US 20070224058A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2007/0224058 A1
(43) Pub. Date: Sep. 27, 2007
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(54) LINEAR COMPRESSOR ASSEMBLY

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(21) Appl. No.: 11/388,432

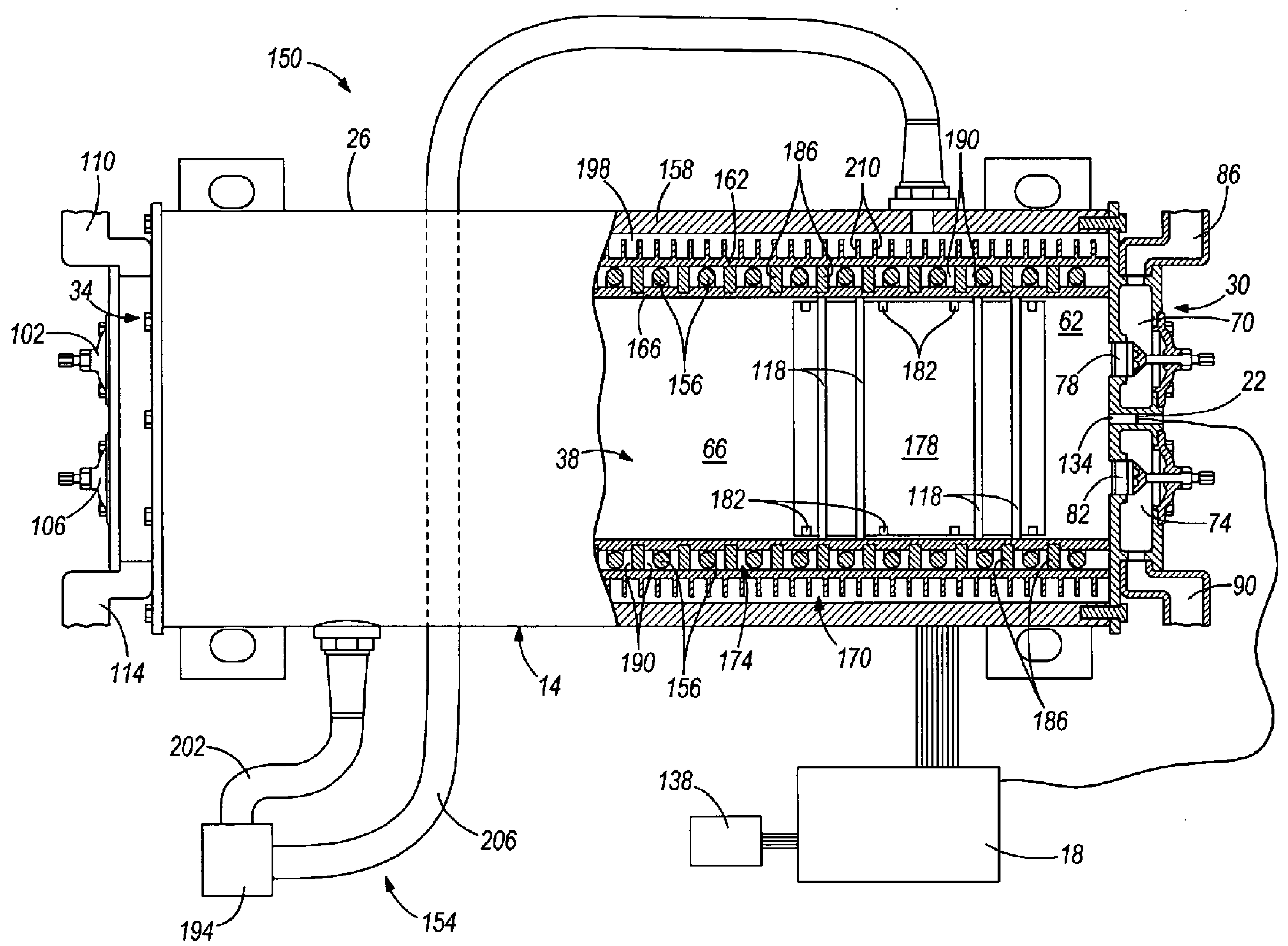
(22) Filed: Mar. 24, 2006

Publication Classification

(51) Int. Cl.
F04B 35/04 (2006.01)
(52) U.S. Cl. 417/415

(57) ABSTRACT

A linear compressor assembly includes a housing having a bore formed therein, the bore being axially oriented along a first axis, a piston reciprocally disposed within the bore, and a plurality of drive coils adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore substantially along the first axis. A controller is used for selectively controlling energizing of the drive coils. A cooling system is at least partially disposed in the housing and the cooling system is used for cooling the apparatus.



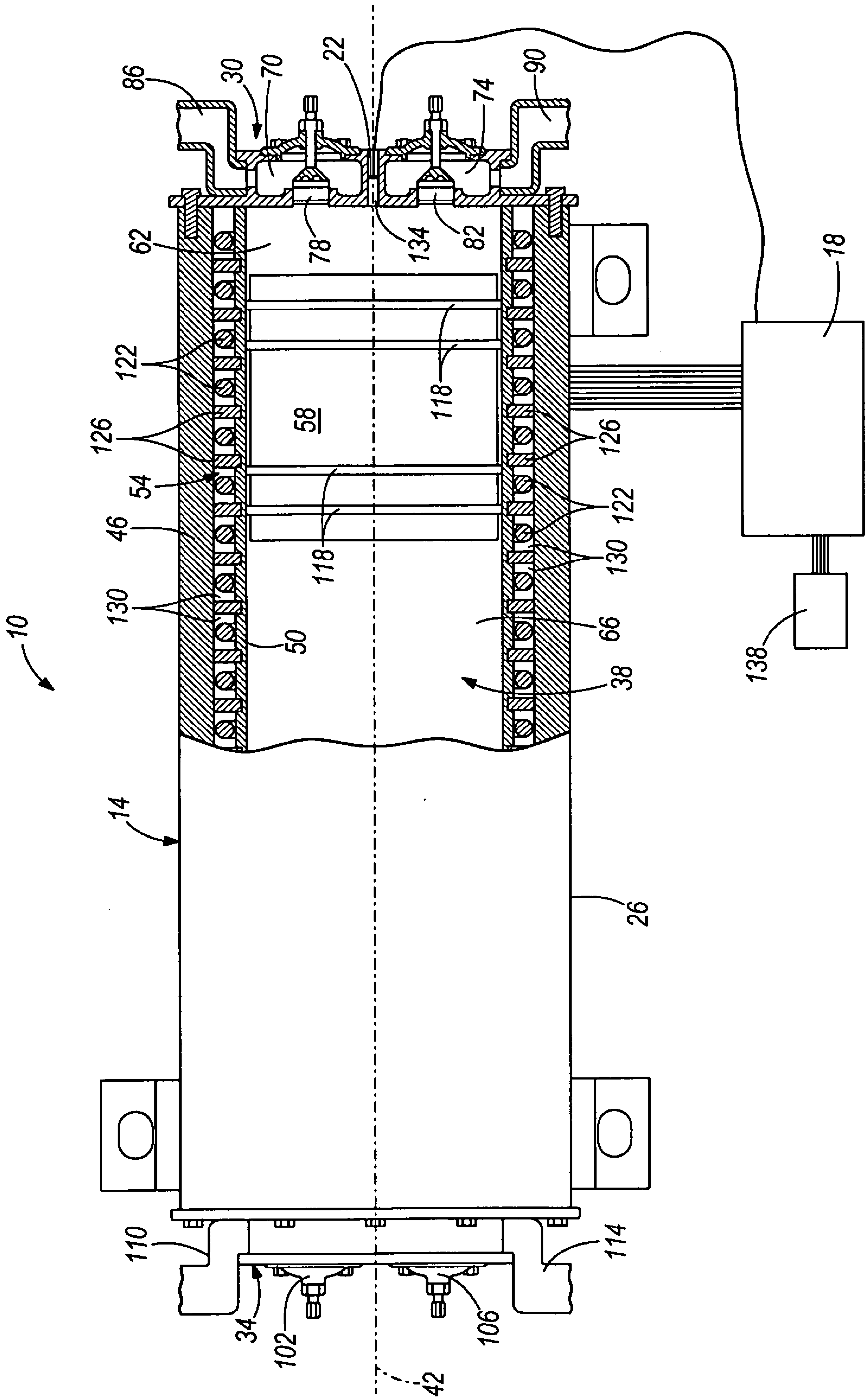

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FIG. 1

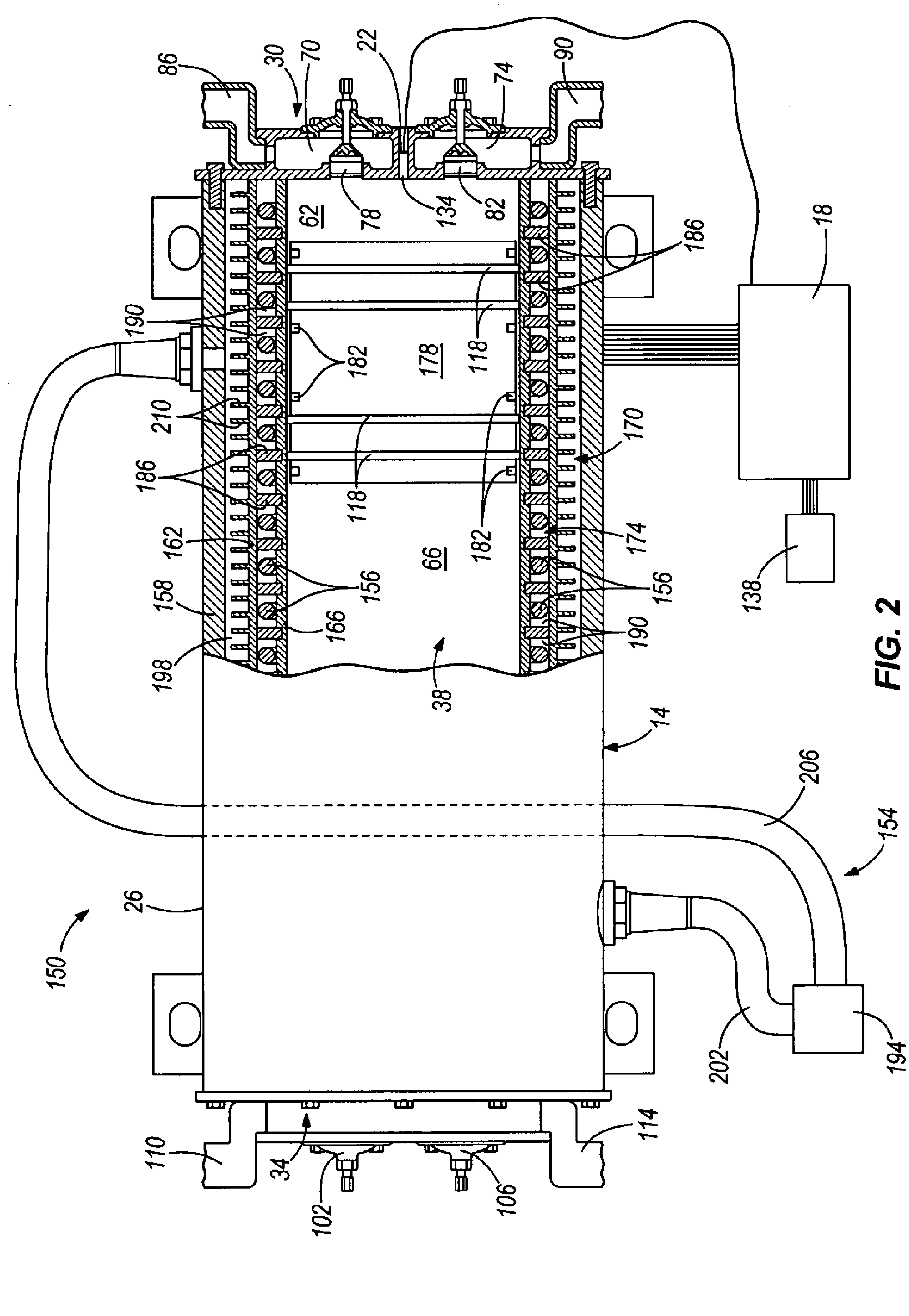
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FIG. 2

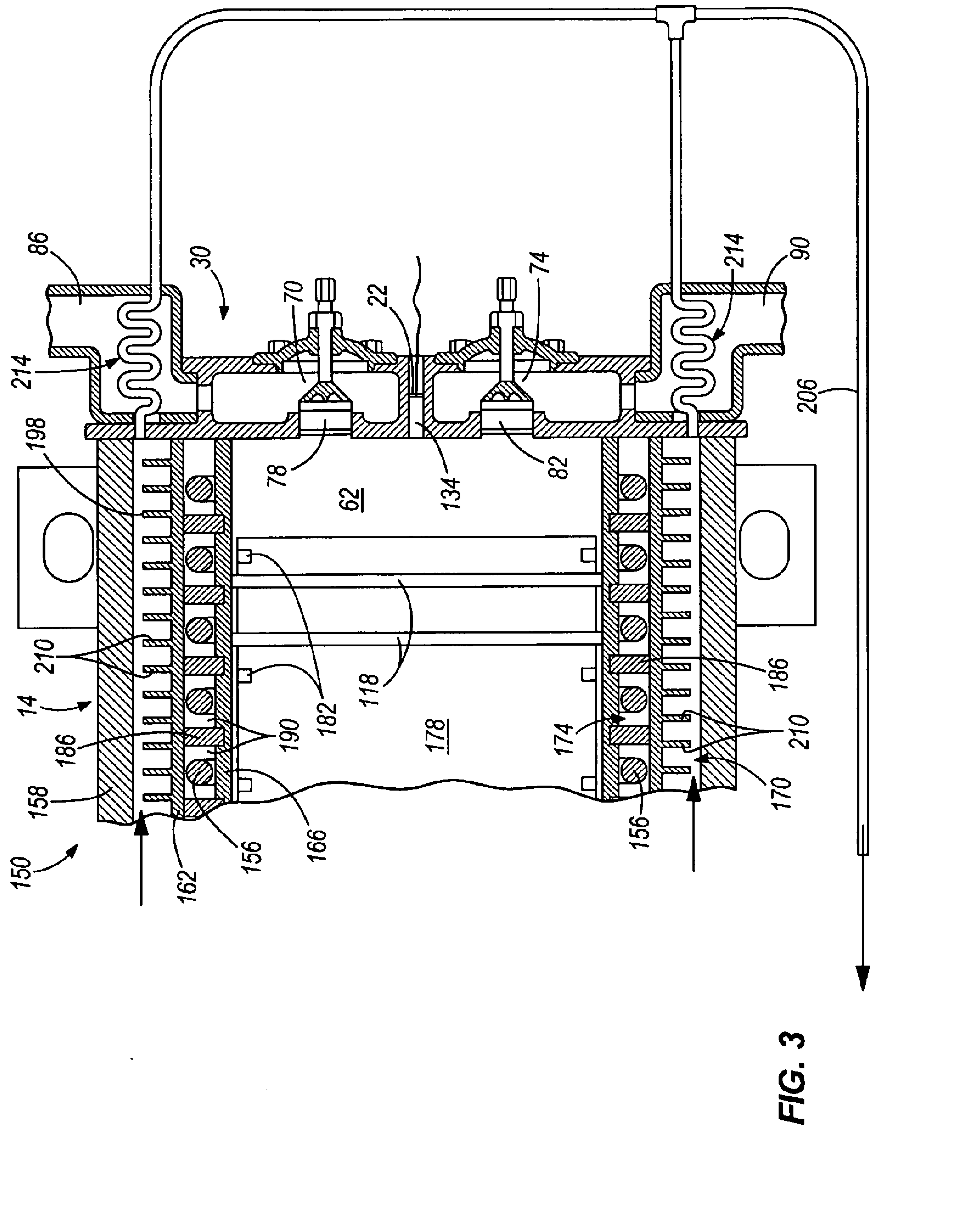
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FIG. 3

LINEAR COMPRESSOR ASSEMBLY

BACKGROUND

[0001] The present invention relates to a compressor and more particularly to a linearly actuated compressor that is electrically driven.

[0002] Linear actuator systems are applied to displace elements as diverse as railways and precision displacement machinery in closed loop and extended systems. The position of the element propelled by the linear actuator has been shown to be determined by a change of current and voltage passing through individual drive coils. For example, a voltage depression in one of the drive coils will indicate passage of the piston adjacent the drive coil. Control of an electric powered linear actuated pump or compressor represents an extremely complex design challenge. Therefore, it is critical to have a sensor which is reliable, simple and capable of responding to varied conditions (such as temperature, differing working fluids and corrosive materials) while responding with quick and repeatable indications about the position and velocity of the piston. It is problematic to precisely locate a piston relative to any drive coil based only upon measured voltage and currents through the drive coils because variations in temperature and the working fluid affect the voltages and currents.

[0003] Prior linear compressor designs have not addressed the problem of heat build-up. In medium and larger sized electric powered linear compressors, heat build-up represents such a problem as to be a limiting factor in compressor design.

SUMMARY

[0004] In one embodiment, the invention provides for an apparatus including a housing having a bore formed therein, the bore being axially oriented along a first axis, a piston reciprocally disposed within the bore, and a plurality of drive coils adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore substantially along the first axis. A controller is used for selectively controlling energizing of the drive coils. The linear compressor also includes a cooling system at least partially disposed in the housing and the cooling system used for cooling the apparatus.

[0005] In another embodiment, the invention provides for an apparatus including a housing having a bore formed therein, the bore being axially oriented along a first axis, a piston reciprocally disposed within the bore, and a plurality of drive coils disposed adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore substantially parallel to the first axis. The apparatus also includes a cooling reservoir positioned between the drive coils and the housing, wherein the cooling reservoir reduces compression heat of the apparatus. A sensor determines position and velocity of the piston relative to the housing, wherein the sensor functions independently of the drive coils, and a controller selectively controls the energizing of the drive coils in response to a signal from the sensor.

[0006] In yet another embodiment, the invention provides for an apparatus including a housing having a central portion and two end portions, the two end portions being mounted at opposite ends of the central portion, wherein the central portion defines a bore. A piston is reciprocally disposed within the bore and a plurality of drive coils are disposed adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore. The apparatus also includes a cooling system at least partially disposed in the housing, the cooling system for reducing compression heat of the apparatus. A sensor is positioned relative to one of the two end portions, the sensor capable of measuring relative distance and velocity between the sensor and the piston. A controller selectively controls the energizing of the drive coils in response to a signal from the sensor.

[0007] The foregoing and other aspects will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a side partially cross sectional view of an electric linear actuated compressor according to one embodiment of the invention.

[0009] FIG. **2** is a side partially cross sectional view of an electric linear actuated compressor having a cooling reservoir contained within a housing of the compressor.

[0010] FIG. **3** is a side partially cross sectional view of the compressor shown in FIG. **2** with a heat exchanger fluidly connected to the cooling reservoir.

[0011] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0012] In this disclosure, the term compressor or pump are intended to be used interchangeably as a mechanism which is designed to displace a working fluid from one location to another.

[0013] FIG. **1** illustrates an electric linear actuated compressor **10**. The compressor **10** includes a housing **14**, a controller **18** and a sensor **22**. The housing **14** includes a cylindrical central portion **26** and two end portions **30** and **34** at opposite ends of the central portion **26**. The central portion **26** defines a bore **38** that is enclosed by the end portions **30**, **34**, and the bore **38** is axially oriented about a longitudinal axis **42** of the compressor **10**. The housing **14** includes an outer wall **46** and an inner wall **50** spaced radially inward from the outer wall **46**, such that the bore **38** is defined by the inner wall **50** of the housing **14**. The outer wall **46** and the inner wall **50** are spaced apart to form a gap **54** therebetween.

[0014] A piston **58** is reciprocally and slidingly disposed within the bore **38**. Generally, the piston **58** is formed from any material, or combination of materials, which may be accelerated and decelerated under the influence of magnetic fields. In the illustrated embodiment, the piston **58** is formed of a ferromagnetic material, however, in a further embodiment, the piston **58** is formed from a plurality of permanent magnets as shown in FIG. **2**. Within the bore **38**, the piston **58** defines a first pressure section **62** proximate the first end portion **30** and a second pressure section **66** proximate the second end portion **34**.

[**0015**] The first end portion **30** includes two chambers, an inlet chamber **70** and an outlet chamber **74**. An inlet valve **78** fluidly connects the first pressure section **62** and the inlet chamber **70** and an outlet valve **82** fluidly connects the first pressure section **62** and the outlet chamber **74**. An inlet conduit **86** fluidly communicates with the inlet chamber **70** of the end portion **30** and provides fluid to the first pressure section **62** through the inlet valve **78**, and an outlet conduit **90** fluidly communicates with the outlet chamber **74** of the end portion **30** and discharges fluid from the first pressure section **62** through the outlet valve **82**. The second end portion **34** also includes an inlet chamber (not shown) and an outlet chamber (not shown) similar to the inlet and outlet chambers described above. An inlet valve **102** fluidly connects the second pressure section **66** and the inlet chamber, and an outlet valve **106** fluidly connects the second pressure section **66** and the outlet chamber. An inlet conduit **110** fluidly communicates with the inlet chamber of the end portion **34** and provides fluid to the second pressure section **66** through the inlet valve **102**, and an outlet conduit **114** fluidly communicates with the outlet chamber of the end portion **34** and discharges fluid from the second pressure section **66** through the outlet valve **114**.

[**0016**] The inlet valves **78**, **102** and the outlet valves **82**, **106** are mounted within the respective end portions **30**, **34**. The inlet valves **78**, **102** and the outlet valves **82**, **106** permit fluid flow from a high pressure side to a low pressure side, as is known in the art. For example, the valves may be a flapper type, a finger type, and a popper type. In a further embodiment, the valves may be spring biased whereby the high pressure side has to be increased above the low pressure side by a desired amount before the valve opens, as is known in the art.

[**0017**] As the piston **58** is driven from left to right in FIG. **1**, pressure in the first pressure section **62** is increased (high pressure side) while pressure in the second pressure section **66** is decreased (low pressure side). Greater pressure in the first pressure section **62** forces the inlet valve **78** closed and the outlet valve **82** open by fluid pressure, thereby permitting fluid passage from the first pressure section **62** through the outlet conduit **90** and preventing fluid passage from the inlet conduit **86** to the first pressure section **62**. Concurrently, movement of the piston **58** from the left to the right reduces pressure in the second pressure section **66**. A reduction of pressure in the second pressure section **66** opens the inlet valve **102** and closes the outlet valve **106**, thereby permitting fluid passage from the inlet conduit **110** to the second pressure section **66** and preventing fluid passage from the second-pressure section **66** to the outlet conduit **114**.

[**0018**] When the piston **58** travels from the right to the left in FIG. **1**, pressure in the first pressure section **62** is decreased such that the section **62** becomes the low pressure side while pressure in the second pressure section **66** is increased such that the section **66** becomes the high pressure. Greater pressure in the second pressure section **66** forces the inlet valve **102** closed and the outlet valve **106** open by fluid pressure, thereby permitting fluid passage from the second pressure section **66** through the outlet conduit **114** and preventing fluid passage from the inlet conduit **110** to the second pressure section **66**. Concurrently, a reduction of pressure in the first pressure section **62** opens the inlet valve **78** and closes the outlet valve **82**, thereby permitting fluid passage from the inlet conduit **86** to the first pressure section **62** and preventing fluid passage from the first pressure section **62** to the outlet conduit **90**. Thereby, low pressure is permitted to pass into the first pressure section **62** from the inlet conduit **86** and high pressure is permitted to exit from the second pressure section **66** to the outlet conduit **114**.

[**0019**] Slide and seal rings **118** are mounted about a periphery of the piston **58** to seal fluid passage along the inner wall **50** of the housing **14** between the first pressure section **62** and the second pressure section **66**. In one embodiment, the rings **118** are formed from Teflon® polymer material, from E. I. du Pont de Nemours and Company (Wilmington, Del.), or a similar material. In the illustrated embodiment, the compressor **10** is non-lubricated, i.e., oil-free.

[**0020**] In order to accomplish the reciprocation of the piston **58**, drive coils **122** are mounted within the gap **54** defined by the outer and inner walls **46**, **50** of the housing **14**. Each drive coil **122** extends around an outer circumference of the bore **38**. A plurality of drive coils **122** are positioned along a length of the bore **38** and are axially spaced apart from each other. The drive coils **122** are selectively energized to produce a magnetic field capable of displacing the piston **58** within the bore **38** substantially along the longitudinal axis **42**.

[**0021**] Each drive coil **122** is separated from an adjacent drive coil **122** by a non-magnetic element **126**, which is non-conductive. The drive coils **122** are capable of carrying individual currents of a positive, negative or neutral polarity. In the illustrated embodiment, the drive coils **122** are surrounded by a thermal insulator **130** to limit or prevent heat damage to portions of the housing **14** and the piston **58** as the drive coils **122** heat up. It should be readily apparent to those of skill in the art that in further embodiments other insulators may be provided to prevent heat damage to the housing **14** and the piston **58**.

[**0022**] The controller **18** and the sensor **22** control charging and discharging of the drive coils **122** to drive the piston **58**. The controller **18** selectively controls energizing of the drive coils **122**, the sensor **22** determines the position and velocity of the piston **58** relative to the housing **14**. The first end portion **30** includes a through channel **134** between the bore **38** and exterior of the compressor **10**. In the illustrated embodiment, the sensor **22** is positioned in the channel **134** and aimed at the drive coils **122**, and is electrically connected to the controller **18**. The sensor **22** is able to precisely sense position and velocity of the piston **58** relative to the housing **14** regardless of temperature, pressure and adverse affects of the fluid being compressed. The sensor **22** may be of the microwave or the optical variety. Some sensors are extremely sensitive to changes in temperature and pressure, which may be commonly encountered in this environment, and should not be used with the compressor **10**.

[**0023**] In the illustrated embodiment, the sensor **22** functions independently of the electric current or voltage in the drive coils **122**, which may vary based on temperature, pressure or some other criterion as well as position of the piston **58** relative to the drive coils **122**. Thus, the sensor **22** will more accurately and directly take positional and velocity measurements. In compressors where there are relatively large distances between adjacent drive coils **122**, sensors that rely upon the current and voltage through the drive coils **122** based upon piston position may have limited accuracy in determining the exact piston position. In the illustrated embodiment, velocity measurements of the sensor **22** are not limited based upon the relative position between the piston **58** and the drive coil **122** or the number bf drive coils **122**. For example, the piston position and velocity sensor **22** of the present invention would function well if there were only two drive coils **122** disposed on opposed axial ends of the bore **38**. By comparison, in other compressors the accuracy of piston position and velocity sensing systems relying upon current and voltage in the drive coils would suffer if the drive coils were disposed adjacent opposed, distant ends of the bore. Further, in the present invention, when the sensor **22** functions independently of current or voltage in the drive coils **122** and one of the drive coils **122** fail, the failure of a drive coil **122** does not result in a disruption of the piston cycle or damage to the compressor **10**. In one embodiment, the sensor operates by utilizing electromagnetic radiation in excess of 1 gigahertz.

[**0024**] The controller **18** includes an electronic sequencer (not shown) and is operable to control selective energizing and de-energizing of the drive coils **122**. The controller **18** controls the drive coils **122** based upon relative velocity and position of the piston **58** within the bore **38** formed in the housing **14** as compared to the desired velocity and stroke of the piston **58** within the bore **38**. The drive coils **122** are charged with either a positive polarity or a negative polarity, based upon the desired travel direction of the piston **58**. With a pre-programmed sequencer, drive coils **122** could be energized, or magnetized, one after another. In the illustrated embodiment, the controller **18** may facilitate variable speed of the piston **58**. Speed is varied by current regulation to the drive coils **122** and variable load does not affect compressor performance because the sequencer can identify where the piston **58** is positioned. Therefore, sequencer speed and coil currents are programmed to compensate for these changes.

[**0025**] In one embodiment, the sensor **22** projects a frequency into the bore **38** that is used to identify the piston location and velocity. The controller **18** receives feedback from the sensor **22**, and load factor and/or reciprocating speeds are compensated for such that the sequencer speed and current are adjusted to the work performed by the compressor **10**.

[**0026**] In the illustrated embodiment, the compressor **10** includes an operator interface **138** electrically connected to the controller **18**. Using the interface **138**, the operator may set a desired velocity (cycles per minute) and a desired stroke (length per stroke) at which the controller **18** will operator the compressor **10** and the piston **58**. Any device that permits an operator to input the desired velocity and stroke to the controller **18** may be used as the interface **138**, as is known in the art.

[**0027**] One factor is using the compressor **10** shown in FIG. **1** is controlling compression heat (i.e., heat produced by the compressor **10** in the process of compressing the working fluid) and energizing heat (i.e., heat generated by the energizing and de-energizing of the drive coils **122**). With an increase in temperature in the compressor **10**, force exerted by the drive coils **122** upon the piston **58** decreases. In one embodiment, a heat removal system is used to remove compression heat and energizing heat, which further decreases the temperature of the compressor **10** to more efficient levels and force exerted by the drive coils **122** upon the piston **58** increases. A heat removal system is critical as the size of the compressor **10** increases due to the large amount of compression heat generated by larger compressors and the large amount of energizing heat produced by large drive coils required for such compressors.

[**0028**] An increased temperature of the drive coils **122** typically results in an increased electric flow through the drive coils **122** to produce the same force on the piston **58** by the drive coils **122**. Therefore, maintaining the piston **58** at a relatively high stroke length and frequency, especially if the working fluid is extremely viscous, may result in a gradual increase in operating temperature of the compressor **10**, which thereby results in damage to, or a failure of, the compressor **10** from overheating.

[**0029**] One system that may be used to reduce the energizing heat in the compressor is to utilize drive coils **122** formed from superconducting material. A superconducting material will exhibit minimal resistance at superconducting temperatures, therefore, the heat produced by a superconductor drive coil will be extremely low compared to that produced from a non-superconductive drive coil. A heat removal system, or cooling system, is still used to remove compression heat from the compressor while maintaining the superconductor at a superconducting temperature (i.e., a temperature wherein the drive coils continue to exhibit superconductive characteristics). A superconductor, as defined herein, covers all materials that display a considerable reduction in electrical resistance, to an extremely low level, when the temperature of the material is lowered below a superconducting temperature specific for that material.

[**0030**] FIG. **2** illustrates an electric linear actuated compressor **150** according to one embodiment of the invention. The compressor **150** is similar to the compressor **10** shown in FIG. **1**, and like elements will be referenced by the same reference numerals. The compressor **150** includes a cooling system **154** for reducing compression heat within the compressor **150** and uses superconducting drive coils **156**, as described above, to reduce energizing heat in the compressor **150**.

[**0031**] The compressor housing **14** includes the central portion **26** that defines a bore **38** enclosed by the end portions **30**, **34**. The housing **14** includes an outer wall **158**, an intermediate wall **162** spaced radially inward from the outer wall **158**, and an inner wall **166** spaced radially inward from the intermediate wall **162**, such that the bore **38** is defined by the inner wall **166** of the housing **14**. The three walls **158**, **162**, **166** are spaced apart from each other to form first and second gaps **170**, **174** therebetween.

[**0032**] In the illustrated embodiment, a piston **178** is reciprocally and slidingly disposed within the bore **38**. The piston **178** is at least partially formed from a plurality of permanent magnets **182** positioned about a periphery of the piston **178**. The piston **178** is accelerated and decelerated under the influence of magnetic fields, as described above with respect to FIG. **1**. In order to accomplish reciprocation of the piston, drive coils **156** are mounted in the second gap **174** defined by the intermediate and inner walls **162**, **166** of the housing **14** similar to the drive coils **122** described above with respect to FIG. **1**. The drive coils **156** are formed of a superconducting material, which reduces the energizing heat generated by the energizing and de-energizing of the drive coils **156**. Each drive coil **156** is separated from an adjacent drive coil **156** by a non-magnetic element **186**, which is non-conductive. Further, each drive coil **156** is surrounded by a thermal insulator **190** to further limit heat damage to portions of the housing **14** and the piston **178** as the drive coils **156** heat up, although other known insulators may be provided.

[**0033**] In order to permit the use of superconducting drive coils **156**, FIG. **2** illustrates the cooling system **154** including a cooling pump **194**, a cooling reservoir **198** within the housing **14**, an inlet conduit **202**, and an outlet conduit **206**. The conduits **202**, **206** fluidly connect the cooling pump **194** and the cooling reservoir **198**. The cooling reservoir **198** is defined by the first gap **170**, which is defined by the outer and intermediate walls **158**, **162** of the housing **14**. The cooling reservoir **198** includes vanes **210** extending radially outward from the intermediate wall **162** of the housing **14**. To cool the compressor **10** and the drive coils **156**, cooling fluid is pumped from the cooling pump **194** to the cooling reservoir **198** via the inlet conduit **202**. The vanes **210** assist in a heat exchange between the compressor **150** and the cooling fluid and also direct the flow of cooling fluid to ensure that the cooling fluid reaches all locations about a circumferential periphery of the housing **14**. Further, the vanes **210** act to slow the flow of cooling fluid at critical locations to ensure proper heat transfer. The cooling fluid is discharged through the outlet conduit **206** back to the cooling pump **194** for reuse.

[**0034**] Examples of the cooling fluids that may be used by the cooling system include Freon® chlorofluorocarbons, from E. I. du-Pont de Nemours and Company (Wilmington, Del.), and argon, which are relatively inexpensive and in ready supply. It should be readily apparent to those of skill in the art that other cryogenic fluids and equipment of a type known in the cooling art may be used in the cooling system.

[**0035**] FIG. **2** limits the passage of the cooling fluid to the cooling reservoir **198** contained within the housing. FIG. **3** illustrates another embodiment of the compressor **150** shown in FIG. **2** including a heat exchanger **214** for further limiting compression heat produced by the compressor **150**. The cooling fluid further passes through the heat exchanger **214** prior to returning to the cooling pump **194** (via the outlet conduit **206**). In the illustrated embodiment, the heat exchanger **214** is formed within an inlet portion and an outlet portion of the compressor **150** formed by the inlet and outlet conduits **86**, **90** of the end portion **30**. It should be readily apparent to those of skill in the art that the heat exchanger **214** may be positioned elsewhere in the compressor **150** or external to the compressor.

[**0036**] Various features and advantages of the invention are set forth in the following claims.

What is claimed is:

1. An apparatus comprising:

a housing having a bore formed therein, the bore being axially oriented along a first axis;

a piston reciprocally disposed within the bore;

a plurality of drive coils adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore substantially along the first axis;

a controller for selectively controlling energizing of the drive coils; and

a cooling system at least partially disposed in the housing, the cooling system for cooling the apparatus.

2. The apparatus of claim 1, and further comprising a sensor positioned relative one end of the housing, the sensor capable of measuring relative distance and velocity between the sensor and the piston, wherein the controller selectively energizes the drive coils in response to a signal from the sensor.

3. The apparatus of claim 1 wherein the cooling system includes a cooling reservoir positioned between the drive coils and the housing.

4. The apparatus of claim 3 where the cooling system includes a pump configured for pumping cooling fluid through the cooling reservoir and conduit for fluidly connecting the pump and the cooling reservoir.

5. The apparatus of claim 3 wherein the cooling reservoir includes vanes formed therein.

6. The apparatus of claim 5 wherein the vanes impact a flow of cooling fluid through the cooling reservoir.

7. The apparatus of claim 5 wherein the vanes facilitate a transfer of heat between heat produced by the apparatus and cooling fluid contained within the cooling reservoir.

8. The apparatus of claim 1, and further comprising a heat exchanger for further reducing compression heat of the apparatus.

9. The apparatus of claim 8 wherein the heat exchanger is positioned within an inlet portion of the housing.

10. The apparatus of claim 8 wherein the heat exchanger is positioned within an outlet portion of the housing.

11. The apparatus of claim 1 wherein the drive coils are formed from a superconductive material to facilitate cooling of the apparatus.

12. The apparatus of claim 11 wherein the cooling system is sufficient to maintain a temperature of the drive coils at a superconducting temperature.

13. An apparatus comprising:

a housing having a bore formed therein, the bore being axially oriented along a first axis;

a piston reciprocally disposed within the bore;

a plurality of drive coils disposed adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore substantially parallel to the first axis;

a cooling reservoir positioned between the drive coils and the housing, wherein the cooling reservoir reduces compression heat of the apparatus;

a sensor for determining position and velocity of the piston relative to the housing, wherein the sensor functions independently of the drive coils; and

a controller for selectively controlling the energizing of the drive coils in response to a signal from the sensor.

14. The apparatus of claim 13 wherein the piston is formed from a ferromagnetic material.

15. The apparatus of claim 13 wherein the piston includes a plurality of permanent magnets.

16. The apparatus of claim 13 wherein the drive coils are formed from a superconductor material.

17. The apparatus of claim 13 wherein cooling fluid circulates through the cooling reservoir.

18. The apparatus of claim 17, and further comprising a pump for pumping cooling fluid through the cooling reservoir.

19. The apparatus of claim 17, and further comprising a heat exchanger for further reducing compression heat of the apparatus, wherein the compressor is fluidly connected to the cooling reservoir.

20. The apparatus of claim 13 wherein the cooling reservoir includes vanes formed within the cooling reservoir.

21. The apparatus of claim 13 wherein application of an electric current to the drive coils produces the magnetic field and the sensor functions independently of the electric current.

22. The apparatus of claim 13 wherein the sensor functions independently of the magnetic field.

23. The apparatus of claim 13 wherein the sensor functions independently of any inductance formed between the piston and the bore.

24. The apparatus of claim 13 wherein the apparatus is a linear compressor.

25. An apparatus comprising:

a housing including a central portion and two end portions, the two end portions being mounted at opposite ends of the central portion, wherein the central portion defines a bore;

a piston reciprocally disposed within the bore;

a plurality of drive coils disposed adjacent the bore for energizing the drive coils to produce a magnetic field capable of displacing the piston within the bore;

a cooling system at least partially disposed in the housing, the cooling system for reducing compression heat of the apparatus;

a sensor positioned relative to one of the two end portions, the sensor capable of measuring relative distance and velocity between the sensor and the piston; and

a controller for selectively controlling the energizing of the drive coils in response to a signal from the sensor.

26. The apparatus of claim 25 wherein the cooling system comprises:

a cooling reservoir positioned between the drive coils and the housing;

a pump configured for pumping cooling fluid through the cooling reservoir; and

conduit for fluidly connecting the pump and the cooling reservoir.

27. The apparatus of claim 26 wherein the cooling reservoir includes vanes formed therein.

28. The apparatus of claim 26 wherein the cooling system includes a heat exchanger positioned between an outlet of the cooling reservoir and the pump, the heat exchanger for further reducing compression heat of the apparatus.

29. The apparatus of claim 25, and further comprising a heat exchanger for further reducing compression heat of the apparatus.

30. The apparatus of claim 25, and further comprising an operator interface for inputting a desired stroke and velocity of the piston relative to the housing, wherein the controller operates the maintain the piston at the desired stroke and velocity based upon measured distance and velocity between the sensor and the piston.

31. The apparatus of claim 25 wherein the controller includes a sequencer to control actuation and de-actuation of the drive coils.

32. The apparatus of claim 25 wherein the sensor operates utilizing electromagnetic radiation in excess of one gigahertz.

33. The apparatus of claim 25 wherein the sensor is a microwave sensor.

34. The apparatus of claim 25 wherein the sensor is an optical sensor.

35. The apparatus of claim 25 wherein the apparatus is a linear compressor.

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