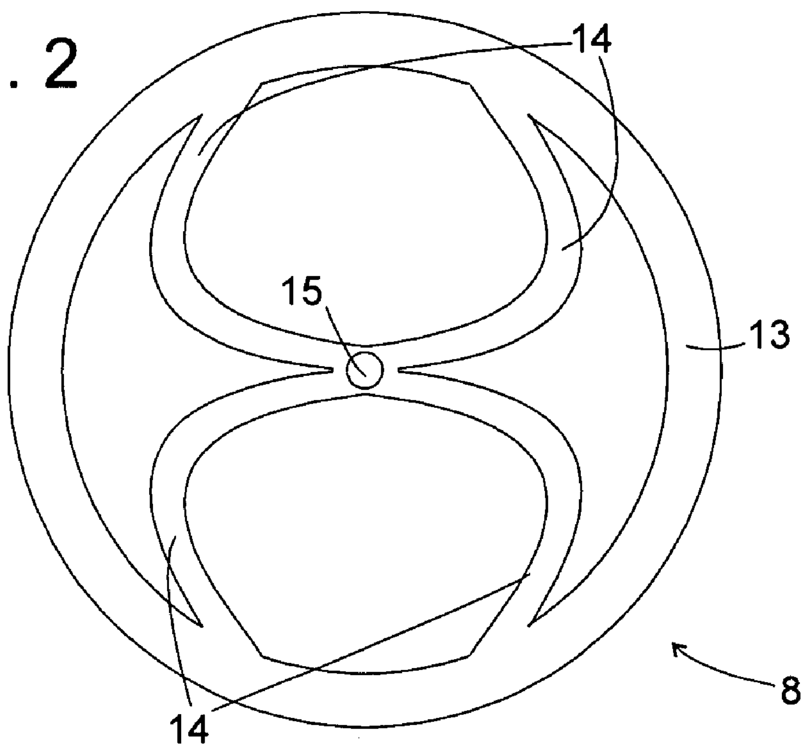

Fig. 3

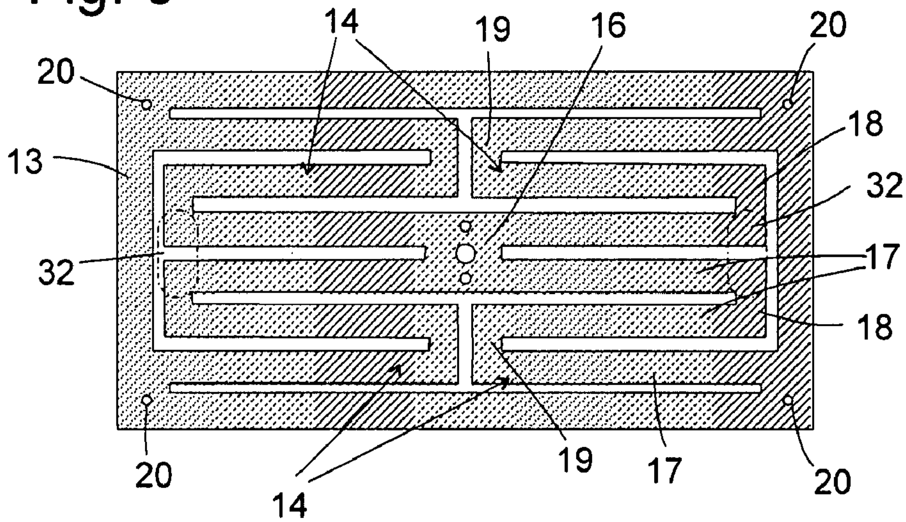
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Fig. 4

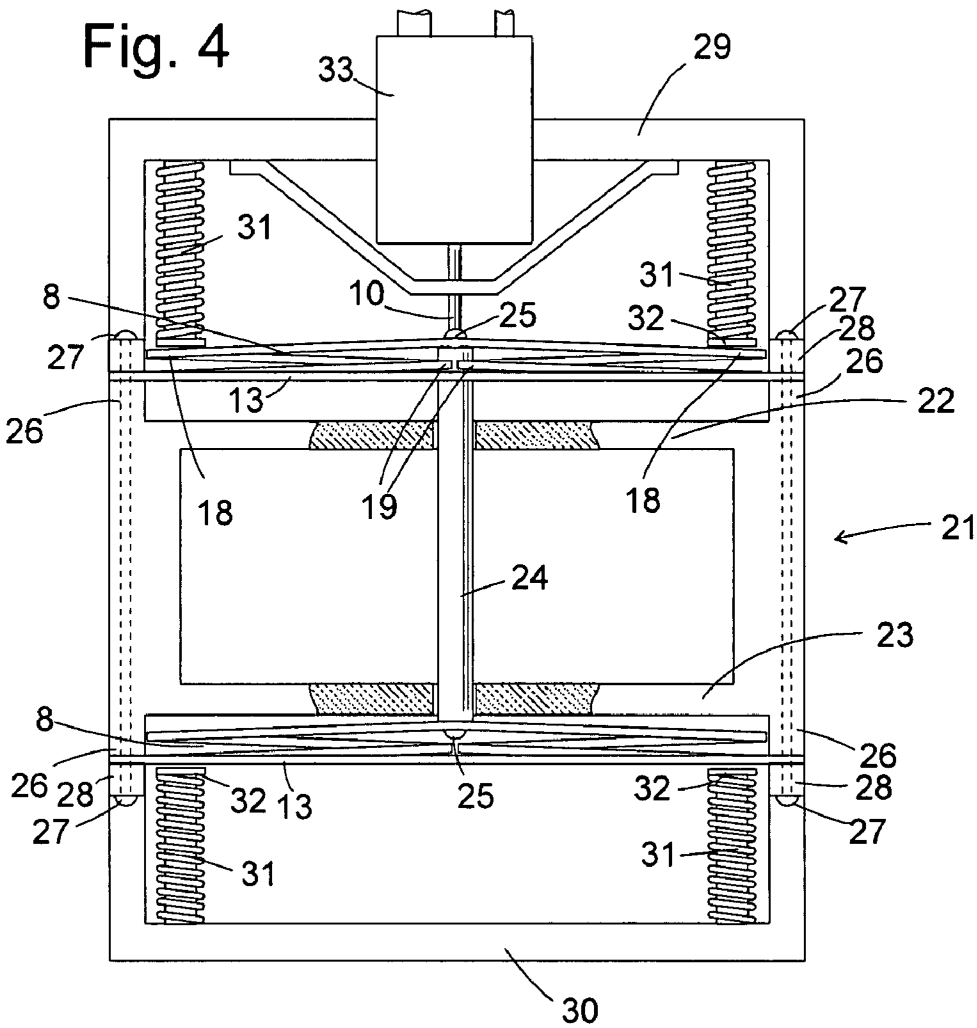
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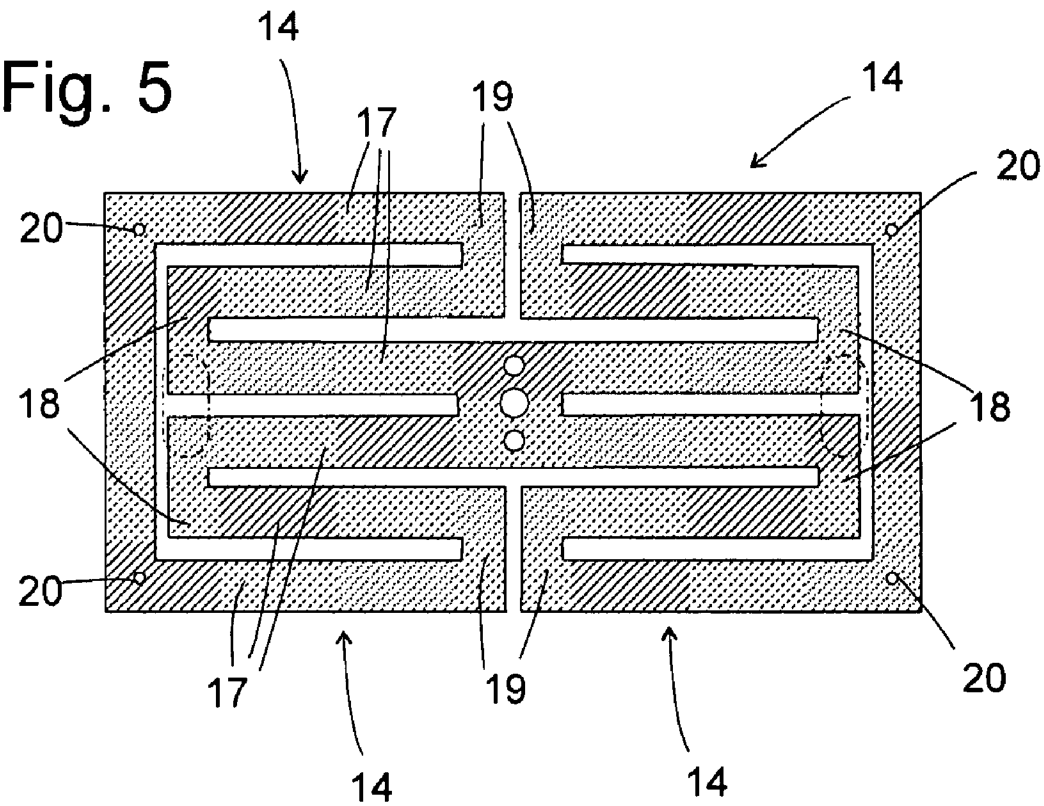
Fig. 5



LINEAR COMPRESSOR AND CORRESPONDING DRIVE UNIT

[0001] This invention relates to a linear compressor, in particular for use for compressing refrigerants in a refrigerating device, and in particular a drive unit for driving an oscillating linear piston movement for such a linear compressor.

[0002] U.S. Pat. No. 6,506,032 B2 discloses a linear compressor whose drive unit comprises a frame and an oscillating body mounted in the frame by means of one diaphragm spring. The oscillating body comprises a permanent magnet, a piston rod rigidly connected to the permanent magnet and a piston articulated to the piston rod, which piston can be moved back and forth in a cylinder. The movement of the piston is driven by an electromagnet arranged around the cylinder, which electromagnet interacts with the permanent magnet. A disc-shaped diaphragm spring is screwed centrally to the piston rod, and the outer edge of the diaphragm spring is connected to a yoke which surrounds the cylinder, the electromagnet and the permanent magnet.

[0003] The oscillating body and the diaphragm spring form an oscillating system whose natural frequency is determined by the mass of the oscillating body and the diaphragm spring, as well as by the stiffness of the diaphragm spring. The diagram spring only permits small oscillation amplitudes because any deflection of the oscillating body is associated with an expansion of the diaphragm spring. Due to the low oscillating amplitude it is difficult to reduce the dead volume of the cylinder reliably. However, the higher the dead volume the lower the efficiency of the compressor. The short stroke also necessitates designing the cylinder with a diameter that is proportional to the length in order to achieve a given throughput. It is expensive to seal the correspondingly large circumference of the piston sufficiently.

[0004] Since the oscillating body is only retained in the radial direction by its connection to the spring, it is possible that the head of the piston rod supporting the piston may oscillate back and forth and grind against the cylinder wall. To prevent this a compressed gas bearing is provided for the piston, i.e. the cylinder wall covered by the piston has openings which are connected to the high pressure outlet of the linear compressor to form a gas cushion between the inner wall of the cylinder and the piston. However, such a compressed gas bearing only functions if the required excess pressure is present at the outlet of the linear compressor, i.e. not when the compressor starts or stops. At these times there is a risk that the piston will grind against the cylinder wall, resulting in premature wear of the compressor.

[0005] A linear compressor is disclosed in U.S. Pat. No. 6,641,377 B2. In this double-piston linear compressor each piston is retained by two two-armed diaphragm springs.

[0006] Due to the curvature of the limbs a longer piston stroke is possible, but each diaphragm spring exerts a torque on the piston when deflected. If this torque is not exactly compensated for, the piston performs a rotary oscillation in addition to its linear oscillating movement, and wobble movements of the piston may be excited which may result in contact between the piston and cylinder and consequently to increased wear.

[0007] The object of this invention is to provide a low-wear drive unit for a linear compressor with a frame and an oscillating body mounted by means of a diaphragm spring, in which the diaphragm spring permits a long stroke of the oscillating body and which is able to achieve a high throughput with a small piston diameter.

[0008] The object is achieved in that the plurality of limbs of the diaphragm spring each engage with one end on the frame and with the other end on the oscillating body, and in that the limbs have pairs of sections with opposing curvature between the two ends. The limbs do not therefore extend along the shortest path between the two ends, so that when the oscillating body is deflected, they stretch and my approach the rectilinear shape without the material of the limbs having to be expanded for this purpose. Within the same workpiece it is very easy to produce the limbs so that their torques exactly compensate each other; if, as described in U.S. Pat. No. 6,641,377 B2, two diaphragm springs are provided with limbs covered in different directions, deviations in material strength from one spring to another may prevent such compensation or at least render it extremely difficult.

[0009] The diaphragm spring preferably has pairs of limbs with sections curved in opposite directions.

[0010] In the simplest case each limb has an individual section curved in one direction. Each such limb also exerts a torque on the oscillating body supported by it when deflected, but this is compensated for by the limb paired with it and curved in the opposite direction.

[0011] Each limb preferably has two sections curved in different directions. Since the differently curved sections also generate torques in opposite directions in this case too, the torque of each individual limb may therefore be made very small or caused to disappear altogether.

[0012] It is also advantageous to provide at least a second diaphragm spring whose limbs engage on a region of the oscillating body which is distant from the region of engagement of the first diaphragm spring in the direction of the oscillating movement. The oscillating body is reliably guided linearly in the direction of the desired oscillating movement by the two diaphragm springs, and a lateral deflection movement, which could result in contact between a piston supported by the oscillating body and a cylinder surrounding the piston, can be avoided.

[0013] The limbs of the same diaphragm spring are preferably joined integrally together at their ends engaging on the frame and/or at their ends engaging on the oscillating body. The ends engaging on the frame may also be connected by a frame integral with the leaf springs.

[0014] To provide a long stroke without risk of material fatigue, the limbs of the at least one diaphragm spring should be produced from a very thin material. Its strength may be dimensioned so small that it is only sufficient to prevent lateral deflection of the oscillating body. However, such a weak diaphragm spring would result in a low natural frequency of the drive unit and hence, at a predetermined stroke, in a low throughput of a compressor driven by the drive unit. To achieve a natural frequency of the drive unit sufficient for the required throughput, each limb is preferably assigned a readjusting spring which counteracts deformation of the limb so that the diaphragm spring, together with the readjusting springs, form an elastic system whose stiffness is considerably higher than that of the diaphragm spring alone.

[0015] The effective spring constant of the correlation of diaphragm and readjusting spring may be made adjustable so that the natural frequency of the drive unit can be adapted as required. A helical spring is preferably used as the readjusting spring.

[0016] A further subject matter of the invention is a linear compressor with a working chamber, a piston that can be moved back and forth in the working chamber to compress a working fluid, and a drive unit of the type described above, coupled to the piston, for driving the back and forth movement.

[0017] Further features and advantages of the invention are evident from the following description of exemplary embodiments with reference to the attached figures.

[0018] FIG. **1** shows a diagrammatic section through a linear compressor;

[0019] FIG. **2** shows an elevation of a diaphragm spring for use in the linear compressor in FIG. **1** according to the invention;

[0020] FIG. **3** shows an elevation of a second design of a diaphragm spring;

[0021] FIG. **4** shows a partially cut side view of a linear compressor with the diaphragm spring shown in FIG. **3**; and

[0022] FIG. **5** shows a further design of a diaphragm spring.

[0023] The linear compressor shown in FIG. **1** for a refrigerating device comprises a compressor chamber **1**, which is delimited by a moving piston **2** on the one hand and a cylinder **3** on the other, joined together by a pipe section **4** and a cover **5**. Cover **5**, not shown, incorporates in an intrinsically known manner a suction connection, a pressure connection and valves which allow refrigerant to flow into the compressor chamber only via the suction connection and discharge only via the pressure connection.

[0024] Pipe section **4** is surrounded concentrically by a second pipe section **6** and is connected to it by a radial flange **7**. The circumference of a diaphragm spring **8** is fastened to the end of pipe section **6** facing away from flange **7**. An oscillating body **9**, which is composed of a piston rod **10**, to which piston **2** is articulated, a flange **11** fastened to piston rod **10** and a permanent magnet **12**, which is fastened to flange **11** and projects into the interval between pipe sections **6**, **4**, is fitted in the centre of diaphragm spring **8**. Electromagnets, also accommodated in the interval, for exerting a force in the direction of piston rod **10** on permanent magnets **12**, are omitted in the figure.

[0025] FIG. **2** shows an elevation of diaphragm spring **8**. It comprises a peripheral outer ring **13** and mirror image limbs **14** which are arranged in pairs and run spirally inwards from ring **13**, which limbs are connected to each other at their ends facing away from ring **13**. A central opening **15** is provided for screwing piston rod **10**.

[0026] Diaphragm spring **8** consists of spring steel or another elastically deformable, but essentially non-expandable material. The central region of diaphragm spring **8** can be elastically deflected with little force in a direction perpendicular to the plane shown in FIG. **2**, the deflection causing the curvature of limbs **14** to be reduced slightly in elevation and the central region to be rotated slightly in the anticlockwise direction. The resistance of diaphragm spring **8** against a displacement of the central region in the plane shown in FIG. **2** is much greater than the resistance against a deflection perpendicular to this plane, so that the end of piston rod **10** fastened to opening **15** of diaphragm spring **8** is reliably guided so that it moves in a linear direction.

[0027] A second design of diaphragm spring **8** is shown in FIG. **3** in elevation. This design also has a closed outer ring **13**. Here this ring is rectangular in shape, but this is insignificant as far as the function of the diaphragm spring is concerned. Four limbs **14** extend from the corners of frame **13** towards central region **16**, each of them being formed from three rectilinear sections **17** and two curved sections **18**, **19** connecting sections **17**. The two sections **18**, **19** of each limb **14** are each curved in opposite directions. Four bores **20** for fastening the diaphragm spring are located in the corners of frame **13**.

[0028] When central region **16** is deflected, this results in slight upward bending of curved sections **18**, **19**. Because of the opposite directions of curvature of the two sections **18**, **19** of each limb, the upward bending gives rise to opposing torques, so that the torque exerted by each individual limb **14** on central region **16** is small. Moreover, the torques of adjacent limbs **14** are mutually compensating because each of them is the mirror image of the other and the torques exerted by them are therefore inversely the same. Central area **16**, and consequently also a piston rod **10** fastened to it, are therefore guided exactly linearly and free from distortion.

[0029] FIG. **4** shows a partially cut side view of a linear compressor in which diaphragm springs **8** of the type shown in FIG. **3** are used. The compressor has a frame with a central chamber **21**, in which openings are formed in two opposing walls, here denoted as ceiling **22** and floor **23** with reference to the representation in the figure, for the purpose of clear illustration, through which openings a rod-shaped oscillating mass **24** extends with a certain clearance. The chamber is provided to accommodate electromagnets, not shown, for driving a back and forth movement of a permanent magnet inserted in the oscillating mass.

[0030] The ends of oscillating mass **24** are fastened to central regions **16** of two diaphragm springs **8** of the shape shown in FIG. **3** by means of screws or rivets **25**. Frame **13** of each diaphragm spring **8** rests in turn on bridges **26** projecting from ceiling **22** and floor **23** of central chamber **221**. The height of bridges **26** establishes the maximum stroke of movement of the oscillating mass **24**; if this maximum stroke is exceeded, central regions **16** of diaphragm spring **8** strike against ceiling **22** and floor **23**.

[0031] Diagram springs **8** are retained on bridges **26** by screws or rivets **27**, each of which intersect a foot piece **28** of an upper and lower yoke **29**, **30** and one of bores **19** in the corners of frame **13**, and engage in central chamber **21**.

[0032] Lower yoke **30** supports two helical springs **31**, each of which is positioned so that free head piece **32** of these springs each touch curved sections **18** of two limbs **14**, as also denoted as a dash-dot outline in FIG. **3**, when they are deflected downwards and therefore resist a downward deflection of oscillating mass **24**. Corresponding helical springs **31**, which touch curved sections **18** of limbs of upper diaphragm spring **8** and counteract an upward deflection of the oscillating mass, are provided on upper yoke **29**.

[0033] Upper yoke **29** also supports a cylinder **33** in which a piston connected to oscillating mass **24** by means of a piston rod **10**, not shown in the figure, is able to move back and forth. Since oscillating mass **24** is guided exactly linearly by the two diaphragm springs **8**, piston rod **12**, and with it the piston supported by it, cannot deviate transversely to the direction of movement and grinding of the piston against the inner wall of cylinder **33** can be avoided.

[0034] When oscillating mass **24** is located at one of the points of inversion on its trajectory, its entire kinetic energy is stored in the diaphragm springs **8** and the helical springs **31** in the form of deformation energy, the distribution of the energy among the spring types depending on their respective spring constants. The diaphragm springs may therefore be made very thin and easily deformable so that no material fatigue occurs even during protracted operation. For the energy which the diaphragm springs are unable to store due to insufficient stiffness may be absorbed by suitably dimensioned helical springs **31**.

[0035] Moreover, compressors with different throughputs can be achieved with the same model of diaphragm spring if the diaphragm springs are each combined with helical springs with different spring constants, resulting in different natural frequencies of the oscillating system.

[0036] It is also conceivable to render the natural frequency of a drive unit adjustable by mounting helical springs **31** displaceably on yokes **29**, **30**. The closer the region of limbs **14** touched by head pieces **32** of helical springs **31** is to central region **16** of diaphragm springs **8**, the stiffer will be the entire system, consisting of the diaphragm spring and helical springs, and the higher will be the natural frequency of the resultant drive unit.

[0037] In the extreme case it is possible to replace the two helical springs **31** of each yoke **29**, **30** by a single helical spring which touches central region **16** directly.

[0038] FIG. **5** shows a modification of diaphragm spring **8** from FIG. **3**, which can be used in its stead in the compressor shown in FIG. **4**. In the case of the diaphragm spring shown in FIG. **5**, outer frame **13** is omitted and instead only the three right and two left limbs **14** are connected at their ends facing away from central region **16** by a material strip **34**. The mode of operation is no different to that of the diaphragm spring shown in FIG. **3**.

1-12. (canceled)

13. A drive unit for a linear compressor comprising a frame and an oscillating body mounted in the frame by means of at least one diaphragm spring and moving back and forth, the diaphragm spring having a plurality of limbs engaging the frame with a first end and the oscillating body with a second end, and a curved path between the two ends, wherein two of the limbs have inversely curved sections.

14. The drive unit according to claim 13, wherein each limb has two sections curved in different directions.

15. The drive unit according to claim 13, further comprising a second diaphragm spring, the first and second diaphragm springs engaging on regions of the oscillating body that are spaced in the direction of the oscillating movement.

16. The drive unit according to claim 13, wherein the limbs of the same diaphragm spring are integrally joined together at their ends engaging on the oscillating body.

17. The drive unit according to claim 13, wherein the limbs of the same diaphragm spring are integrally joined together at their ends engaging on the frame.

18. The drive unit according to claim 17, wherein the ends engaging on the frame are connected by a frame integral with the limbs.

19. The drive unit according to claim 13, further comprising a readjusting spring assigned to each limb and counteracting deformation of the limb.

20. The drive unit according to claim 19, wherein the stiffness of the diaphragm spring is lower in the direction of deformation than that of the readjusting spring.

21. The drive unit according to claim 19, wherein an effective spring constant of the combination of diaphragm spring and readjusting spring is adjustable.

22. The drive unit according to claim 19, wherein the readjusting spring includes a helical spring.

23. The drive unit according to claim 13, wherein the mass of the oscillating body is greater than the mass of all the springs.

24. A linear compressor comprising:

a working chamber;

a piston being movable back and forth in the working chamber for compressing a working fluid; and

a drive unit coupled to the piston for driving the back and forth movement and comprising a frame and an oscillating body mounted in the frame by means of at least one diaphragm spring and moving back and forth, the diaphragm spring having a plurality of limbs engaging the frame with a first end and the oscillating body with a second end, and a curved path between the two ends, wherein two of the limbs have inversely curved sections.

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