United States Patent

Heitmann et al.

[15] **3,658,442**

[45] **Apr. 25, 1972**

[54] COMPRESSOR

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[73] Assignee: **Northern Research and Engineering Corporation**, Cambridge, Mass.

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[21] Appl. No.: **44,131**

[52] **U.S. Cl.** **417/243**, 415/60, 415/179, 415/219

[51] **Int. Cl.** **F04b 23/00**

[58] **Field of Search** 415/60, 179, 219; 417/243, 417/244

[56] **References Cited**

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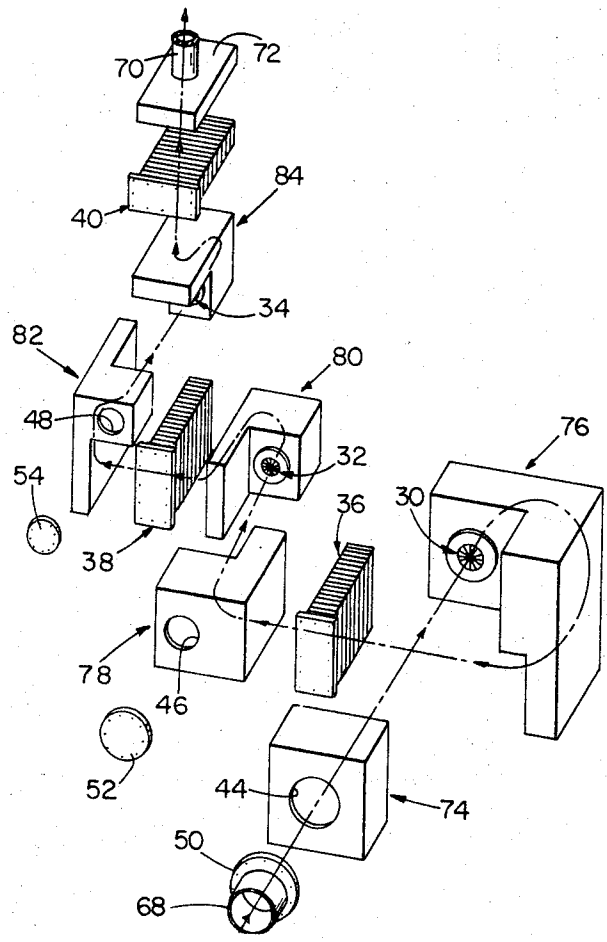
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Primary Examiner—C. J. Husar
Attorney—Willis M. Ertman

[57] **ABSTRACT**

A centrifugal compressor system has a compressor housing partitioned into a plurality of chambers and a gear chamber that has a common wall with the compressor housing. A compressor module support structure is mounted in each chamber on the common wall and receives a compressor module that has a pinion gear that extends past the common wall for engagement with a bull gear mounted for rotation in the gear chamber. Each compressor module has an inlet shroud that is supported on an intermediate partition of the compressor housing and a large plenum chamber is defined in front of each compressor module in part by that intermediate partition.

16 Claims, 13 Drawing Figures



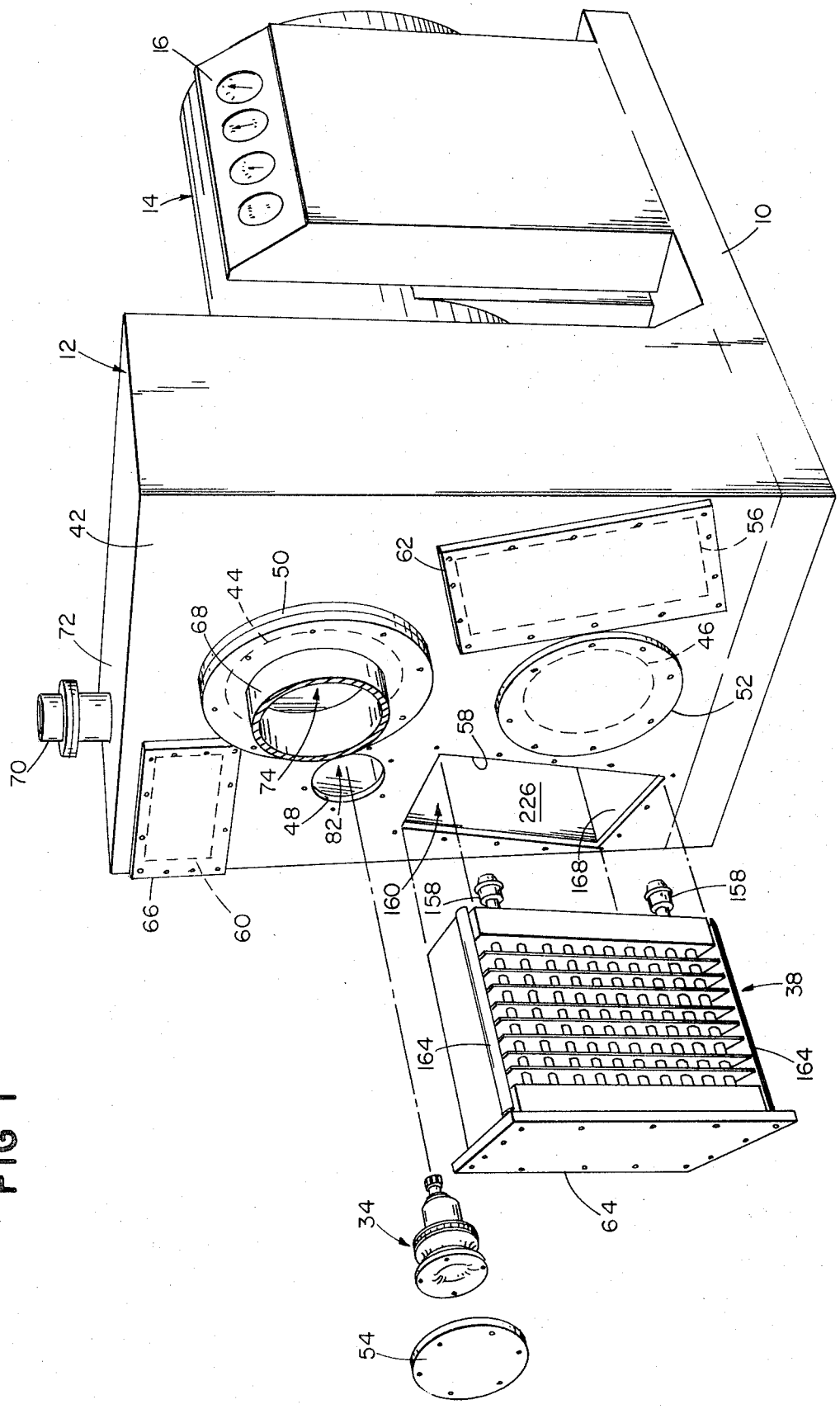

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FIG 1

FIG 2

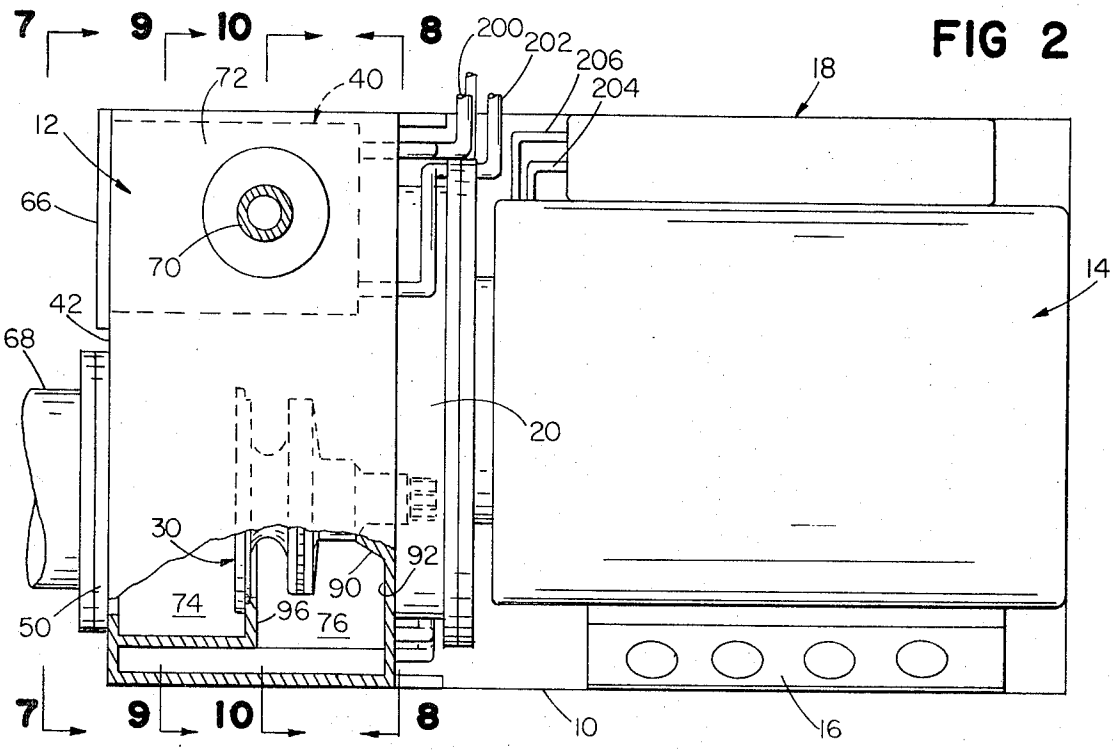

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FIG 3

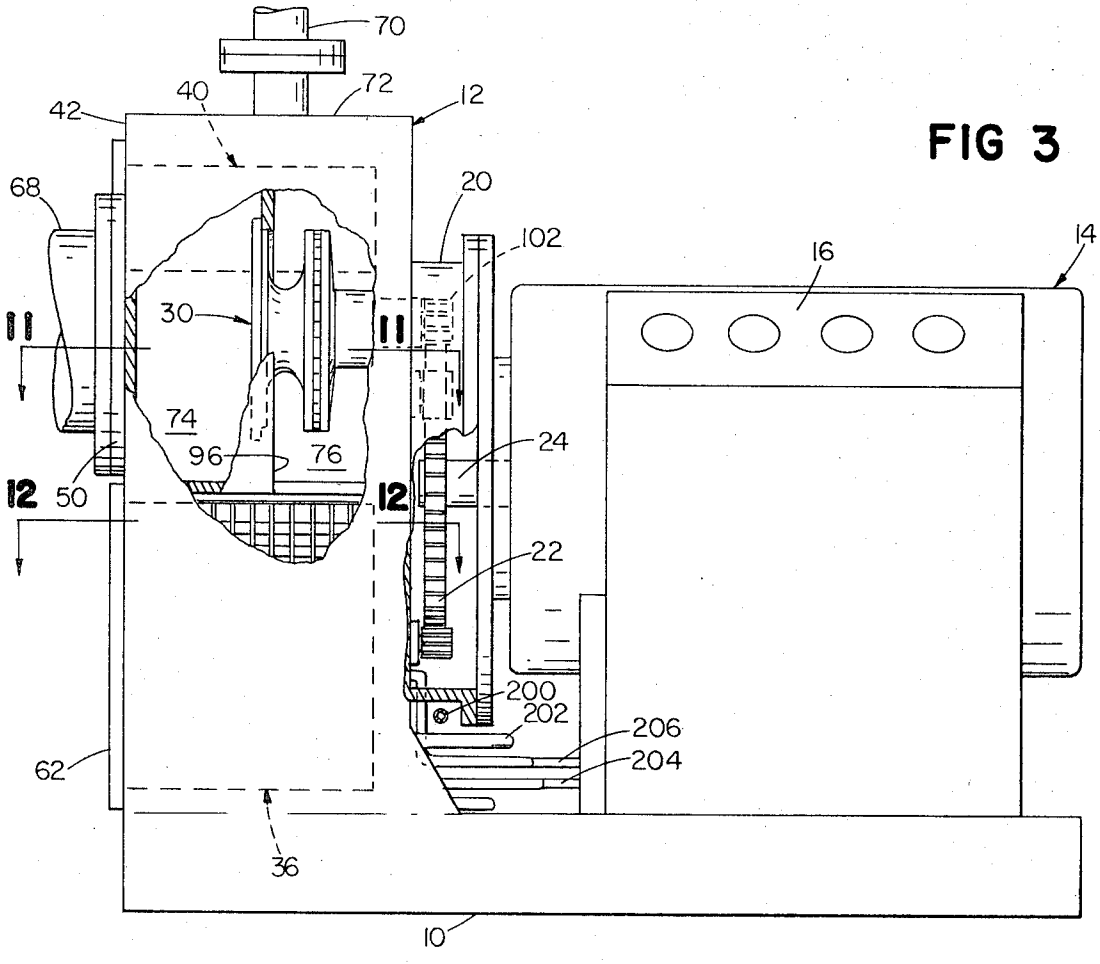

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FIG 11

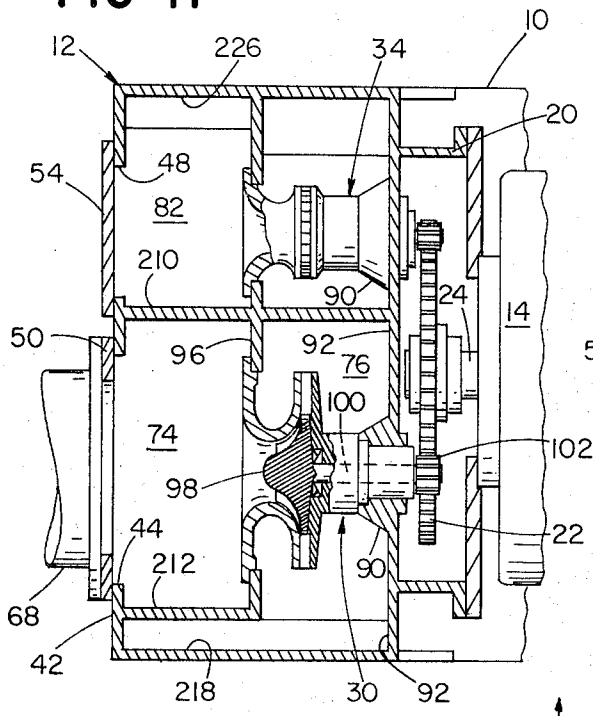
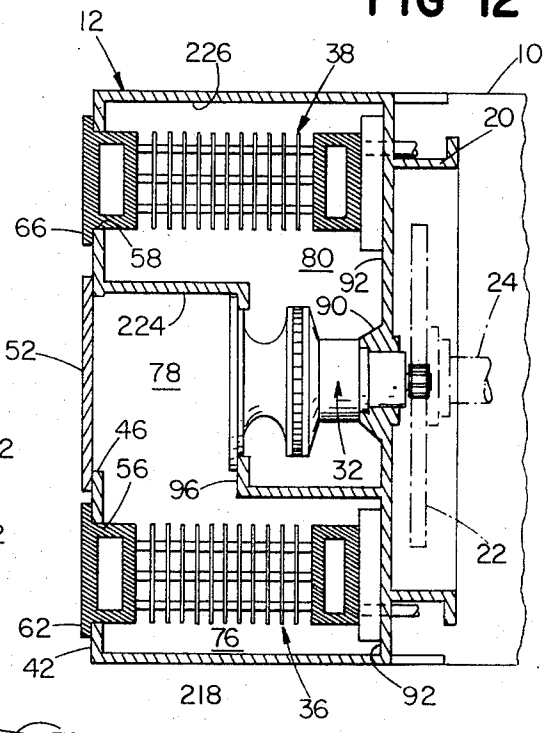


FIG 12



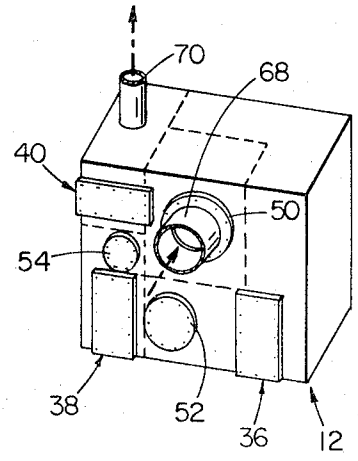


FIG 4a

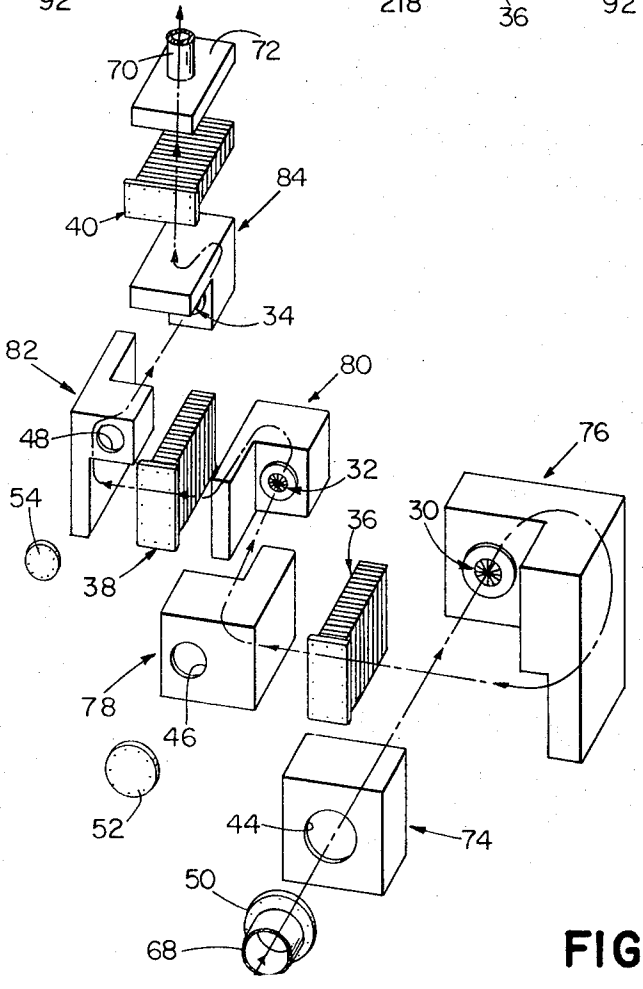
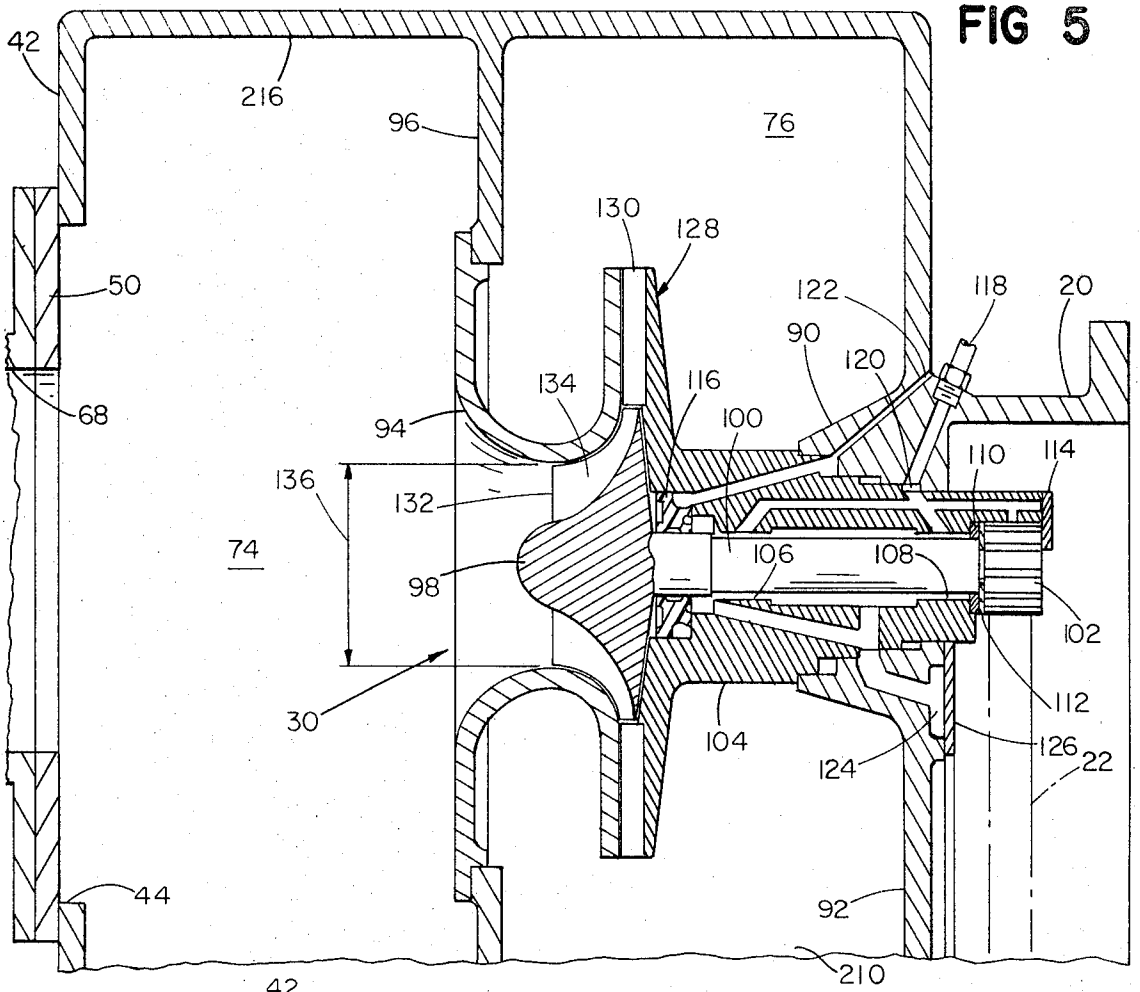


FIG 4b

FIG 5


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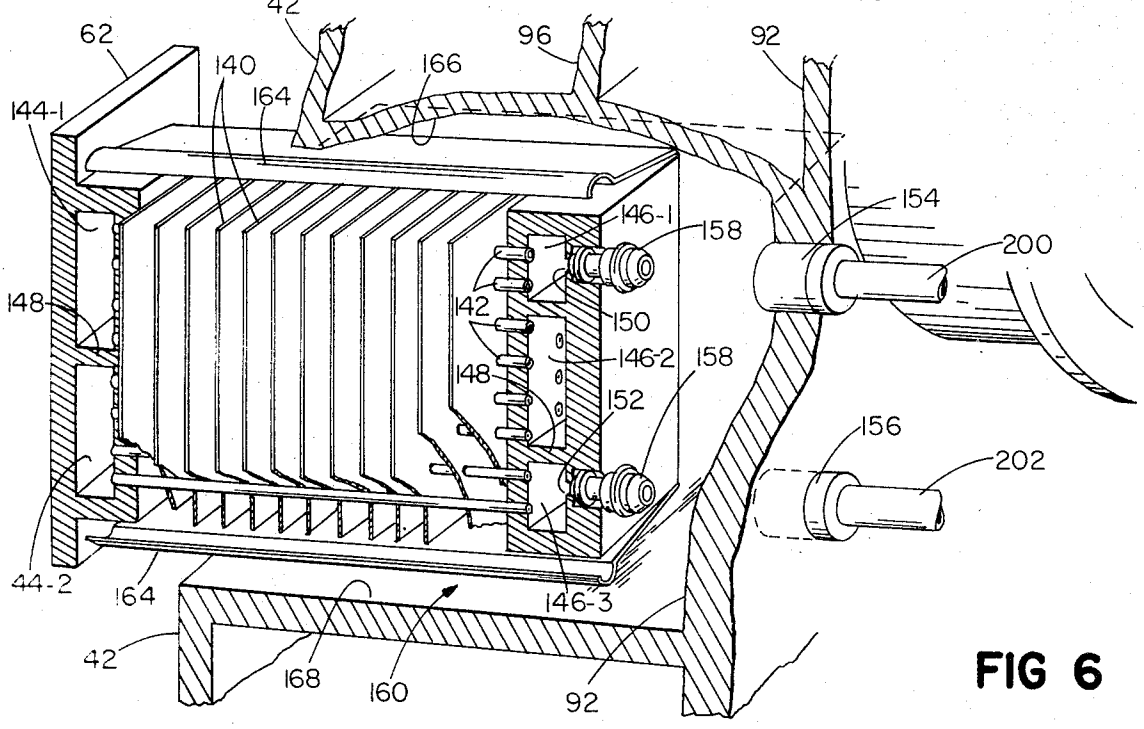

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FIG 6

FIG 8

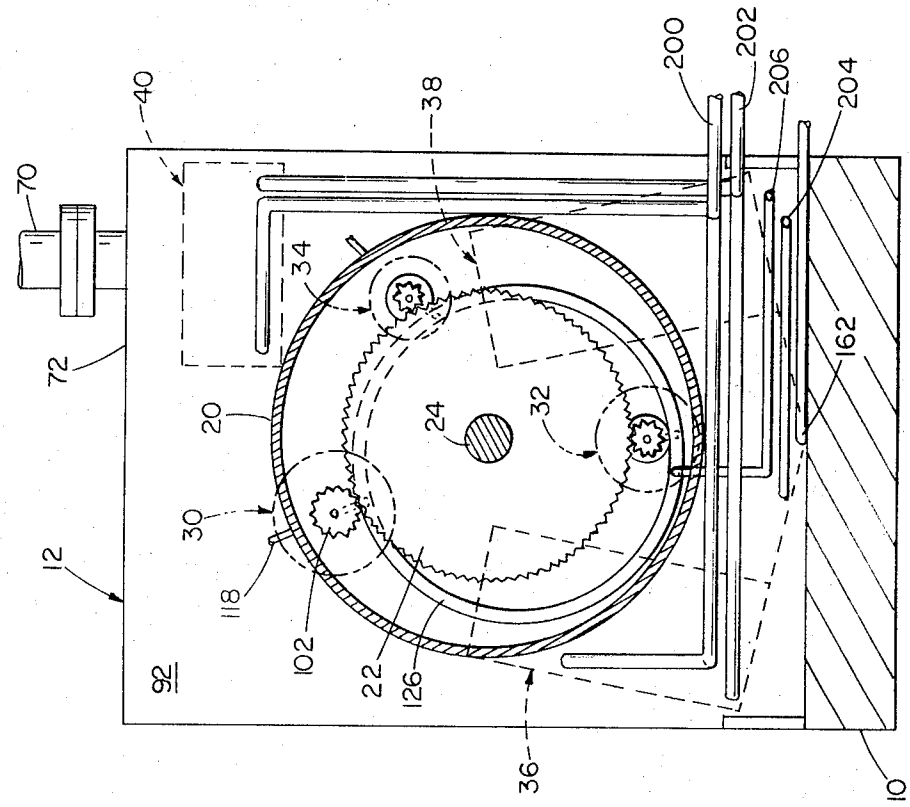

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FIG 7

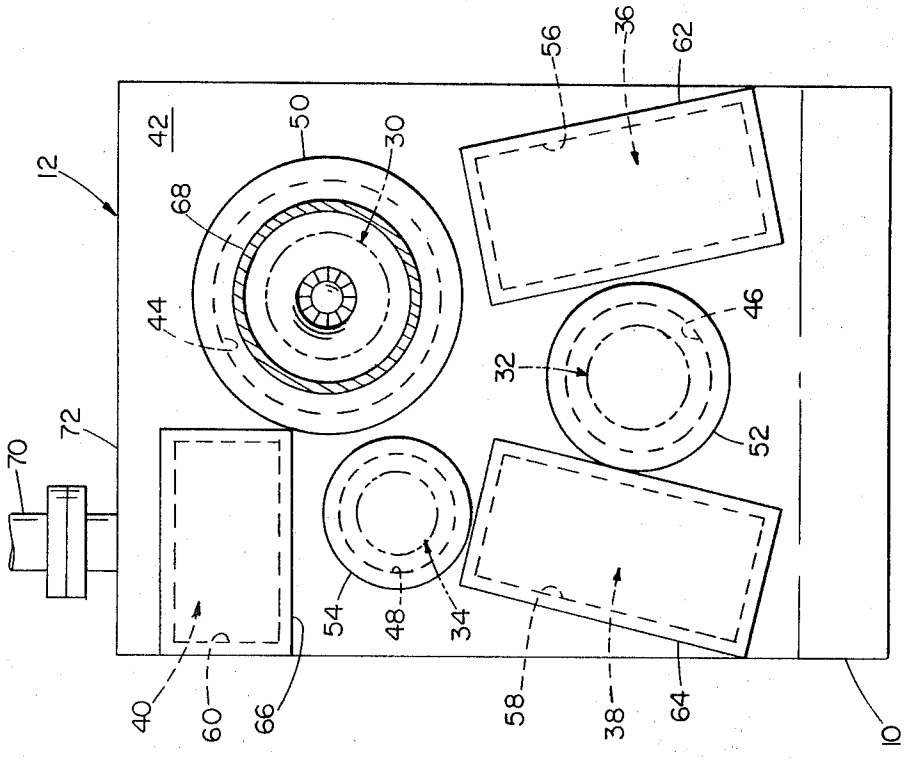

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FIG 10

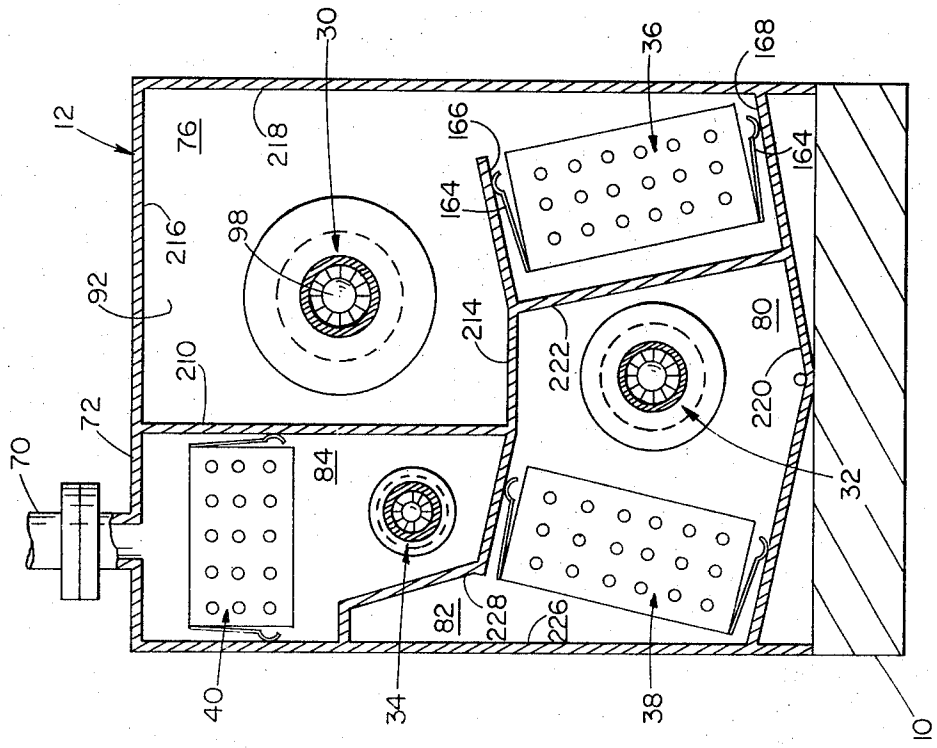
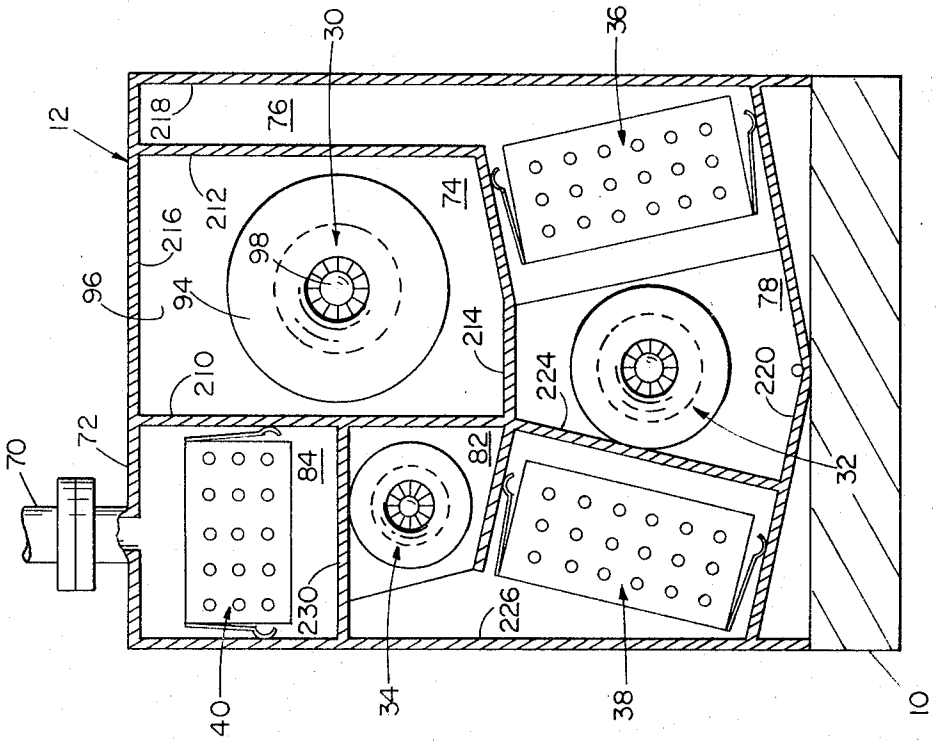

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FIG 9


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COMPRESSOR

SUMMARY OF INVENTION

This invention relates to centrifugal gaseous medium compressors, and more particularly to multi-stage centrifugal compressor systems.

An object of this invention is to provide a novel and improved multi-stage centrifugal compressor system which incorporates modular components, and which facilitates manufacture and maintenance.

Another object of the invention is to provide a novel and improved compressor arrangement.

Another object of the invention is to provide a novel and improved multi-stage centrifugal compressor arrangement employing a modular arrangement of impeller shafts having graduated rotational speeds so as to achieve advantageous compression conditions per compressor stage for the several impellers while providing a convenient and economical drive arrangement.

A further object of the invention is to provide novel and improved multi-stage centrifugal compressor arrangement which has a compact flow path arrangement through the impeller and cooler stages, requires a small amount of space and presents an attractive appearance.

A further object of the invention is to provide a novel and improved multi-stage centrifugal compressor arrangement having conveniently arranged cooling and lubrication arrangements.

Still another object of the invention is to provide novel and improved arrangements for driving a multi-stage centrifugal compressor assembly.

A further object of the invention is to provide a gaseous medium compressor arrangement having improved efficiency.

In accordance with one feature of the invention there is provided a centrifugal gaseous medium compressor system having a compressor housing, with a plurality of compressor module support structures in the housing which support a corresponding plurality of compressor modules each of which includes an impeller and bearing assembly. Partition means in the housing divides the housing into a plurality of chambers with an inlet plenum chamber and a discharge chamber associated with each compressor module. The partition means further defines a flow path between the discharge chamber of one compressor module and the inlet plenum chamber of the next compressor module, and a cooler module including a series of heat exchanger surface elements is disposed in that flow path. The housing has an outer wall with individual ports in it through which the compressor and cooler modules may be withdrawn as individual units.

In a preferred embodiment each compressor module includes a centrifugal compressor impeller, a diffuser, and the necessary seals, bearings and pinion gear in a modular assembly, and each cooler module is a self-contained unit having heat exchanger surface elements and water manifolds and the partition means. The system further includes a gear casing that has a common wall with the compressor housing. A bull gear is mounted in that casing and the pinion gears of the compressor modules extend through the common wall into the gear casing and are engaged by the bull gear. A drive motor is disposed adjacent the gear casing and has a motor shaft that extends into the gear casing and the bull gear is mounted directly on that motor shaft.

In accordance with another features of the invention there is provided centrifugal gaseous medium compressor apparatus having a housing and a compressor assembly mounted within the housing. The compressor assembly includes an impeller assembly and an inlet shroud defining an inlet passage. A plenum chamber through which the gaseous medium to be compressed passes is immediately adjacent the compressor assembly inlet shroud; the plenum chamber being within a distance equal to the inlet diameter of the inlet shroud from the forward blade edge of the impeller and having a cross-sectional area at least four times the cross-sectional inlet area of

the compressor assembly as defined by its inlet shroud. In preferred embodiments the cross-sectional area of the plenum chamber is at least ten times the cross-sectional inlet area of the compressor assembly. This close coupled plenum chamber-compressor assembly arrangement provides a significant increase in compressor efficiency. Such arrangement also permits the close positioning of an inlet throttle valve without adversely affecting the performance of the compressor.

In a particular embodiment, the compressor housing is a rectangular housing in which three compressor modules and three cooler modules are mounted. This housing has dividing partitions which define the air passages and close coupled plenum chambers that route the air in the required sequence through the compressor and cooler modules. The compressor and cooler modules are assembled into the housing through access ports in the front of the housing and are easily inspectable from these ports and easily removed without disconnecting drive structure or piping. Water connections to the cooler modules are made on the back side of the compressor housing through appropriately sealed ferrule assemblies that facilitate insertion and removal.

The drive motor is of the face mounting configuration and an adapter plate bolted to the face of the motor serves as the rear wall of the gear casing. The bull gear is mounted directly on the drive motor shaft, thus eliminating the need for bull gear bearings and the problems of couplings and coupling misalignment. A common base for the compressor housing and the drive motor contains a lubrication oil module and control cabinet. The lubrication module is an assembly of the necessary lubrication oil conditioning equipment and typically includes a lubrication oil cooler, a pump, pressure regulating valves and temperature sensors.

Compressor controls include throttling means for throttling the compressor inlet to maintain constant discharge pressure and also to prevent surge. Other controls include sensing, drive motor overload protection and lube oil temperature pressure sensing, cooling water pressure and vibration sensors. Any one of the key elements of the assembly can be removed without disturbing other elements, including any of the rotor assemblies, any of the coolers, the lubrication oil module, or the control module.

Other objects, features and advantages of the invention will be seen as the following description of a particular embodiment progresses, in conjunction with the drawings, in which:

FIG. 1 is a perspective view of a three-stage centrifugal air compressor system constructed in accordance with the invention, showing a compressor module and a cooler module spaced from the compressor assembly housing;

FIG. 2 is a top plan view with parts broken away of the compressor system shown in FIG. 1;

FIG. 3 is side elevational view with parts broken away of the compressor system shown in FIG. 1;

FIG. 4*a* is a diagrammatic view of components of the compressor system;

FIG. 4*b* is an exploded diagrammatic view corresponding to FIG. 4*a*, showing the air flow path through components of the compressor system;

FIG. 5 is a sectional view showing details of a compressor module employed in the system shown in FIG. 1;

FIG. 6 is a perspective view with parts broken away showing details of a cooler module employed in the system shown in FIG. 1;

FIGS. 7–10 are sectional views taken along the lines 7—7, 8—8, 9—9, and 10—10, respectively, of FIG. 2; and

FIGS. 11 and 12 are sectional views taken along the lines 11—11 and 12—12, respectively, of FIG. 3.

DESCRIPTION OF PARTICULAR EMBODIMENT

With reference to FIGS. 1–3, the apparatus includes a base 10 on which a compressor assembly housing 12 is mounted at its left end and a prime mover 14 in the form of an electric motor is mounted at its right end. A control panel 16 is

mounted on one side of motor **14** and a system for supplying lubricating oil to the compressor assembly is mounted on the opposite side of motor **14**. Chamber **20** disposed between motor **14** and compressor housing **12** houses a bull gear **22** that is mounted directly on the shaft **24** of motor **14**.

The compressor assembly in housing **12** includes three compressor stages **30, 32** and **34** and three cooler structures **36, 38** and **40** disposed in rectangular housing **12**. Each compressor stage and cooler structure is removable as a unit through an access port in the left end wall **42** of housing **12**, compressor stages **30, 32** and **34** being removable through ports **44, 46** and **48** covered by plates **50, 52** and **54**, respectively; and cooler stages **36, 38** and **40** being removable through ports **56, 58, 60** and having integral cover plates **62, 64** and **66**, respectively. Inlet conduit **68** is attached to plate **50** and may include a throttling valve; and outlet conduit **70** extends upwardly from the top wall **72** of housing **12**.

A diagrammatic view of the compressor assembly is shown in FIG. **4***a* and a corresponding exploded view is shown in FIG. **4***b*. Air is introduced into the compressor assembly through inlet conduit **68** to plenum chamber **74** which communicates with the inlet of first compressor stage **30**. That compressor stage discharges air into discharge chamber **76** which translates the compressed air through cooler **36** to plenum chamber **78** at the inlet to compressor stage **32**. The compressed air from that stage is discharged into chamber **80** for transfer to cooler **38** to plenum chamber **82** which communicates with the inlet to compressor stage **34**. Compressor stage **34** is mounted to discharge air into discharge chamber **84** and transfer that air through aftercooler **40** and chamber **86** to outlet conduit **70**.

A sectional view of compressor module stage **30** and plenum chamber **74** which is illustrative of the construction of module stages **32** and **34** (although those stages are of graduated smaller size) and their associated plenum chambers, is shown in FIG. **5**.

The compressor module is received directly in a mounting boss **90** that projects forwardly from the front wall **92** of the gear case **20** and receives its primary support from this mounting structure. Additional support is provided by the interconnection of the inlet shroud **94** of the module with partition **96** in the compressor case between chambers **74** and **76**. The compressor impeller **98** and shaft **100** are an integral assembly, the impeller **98** being cast from a corrosion resistant steel and welded to shaft **100**. The pinion gear **102** is press fitted on shaft **100**. Shaft housing **104** includes hydrodynamic radial bearings **106, 108**, the impeller end bearing **106** of the three lobed type and the pinion end bearing **108** is of the simple journal type. Thrust bearing **110** is of the simple stepped type. The main thrust is towards the impeller and a thrust washer **112** captured by the pinion **102** provides the main positioning surface. A position control thrust bearing **114** located at the end of the bearing housing **104** uses the back face of the pinion as a runner surface. The shaft seal **116** is a two-stage seal, the primary seal or oil side being a mechanical or nose type seal and the second stage a simple labyrinth. The oil to the radial and thrust bearings is supplied from the lubrication supply line **118** into the compressor cartridge via an annular passage **120** formed by the stepped diameter of the bearing housing **104** and the receiving bore in the support boss **90**. Lubrication flow control is established by the sizing of the drilled holes required to port the oil to various bearing supply areas. Passage **122** provides a vent. Drainage from the bearings is ported away from the bull gear and flows to an annular recess **124** covered by plate **126** in the forward face of the bull gear chamber **20**.

The compressor diffuser **128** is formed by a flat plate having a series of vanes **130** cast thereon. This plate is bolted to the housing **104** and the shroud **94** is secured in accurately centered relation to the diffuser **128** and bearing cartridge **104** by dowel pins and bolts. The entire compressor module may be removed as a unit by unbolting the inlet bellmouth shroud structure **94** from partition **96** and sliding the unit out to initially disengage pinion **102** from bull gear **22** and then to remove the unit through the plenum chamber **74** and port **44**.

Plenum chamber **74** is close coupled to compressor module **30**, wall **96** being a partition separating plenum chamber **74** from compressor discharge chamber **76**. The plenum chamber side of wall **96** is located at a distance from the front end **132** of impeller blades **134** of about one-half the compressor inlet diameter indicated by dimension **136** and chamber **74** has a cross-sectional area about 25 times the cross-sectional area of the compressor inlet and a length of about twice the inlet diameter **136**.

A diagrammatic view of a cooler module is shown in FIG. **6**. In a typical module, the intercooler includes a multipass, cross-counterflow arrangement having tube-fin heat exchange surfaces. The air side is formed of aluminum plates **140** spaced approximately 0.050 inch apart and the water side formed by ¾ inch copper tubing **142**. Each intercooler module has two headers **144, 146**, both headers having baffling **148** to provide the appropriate number of water passes. The inner header **146** containing inlet and discharge ports **150, 152**. The flow is from header section **146-1** through tubes **142** to header section **144-1** and return through a second set of tubes **142** to header section **146-2** and then return again to header section **144-2** for final pass back through still another set of tubes **142** to header section **146-3** and discharge through connection **152**. These ports match up with appropriate water supply and drain port structures **154, 156** in wall **92** of the compressor case and the interface junction is sealed by O-ring seal ferrules **158**. Moisture condensed out during the intercooling process is collected by the fins **140** and drained to the bottom of the intercooler chamber chamber **160** and to a sump **162** (FIG. **8**) which is piped through usual water traps to an overboard drain. Flexible seal structures **164** are mounted on either side of the cooler module and engage two opposed walls **166, 168** of the chamber **160** in which the module is received. At the front end of the cooler module is a flange structure which is bolted with appropriate seals to the wall **42** of the compressor assembly housing **12**, securing the module in position in the flow path in the compressor system. The entire cooler module may be removed as a unit by unbolting the plate structure and sliding the unit out to remove the unit through the port.

Further details of the assembly are indicated in FIGS. **7–12**. An end view of the compressor assembly in FIG. **7** shows the access plates over the access ports in wall **42**. In FIG. **8** there are indicated the cooling water inlet line **200** and cooling water outlet line **202** that communicate with each of the three cooler modules, lubrication supply line **204** which communicates with supply manifold **122** and lubrication drain line **206** which communicates with annular drain manifold **124**. This manifold, as indicated in FIGS. **5** and **8**, may be machined directly in the wall **92**. With reference to FIGS. **9–12**, plenum chamber **74** is defined by partitions **210, 212, 214**, top wall **72**, transverse wall **96** and front wall **42**. Discharge chamber **76** is defined by rearward extension of wall **210**, side wall **218**, top wall **216**, lower wall **220**, partition walls **96, 212** and **214**, and wall **92** between the compressor compartment and the bull gear compartment. Thus discharge chamber **76** has common walls with plenum chamber **74**. Intercooler module **36** is disposed in a chamber whose upper wall is an extension of partition **214** and lower wall is a portion of the drain floor wall **220**, the inner side wall is partition **222**; and front and rear walls are structures **42** and **92**, respectively.

The plenum chamber **78** has as a top wall a portion of partition **214**, a bottom wall part of partition **220**, a side wall as partition **224**, front wall **42** and rear wall **96**. The discharge chamber **80** for compressor module **32** is defined by partitions **214, 220, 222, 224**, front wall **42** and rear wall **92**. Intercooler **38** is disposed between the discharge chamber **80** and inlet plenum chamber **82** to the third compressor module. Chamber **82** is bounded by side wall **226**, partitions **96** and **214**, top wall **216**, and front wall **42**. The discharge chamber **84** for the third stage is formed between partition **230** and top wall **216**, partition **210** and side wall **226**, and partition **96** and

rear wall **92**. Aftercooler **40** is disposed in this chamber and the air after flowing through that aftercooler is discharged to conduit **70**.

As an illustrative example, in this compressor assembly with an 800 horsepower motor, compressor stage **30** has a shaft speed of 61,800 rpm, compressor stage **32** has a shaft speed of **42**, 400 rpm, and compressor stage **34** has a shaft speed of 29,100 rpm. A compressor unit of this frame size has an overall width of 4 feet and an overall height of 5 feet and is 6 feet, 9 inches long.

While a particular embodiment of the invention has been shown and described, various modifications thereof will be apparent to those skilled in the art and therefore it is not intended that the invention be limited to the disclosed embodiment or to details thereof and departures may be made therefrom within the spirit and scope of the invention as defined in the claims.

What is claimed is:

1. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into a plurality of chambers, a gear casing having a common wall with said compressor housing, a bull gear mounted for rotation in said gear casing, a plurality of compressor module support structures mounted directly on said common wall, a housing outer wall structure opposite to and spaced from said common wall, said outer wall structure having a plurality of ports therein aligned with corresponding ones of said compressor module support structures, and a corresponding plurality of compressor modules supported in said module support structures, each said compressor module including a shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, each said inlet shroud being supported on an intermediate partition of said housing and each said pinion gear being disposed in said gear casing for driving by said bull gear, each said compressor module being removable as a unit from its support structure through the corresponding port in said outer wall structure of said housing.

2. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into a plurality of chambers, a gear casing having a common wall with said compressor housing, a bull gear mounted for rotation in said gear casing, a plurality of compressor module support structures mounted directly on said common wall, a corresponding plurality of compressor modules supported in said module support structures, each said compressor module including a shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, each said inlet shroud being supported on an intermediate partition of said housing and each said pinion gear being disposed in said gear casing for driving by said bull gear, and an outer wall of said housing opposite said common wall having corresponding ports through which said compressor modules may be removed from said housing as units, and a cooler module disposed in said housing in a flow path between the discharge chamber of one compressor module and the plenum chamber of another compressor module, said cooler module including a series of heat exchanger surface elements, and said outer wall further including a port through which said cooler module may be withdrawn from said housing as a unit.

3. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into a plurality of chambers, a gear casing having a common wall with said compressor housing, a bull gear mounted for rotation in said gear casing, a plurality of compressor module support structures mounted directly on said common wall, a corresponding plurality of compressor modules supported in said module support structures, each said compressor module including a shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, each said inlet shroud being supported on an intermediate partition of said housing and each said pinion gear being disposed in said gear casing for driving by said bull gear and an outer wall of said housing opposite said common wall having corresponding ports through which said compressor modules may be removed from said housing as units, said partitioning means cooperating with each said inlet shroud to define a plurality of plenum chambers between said inlet shroud and said outer wall, and each said plenum chamber being associated with a corresponding compressor module and having a cross-sectional area at least four times the cross-sectional area of the compressor module inlet passage as defined by said inlet shroud.

4. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into a plurality of chambers, a gear casing having a common wall with said compressor hosuing, a bull gear mounted for rotation in said gear casing, a plurality of compressor module support structures mounted directly on said common wall, a corresponding plurality of compressor modules supported in said module support structures, each said compressor module including a shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, each said inlet shroud being supported on an intermediate partition of said housing and each said pinion gear being disposed in said gear casing for driving by said bull gear and an outer wall of said housing opposite said common wall having corresponding ports through which said compressor modules may be removed from said housing as units and an annular drain channel formed in said common wall and communicating via said module support structures with said shaft and bearing assemblies.

5. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into a plurality of chambers, a gear casing having a common wall with said compressor housing, a bull gear mounted for rotation in said gear casing, a plurality of compressor module support structures mounted directly on said common wall, a corresponding plurality of compressor modules supported in said module support structures, each said compressor module including a shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, each said inlet shroud being supported on an intermediate partition of said housing and each said pinion gear being disposed in said gear casing for driving by said bull gear and an outer wall of said housing opposite said common wall having corresponding ports through which said compressor modules may be removed from said housing as units and a drive motor disposed adjacent said gear casing, said drive motor having a motor shaft extending into said gear casing and said bull gear being mounted directly on said motor shaft.

6. The system as claimed in claim **5** wherein each said plenum chamber has a cross-sectional area at least four times the cross-sectional area of the compressor module inlet passage as defined by said inlet shroud.

7. The system as claimed in claim **6** wherein said partitioning means cooperates with each said inlet shroud to define a plenum chamber between said inlet shroud and said outer wall.

8. The system as claimed in claim **7** and further including a cooler module disposed in said housing in a flow path between the discharge chamber of one compressor module and the plenum chamber of another compressor module, said cooler module including a series of heat exchanger surface elements, and said outer wall further including a port through which said cooler module may be withdrawn from said housing as a unit.

9. The system as claimed in claim **8** and further including an annular drain channel formed in said common wall and communicating via said module support structures with said shaft and bearing assemblies.

10. A centrifugal gaseous medium compressor system comprising a compressor housing, a plurality of compressor module support structures in said housing, a corresponding plurality of compressor modules supported in said module

support structures, partition means in said housing dividing said housing into a plurality of chambers with an inlet plenum chamber and a discharge chamber associated with each compressor module, said partition means further defining a flow path between the discharge chamber of one compressor module and the inlet plenum chamber of another compressor module, a cooler module support structure disposed in said flow path, a cooler module including a series of heat exchanger surface elements releasably secured to said cooler module support structure, said housing having an outer wall with individual spaced ports therein and aligned with corresponding ones of said compressor module support structures and said cooler module support structure through which said compressor and coller modules may be withdrawn as individual units and means for sealing said ports.

11. A centrifugal gaseous medium compressor system comprising a compressor housing, means partitioning said housing into two chambers, an aperture in said partitioning means, a gear casing having a common wall with said compressor housing, a bull gear mounted for rotation in said gear casing, a compressor module support structure on said common wall and extending into one of said chambers, a housing outer wall on the opposite side of said chambers from said common wall, said outer wall having a port therein aligned with said compressor module support structure, a compressor module supported in said module support structure, said compressor module including shaft and bearing assembly, an impeller, a pinion gear, a diffuser structure and an inlet shroud supported on said shaft and bearing assembly, said inlet shroud being secured in sealing relation in said aperture of said partitioning means, the second of said chambers being a plenum chamber through which the medium to be compressed is supplied and having a cross-sectional area at least four times the cross-sectional area of the compressor module inlet passage as defined by said inlet shroud, and said shaft and bearing assembly extending through said common wall so that said pinion gear is disposed in said gear casing for driving by said bull gear, said compressor module being removable as a unit from its support structure through said port in said outer wall of said housing.

12. Centrifugal gaseous medium compressor apparatus comprising a housing, a compressor assembly mounted within the housing, said compressor assembly including an impeller assembly and an inlet shroud that defines an inlet passage to said impeller assembly, structure defining a plenum chamber through which the gaseous medium to be compressed passes immediately adjacent the compressor assembly inlet shroud, said plenum chamber being within a distance equal to the inlet diameter of said inlet shroud from the forward blade edge of said impeller assembly and having a cross-sectional area at least four times the cross-sectional inlet area of said compressor assembly as defined by said inlet shroud.

13. The compressor assembly as claimed in claim 12 wherein the cross-sectional area of said plenum chamber is at least ten times said cross-sectional inlet area of said compressor assembly.

14. The apparatus as claimed in claim 13 wherein said apparatus includes a plurality of compressor assembly modules and associated close coupled plenum chambers and further including a cooler module disposed in said housing in a flow path between the discharge chamber of one compressor module and the plenum chamber of another compressor module, said cooler module including a series of heat exchanger surface elements, and said housing further including a port through which said cooler module may be withdrawn from said housing as a unit.

15. The apparatus as claimed in claim 14 and further including partitioning means cooperating with each said inlet shroud to define a plenum chamber between said inlet shroud and the outer wall of said housing.

16. The apparatus as claimed in claim 15 and further including a drive motor having a motor shaft, and a bull gear mounted directly on said motor shaft for engaging drive pinions of said compressor assembly modules.

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