US00RE44636E

(19) United States
(12) Reissued Patent
Caillat

(10) Patent Number: US RE44,636 E
(45) Date of Reissued Patent: Dec. 10, 2013

(54) **COMPRESSOR CAPACITY MODULATION**

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(21) Appl. No.: **11/152,836**

(22) Filed: **Jun. 15, 2005**

Related U.S. Patent Documents

Reissue of:
(64) Patent No.: **6,206,652**
Issued: **Mar. 27, 2001**
Appl. No.: **09/139,865**
Filed: **Aug. 25, 1998**

U.S. Applications:
(63) Continuation-in-part of application No. 08/939,779, filed on Sep. 29, 1997, now Pat. No. 6,047,557.

(51) **Int. Cl.**
F04B 49/00 (2006.01)

(52) **U.S. Cl.**
USPC **417/298**; 417/222.1

(58) **Field of Classification Search**
None
See application file for complete search history.

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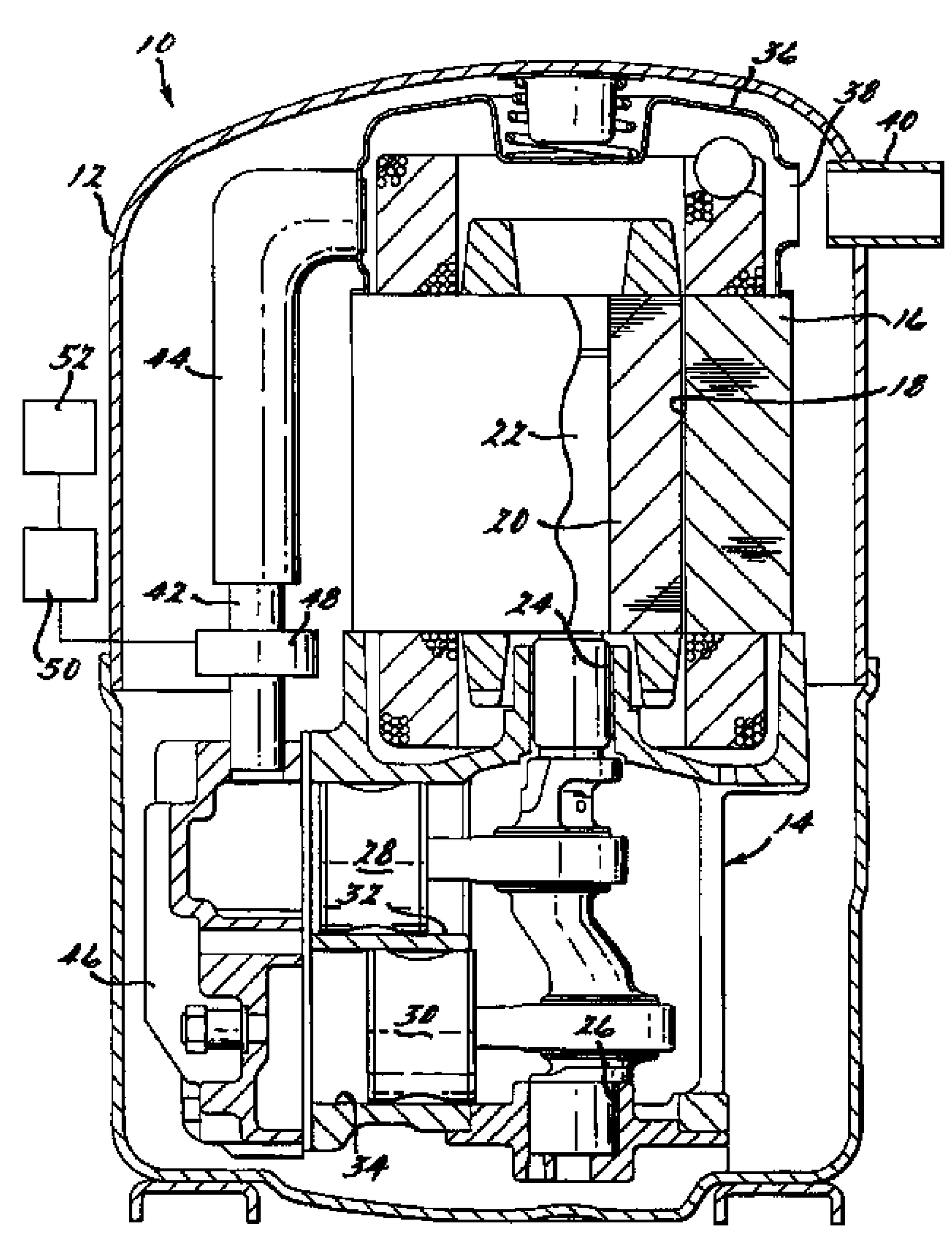
(57) **ABSTRACT**

A pulsed modulated capacity modulation system for refrigeration, air conditioning or other types of compressors is disclosed in which suitable valving is provided which operates to cyclically block flow of suction gas to a compressor. A control system is provided which is adapted to control both the frequency of cycling as well as the relative duration of the on and off time periods of each cycle in accordance with sensed system operating conditions so as to maximize the efficiency of the system. Preferably the cycle time will be substantially less than the time constant of the load and will enable substantially continuously variable capacity modulation from substantially zero capacity to the full capacity of the compressor. Additional controls may be incorporated to modify one or more of the motor operating parameters to improve the efficiency of the motor during periods of reduced load.

11 Claims, 6 Drawing Sheets



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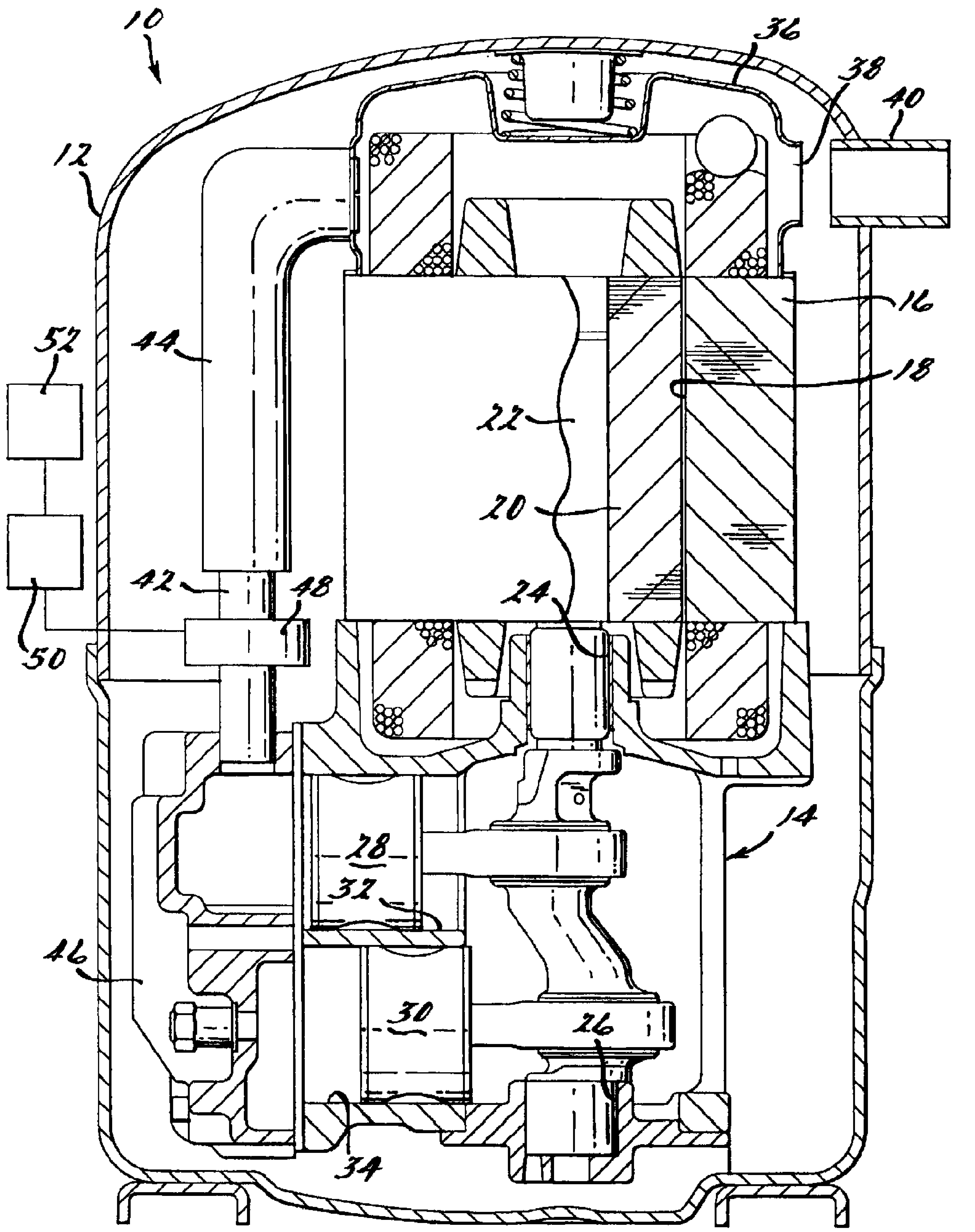

FIG. 1.

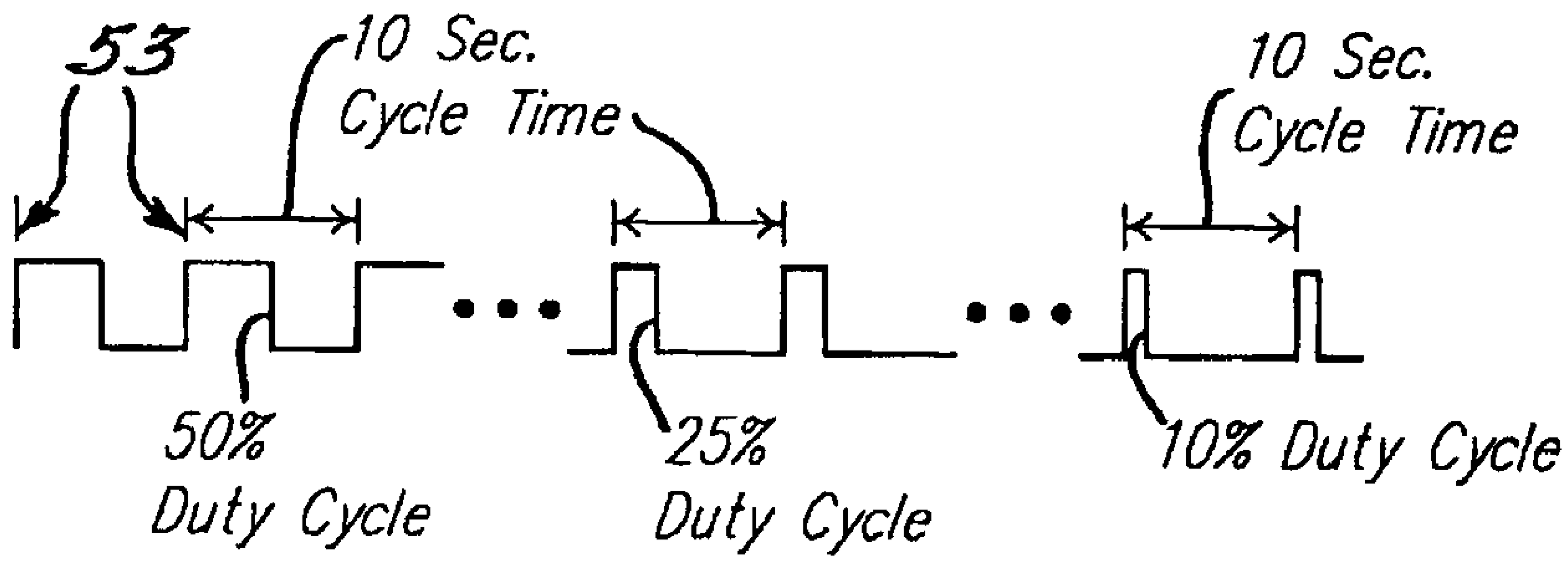

FIG. 2.

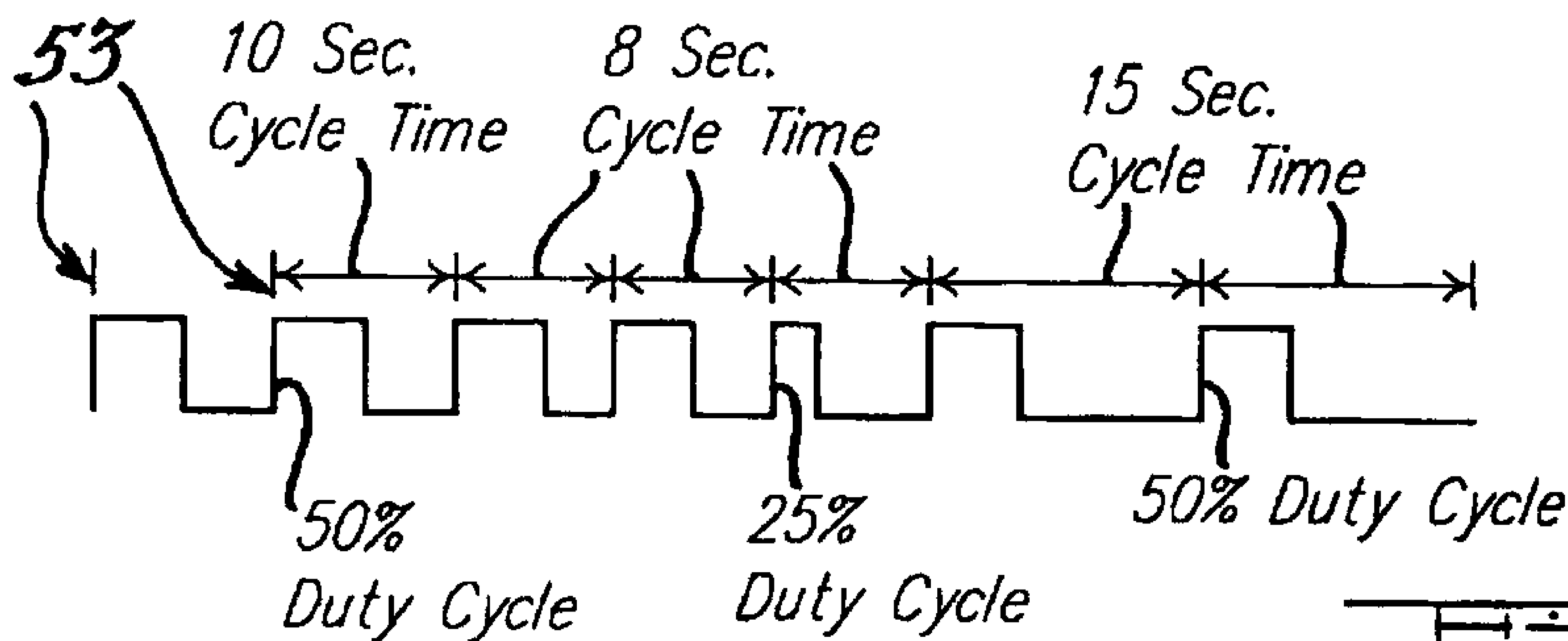

FIG. 3.

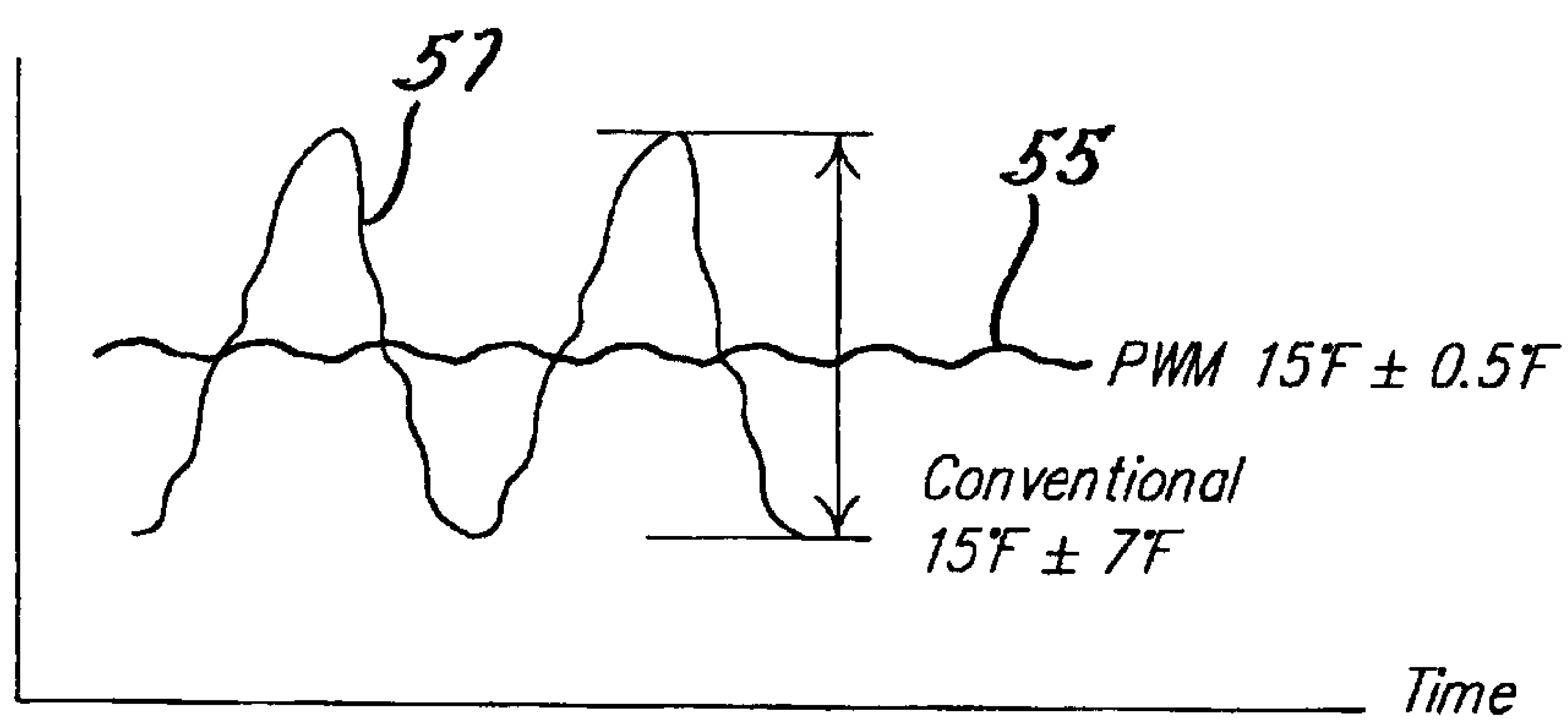

FIG. 4.

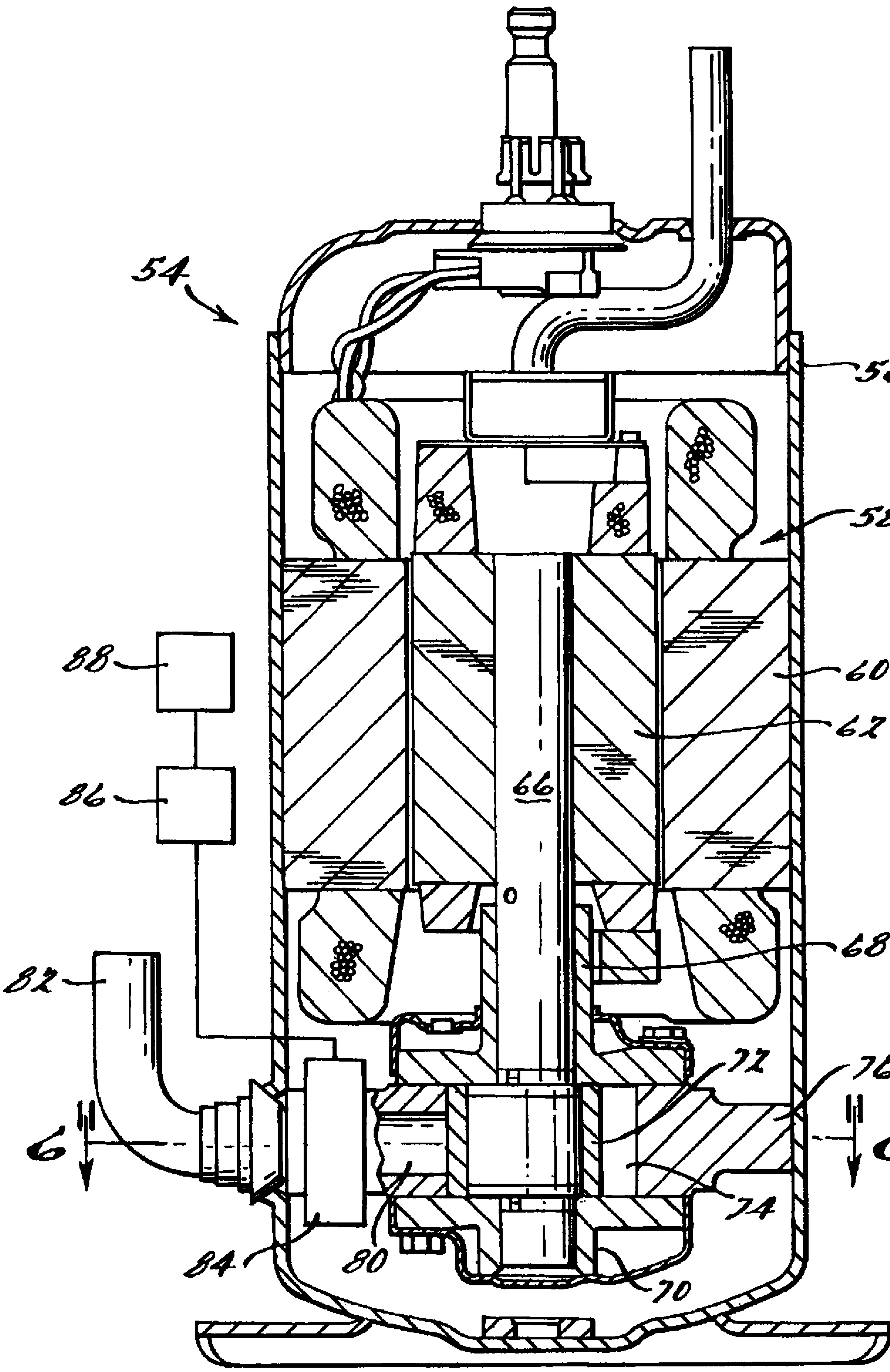

Fig. 5.

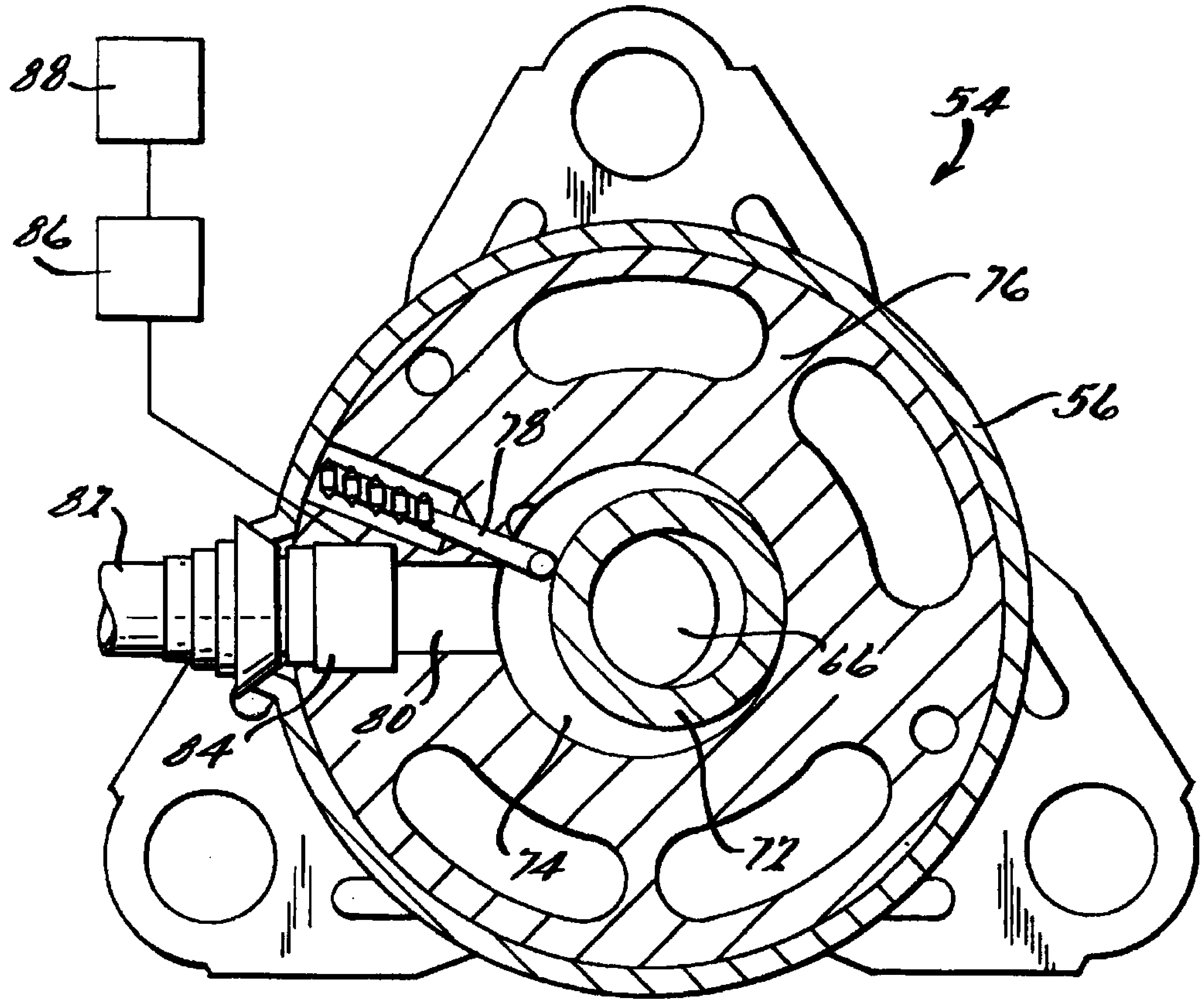

FIG. 6.

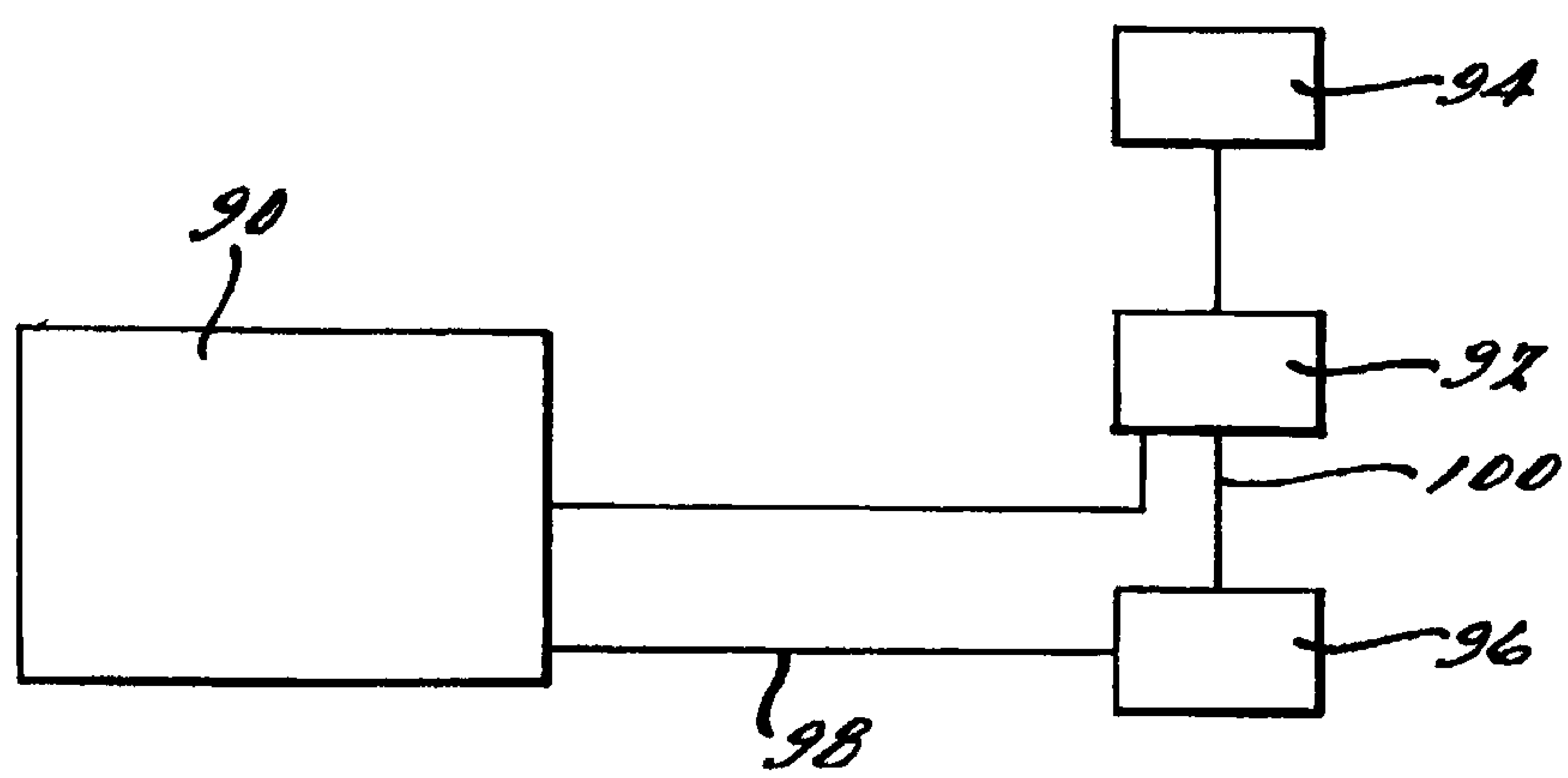

FIG. 8.

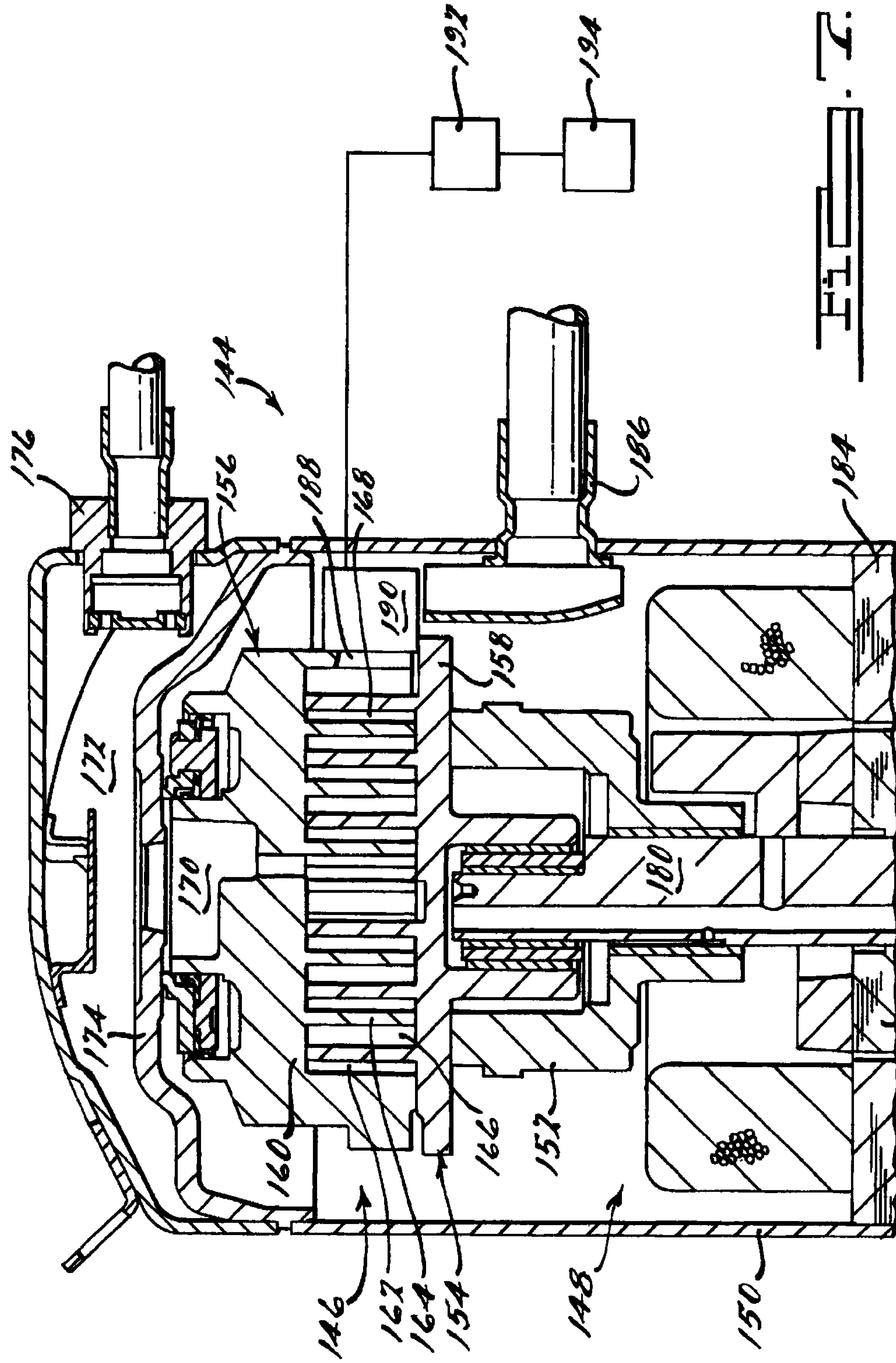
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Fig. 7

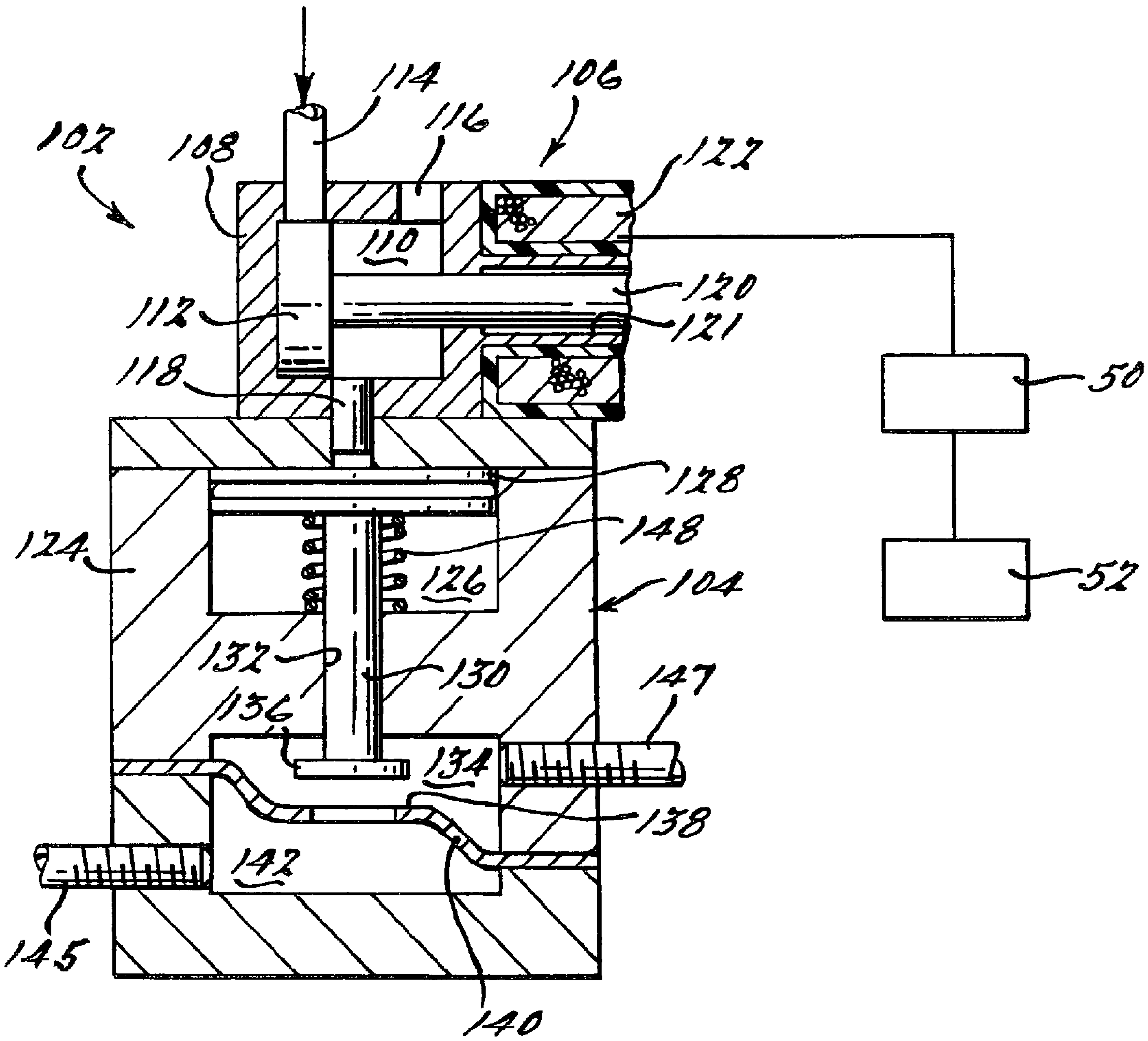

FIG. 9.

AMENDED

COMPRESSOR CAPACITY MODULATION

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

More than one reissue application has been filed for the reissue of U.S. Pat. No. 6,206,652. The reissue applications are application Ser. No. 11/152,834 (now U.S. Pat. No. RE40,830) and Ser. No. 11/152,836 (the present application), all of which are reissue applications of U.S. Pat. No. 6,206,652.

The present application is a continuation-in-part of U.S. application Ser. No. 08/939,779 filed Sep. 29, 1997, which is now U.S. Pat. No. 6,047,557 issued Apr. 11, 2000.

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention is directed to a system for modulating the capacity of a positive displacement compressor such as a refrigeration and/or air conditioning compressor and more specifically to a system incorporating a valving arrangement for cyclically blocking suction gas flow to the compressor while the compressor is continuously driven.

Capacity modulation is often a desirable feature to incorporate in refrigeration and air conditioning compressors as well as compressors for other applications in order to enable them to better accommodate the wide range of loading to which systems incorporating these compressors may be subjected. Many different approaches have been utilized for providing this capacity modulation feature ranging from controlling of the suction inlet flow such as by throttling to bypassing discharge gas back to the suction inlet and also through various types of cylinder or compression volume porting arrangements.

In multicylinder reciprocating piston type compressors utilizing suction gas control to achieve capacity modulation, it is common to block the flow to one or more but not all of the cylinders. When activated, the capacity of the compressor will be reduced by a percentage nominally equal to the number of cylinders to which suction gas flow has been blocked divided by the total number of cylinders. While such arrangements do provide varying degrees of capacity modulation, the degree of modulation that can be achieved is available only in relatively large discrete steps. For example, in a six cylinder compressor, blocking suction to two cylinders reduces the capacity by ⅓ or 33.3% whereas blocking suction gas flow to four cylinders reduces capacity by ⅔ or 66.6%. This discrete step form of modulation does not allow the system capacity to be matched to the load requirement conditions at all but rather only to very roughly approach the desired capacity resulting in either an excess capacity or deficient capacity. As system conditions will rarely if ever match these gross steps of modulation, the overall operating system efficiency will not be able to be maximized.

Compressors in which discharge gas is recirculated back to suction offer quasi-infinite step modulation of the capacity depending upon the variation and complexity of the bypassing means. However, when discharge gas is recirculated back to suction, the work of compression is lost for that fraction of the gas recirculated thus resulting in reduced system efficiency. Combinations of the aforementioned methods enables substantially quasi-infinite capacity modulation at slightly better efficiency but still fails to provide the ability to closely match the compressor capacity to the load being served.

Other approaches, which can result in selectively disabling the compression process of one or more of the cylinders of a multi-cylinder compressor, such as cylinder porting, stroke altering or clearance volume varying methods result in similar step modulation with a resulting mismatch between load and capacity and additionally suffer from dynamic load unbalance and hence vibration.

The present invention, however, provides a capacity control arrangement which utilizes a pulse width modulation of suction gas flow to the compressor which enables substantially continuous modulation of the capacity from 0% up to 100% or full capacity. Thus the capacity output of the compressor can be exactly matched to system loading at any point in time. Further, in reciprocating piston type compressors, the suction gas flow to each of the cylinders may be controlled simultaneously by this pulse width modulation system so as to eliminate unbalanced operation of the compressor.

The pulse width modulated compressor is driven by a control system that supplies a variable duty cycle control signal based on measured system load. The controller may also regulate the frequency (or cycle time) of the control signal to minimize pressure fluctuations in the refrigerant system. The on time is thus equal to the duty cycle multiplied by the cycle time, where the cycle time is the inverse of the frequency.

The pulse width modulated compressor of the present invention has a number of advantages. Because the instantaneous capacity of the system is easily regulated by variable duty cycle control, an oversized compressor can be used to achieve faster temperature pull down at startup and after defrost without causing short cycling as conventional compressor systems would. Another benefit of the present invention is that the system can respond quickly to sudden changes in condenser temperature or case temperature set points. The controller adjusts capacity in response to disturbances without producing unstable oscillations and without significant overshoot. This capability is of particular advantage in applications involving cooling of display cases in that it allows a much tighter control of temperature within the case thereby enabling the temperature setting to be placed at a higher level without concern that cyclical temperature swings will exceed the temperatures which are considered safe for the particular goods contained therein.

Operating at higher evaporator temperatures reduces the defrost energy required because the system develops frost more slowly at higher temperatures. This also enables the time between defrost cycles to be lengthened.

The pulse width modulated compressor also yields improved oil return. The volume of oil returned to the compressor from the system is dependent in part on the velocity of gas flow to the compressor. In many capacity modulation systems, the return gas flow to the compressor is maintained at a relatively low level thus reducing the return oil flow. However, in the present invention the refrigerant flow pulsates between high capacity and low capacity (e.g. 100% and 0%), thus facilitating increased oil return due to the periods of high velocity gas flow.

Additionally, the pulse width modulated blocked suction system of the present invention is relatively inexpensive to incorporate into a compressor in that only a single valve assembly is required. Further, because of the system's simplicity, it can be easily added to a wide variety of compressor designs including both rotary and scroll as well as reciprocating piston type compressors. Also, because the present invention keeps the driving motor operating while the suction gas flow is modulated, the stress and strain on the motor resulting from periodic start-ups is minimized. Additional improvements in efficiency can be achieved by incorporating a motor control module which may operate to control various operating parameters thereof to enhance its operating efficiency during periods when the motor load is reduced due to unloading of the compressor.

Additional features and benefits of the present invention will become apparent to one skilled in the art from the following detailed description taken in conjunction with the appended drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a section view of a reciprocating piston type compressor incorporating apparatus by which the suction gas flow to the compressor may be blocked in a pulse width modulated manner in accordance with the present invention;

FIG. **2** is a waveform diagram illustrating the variable duty cycle signal produced by the controller and illustrating the operation at a constant frequency;

FIG. **3** is a waveform diagram of the variable duty cycle signal, illustrating variable frequency operation;

FIG. **4** is a graph comparing anticipated temperature dynamics of a system employing the invention with a system of conventional design;

FIG. **5** is a view similar to that of FIG. **1** but showing a rotary type compressor incorporating the pulse width modulation system of the present invention;

FIG. **6** is a section view of the compressor of FIG. **5**, the section being taken along line **6-6** thereof;

FIG. **7** is a view similar to that of FIGS. **1** and **5** but showing a scroll type compressor incorporating the pulse width modulation system of the present invention;

FIG. **8** is a schematic diagram illustrating the inclusion of a motor control module to modify one or more of the compressor motor operating parameters during periods of reduced load; and

FIG. **9** is a section view generally illustrating a preferred valving arrangement for use in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and more specifically to FIG. **1** there is shown a reciprocating piston type refrigeration compressor **10** comprising an outer shell **12** within which is disposed reciprocating compressor housing **14** on which is mounted an associated driving motor including stator **16** having a bore **18** provided therein. A rotor **20** is disposed within bore **18** being secured to crankshaft **22** which is rotatably supported within housing **14** by upper and lower bearings **24** and **26** respectively. A pair of pistons **28** and **30** are connected to crankshaft **22** and reciprocably disposed in cylinders **32** and **34** respectively. A motor cover **36** is secured in overlying relationship to the upper end of stator **16** and includes an inlet opening **38** aligned with a suction inlet fitting **40** provided through shell **12**. A suction muffler **44** is provided on the opposite side of motor cover **36** and serves to direct suction gas from the interior of motor cover **36** to respective cylinders **32**, **34** via suction pipe **42** and head assembly **46**.

As thus far described, compressor **10** is a typical hermetic reciprocating piston type motor compressor and is described in greater detail in U.S. Pat. No. 5,015,155 assigned to the assignee of the present application, the disclosure of which is hereby incorporated by reference.

A bidirectional solenoid valve assembly **48** is provided in suction pipe **42** between suction muffler **44** and head assembly **46**. Solenoid valve assembly operates to control suction gas flow through pipe **42** to thereby modulate the capacity of motor compressor **10**. An exemplary valve assembly suitable for this application is described in greater detail below.

In order to control solenoid valve assembly **48**, a control module **50** is provided to which one or more suitable sensors **52** are connected. Sensors **52** operate to sense operating system conditions necessary to determine system loading. Based upon signals received from sensors **52** and assuming system conditions indicate a less than full capacity is required, control module **50** will operate to pulse solenoid valve assembly **48** so as to alternately allow and prevent the flow of suction gas through conduit **42** to compression cylinders **32** and **34** while the motor continues to drive pistons **28** and **30**. The variable duty cycle control signal generated by the control module **50** can take several forms. FIGS. **2** and **3** give two examples. FIG. **2** shows the variable duty cycle signal in which the duty cycle varies, but the frequency remains constant. In FIG. **2**, note that the cycle time, indicated by hash marks **53**, are equally spaced. By comparison, FIG. **3** illustrates the variable duty cycle signal wherein the frequency is also varied. In FIG. **3**, note that the hash marks **53** are not equally spaced. Rather, the waveform exhibits regions of constant frequency, regions of increasing frequency and regions of decreasing frequency. The variable frequency illustrated in FIG. **3** is the result of the adaptive modulation of the cycle time to further optimize system operation. An adaptive modulation control system is described in greater detail in assignee's copending application Ser. No. 08/939,779 the disclosure of which is hereby incorporated by reference.

Given the speed of rotation of the compressor there would be a substantial number of compression cycles during which no suction gas would be supplied to the compression chambers. However thereafter there would be another number of compression cycles during which full suction gas flow would be supplied to the cylinders. Thus on average, the mass flow would be reduced to a desired percentage of full load capacity. Because the mass flow to each cylinder is reduced at the same time, the operating balance between the respective cylinders will be maintained thus avoiding the possibility of increased vibration. Further, this pulsed form of capacity modulation will result in alternating periods during which the driving motor is either operating at full load or substantially reduced loading. Thus it is possible to incorporate additional apparatus to vary one or more of the operating parameters of the motor during the reduce load period of operation thereby further improving system efficiency as discussed in greater detail below.

FIG. **4** graphically represents the benefits that the present invention may offer in maintaining tighter temperature control in a refrigerated storage case for example. Note how the temperature curve **55** of the invention exhibits considerably less fluctuation than the corresponding temperature curve **57** of a conventional controller.

It should be noted that valve assembly **48** will be activated between open and closed positions in a pulsed manner to provide the desired capacity modulation. Preferably, the cycle time duration will be substantially less than the time constant of the system load which typically may be in the range of about one to several minutes. In a preferred embodiment, the cycle time may be as much as 4 to 8 times less than the thermal time constant of the load or even greater. The thermal time constant of system may be defined as the length of time the compressor is required to run in order to enable the system to cool the load from an upper limit temperature at which the system is set to turn on, down to a point at which the evaporator pressure reaches a lower limit at which the compressor is shut down. More specifically, in a typical refrigeration system, flow of compressed fluid to the evaporator is controlled by a temperature responsive solenoid valve and operation of the compressor is controlled in response to evaporator pressure. Thus in a typical cycle, when the temperature in the cooled space reaches a predetermined upper limit, the solenoid valve opens allowing compressed fluid to flow to the evaporator to begin cooling the space. As the compressed fluid continues to flow to the evaporator and absorb heat, the pressure in the evaporator will increase to a point at which the compressor is actuated. When the temperature in the cooled spaces reaches a predetermined lower limit, the solenoid valve will be closed thereby stopping further flow of compressed fluid to the evaporator but the compressor will continue to run to pump down the evaporator. When the pressure in the evaporator reaches a predetermined lower limit, the compressor will be shut down. Thus, the actual running time of the compressor is the thermal time constant of the load.

By use of this pulse width modulated blocked suction system, it is possible to optimize compressor run times which minimizes the number of on/off cycles and provides excellent load capacity matching and superior temperature control for the area being cooled along with improved overall system efficiency as compared to conventional capacity modulation systems. As is illustrated in FIG. **4**, the pulse width modulated capacity compressor of the present invention enables extremely tight control of temperature as compared to conventional capacity modulation systems. When applied to refrigeration systems, this tight temperature control enables the average operating temperature to be set at a level more closely approaching the upper acceptable temperature limit whereas with conventional systems, the average operating temperature must be set well below the upper acceptable temperature limit so as to avoid the larger temperature swings encountered therein from exceeding this upper acceptable limit. Not only does the use of a higher average operating temperature result in substantial direct energy cost savings but the higher average operating temperature maintains the dew point of the enclosed space at a higher level thus greatly reducing the formation of frost. Similarly, when applied to air conditioning systems, the pulse width modulated compressor of the present invention enables the temperature of the conditional space to be controlled within a much smaller range than with conventional systems thus greatly enhancing the comfort level of the occupants of such space. Even further, this capacity modulation system may also be advantageously applied to air compressor applications. Because of the ability of the compressor to very closely track the load (which in air compressor applications will be the volume of air being used at a desired pressure), it is possible to greatly reduce the size of the pressure vessel if not completely eliminate same. Further, in airconditioning applications additional energy savings may be realized because the compressor is able to very closely match the load. This results in lower condensing temperatures and hence pressures which means that the pressure against which the compressor is working is lower.

In most air conditioning and refrigeration compressors, the suction gas flow operates to cool the motor prior to compression. Because presently existing blocked suction type capacity modulation systems operate to prevent flow of suction gas to the compression chamber the compressor cannot be operated in a reduced capacity mode for an extended period without overheating of the compressor motor. The present invention, however, offers the additional advantage of greatly reducing this overheating possibility because the relatively cool suction gas is supplied to the cylinders on a rapidly cycling basis. This enables such compressors to operate at reduced capacity for substantially longer time periods thus also contributing to its ability to provide tighter temperature control of the spaces being cooled on a continuous basis as well as reduced frost build-up in low temperature refrigeration applications.

In determining the desired cycle frequency as well as the duration of the duty cycle or time period during which suction gas is to be supplied to the compressor, it is generally desirable to first select a cycle time which is as long as possible but yet minimizes suction pressure fluctuations. Next the duty cycle will be determined which will be sufficiently high so as to satisfy the load. Obviously, the duty cycle and cycle time are interrelated and other factors must also be taken into account in selection thereof. For example, while it is desirable to make the cycle time as long as possible, it can not be so long that the time period during which suction gas flow is interrupted results in excessive heating of the compressor motor.

While the capacity modulation system of the present invention has been described above with reference to a multicylinder reciprocating piston type compressor, it is also equally applicable to other types of compressors such as, for example, a rotary type compressor or a scroll compressor. A rotary type compressor incorporating the capacity modulation system of the present invention is illustrated in and will be described with reference to FIGS. **5** and **6** and a scroll compressor incorporating same is illustrated and will be described with reference to FIG. **7**.

As shown in FIG. **5**, a hermetic rotary type compressor **54** includes an outer shell **56** within which is disposed a compressor assembly and a driving motor **58** incorporating a stator **60** and rotor **62**. Rotor **62** is rotatably supported by and fixed to crankshaft **66** which in turn is rotatably supported by upper and lower bearings **68** and **70**. A compression rotor **72** is eccentrically mounted on and adapted to be driven by crankshaft **66**. Compression rotor **72** is disposed within cylinder **74** provided in housing **76** and cooperates with vane **78** (*shown in FIG. 6*) to compress fluid drawn into cylinder **74** through inlet passage **80**. Inlet passage **80** is connected to suction fitting **82** provided in shell **56** to provide a supply of suction gas to compressor **54**. As thus far described, rotary compressor **54** is typical of rotary type refrigeration and air conditioning compressors.

In order to incorporate the pulse width capacity modulation system of the present invention into rotary compressor **54**, a valve assembly **84** is provided being disposed within shell **56** and between suction fitting **82** and **[**suction gas flow path**]** *inlet passage* **80**. Operation of valve assembly **84** is controlled by a control module **86** which receives signals from one or more sensors **88** indicative of the system operating conditions.

Operation of valve assembly **84**, control module **86** and sensors **88** will be substantially identical to that described above with valve assembly **84** operating under the control of control module **86** to cyclically open and close to thereby modulate the flow of suction gas into cylinder **74**. As with compressor **10**, both the cycle frequency as well as the relative duration of the open and closed portions of the cycle may be varied by control module **86** in response to system operating conditions whereby the system efficiency may be maximized and the capacity varied to any desired capacity between zero and full load.

FIG. **7** shows a scroll type compressor **144** which includes a compressor assembly **146** and a driving motor **148** both disposed within hermetic shell **150**.

Compressor assembly **146** includes a mean hearing housing **152** secured within and supported by outer shell **150**, an orbiting scroll member **154** movably supported on bearing housing **152** and a nonorbiting scroll member **156** axially movably secured to bearing housing **152**. Scroll members **154** and **156** each include end plates **158** and **160** from which interleaved spiral wraps **162** and **164** extend outwardly. Spiral wraps **162** and **164** together with end plates **158** and **160** cooperate to define moving fluid pockets **166**, **168** which decrease in size as they move from a radially outer position to a radially inner position in response to relative orbital movement between scroll members **154** and **156**. Fluid compressed within the moving fluid pockets **166**, **168** is discharged through a centrally located discharge passage **170** provided in nonorbiting scroll member **156** into a discharge chamber **172** defined by the upper portion of hermetic shell **150** and muffler plate **174** and thereafter is supplied to the system via discharge fitting **176**. An Oldham coupling is also provided acting between scroll members **154** and **156** to prevent relative rotation therebetween.

A drive shaft **180** is also provided being rotatably supported in bearing housing **152** and having one end thereof drivingly coupled to orbiting scroll member **154**. A motor rotor **182** is secured to drive shaft **180** and cooperates with motor stator **184** to rotatably drive drive shaft **180**. As thus far described, scroll compressor **144** is typical of scroll type compressors and will operate to draw fluid to be compressed flowing into hermetic shell **150** via inlet **186** into the moving fluid pockets via suction inlet **188** provided in nonorbiting scroll member **156**, compress same and discharge the compressed fluid into discharge chamber **172**.

In order to incorporate the pulse width capacity modulation system into scroll compressor **144**, a valve assembly **190** is provided being positioned in overlying relationship to suction inlet **188** so as to be able to selectively control flow of fluid to be compressed into respective moving fluid pockets **166** and **168**. Operation of valve assembly **190** is controlled by control module **192** in response to signals received from one or more sensors **194** in substantially the same manner as described above. It should be noted that while the present invention has been shown and described with reference to a scroll compressor in which the hermetic shell is substantially at suction pressure, it may also be easily incorporated in other types of scroll compressors such as those in which the interior is at discharge pressure or in which both scrolls rotate about radially offset axes.

As may now be appreciated, the pulsed capacity modulation system of the present invention is extremely well suited for a wide variety of compressors and is extremely effective in providing a full range of modulation at relatively low costs. It should be noted that if desired the pulsed capacity modulation system of the present invention may also be combined with any of the other known types of capacity modulation systems for a particular application.

In the above embodiments, it is intended that the compressor continue to be driven while in an unloaded condition. Obviously, the power required to drive the compressor when unloaded (no compression taking place) is considerably less than that required when the compressor is fully loaded. Accordingly, it may be desirable to provide additional control means operative to improve motor efficiency during these periods of reduced load operation.

Such an embodiment is shown schematically in FIG. **8** which comprises a motor compressor **90** which may be of the type described above with respect to FIG. **1**, FIGS. **5** and **6**, or FIG. **7** and includes a solenoid valve assembly connected to a suction line which is operative to selectively block the flow of suction gas to the compressing mechanism. The solenoid valve assembly is intended to be controlled by a control module **92** in response to system conditions sensed by sensors **94**. As thus far described, the system represents a schematic illustration of any of the embodiments described above. In order to improve efficiency of the driving motor during reduced load operation, a motor control module **96** is also provided which is connected to the compressor motor circuit via line **98** and to control module **92** via line **100**. It is contemplated that motor control module **96** will operate in response to a signal from control module **92** indicating that the compressor is being placed in reduced load operating condition. In response to this signal, motor control module **96** will operate to vary one or more of the compressor motor operating parameters to thereby improve its efficiency during the period of reduced load. Such operating parameters are intended to include any variably controllable factors which affect motor operating efficiency including voltage reduction or varying the running capacitance used for the auxiliary winding of a single phase motor. Once control module **92** signals motor control module **96** that the compressor is being returned to fully loaded operation, motor control module **96** will then operate to restore the affected operating parameters to maximize motor efficiency under full load operation. There may be some time lag between the closing of the solenoid valve assembly and the reduced loading on the compressor which will be primarily dependent upon the volume of suction gas in the area between the solenoid valve assembly and the compression chamber. As a result, it may be desirable to provide for an appropriate time delay before the motor operating parameter is adjusted for the reduced loading. Of course, it is desirable that the solenoid valve assembly be positioned as close as possible to the compression chamber so as to minimize this delayed reaction time.

It should also be noted that while each of the embodiments has been described as incorporating a solenoid valve which operates to control the flow of pressurized discharge gas to the suction gas flow control valve for controlling suction gas flow, it is also possible to substitute other types of valves therefor such as, for example, solenoid valves by themselves or any other suitable valving arrangement. It is, however, believed that the use of a solenoid valve for controlling the flow of a pressurized fluid such as discharge gas to the suction control valve is preferred because it allows for application of greater actuating forces to the suction gas control valve and hence faster operation thereof. An exemplary embodiment of such a valve assembly is shown and will be described with reference to FIG. **9** it being noted that this valve assembly may be used in any of the embodiments described above.

As shown in FIG. **9**, valve assembly **102** comprises a solenoid control valve **106** and a pressure actuated valve **104**.

Solenoid [valve assembly] *control valve* **106** includes a housing **108** within which is provided a valve chamber **110** having a valve member **112** movably disposed therein. A pressurized fluid supply line **114** opens into chamber **110** adjacent one end thereof and a vent passage **116** opens outwardly from chamber **110** adjacent the opposite end thereof. An outlet passage **118** is also provided opening into chamber **110** approximately midway between the opposite ends thereof. Valve member **112** is secured to one end of plunger **120** the other end of which extends axially movably along hermetically sealed bore **121** about which a solenoid coil **122** is positioned. As shown, plunger **120** will be biased into the position shown in which valve member **112** overlies and closes off pressurized fluid supply line **114** and outlet passage **118** is in open communication with vent passage **116**. When solenoid coil **122** is energized, [shaft] *plunger* **120** will operate to move valve member **112** into a position in which it overlies and closes off vent passage **116** and allows open communication between pressurized fluid supply line **114** and outlet **118**. The opposite end of pressurized fluid supply line *114* will be connected to a suitable source of pressurized fluid such as for example discharge gas from the compressor.

Pressure actuated valve assembly **104** includes a housing **124** having a cylinder **126** provided therein within which piston **128** is movably disposed. A shaft **130** has one end connected to piston **128** and extends from cylinder **126** through bore **132** into a chamber **134** provided in housing **124**. A valve member **136** is secured to the end of shaft **130**, is positioned within chamber **134** and is movable by shaft **130** into and out of sealing engagement with valve seat **138** provided on partition **140** so as to selectively control flow of suction gas from chamber **134** into chamber **142** and then through **[**outlet **144]** *outlet 145*. An **[**inlet **146]** *inlet 147* is provided for supplying suction gas to chamber **134**.

Fluid outlet line **118** opens into one end of cylinder **126** and serves to provide pressurized fluid thereto to bias piston **128** in a direction such that valve **136** moves into sealing engagement with valve seat **138** to thereby interrupt the flow of suction gas from **[**inlet **146** to outlet **144]** *inlet 147 to outlet 145*. A **[**return spring **148]** *return spring 149* is **[**also**]** provided within cylinder **126** which serves to bias piston **128** in a direction so as to move valve member **136** out of sealing engagement with valve seat **138** in response to venting of the pressurized fluid from cylinder **126**.

In operation, when control module **50** determines that capacity modulation is in order, it will operate to energize solenoid control valve **106** thereby moving valve **112** to the right as shown and allowing pressurized fluid to flow through chamber **110** to cylinder **126**. This pressurized fluid then operates to move piston **128** in a direction to close valve **136** thereby preventing further flow of suction gas to the compression mechanism. When solenoid control valve **106** is deenergized by control module **50**, valve **112** will move into **[**a**]** position to interrupt the supply of pressurized fluid to cylinder **126** and to vent same via passage **116** thereby enabling **[**return spring **148]** *return spring 149* to move piston **128** in a direction to open valve member **136** such that the flow of suction gas to the compressor is resumed.

It should be noted that valve assembly **102** is exemplary only and any other suitable arrangement may be easily substituted therefor. As noted before, in order to facilitate rapid response to capacity modulation signals, it is desirable that the suction flow shut off valve be located as close to the compression chamber as possible. Similarly, the pressurized fluid supply line and vent passages should be sized relative to the volume of the actuating cylinder being supplied thereby to ensure rapid pressurization and venting of same.

It will be appreciated by those skilled in the art that various changes and modifications may be made to the embodiments discussed in this specification without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

[1. A capacity modulated compressor comprising:

a compression mechanism having a compression chamber therein, a suction inlet for supplying suction gas to the compression chamber and a movable member operative to vary the volume of said compression chamber;

a power source operatively connected to effect movement of said movable member to thereby compress gas drawn into said compression chamber through said suction inlet;

a valve provided in the suction gas flow path to said compression mechanism, said valve being operable between open and closed positions to cyclically allow and prevent flow of suction gas into said compression chamber; and

control apparatus for actuating said valve between said open and closed positions, said control apparatus being operative to cycle said valve such that its cycle time is substantially smaller than the time constant of the load on said compressor.**]**

[2. A capacity modulated compressor as set forth in claim **1** wherein said valve is positioned in close proximity to said compression chamber.**]**

[3. A capacity modulated compressor as set forth in claim **1** wherein said valve is a bidirectional valve.**]**

[4. A capacity modulated compressor as set forth in claim **1** wherein at least one of said cycle time and the time duration said valve is in said closed position is varied in response to sensed operating conditions.**]**

[5. A capacity modulated compressor as set forth in claim **4** wherein said power source continues to effect movement of said movable member as said valve is cycled between said open and closed positions.**]**

[6. A capacity modulated compressor as set forth in claim **4** wherein said cycle time and said time duration are varied in response to said sensed operating condition.**]**

[7. A capacity modulated compressor as set forth in claim **1** wherein said valve is actuated by pressurized fluid.**]**

[8. A capacity modulated compressor as set forth in claim **7** further comprising a control valve operative to control the flow of pressurized fluid to said valve.**]**

[9. A capacity modulated compressor as set forth in claim **8** wherein said control valve is a solenoid actuated valve.**]**

[10. A capacity modulated compressor as set forth in claim **7** wherein said pressurized fluid is supplied from said compression mechanism.**]**

[11. A capacity modulated compressor as set forth in claim **1** wherein said power source comprises an electric motor.**]**

[12. A capacity modulated compressor as set forth in claim **11** wherein said control module operates to vary an operating parameter of said electric motor when said valve is in said closed position so as to thereby improve the operating efficiency of said motor.**]**

[13. A capacity modulated compressor as set forth in claim **12** wherein said operating parameter of said motor is varied a predetermined time period after said valve is moved to said closed position.**]**

[14. A capacity modulated compressor as set forth in claim **1** wherein said compression mechanism is a reciprocating piston compressor.**]**

[15. A capacity modulated compressor as set forth in claim **14** wherein said reciprocating piston compressor includes a plurality of pistons and cylinders, said valve being operative to prevent flow of suction gas to all of said cylinders.**]**

[16. A capacity modulated compressor as set forth in claim **15** wherein said valve operates to prevent flow of suction gas to all of said cylinders simultaneously.**]**

[17. A capacity modulated compressor comprising:

a hermetic shell;

a compression mechanism disposed within said shell, said compression mechanism including a compression chamber defined in part by a moveable member, said moveable member operating to vary the volume thereof;

a drive shaft rotatably supported within said shell and drivingly coupled to said movable member;

a suction inlet passage for supplying suction gas to said compression chamber from a source remote from said shell;

a valve within said suction inlet passage, said valve being actuable between an open position to allow flow of suction gas through said inlet passage and a closed position to substantially prevent flow of suction gas through said inlet passage;

a controller for cyclically actuating said valve to an open position for first predetermined time periods and to a closed position for second predetermined time periods, the ratio of said first predetermined time period to the sum of said first and second predetermined time periods being less than a given load time constant and determining the percentage modulation of the capacity of said compressor.]

[**18**. A capacity modulated compressor as set forth in claim **17** wherein said valve is a bidirectional valve and is actuable to said closed position by pressurized fluid.]

[**19**. A capacity modulated compressor as set forth in claim **18** further comprising a solenoid valve actuable by said controller to control flow of said pressurized fluid to said valve.]

[**20**. A capacity modulated compressor as set forth in claim **19** wherein said pressurized fluid is discharge gas from said compressor.]

[**21**. A capacity modulated compressor as set forth in claim **17** wherein said valve is positioned in close proximity to said compression chamber.]

[**22**. A capacity modulated compressor as set forth in claim **17** wherein said compressor is a refrigeration compressor.]

[**23**. A capacity modulated compressor as set forth in claim **17** wherein said compressor is an air compressor.]

[**24**. A capacity modulated compressor as set forth in claim **17** wherein said compressor is a rotary compressor.]

[**25**. A capacity modulated compressor as set forth in claim **17** wherein said compressor is a scroll compressor.]

[**26**. A capacity modulated compressor as set forth in claim **17** wherein said sum of said first and second time periods is less than one half of said load time constant.]

[**27**. A capacity modulated compressor as set forth in claim **17** further comprising a motor for rotatably driving said drive shaft, said valve being actuable between said open and closed positions while said motor continues to rotatably drive said drive shaft.]

[**28**. A capacity modulated compressor as set forth in claim **27** wherein said controller operates to vary an operating parameter of said motor between periods in which said valve is in said closed position and in said open position to thereby improve the operating efficiency of said motor.]

[**29**. A method of modulating the capacity of a compressor forming a part of a cooling system to accommodate varying cooling load conditions comprising:

sensing an operating parameter of said cooling system, said parameter being indicative of the system load;

determining a cycle frequency of a maximum duration which will minimize variation in the suction pressure of refrigerant being supplied to said compressor;

determining a first time period during which suction gas will be supplied to said compressor and determining a second time period during which suction gas will be prevented from flowing to said compressor, said first and second time periods being equal to said cycle frequency; and

pulsing a valve between open and closed positions for said first and second time periods respectively to thereby modulate the capacity of said compressor in response to said system operating parameter.]

30. A capacity modulated compressor comprising:

a compression mechanism having a compression chamber therein, a suction inlet for supplying suction gas to the compression chamber and a movable member operative to vary the volume of said compression chamber;

a power source operatively connected to effect movement of said movable member to thereby compress gas drawn into said compression chamber through said suction inlet;

a valve provided in the suction gas flow path to said compression mechanism and actuated by pressurized fluid, said valve being operable between open and closed positions to cyclically allow and prevent flow of suction gas into said compression chamber; and

control apparatus for actuating said valve between said open and closed positions, said control apparatus being operative to cycle said valve such that its cycle time is substantially smaller than the time constant of the load on said compressor.

31. A capacity modulated compressor as set forth in claim 30 further comprising a control valve operative to control the flow of pressurized fluid to said valve.

32. A capacity modulated compressor as set forth in claim 31 wherein said control valve is a solenoid actuated valve.

33. A capacity modulated compressor as set forth in claim 30 wherein said pressurized fluid is supplied from said compression mechanism.

34. A capacity modulated compressor comprising:

a compression mechanism having a compression chamber therein, a suction inlet for supplying suction gas to the compression chamber and a movable member operative to vary the volume of said compression chamber;

an electric motor operatively connected to effect movement of said movable member to thereby compress gas drawn into said compression chamber through said suction inlet;

a valve provided in the suction gas flow path to said compression mechanism, said valve being operable between open and closed positions to cyclically allow and prevent flow of suction gas into said compression chamber; and

a control apparatus for actuating said valve between said open and closed positions, said control apparatus being operative to cycle said valve such that its cycle time is substantially smaller than the time constant of the load on said compressor and operable to vary an operating parameter of said electric motor when said valve is in said closed position so as to thereby improve the operating efficiency of said motor.

35. A capacity modulated compressor as set forth in claim 34 wherein said operating parameter of said motor is varied a predetermined time period after said valve is moved to said closed position.

36. A capacity modulated compressor comprising:

a hermetic shell;

a compression mechanism disposed within said shell, said compression mechanism including a compression chamber defined in part by a movable member, said movable member operating to vary the volume thereof;

a drive shaft rotatably supported within said shell and drivingly coupled to said movable member;

a suction inlet passage for supplying suction gas to said compression chamber from a source remote from said shell;

a valve within said suction inlet passage, said valve being actuable between an open position to allow flow of suction gas through said inlet passage and a closed position *to substantially prevent flow of suction gas through said inlet passage, said valve being a bidirectional valve actuable to said closed position by pressurized fluid; and*

a controller for cyclically actuating said valve to an open position for first predetermined time periods and to a closed position for second predetermined time periods, the ratio of said first predetermined time period to the sum of said first and second predetermined time periods being less than a given load time constant, determining the percentage modulation of the capacity of said compressor.

37. A capacity modulated compressor as set forth in claim 36 further comprising a solenoid valve actuable by said controller to control flow of said pressurized fluid to said valve.

38. A capacity modulated compressor as set forth in claim 37 wherein said pressurized fluid is discharge gas from said compressor.

39. A capacity modulated compressor comprising:

a hermetic shell;

a compression mechanism disposed within said shell, said compression mechanism including a compression chamber defined in part by a movable member, said movable member operating to vary the volume thereof;

a drive shaft rotatably supported within said shell and drivingly coupled to said movable member;

a suction inlet passage for supplying suction gas to said compression chamber from a source remote from said shell;

a valve within said suction inlet passage, said valve being actuable between an open position to allow flow of suction gas through said inlet passage and a closed position to substantially prevent flow of suction gas through said inlet passage;

a controller for cyclically actuating said valve to an open position for first predetermined time periods and to a closed position for second predetermined time periods, the ratio of said first predetermined time period to the sum of said first and second predetermined time periods being less than a given load time constant, determining the percentage modulation of the capacity of said compressor; and

a motor for rotatably driving said drive shaft, said valve being actuable between said open and closed positions while said motor continues to rotatably drive said drive shaft;

wherein said controller operates to vary an operating parameter of said motor between periods in which said valve is in said closed position and in said open position to thereby improve the operating efficiency of said motor.

40. A method of modulating the capacity of a compressor forming a part of a cooling system to accommodate varying cooling load conditions comprising:

sensing an operating parameter of said cooling system, said parameter being indicative of the system load;

determining a cycle frequency of a maximum duration which will minimize variation in the suction pressure of refrigerant being supplied to said compressor;

determining a first time period during which suction gas will be supplied to said compressor and determining a second time period during which suction gas will be prevented from flowing to said compressor, said first and second time periods being equal to said cycle frequency; and

pulsing a valve between open and closed positions for said first and second time periods respectively to thereby modulate the capacity of said compressor in response to said system operating parameter.

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