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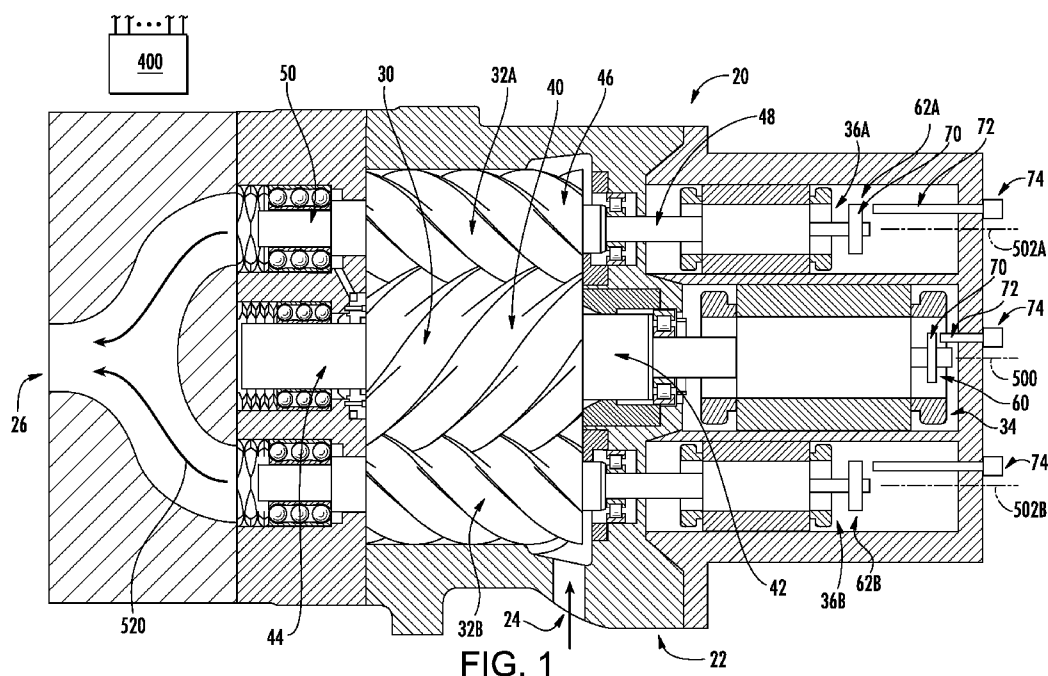
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(54) Title: SCREW COMPRESSOR WITH ROTOR SYNCHRONIZATION



(57) Abstract: A compressor (20, 100, 200, 300) comprises: a housing (22); a first rotor (30) mounted for rotation about a first axis (500); a first motor (34) coupled to the first rotor to drive rotation of the first rotor about the first axis; a second rotor (32A) mounted for rotation about a second axis (502A) and enmeshed with the first rotor; a second motor (36A) coupled to the second rotor to drive rotation of the second rotor about the second axis; and means (60, 62A) for detecting a phase relationship between the first rotor and the second rotor.

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
KM, ML, MR, NE, SN, TD, TG).

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SCREW COMPRESSOR WITH ROTOR SYNCHRONIZATION

CROSS-REFERENCE TO RELATED APPLICATION

[0001] Benefit is claimed of U.S. Patent Application No. 62/423,123, filed November 16, 2016, and entitled "Screw Compressor with Rotor Synchronization", the disclosure of which is incorporated by reference herein in its entirety as if set forth at length.

BACKGROUND

[0002] The disclosure relates to screw compressors. More particularly, the disclosure relates to rotor synchronization in screw compressors.

[0003] In an exemplary screw compressor, a motor drives one rotor. The rotor is enmeshed with other rotors. Specifically, if the motor-driven rotor is a male rotor, its lobes are enmeshed with the lobes of one or more female rotors so that cooperation of the enmeshed lobes drives rotation of the female rotors. The lobe engagement may produce wear.

[0004] Alternative compressors have used synchronizing gears to reduce lobe wear. One proposal is reflected in US Patent 5910001.

SUMMARY

[0005] One aspect of the disclosure involves a compressor comprising: a housing; a first rotor mounted for rotation about a first axis; a first motor coupled to the first rotor to drive rotation of the first rotor about the first axis; a second rotor mounted for rotation about a second axis and enmeshed with the first rotor; a second motor coupled to the second rotor to drive rotation of the second rotor about the second axis; and means for detecting a phase relationship between the first rotor and the second rotor.

[0006] In one or more embodiments of any of the foregoing embodiments, the means comprises: a first sensor for measuring an orientation of the first rotor about the first axis; and a second sensor for measuring an orientation of the second rotor about the second axis..

[0007] In one or more embodiments of any of the foregoing embodiments, the first sensor is an optical sensor; and the second sensor is an optical sensor.

[0008] In one or more embodiments of any of the foregoing embodiments, the compressor does not have synchronizing gears between the first rotor and second rotor.

[0009] In one or more embodiments of any of the foregoing embodiments, the first rotor
5 is a male rotor and the second rotor is a female rotor.

[0010] In one or more embodiments of any of the foregoing embodiments, the first motor is an electric motor and the second motor is an electric motor.

10 **[0011]** In one or more embodiments of any of the foregoing embodiments, the first motor is axially opposite the second motor.

[0012] In one or more embodiments of any of the foregoing embodiments, the first motor is at a suction end of the compressor and the second motor is at a discharge end of the
15 compressor.

[0013] In one or more embodiments of any of the foregoing embodiments, the compressor further comprises: a third rotor mounted for rotation about a third axis and enmeshed with the first rotor; and a third motor coupled to the third rotor to drive rotation of
20 the third rotor about the third axis.

[0014] In one or more embodiments of any of the foregoing embodiments, the means is also means for detecting a phase relationship between the first rotor and the third rotor.

25 **[0015]** In one or more embodiments of any of the foregoing embodiments, the means comprises: a first sensor for measuring an orientation of the first rotor about the first axis; a second sensor for measuring an orientation of the second rotor about the second axis; and a third sensor for measuring an orientation of the third rotor about the third axis.

30 **[0016]** In one or more embodiments of any of the foregoing embodiments, the compressor further comprises a controller configured to: operate the first motor and the second motor to maintain a synchronized phase relationship between the first rotor and the second rotor.

[0017] In one or more embodiments of any of the foregoing embodiments, the controller is configured to: operate the first motor and the second motor to avoid contact between the first rotor and the second rotor.

5 [0018] In one or more embodiments of any of the foregoing embodiments, the compressor further comprises a controller configured to: operate the first motor and the second motor to avoid contact between the first rotor and the second rotor.

[0019] In one or more embodiments of any of the foregoing embodiments, a method for
10 using the compressor comprises operating the first motor and the second motor to avoid contact between the first rotor and the second rotor.

[0020] In one or more embodiments of any of the foregoing embodiments, the method
15 further comprises determining a backlash between the first rotor and the second rotor.

[0021] Another aspect of the disclosure involves a compressor comprising: a housing; a first rotor mounted for rotation about a first axis; a first motor coupled to the first rotor to drive rotation of the first rotor about the first axis; a second rotor mounted for rotation about a second axis and enmeshed with the first rotor; a second motor coupled to the second rotor to
20 drive rotation of the second rotor about the second axis; a first sensor for measuring an orientation of the first rotor about the first axis; and a second sensor for measuring an orientation of the second rotor about the second axis.

[0022] In one or more embodiments of any of the foregoing embodiments, the
25 compressor further comprises a controller configured to operate the first motor and the second motor responsive to input from the first sensor and the second sensor to avoid contact between the first rotor and the second rotor.

[0023] In one or more embodiments of any of the foregoing embodiments, the
30 compressor further comprises: a third rotor mounted for rotation about a third axis and enmeshed with the first rotor; and a third motor coupled to the third rotor to drive rotation of the third rotor about the third axis.

[0024] In one or more embodiments of any of the foregoing embodiments, the first motor is axially opposite the second motor.

[0025] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] FIG. 1 is a longitudinal cutaway view of a first compressor.

10 **[0027]** FIG. 2 is a longitudinal cutaway view of a second compressor.

[0028] FIG. 3 is a longitudinal cutaway view of a third compressor.

[0029] FIG. 4 is a longitudinal cutaway view of a fourth compressor.

[0030] Like reference numbers and designations in the various drawings indicate like elements.

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DETAILED DESCRIPTION

[0031] FIG. 1 shows a compressor 20 having a housing assembly 22 defining at least one inlet or suction port 24 and at least one outlet or discharge port 26 with a flowpath therebetween. To drive a flow 520, the compressor includes a plurality of lobed rotors 30, 32A, 32B respectively driven by motors 34, 36A, 36B. As is discussed below, synchronized driving of the rotors via their respective associated motors may reduce or even eliminate engagement forces between the rotors and thereby may reduce wear and other detriments. In an exemplary embodiment, the rotor 30 is a male rotor having a male-lobed working portion 40 and shaft portions 42 and 44 protruding from opposite ends of the working portion 40. Similarly, each of the female rotors 32A, 32B has a working portion 46 enmeshed with the working portion 40 and has shaft portions 48 and 50. The shaft portions are supported by appropriate bearings for rotation of the rotors about respective axes 500, 502A, 502B.

[0032] Each exemplary motor is an electric motor (e.g., induction, permanent magnet (PM), or switch reluctance) having a rotor and a stator and is independently powered. By independently powering and controlling the motors, minimal to no engagement torque may be transmitted by contact of the rotors with each other. To do this, rotor position sensors 60, 62A, 62B may be provided. These may measure the angular position of each rotor about its axis. This may be a unique position (i.e., so as to know exactly where a given point on the rotor is in its 360° cycle) or may be a more limited measurement (e.g., due to the symmetry of the rotor having a given number of lobes, one does not need to know the exact position of a given lobe but only the general phase of operation).

[0033] Thus, for example, the sensor input may be utilized such that there is no hard contact between rotors (sealing between rotors will nevertheless likely be accomplished by oil but there will be little or no squeezing of the oil).

[0034] Exemplary sensors have elements 70 rotating with the rotor (e.g., encoder disks) and fixed elements 72 interacting therewith (e.g., optical or Hall effect sensors). Thus, depending on context, the term “sensor” may identify only the element 72 or the combination of elements 70 and 72. FIG. 1 also shows each exemplary sensor as having a connector 74 on the housing for electrically connecting the sensor to wiring which, in turn, connects to a controller (e.g., a system controller or a dedicated controller of the compressor).

[0035] In operation, there may be feedback control. One example of control is envisioned by comparison to a baseline single-motor compressor wherein motor speed is controlled. Thus, an exemplary baseline controller may, depending upon conditions, output or utilize a speed parameter. This may be used in simple feedback control of that single motor. In a

modified system, this target speed may similarly be used to control the motor 34. Within this basic example, control of the motors 36A and 36B may follow one or more of several processes. One process is purely responsive/reactive. For example, based upon the output of the sensor 60 on the one hand and the sensors 62A and 62B on the other hand, the motors

36A and 36B may be controlled to maintain the exact desired phase relationship. For example, there is a very small amount of backlash possible between the mated rotors. The backlash or rotor clearance amount may be quantified in any of several ways. One way is a tangential linear distance at the center of the enmeshed lobes. One example below is in the range of 5 to 20 micrometers. Another way is an angle of backlash about the axis of a rotor. If the rotors are of different sizes, a given backlash will have different angles depending on which one of the rotors is used as the reference. Relative rotor phase within that range of backlash may, similarly, be expressed as a linear dimension or an angle.

[0036] It may be desired to maintain rotor phase directly in the middle of this range of backlash. If the sensors show lagging of the female rotors (e.g., so that they risk contact with the male rotor), power applied to the motor of the female rotor(s) may be increased. If excessive power is being applied to the motors of the female rotors, the sensors will indicate phase toward the opposite end of that range of backlash and the power to the motors 36A and/or 36B may be reduced. This may be an iterative feedback process.

[0037] FIG. 2 shows a compressor 100 otherwise similar to the compressor 20 except that the motors 36A, 36B are axially opposite the motor 34 rather than at the same end of the compressor. This configuration may offer better accessibility of motors for servicing and repair.

[0038] FIG. 3 shows a two-rotor compressor 200 with a single female rotor. Both motors are at the same end of the compressor.

[0039] FIG. 4 shows a two-rotor compressor 300 where the motors are at opposite ends.

[0040] The compressors may be used in a vapor compression system such as a refrigeration system. An exemplary refrigeration system is a vapor compression system comprising a compressor for driving refrigerant flow along a recirculating refrigerant flowpath. In normal cooling mode, the refrigerant flowpath proceeds downstream from the outlet or discharge port of the compressor through a heat rejection heat exchanger to reject heat such as to an external environment (e.g., via a fan-forced external airflow or via a heat transfer liquid). Refrigerant may then be expanded such as in an expansion device (e.g., electronic expansion valve, thermal expansion valve, orifice, capillary device, or the like) and passed to a heat absorption to absorb heat (e.g., from a fan forced airflow or from a heat

transfer liquid). After absorbing heat, refrigerant may return to the suction port or inlet of the compressor.

[0041] FIG. 1 further shows a controller 400. The controller may receive user inputs from an input device (e.g., switches, keyboard, or the like) and sensors (60, 62A, 62B, and other system sensors, not shown, e.g., pressure sensors and temperature sensors at various system locations). The controller may be coupled to the sensors and controllable system components (e.g., valves, the bearings, the compressor motors 34, 36A, 36B, vane actuators, and the like) via control lines (e.g., hardwired or wireless communication paths). The controller may include one or more: processors; memory (e.g., for storing program information for execution by the processor to perform the operational methods and for storing data used or generated by the program(s)); and hardware interface devices (e.g., ports) for interfacing with input/output devices and controllable system components.

[0042] The compressor may be made using otherwise conventional or yet-developed materials and techniques. Exemplary motors can be induction, permanent magnet, or switch reluctance. Both axial and radial flux can be used. In exemplary embodiments, the motors are all of the same general type but may be differently sized.

[0043] Motor sizes can be tailored to for different torque transmission to avoid rotordynamic issues with overhung motor rotor. For example, typical torque transmission between male and female rotors is 5 to 10%. Thus, in the separate motor arrangement, the male motor may be 5-10% smaller than compared to a single motor driven design. The smaller motor overhang may allow operating the compressor at higher speed.

[0044] Potential advantages may depend on the particular implementation and the particular comparative baseline. Advantages may include one or more of: reduced wear on rotor lobes; elimination of synchronizing gears; reduced oil use and/or use of less viscous oil and or no oil; reduced heat generation; and improved efficiency. Several of these may be interrelated or lead to other benefits. For example, reduced oil use (e.g., reduced oil content entering the compressor in the refrigerant flow and/or as separate injections) may lead to increased thermal efficiency (e.g., via improved heat exchanger performance) and/or may allow removal of or reduction in oil separators.

[0045] Depending on the sensors used and the controller sophistication, various setup steps may be taken, if at all, with various combinations of manual and automated actions. These can include determining the amount of backlash and initializing the controller to be able to correlate sensor outputs with the relative position of the rotors within the backlash

range so that the controller can then control motor operation to achieve a desired relative position (phase).

[0046] With sufficiently precise manufacturing tolerances and no wear concerns, the backlash amount may be already known from engineering data. Otherwise, this may be determined. In one example of a largely manual determination, specimens of a given compressor model might have backlash in a range of 5 to 20 micrometers. For a given such compressor, the backlash may be measured electronically after the rotors are assembled. This is done by rotating one of the rotors and holding the other rotor stationary. Sensor output may be used by the controller to determine the amount of backlash and relative phase. With lobe count programmed into the controller, the controller may be able to then determine relative phase as the rotors rotate.

[0047] Due to machining tolerances the backlash may have range for a given rotor pair (e.g., there may be different backlash when different lobes on a given rotor are interacting with different lobes on the mating rotor). This involves, not merely rotor manufacturing tolerance but housing or other manufacturing tolerance. Thus, possible implementations may include multiple measurements. These might determine an average backlash and may allow the controller to select a phase relationship that compensates for irregularity. For example, if it is desired to have meshing at the middle of the backlash range but one lobe on one rotor is slightly mis-positioned or mis-sized. In that situation, the speed may be set so that meshing involving said lobe is slightly out of phase with the meshing involving the other lobes (e.g., to one side of that lobe meshing occurs early and to another side meshing occurs late if mis-positioned or meshing occurs late or early to both sides if mis-sized).

[0048] Alternatively, profile measurements may be taken of each rotor. Based on the rotor profile measurements, analytical methods can be used to determine the backlash range. This can also be measured by mating different combinations of teeth on each rotor on a bench and then averaging or using the worst-case numbers to provide safe operation.

[0049] In a more automated arrangement, the controller itself may operate the motors to determine backlash. For example, the controller may rotate one motor in opposite directions determining from the sensor of the other rotor or from some other means when contact is made. Correlating the contact events with the sensor outputs of both sensors (or more in the case of a three-rotor system) allows the controller to determine the amount of backlash and calibrate the relationship of sensor output to rotor orientation. This is the kind of thing that could be done prior to startup, at startup, once up to speed, and/or periodically during operation.

[0050] Based on the determined characteristic backlash, in some implementations the controller may create a map or equation relating a time difference in rotor position to speed to achieve the desired relationship. For example, the time difference may be a difference between the center of a lobe of one rotor reaching the shared plane of the rotor axes and the center of the next lobe of the other rotor reaching that plane.

[0051] Depending on implementation, there may be a variety of options for when the controller provides the active control of phase. In some, the controller may wait until an operating speed is reached. In others, the controller may try to maintain the desired phase from start-up. In an example of the latter, one operational sequence may reflect knowledge that due to pressure, the rotors may be contacting at one end of the range of backlash. The controller may start whichever of the motors would disengage that contact and then start the other motor(s) after a calculated time difference. As the first motor is accelerated, the speed of the second motor may be iteratively controlled to maintain the desired phase relationship.

[0052] The control routine which may be programmed or otherwise configured into the controller. The routine provides for the desired phase relationship and may be superimposed upon the controller's normal programming/routines (not described, e.g., providing the basic operation of a baseline system to which the foregoing control routine is added). In the example above, the targeted phase relationship is to keep the lobes exactly out of phase (dead center in the range of backlash). That dead center condition might be a dead-center condition for the average interaction or the worst case interaction. However, as noted above, other targets might be at different points in the range of backlash. These might be anywhere from 15% to 95% (or 10% to 90% or 25% to 75%) along the range of such average or worst case backlash.

[0053] The use of "first", "second", and the like in the description and following claims is for differentiation within the claim only and does not necessarily indicate relative or absolute importance or temporal order. Similarly, the identification in a claim of one element as "first" (or the like) does not preclude such "first" element from identifying an element that is referred to as "second" (or the like) in another claim or in the description.

[0054] One or more embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, when applied to an existing basic system, details of such configuration or its associated use may influence details of particular implementations. Accordingly, other embodiments are within the scope of the following claims.

CLAIMS

What is claimed is:

1. A compressor (20; 100; 200; 300) comprising:
 - a housing (22);
 - 5 a first rotor (30) mounted for rotation about a first axis (500);
 - a first motor (34) coupled to the first rotor to drive rotation of the first rotor about the first axis;
 - a second rotor (32A) mounted for rotation about a second axis (502A) and enmeshed with the first rotor;
 - 10 a second motor (36A) coupled to the second rotor to drive rotation of the second rotor about the second axis; and
 - means (60, 62A) for detecting a phase relationship between the first rotor and the second rotor.
- 15 2. The compressor of claim 1 wherein the means comprises:
 - a first sensor (60) for measuring an orientation of the first rotor about the first axis; and
 - a second sensor (62A) for measuring an orientation of the second rotor about the second axis.
- 20 3. The compressor of claim 2 wherein:
 - the first sensor is an optical sensor; and
 - the second sensor is an optical sensor.
4. The compressor of claim 1 wherein:
 - 25 the compressor does not have synchronizing gears between the first rotor and second rotor.
5. The compressor of claim 1 wherein:
 - the first rotor is a male rotor; and
 - 30 the second rotor is a female rotor.
6. The compressor of claim 1 wherein:
 - the first motor is an electric motor; and
 - the second motor is an electric motor.

7. The compressor (100; 300) of claim 1 wherein:
the first motor is axially opposite the second motor.
- 5 8. The compressor (100; 300) of claim 1 wherein:
the first motor is at a suction end of the compressor; and
the second motor is at a discharge end of the compressor.
9. The compressor of claim 1 further comprising:
10 a third rotor (32B) mounted for rotation about a third axis (502B) and enmeshed with the
first rotor; and
a third motor (36A) coupled to the third rotor to drive rotation of the third rotor about the
third axis.
- 15 10. The compressor of claim 9 wherein the means is also means for detecting a phase
relationship between the first rotor and the third rotor.
11. The compressor of claim 10 wherein the means comprises:
a first sensor (60) for measuring an orientation of the first rotor about the first axis;
20 a second sensor (62A) for measuring an orientation of the second rotor about the second
axis; and
a third sensor (62B) for measuring an orientation of the third rotor about the third axis.
12. The compressor of claim 1 further comprising a controller (400) configured to:
25 operate the first motor and the second motor to maintain a synchronized phase
relationship between the first rotor and the second rotor.
13. The compressor of claim 12 wherein the controller is configured to:
operate the first motor and the second motor to avoid contact between the first rotor and
30 the second rotor.
14. The compressor of claim 1 further comprising a controller (400) configured to:
operate the first motor and the second motor to avoid contact between the first rotor and
the second rotor.

15. A method for using the compressor of claim 1, the method comprising:
operating the first motor and the second motor to avoid contact between the first rotor and
the second rotor.

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16. The method of claim 15 further comprising:
determining a backlash between the first rotor and the second rotor.

17. A compressor (20; 100; 200; 300) comprising:

10

a housing (22);

a first rotor (30) mounted for rotation about a first axis (500);

a first motor (34) coupled to the first rotor to drive rotation of the first rotor about the first
axis;

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a second rotor (32A) mounted for rotation about a second axis (502A) and enmeshed with
the first rotor;

a second motor (36A) coupled to the second rotor to drive rotation of the second rotor
about the second axis;

a first sensor (60) for measuring an orientation of the first rotor about the first axis; and

a second sensor (62A) for measuring an orientation of the second rotor about the second

20

axis.

18. The compressor of claim 17 further comprising a controller (400) configured to:
operate the first motor and the second motor responsive to input from the first sensor and
the second sensor to avoid contact between the first rotor and the second rotor.

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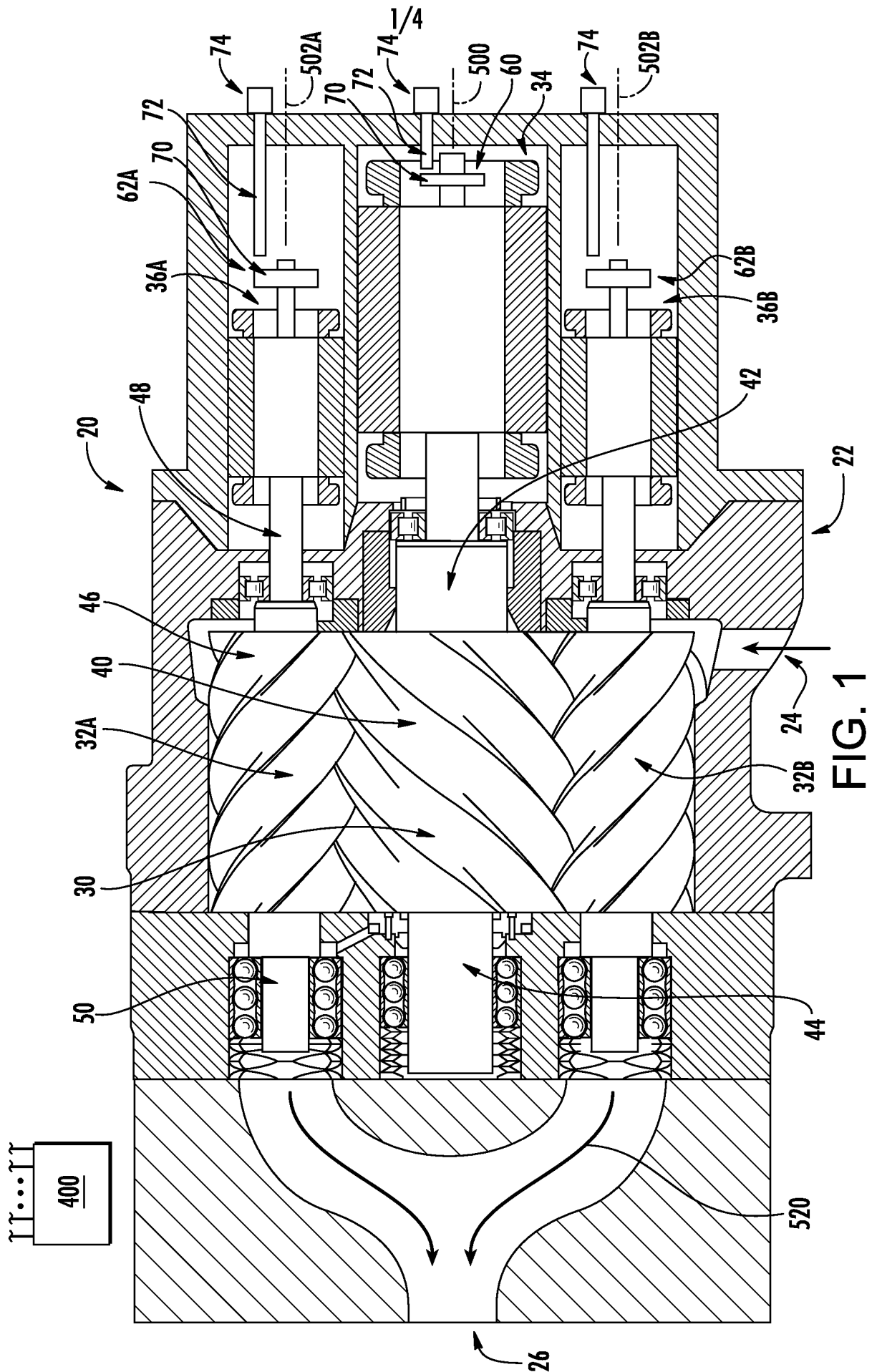
19. The compressor of claim 17 further comprising:

a third rotor (32B) mounted for rotation about a third axis (502B) and enmeshed with the
first rotor; and

a third motor (36A) coupled to the third rotor to drive rotation of the third rotor about the
third axis.

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20. The compressor of claim 17 wherein:
the first motor is axially opposite the second motor.



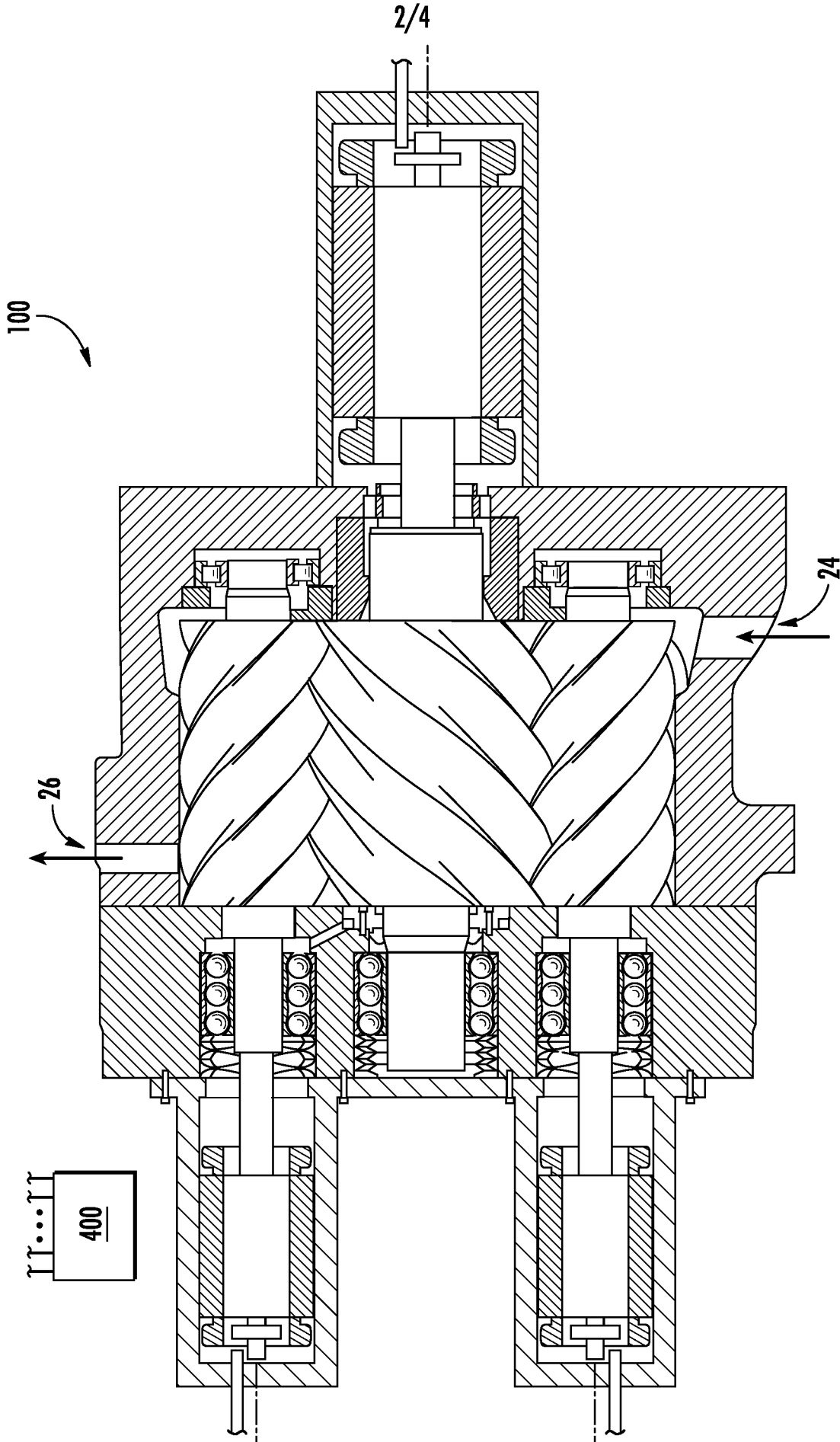


FIG. 2

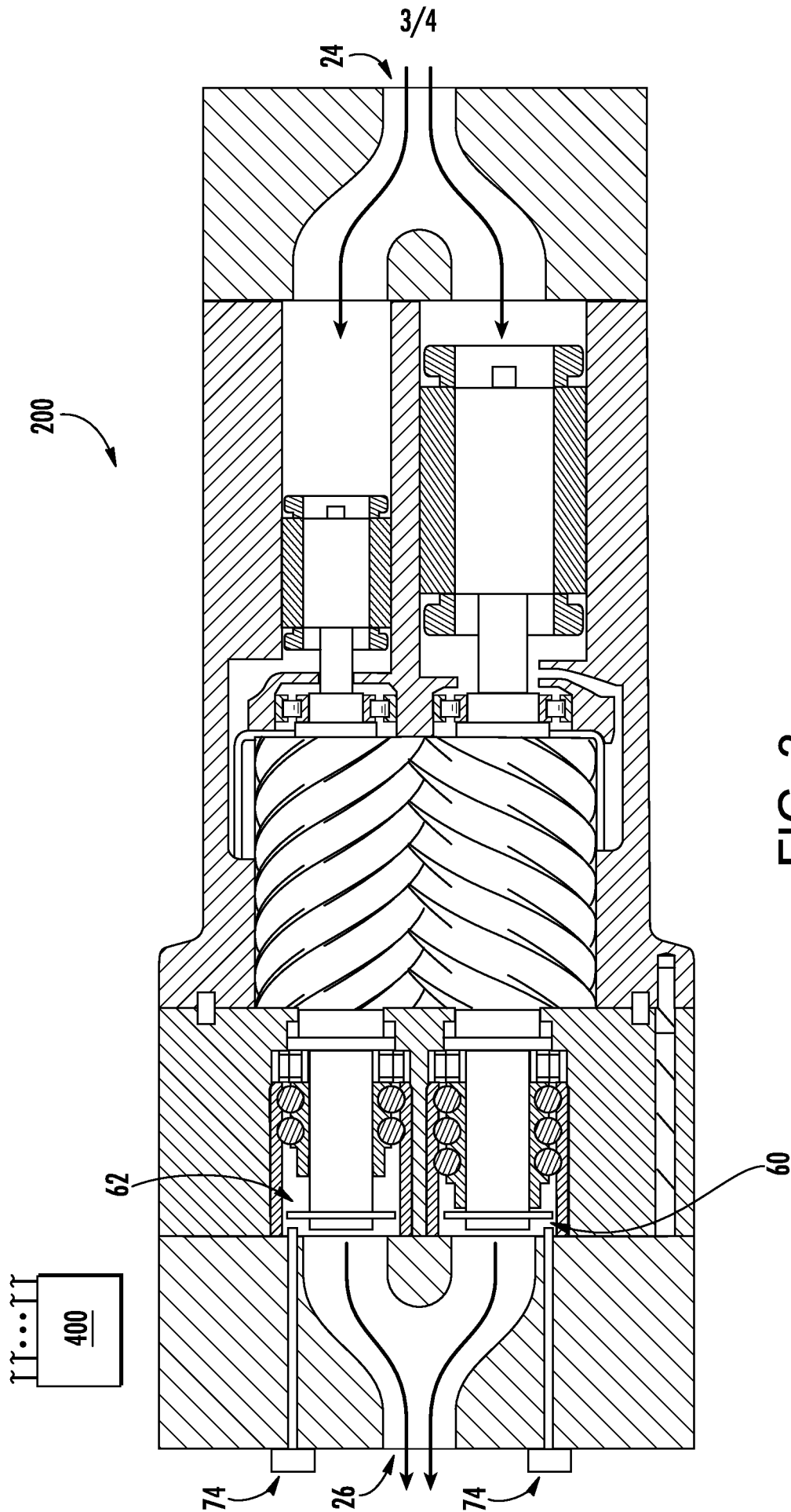


FIG. 3

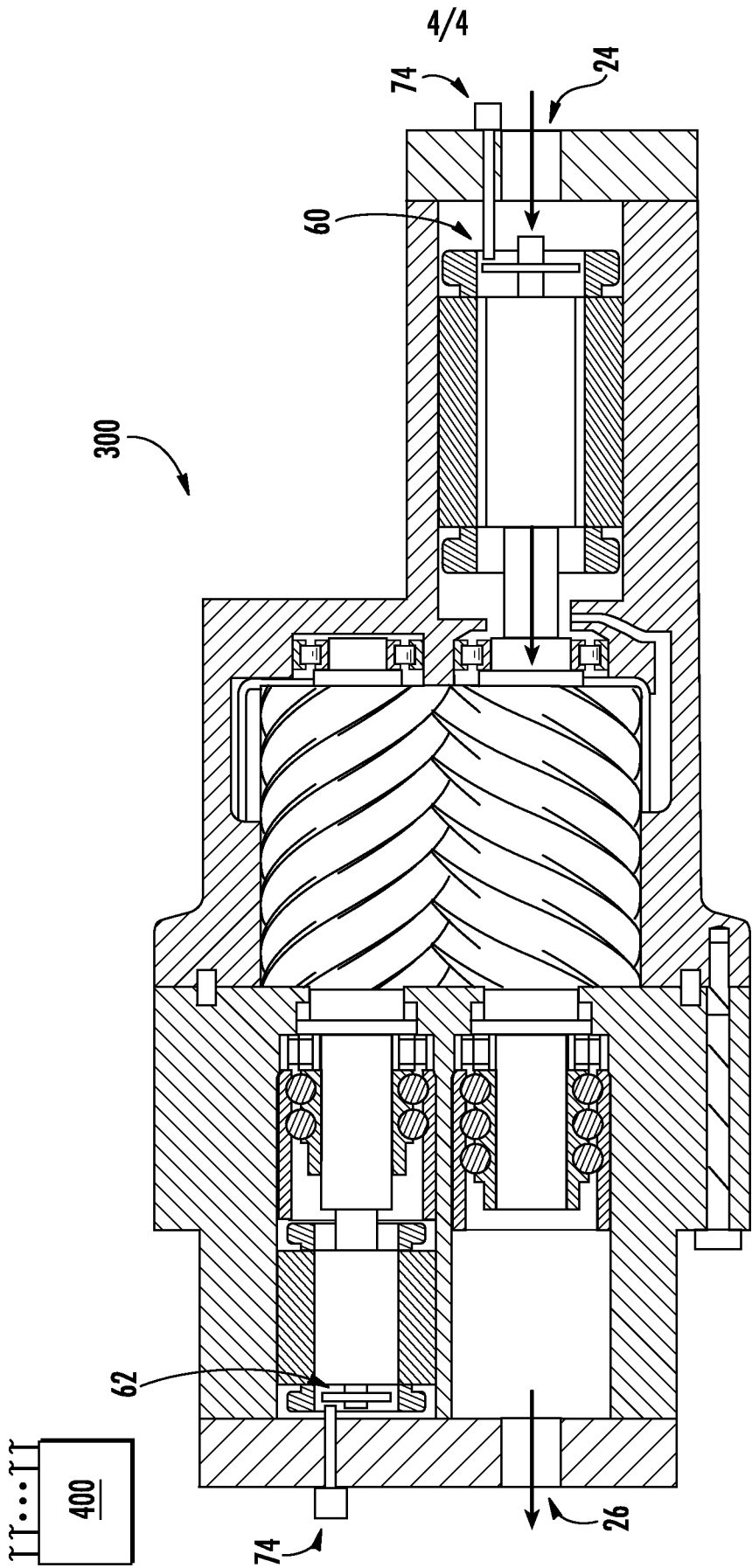


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/049588

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04C2/16
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 558 921 A1 (MATSUSHITA ELECTRIC IND CO LTD [JP]) 8 September 1993 (1993-09-08) column 5, line 16 - line 22 column 7, line 26 - line 33 column 8, line 40 - column 9, line 22 column 10, line 38 - column 12, line 2 column 13, line 18 - column 15, line 28 column 17, line 13 - column 18, line 24 figures 2,6,9,10A-13	1-20
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A	column 3, line 11 - line 34 column 5, line 8 - line 37 figures	8-11
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Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search

8 November 2017

Date of mailing of the international search report

15/11/2017

Name and mailing address of the ISA/

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Bocage, Stéphane

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/049588

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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