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(72) Inventor: **Buckland, Michael**
60325 Frankfurt (DE)

(74) Representative: **Mercey, Fiona Susan**
L'Air Liquide SA
Direction de la Propriété Intellectuelle
75, Quai d'Orsay
75321 Paris Cedex 07 (FR)

(71) Applicant: **L'AIR LIQUIDE, SOCIETE ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCEDES GEORGES CLAUDE**
75007 Paris (FR)

(54) **An integrally-gearred centrifugal compressor and a method for building an integrally-gearred centrifugal compressor**

(57) An integrally-gearred compressor including a bull gear (12), and at least two pinions (13,14,15) able to be driven by the bull gear, at least three compressor wheels, one of the pinions being connected to at least one compressor wheel and the other pinion being connected to two compressor wheels, wherein the compressor corresponds to a given predetermined compressor size, selected from a plurality of different standard sizes (A, B, C, D, E), each standard size being capable of producing output flowrates over a defined range at an output pressure over a defined range, wherein certain elements of the compressor correspond either to a single predetermined element size or one of only two predetermined element sizes, the predetermined element size or sizes being fixed for each compressor size and the certain elements being the bullgear, the first pinion (13,14), the first pinion shaft (18), the second pinion (14,15) and the second pinion shaft (18), the gear case and at least one volute (20).

Method for building an integrally geared centrifugal compressor to produce compressed gas at a given outlet flowrate and a given outlet pressure

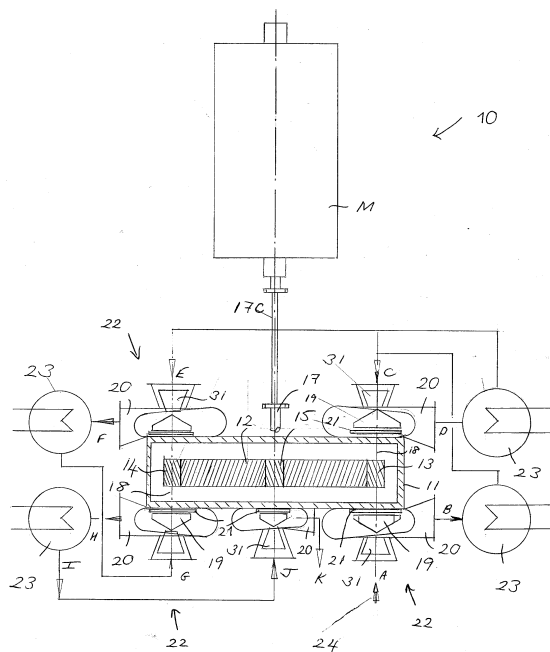


FIG. 4

Description

[0001] This invention relates to a integrally geared compressor. The integrally geared compressor may be used to compress an air feed to an air separation plant. The compressor may, for example, be a centrifugal compressor.

[0002] It is common to use integrally geared compressors to provided compressed fluid, such as feed air for other processes, for example air separation plants. Compressors supply air at a specified output flow rate and output pressure, for example to an air separation plant and are required to have the lowest possible total cost of ownership, taking into account power consumption among other aspects. The duty specification for each compressor is in most cases unique, due to variation in ambient conditions (altitude, temperature, humidity), variation in customerspecific needs from the air separation unit, (flow rate, pressure and purity) and variations in energy cost that need to be evaluated (capital cost vs. operating energy operating cost). It is therefore necessary, during the design of each air separation plant, to customise each compressor so that the above needs are optimised.

[0003] However, it is desirable to reduce the cost and time of construction of a compressor, by standardizing the compressor to the greatest extent, whilst still achieving the required output properties for the fluid to be compressed and cost of energy to operate.

[0004] In addition it is also desirable to reduce the total cost of the capital spare parts of the compressors which are stored, as insurance in case they are needed to repair a compressor.

[0005] EP-A-1302668 described a compressor comprising a number of standardized elements and a number of purpose built elements. This document identifies the problem of the present invention and provides insight into standardizing the compressor optimisation but does not consider the long lead time or commonality of capital spares. It describes the application of multiple pinions and the customisation of volutes.

[0006] In this prior art document, a series of compressor sizes are defined, each corresponding to a range of outlet flowrates. Once the flowrate required is known and thus the corresponding compressor size, the compressor designer defines a single size of bull gear for that compressor. In one embodiment, it is suggested that the first pinion (i.e. the pinion carrying the first wheel compressing the fluid from the starting pressure) should also have a fixed size for any given compressor size. However the remaining pinions are not standardized and correspond to the specific flow rate which the compressor is intended to produce.

[0007] This approach means that inter-changeability of spare parts is at least in part negated since different pinion sizes will require different gear case centres to be used and of course a multiple number of different pinion shafts to be held as capital spares. Further the customisation of the volutes and gear case negates lead time reduction and pre-design followed by pre-order.

[0008] According to the present invention there is provided an integrally-geared compressor including a bull gear, and at least two pinions able to be driven by the bull gear, at least three compressor wheels, one of the pinions being connected to at least one compressor wheel and the other pinion being connected to two compressor wheels, wherein the compressor corresponds to a given predetermined compressor size, selected from a plurality of different standard sizes, each standard size being capable of producing output flowrates over a defined range at an output pressure over a defined range, wherein certain elements of the compressor correspond either to a single predetermined element size or one of only two predetermined element sizes, the predetermined element size or sizes being fixed for each compressor size and the certain elements being the bullgear, the first pinion, the first pinion shaft, the second pinion and the second pinion shaft, the gear case and at least one volute.

[0009] Any one volute may be of a fixed size or of one of two fixed sizes. Preferably the volute contains one of the compressor wheels fixed to one of the at least two pinions.

[0010] The first pinion may drive at least a first compressor wheel compressing the gas having the lowest inlet pressure (ie the inlet wheel of the compressor). The second pinion may drive at least one further compressor wheel downstream of the first compressor wheel.

[0011] Preferably the volute contains a compressor wheel which may be one of the first and further compressor wheels. Furthermore, a first volute having a fixed size for a first volute or one of two fixed sizes for a first volute may contain the first compressor wheel.

[0012] Additionally a second volute having a fixed size for a second volute or one of two fixed sizes for a second volute may contain the further compressor wheel.

[0013] According to one variant of the invention, the compressor corresponds to a single predetermined fixed size, the bull gear corresponds to a single predetermined bull gear size fixed for each compressor size and the first pinion corresponds a single pinion size, fixed for each compressor size and the second pinion corresponds to a single predetermined second pinion size fixed for each compressor size, the gear case corresponds to a single predetermined gear case size fixed for each compressor size and at least an Nth volute corresponds to a single predetermined size of Nth volute fixed for each compressor size, N being a whole number equal to at least 1.

[0014] In this case, the compressor may include at least first and second volutes, the first volute corresponding to a single first volute size, fixed for the first volute of the compressor size and the second volute corresponding to a single

second volute size, fixed for the second volute of the compressor size..

[0015] In an alternative variant, the compressor corresponds to one of only two predetermined fixed sizes, each corresponding to a different electricity frequency, the bull gear corresponds to one of only two predetermined bull gear sizes, each corresponding to a different electricity frequency, which are fixed for each compressor size, the first pinion corresponds to one of only two predetermined first pinion sizes each corresponding to a different electricity frequency, which are fixed for each compressor size and the second pinion corresponds to a one of only two predetermined second pinion sizes, each corresponding to a different electricity frequency, which are fixed for each compressor size, the gear case corresponds to one of only two predetermined gear case sizes fixed for each compressor size and at least one Nth volute corresponds to a single predetermined size of Nth volute or one of only two predetermined Nth volute sizes fixed for each a compressor size.

[0016] According to this variant, the compressor may include at least first and second volutes, the first volute corresponding to one of only two first volute sizes, fixed for the first volute of the compressor size and the second volute corresponding to one of only two second volute sizes, fixed for the second volute of the compressor size.

[0017] Alternatively, the compressor according to Claim 4 wherein the compressor includes at least first and second volutes, the first volute corresponding to a single predetermined first volute size, fixed for the first volute of the compressor size and the second volute corresponding to a single second volute size, fixed for the second volute of the compressor size. Thus even though other components of the compressor are chosen between two sizes, it is possible to have a single size for the volutes.

[0018] The standardization of the compressor can involve one of two approaches. Either the designer decides to provide compressors according to the invention only to those countries all using the same electrical frequency, in which case only one size of frame, bull gear, first pinion and second pinion need be held for each compressor size.

[0019] Alternatively, the supplier may choose to supply the compressor to a group of countries, including at least one country using at least one of the two different frequencies and at least one country, using at least the other of the two different frequencies. In this case he will need to stock a 50 Hz version and a 60 Hz version for each of the standardized elements ie the frame, bull gear, first pinion and second pinion.

[0020] The compressor according to the invention is thus able to be built in part from preselected standardized components and in part from purpose-built components.

[0021] The preselected standardized components therefore include bull gears and pinions within a family of machine frame sizes.

[0022] The compressor frame size may be selected from a group of predetermined frame sizes according to the required output volumetric flow rate.

[0023] The size of the bull gears is preferably selected according to the selected frame.

[0024] The pinions are preferably selected according to the selected frame without taking into account specified requirements of output flow rate and output pressure.

[0025] Ideally, for any given pinion, once the output and/or inlet pressure and inlet and/or outlet flowrate are known, this alone determines the size of the pinion to be used, as one of a set of fixed pinion sizes.

[0026] The same strategy is applied for the choice of the bull gear and gear case.

[0027] Diffusers, impellers, and possibly at least one volutes are configured to refine the output flow rate, output pressure, and performance of the compressor.

[0028] As a preferred option, only one or none of the volutes is configured to refine the output flow rate, output pressure and performance of the compressor.

[0029] In this way, for any given volute, once the output and/or inlet pressure and inlet and/or outlet flowrate are known, this alone determines the size of the volute to be used, as one of a set of fixed volute sizes.

[0030] The impellers and/or the diffusers and/or the inlet guide nozzles for a given compressor may be customized for a specific output pressure and output flowrate.

[0031] This invention teaches, for a given manufacturer's frame size, to fix a single set of components for each electricity frequency (no plurality) and vary only the gas path components of impellers and/or diffusers and/or inlet flow nozzles to achieve optimal aerodynamic efficiency.

[0032] Preferably all the impellers, diffusers and inlet flow nozzles of the compressor are customised to achieve optimal aerodynamic efficiency.

[0033] Specifically for a given compressor size, often known as frame size, only one bull gear, one set of pinions, one gear case and preferably one set of volutes are required whilst the impellers, inlet flow nozzles and diffusers are varied to achieve the required flow rate, discharge pressure and optimal gas power.

[0034] This application enables the supplier to pre-design and the customer or supplier to pre-purchase either as raw material or semi finished or fully finished condition the long lead-time components for the compressor. In this way, during the project execution phase, it is required to customise the inlet flow nozzles, impellers and diffusers only. These customised components are not critical time items and there is therefore the opportunity to optimise fully their performance.

[0035] The global efficiency of a compressor designed in this way (reduction in design degrees of freedom) is limited

to a typical 0.2% to 0.3% efficiency degradation whereas the attendant improvement in capital cost through capital spares sharing, reduction in suppliers' and purchasers' engineering hours, leverage of the upstream supply chain and, when required, time to market negates this minor loss in efficiency.

[0036] It will be obvious to those knowledgeable and skilled in compressor design and applications that the gear system of such a compressor will be rated for the maximum loading of the frame size.

[0037] The electric drive motor for such an arrangement can also be pre-designed and the customer or supplier able to pre-purchase, either as raw material or semi finished or fully finished condition, the long lead-time components for the motor. Capital spares sharing of the motor is then enabled where the motor is either fully spared (complete motor), partially spared (typically the motor stator is held as a spare) or insulated stator windings are held as shared spares.

[0038] The motor is connected to the compressor by a coupling and it is only necessary to optimise the coupling to interface the motor to the compressor. This is because the bull gear, pinion shafts and pinions are fixed components and therefore their rotating masses are also fixed.

[0039] The changes that occur in the impellers' masses (flow cut and diameters), to achieve optimal aerodynamic efficiency do not vary to an extent such that the rotordynamic map of the compressor changes significantly enough to affect any motor considerations.

[0040] The power rating of such a motor arrangement is based on the maximum power rating of the compressor. If the motor is used at a lower power rating the attendant loss in efficiency is negligible.

[0041] The compressor according to the invention is thus able to be built from in part from preselected standardized components and in part from purpose built components.

[0042] These preselected parts are:

- the bull gear, which drives the pinions
- the bull gear shaft, which drives the bull gear
- the gear case, which provides a geometric location for the bull gear shaft, pinion shafts and volutes
- the pinions, which drive the pinion shafts
- the pinion shafts, which drive the impellers
- preferably at least one volute or even all the volutes.

[0043] The volutes each house an impeller diffuser and an inlet guide nozzle and provide part of the conversion of kinetic energy to pressure.

[0044] Optionally the preselected parts may include inter-coolers and/or an electric motor to drive the compressor.

[0045] The preselected standardized components therefore include bull gears and pinions within a family of machine frame sizes.

[0046] Preferably the compressor is to be operated at fixed speed.

[0047] The compressor frame size may be selected from a group of predetermined frame sizes according to the required output volumetric flow rate.

[0048] The size of the bull gears is preferably selected according to the selected frame and is fixed for any one given frame

[0049] The pinions are preferably selected according to the selected frame. Thus for each pinion, once the frame size is known, the size of the pinion is fixed for that frame size, without taking into account specified requirements of input or output flow rate and inlet or output pressure, other than using these values to determine the frame size.

[0050] Diffusers, impellers and inlet flow nozzles, are configured to refine the output flow rate, output pressure, and performance of the compressor.

[0051] The invention also provides a method of building an integrally geared compressor according to produce compressed gas at a given outlet flowrate and a given outlet pressure, the compressor including a gear case, a bull gear and at least first and second pinions, the pinions being driven by the bull gear, at least three compressor wheels, one of the pinions being connected to at least one compressor wheel and the other pinion being connected to two compressor wheels and a volute encasing a compressor wheel, comprising

- a) defining a series of compressor sizes, each compressor size being capable of providing a defined range of output pressures and a defined range of output flowrates,
- b) for each compressor size, defining a single size of bull gear or at most two sizes of bull gear, a single size for the first pinion or at most two sizes for the first pinion and a single size for the second pinion or at most two sizes for the second pinion and a single size for a volute or at most two sizes for a volute
- c) for a given compressor, choosing the compressor size corresponding to the given outlet pressure and given output flowrate required for the compressor,
- d) choosing the single size of bull gear or one of the at most two sizes for the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined

corresponding range

e) choosing the single size of first pinion or one of the at most two sizes for the first pinion of the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined corresponding range

f) choosing the single size of second pinion or one of the at most two sizes for the second pinion of the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined corresponding range and

g) choosing the single size of at least one volute, encasing a compressor wheel or at least one of the at most two sizes of volute for the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate with the defined corresponding range.

[0052] Optionally, the method comprises for each N stages of each compressor size, defining a single size of Nth volute or at most two sizes of volute for the Nth stage and for a given compressor, choosing the single size of Nth volute or one of the at most two sizes of Nth volute for at least one volute.

[0053] The series of compressor sizes may comprise at least three compressor sizes, each defined for a range of output pressures and a range of output flow rates.

1. A compressor having a given compressor size may be used to compress gas for any flowrate

i) above a first limit (A) and below a second limit (B), provided the outlet pressure/ flow rate ratio is below a given threshold and

ii) above the second limit (B) and below a third limit (C) and

iii) above the third limit (C) and below a fourth limit (D), provided the outlet pressure/flowrate ratio is above a given threshold.

The compressor may include an electric motor to drive the compressor, a single motor size being defined for each compressor size.

2. The compressor having a given compressor size may be capable of providing a range of output flowrates wherein the ratio between the highest flowrate (D) in the range and the lowest flowrate (A) is between 1.2 and 1.6, preferably between 1.3 and 1.5.

The compressor may include an electric motor to drive the compressor, only first and second motor sizes being defined for each compressor size, the first motor size corresponding to 50Hz electricity and the second motor size corresponding to 60 Hz electricity and the motor being chosen from the group comprising the first and second sizes only.

The coupling between the motor and the bull gear is customized for a specific output pressure and output flowrate.

3. The impellers and/or the diffusers and/or the inlet guide nozzles are customized for a specific output pressure and output flowrate.

A preferred exemplary integrally-gearred compressor and a method of designing and building it are described below by way of example with reference to the accompanying drawings, in which:

☐ Figure 1 is a schematic depiction of an integrally geared compressor including the flow paths

☐ Figure 2 is a schematic depiction of an individual compression assembly;

☐ Figure 3 is a graph of the compressor performance for main air and booster service according to compressor size; and

☐ Figure 4 is a schematic depiction of an integrally geared compressor including the flow paths for main air service only.

[0054] An arrangement for an integrally geared compressor is schematically shown in Figure 1 and is generally indicated by the numeral 10. Compressor 10 includes a frame 11 which provides support for the components of compressor 10. Frame 11 includes a cavity which acts as a gear casing providing support for a bull gear 12 and pinions 13, 14, 15, and 16. As such, pinion 15 cannot be shown in Figure 1, but it is indicated as being coupled with pinion 16 because it is located under bull gear 12 opposite pinion 16. Bull gear 12 is positioned generally in the center of the cavity and is driven by a drive shaft 17 normally powered by an electric motor (not shown).

[0055] Pinions 13, 14, 15, and 16 are positioned equidistant to each other around the circumference of bull gear 12. Analogizing this arrangement to the face of a clock, pinion 13 is positioned at three o'clock, pinion 14 is positioned at nine o'clock, pinion 15 is positioned at six o'clock, and pinion 16 is positioned at twelve o'clock. Pinions 13, 14, 15, and 16 interface with and are driven by bull gear 12 at each of these positions, and are connected to pinion shafts 18 that drive impellers 19.

[0056] As seen in Figure 1 and, more specifically, in Figure 2, impellers 19, along with volutes 20 and diffusers 21, form the compression assemblies 22. A compression assembly 22 is positioned at each end of the pinions 13, 14, 15, and 16 thereby defining the connection between these pinions and impellers 19 through shafts 18. Each compression assembly 22 constitutes a stage of compression.

[0057] The configuration of compressor 10 allows multiple compression assemblies 22 to be attached in series to form paths of compression. As a result, multiple stages of compression can be used to compress the air in each path of compression. The use of multiple stages of compression is advantageous because as the air is compressed, the temperature of the air increases which increases the amount of work required to continue compression. However, when multiple stages of compression are used in conjunction with interstage gas coolers 23, the gas can be cooled between stages which decreases the work of compression thereby, increasing the efficiency of compressor 10

[0058] The air separation plant requires two different supplies, one for main air service and one for booster air service. As a result, there are two paths of compression through compressor 10, one for main air service 24 and another for booster air service 25. Each path of compression uses multiple compression assemblies 22 to compress air over a number of compression stages. The number of compression stages in each path is determined by the specified output pressure requirements and the design of the compressor 10.

[0059] Main air service path 24 has three stages of compression and booster air service path 25 has up to a maximum of four stages of compression (as shown in Figure 1, The configuration of compressor 10 designed in accordance with the present invention and is intended to meet the specified requirements of air separation plant for both main air service and booster air service. The present invention involves the selection of components of compressor 10 from a range of predetermined sizes. The configuration of each component affects the output flow rate and output pressure of compressor 10. Therefore, each progressive selection is directed toward configuring the design of compressor 10 to meet the specified compressor performance requirements of output flow rate and output pressure. In fact, each progressive selection further narrows the output flow rate and output pressure of compressor 10 to a more specific range of output flow rate and output pressure as required by the air separation plant.

[0060] First, the compressor size is selected from a number of predetermined sizes (frames) dependent on the specified output flow rate requirements and the output pressure for main air service. This determines the choice of bull gear since for any one compressor size, two and only two sizes of bull gear exist. One size will be chosen if the country of the compressor in use is a 50 Hz location and the other size if the country of the compressor in use is a 60 Hz location. This then determines the available motor input shaft speed for the bull gear 12. Next, first and second pinions 13 and 14 which are associated with main air service and third and fourth pinions 15 and 16 which are associated with booster air service are selected from a number of predetermined sizes dependent on the chosen compressor size. Thus for each pinion 13,14,15,16, there is a choice between only two possible pinion sizes, one size being adapted for 50Hz sites and the other for 60 Hz sites. In addition the volute 20 for at least one compression stage preferably exists in a single size , since for the volute, it is not necessary to provide a 50Hz option and a 60Hz option. Preferably all the volutes for the compressor are standardized in this way. Finally, impellers 19, , inlet flow nozzles (not shown) and diffusers 21, are configured according to the specified output flow rate and output pressure requirements and electricity supply or, . Each step further narrows the output flow rate and output pressure of compressor 10 to meet the specified requirements. Thus according to the invention, the specific designing of the impellers and diffusers is sufficient to provide adequate performance, the bull gear and pinions and all volutes of the compressor being standardized for any given compressor size, thus also the gear case.

[0061] The raw material purchased to build the impellers, inlet guide nozzles and diffusers can be eventually finished at any time before the completed compressor is required.

[0062] Adaptors may of course be required to allow the impellers, diffusers and inlet flow nozzles to be used in the fixed size volutes. They allow a maximum inter-changeability of the variable components to the fixed components.

[0063] The aerodynamic efficiency is optimised in order to meet the actual flow and pressure requirements based on customer needs and ambient conditions such as atmospheric pressure, temperature and humidity through customising only the impellers, diffusers and inlet flow nozzles (often referred to as a contour ring).

[0064] Interstage gas coolers 23, if present, may also be standardized for a given compressor size. This can be done by dimensioning the gas coolers to treat a maximum output volume flowrate for the compression stage I feeding the gas cooler for a standardized approach temperature and cooling water inlet temperature. In other words, for each stage of the compressor having a downstream cooler, only one size of cooler per compression stage will be available for any given compressor size. Thus, in the majority of cases, the cooler may be said to be oversized. Alternatively, for certain stages of the compressor, the gas cooler can have a single size and for other coolers, the cooler may be dimensioned according to the gas flow it is intended to cool.

[0065] Thus at least some, or even all, gas coolers for such an arrangement can also be pre-designed and the customer or supplier is then able to pre-purchase either as raw material or in semi finished or fully finished condition the long lead-time components for the gas coolers. The size of the gas coolers is chosen based on the maximum power rating of the compressor size chosen and maximum cooling water temperature required. This in practice means that the coolers will

be oversized for other ambient conditions. The over-sizing cost is off-set by the pre-design and supply chain leverage that is enabled.

[0066] Further it is practical to design the coolers such that all cooler bundles are inter-changeable and the sharing of a cooler bundle capital spare.

[0067] The electric drive motor for the compressor can also be pre-designed and the customer or supplier able to pre-purchase either as raw material or semi finished or fully finished condition the long lead-time components for the motor. Capital spares sharing of the motor is then enabled where the motor is either fully spared (i.e. the complete motor is held as a spare), partially spared (i.e. only a certain part or parts of the motor, typically the motor stator, are held as spares) or insulated stator windings are held as shared spares.

[0068] The motor is connected to the compressor by a coupling to transmit motor shaft power to the compressor bull gear shaft and it is only necessary to optimise the coupling to interface the motor to the compressor. This is because the bull gear, pinion shafts and pinions are fixed components and therefore their rotating masses are also fixed.

[0069] The changes that occur in the impellers' masses (flow cut and diameters), to achieve optimal aerodynamic efficiency do not vary to an extent such that the rotordynamic map of the compressor changes significantly enough to affect any motor considerations.

[0070] The motor to coupling to compressor mechanical connections are each designed iteratively to achieve a stable rotordynamic system for start-up / shut-down and steady state operation. To tune the system, the compressor, motor and coupling

according to the prior art were custom designed. The present invention fixes the design of the motor and compressor, leaving only the coupling to be customized. The rotordynamic map (due to fixing the gear box and motor inertia) can be tuned if when impeller diameters and flow cuts are changed by altering the coupling only.

[0071] The power rating of such a motor arrangement is based on the maximum power rating of the compressor. If the motor is used at a lower power rating the attendant loss in efficiency is negligible.

[0072] For the case where 5 sizes of compressor are predefined (known as frame sizes), size A, size B, size C, size D and size E, going from the smallest to the largest, it can be seen that the common storage for bullgears would need to contain only ten sizes of bull gear, two for A (for 50 and 60 Hz zone), two for size B (for 50 and 60 Hz zone) and so on.

[0073] In addition, as spare parts for the pinions, the storage would contain two types of pinion (50 Hz and 60Hz) for each of the at least two pinions for each of the five sizes of compressor.

[0074] In this standardized process, the manner in which frame 11 is selected can be best described with reference to Figure 3.

[0075] As shown in Figure 3, three sizes of compressor 1,2,3 are chosen to allow compression of gas over a wide range of flowrates and pressures. For the first compressor, the flowrate is either below A or between B and A with a pressure/flowrate ratio above a given value. For flowrates between B and A with a pressure/flowrate below that given value, it is necessary to use size 2, since the adjustment of the impellers, diffusers and inlet nozzles is no longer sufficient to allow use at such high flowrates.

[0076] Size 2 also is used for flowrates between B and C and for flowrates between C and D, provided in this last case, that the pressure/flowrate ratio is high enough.

[0077] For lower pressure/flowrate ratios, the size 3 has to be used for flowrates between C and D. For flowrates from D to E, size 3 is used.

[0078] The table below illustrates 9 sizes of compressor which can treat gas flowrates from 144 to 2500 tonnes per day. As also shown in Figure 3, the maximum flowrate of the compressor for a given size corresponds to the maximum turndown flowrate for the compressor of the next size in the range.

Compressor size	Plant Size TpD	Turndown of compressor 30%	Plant turndown TpD
9	2500	1750	1750
8	1750	1225	1225
7	1225	857,5	857,5
6	857	599,9	599,9
5	600	420	420
4	420	294	294
3	294	205,8	205,8
2	206	144,2	144,2
1	144	100,8	100,8

[0079] The selection of frame 11, bull gear 12, pinions 13, 14, 15, and 16 and volutes 20 with the specified method allows compressor 10 to be designed to supply a specific range of output flow rates and output pressures. Once the desired frame 11, bull gear 12, pinions 13, 14, 15, and 16 have been selected, the compression assemblies 22, composed of impellers 19, inlet guide nozzles, and diffusers 21 are configured to optimize the design of compressor 10 to supply an even more specific range of output flow rates and output pressures. The inlet guide nozzles serve to direct the gas flow into the inlet of the impeller and the diffuser converts kinetic energy to pressure. The impeller imparts kinetic energy to the gas and partial conversion of this energy to pressure.

[0080] The impellers 19, inlet guide nozzles, and diffusers 21 are each designed, using computer modeling techniques, to function in conjunction with each other to affect the compressor performance. Specifically, the design of the impellers 19, inlet guide nozzles, and diffusers 21 can be modified in the following ways to affect the performance of the compressor. For example, diffusers 21 can be modified by adding or subtracting the number of vanes, altering the curvature of the vanes, or deciding to eliminate the vanes altogether. Furthermore, impellers 19 can be modified by changing diameter of the impeller, the height of the impeller blading (or wheel cuts), and the curvature of the impeller blading. The computer modeling techniques are used to reconcile the most efficient configuration of each of these components to produce a design for achieving the specified compressor performance requirements. As described above, the use of computer modeling techniques allows for some customization to refine the results of the present invention.

[0081] Once the configuration of the compression assemblies 22 has been finalized, the interstage gas coolers 23 are chosen to correspond to the maximum heat load requirements for the compressor size. The interstage gas coolers 23 are placed after each stage of compression. Cooling the compressed gas after each stage of compressions enhances the efficiency of the compression process, as is well known in the art.

[0082] In Figure 4, compressor 10 includes a frame 11 which provides support for the components of compressor 10. Frame 11 includes a cavity which acts as a gear casing providing support for a bull gear 12 and pinions 13, 14 and 15. Bull gear 12 is positioned generally in the center of the cavity and is driven by a drive shaft 17 normally powered by an electric motor M.

[0083] Pinions 13, 14 and 15 are positioned equidistant to each other around the circumference of bull gear 12. Analogizing this arrangement to the face of a clock, pinion 13 is positioned at three o'clock, pinion 14 is positioned at nine o'clock, and pinion 15 is positioned at six o'clock. Pinions 13, 14 and 15 interface with and are driven by bull gear 12 at each of these positions, and are connected to shafts 18 that drive impellers 19.

[0084] The configuration of compressor 10 allows five compression assemblies 22 to be attached in series to form paths of compression. The gas can be cooled between stages which increases the efficiency of compressor 10 thereby decreasing the work of compression.

[0085] The air separation plant requires a single main air compressor in this case. As a result, there is a single path of compression through compressor 10 for main air service 24. The path of compression uses five compression assemblies 22 to compress air over five compression stages. The number of compression stages in each path is determined by the specified output pressure requirements and the design of the compressor 10.

[0086] The configuration of compressor 10 designed in accordance with the present invention and is intended to meet the specified requirements of air separation plant for main air service. The present invention involves the selection of components of compressor 10 from a range of predetermined sizes. The configuration of each component affects the output flow rate and output pressure of compressor 10. Therefore, each progressive selection is directed toward configuring the design of compressor 10 to meet the specified compressor performance requirements of output flow rate and output pressure. In fact, each progressive selection further narrows the output flow rate and output pressure of compressor 10 to a more specific range of output flow rate and output pressure as required by the air separation plant.

[0087] First, the compressor size is selected from a number of predetermined sizes dependent on the specified output flow rate requirements and the output pressure for main air service. This determines the choice of bull gear since for any one compressor size, two and only sizes of bull gear exist. One size will be chosen if the site of the compressor in use is a 50 Hz location and the other size if the site of the compressor in use is a 60 Hz location. This then determines the available motor input shaft speed for the bull gear 12. Next, first, second and third pinions 13, 14 and 15 are selected from a number of predetermined sizes dependent on the chosen compressor size. Thus for each pinion 13, 14, 15 there is a choice between only two possible pinion sizes, one size being adapted for 50 Hz sites and the other for 60 Hz sites. In addition the volute 20 for at least one compression stage is preferably to be chosen between two sizes, one for the 50 Hz sites and the other for 60 Hz sites. Preferably all the volutes for the compressor are standardized in this way. Finally, impellers 19, volutes 20, inlet flow nozzles 31 and diffusers 21, are configured according to the specified output flow rate and output pressure requirements and electricity supply or, in the case where at least one volute is standardized, the impellers 19, diffuser 21 and any remaining non-standardised volutes 20 are configured according to the specified output flow rate and output pressure requirements and electricity supply. Each step further narrows the output flow rate and output pressure of compressor 10 to meet the specified requirements. Thus according to the invention, the specific designing of the impellers 19 and diffusers 21 and possibly at least some volutes 20 is sufficient to provide adequate performance, the bull gear and pinions and optionally at least one volute 20 of the compressor being standardized for

any given compressor size.

[0088] The raw material purchased to build the impellers 19, inlet guide nozzles 31 and diffusers 21 can be eventually customised to suit the specific application at any time before the completed compressor is required.

[0089] Adaptors may of course be required to allow the impellers 19, diffusers 21 and inlet flow nozzles 31 to be used in the fixed size volutes 20. They allow a maximum inter-changeability of the variable components to the fixed components.

[0090] The aerodynamic efficiency is optimised in order to meet the actual flow and pressure requirements based on customer needs and ambient conditions such as atmospheric pressure, temperature and humidity through customising only the impellers, diffusers and inlet flow nozzles (often referred to as a contour ring).

[0091] Interstage gas coolers 23, if present, may also be standardized for a given compressor size. This can be done by dimensioning the gas coolers to treat a maximum output flowrate for the compressor wheel feeding the gas cooler. In other words, for each stage of the compressor having a downstream cooler, only one size of cooler will be available for any given compressor size. Thus, in the majority of cases, the cooler may be said to be oversized. Alternatively, for certain stages of the compressor, the gas cooler can have a single size and for other coolers, the cooler may be dimensioned according to the gas flow it is intended to cool.

[0092] Thus at least some, or even all, gas coolers for such an arrangement can also be pre-designed and the customer or supplier is then able to pre-purchase either as raw material or in semi finished or fully finished condition the long lead-time components for the gas coolers. The size of the gas coolers is chosen in dependence on based on the maximum power rating of the compressor size chosen and maximum cooling water temperature required. This in practice means that the coolers will be oversized for other ambient conditions. The over-sizing cost is off-set by the pre-design and supply chain leverage that is enabled.

[0093] Further, it is practical to design the coolers such that all cooler bundles are inter-changeable allowing the sharing of a cooler bundle capital spare.

[0094] The electric drive motor M for the compressor 10 can also be pre-designed and the customer or supplier able to pre-purchase either as raw material or semi finished or fully finished condition the long lead-time components for the motor. Capital spares sharing of the motor is then enabled where the motor is either fully spared (ie the complete motor is held as a spare), partially spared (ie only a certain part or parts of the motor, typically the motor stator, are held as spares) or insulated stator windings are held as shared spares.

[0095] The motor M is connected to the compressor bull gear shaft 17 by a coupling 17C and it is only necessary to optimise the coupling to interface the motor to the compressor. This is because the bull gear 12, pinion shafts 18 and pinions 13,14,15 are fixed components and therefore their rotating masses are also fixed.

[0096] The changes that occur in the impellers' masses (flow cut and diameters), to achieve optimal aerodynamic efficiency do not vary to an extent such that the rotordynamic map of the compressor changes significantly enough to affect any motor considerations.

[0097] The motor-to-coupling-to-compressor mechanical connections are each designed iteratively to achieve a stable rotordynamic system for start-up / shut-down and steady state operation. To tune the system, the compressor, motor and coupling

according to the prior art were custom designed. The present invention fixes the design of the motor and most of the compressor elements, leaving only the coupling 17C to be customized. The rotordynamic map (due to fixing the gear box and motor inertia) can be tuned when impeller diameters are changed by altering the coupling 17C only.

[0098] The power rating of such a motor arrangement is based on the maximum power rating of the compressor. If the motor is used at a lower power rating the attendant loss in efficiency is negligible.

[0099] For the case where 5 sizes of compressor are predefined, size A, size B, size C, size D and size E, going from the smallest to the largest, it can be seen that the common storage for bullgears would need to contain only ten sizes of bull gear, two for A (for 50 and 60 Hz zone), two for size B (for 50 Hz zone and 60 Hz zone) and so on.

[0100] In addition, as spare parts for the pinions, the storage would contain two types of pinion (50 Hz and 60Hz) for each of the at least two pinions for each of the five sizes of compressor. In general terms, it would hold two sizes of first pinion, two sizes of second pinion and so on up to the Nth pinion, for a compressor having N pinions. However it is recommended to hold a single volute size for at least one, preferably each, volute, even if countries using different frequencies are to be supplied.

[0101] As already explained, for all the cases described previously, the manufacturer may opt to use the procedure for building a compressor for only those countries using the same electricity frequency. In this case, it is not necessary to hold in stock the two variants of different components, corresponding to the two standard frequencies used in the world.

[0102] Thus, as spare parts for the pinions, the storage would contain a single type of pinion (50 Hz or 60Hz) for each of the at least two pinions for each of the five sizes of compressor. In general terms, it would hold a single size of first pinion, a single size of second pinion and so on up to the Nth pinion, for a compressor having N pinions.

[0103] Finally, the storage would contain a single size of volute of the volute(s) to be standardized for each volute of

each size of compressor. In other words, it would hold a single size of first volute, a single size of second volute and so on up to the Nth volute, for a compressor having N volutes.

[0104] For the case where 5 sizes of compressor are predefined, size A, size B, size C, size D and size E, going from the smallest to the largest, it can be seen that the common storage for bullgears would need to contain only five sizes of bull gear, one for A (for 50 or 60 Hz zone), one for size B (for 50 Hz zone or 60 Hz zone) and so on.

[0105] If it is decided not to standardize all the volutes, the manufacturer may decide only to standardize the first volute or the first and second volutes, the first volute being the most upstream volute of the compressor and the second volute being just downstream the first volute, with no intervening volute.

[0106] In this way at least one of the most downstream volutes can be adjusted to arrive at the desired output pressure and flowrate.

Claims

1. An integrally-gearred compressor including a bull gear (12), and at least two pinions (13,14,15) able to be driven by the bull gear, at least three compressor wheels, one of the pinions being connected to at least one compressor wheel and the other pinion being connected to two compressor wheels, wherein the compressor corresponds to a given predetermined compressor size, selected from a plurality of different standard sizes (A,B,C,D,E), each standard size being capable of producing output flowrates over a defined range at an output pressure over a defined range, wherein certain elements of the compressor correspond either to a single predetermined element size or one of only two predetermined element sizes, the predetermined element size or sizes being fixed for each compressor size and the certain elements being the bullgear, the first pinion (13,14), the first pinion shaft (18), the second pinion (14,15) and the second pinion shaft (18), the gear case and at least one volute (20).
2. Compressor according to claim 1 corresponding to a single predetermined fixed size, the bull gear (12) corresponds to a single predetermined bull gear size fixed for each compressor size (A,B,C,D,E) and the first pinion (13,14) corresponds to a single pinion size, fixed for each compressor size and the second pinion (14,15) corresponds to a single predetermined second pinion size fixed for each compressor size, the gear case corresponds to a single predetermined gear case size fixed for each compressor size and at least an Nth volute (20) corresponds to a single predetermined size of Nth volute fixed for each compressor size, N being a whole number equal to at least 1.
3. Compressor according to Claim 2 wherein the compressor includes at least first and second volutes (20), the first volute corresponding to a single first volute size, fixed for the first volute of the compressor size (A,B,C,D,E) and the second volute corresponding to a single second volute size, fixed for the second volute of the compressor size.
4. Compressor according to claim 1 corresponding to a one of only two predetermined fixed sizes, each corresponding to a different electricity frequency, the , the bull gear (12) corresponds to one of only two predetermined bull gear sizes, each corresponding to a different electricity frequency, which are fixed for each compressor size , the first pinion (13,14) corresponds to one of only two predetermined first pinion sizes each corresponding to a different electricity frequency, which are fixed for each compressor size and the second pinion (14,15) corresponds to a one of only two predetermined second pinion sizes, each corresponding to a different electricity frequency, which are fixed for each compressor size, the gear case corresponds to one of only two predetermined gear case sizes fixed for each compressor size and at least one Nth volute (20) corresponds to a single predetermined size of Nth volute or one of only two predetermined Nth volute sizes fixed for each a compressor size.
5. Compressor according to Claim 4 wherein the compressor includes at least first and second volutes (20), the first volute corresponding to one of only two first volute sizes, fixed for the first volute of the compressor size and the second volute corresponding to one of only two second volute sizes, fixed for the second volute of the compressor size.
6. Compressor according to Claim 4 wherein the compressor includes at least first and second volutes (20), the first volute corresponding to a single predetermined first volute size, fixed for the first volute of the compressor size and the second volute corresponding to a single second volute size, fixed for the second volute of the compressor size.
7. Method for building an integrally geared centrifugal compressor to produce compressed gas at a given outlet flowrate and a given outlet pressure, the compressor including a gear case, a bull gear (12) and at least first and second pinions (13,14,15), the pinions being driven by the bull gear, at least three compressor wheels, one of the pinions being connected to at least one compressor wheel and the other pinion being connected to two compressor wheels and a volute encasing a compressor wheel, comprising

a) defining a series of compressor sizes (A,B,C,D,E), each compressor size being capable of providing a defined range of output pressures and a defined range of output flowrates,
 b) for each compressor size, defining a single size of bull gear (12) or at most two sizes of bull gear, a single size for the first pinion (13,15) or at most two sizes for the first pinion and a single size for the second pinion (14,15) or at most two sizes for the second pinion and a single size for a volute or at most two sizes for a volute
 c) for a given compressor, choosing the compressor size corresponding to the given outlet pressure and given output flowrate required for the compressor,
 d) choosing the single size of bull gear or one of the at most two sizes for the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined corresponding range
 e) choosing the single size of first pinion or one of the at most two sizes for the first pinion of the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined corresponding range
 f) choosing the single size of second pinion or one of the at most two sizes for the second pinion of the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate within the defined corresponding range and
 g) choosing the single size of at least one volute, encasing a compressor wheel or at least one of the at most two sizes of volute for the compressor of step c), irrespective of the output pressure within the defined corresponding range and irrespective of the output flowrate with the defined corresponding range.

8. Method according to Claim 7 comprising, for each N stages of each compressor size, defining a single size of Nth volute (20) or at most two sizes of volute for the Nth stage and for a given compressor, choosing the single size of Nth volute or one of the at most two sizes of Nth volute for at least one volute.

9. A method according to claim 7 or 8, wherein the series of compressor sizes comprises at least three compressor sizes (A,B,C,D,E), each defined for a range of output pressures and a range of output flow rates.

10. A method according to any of claims 7 to 9, wherein a compressor having a given compressor size is used to compress gas for any flowrate

i) above a first limit (A) and below a second limit (B), provided the outlet pressure/ flow rate ratio is below a given threshold and
 ii) above the second limit (B) and below a third limit (C) and
 iii) above the third limit (C) and below a fourth limit (D), provided the outlet pressure/flowrate ratio is above a given threshold.

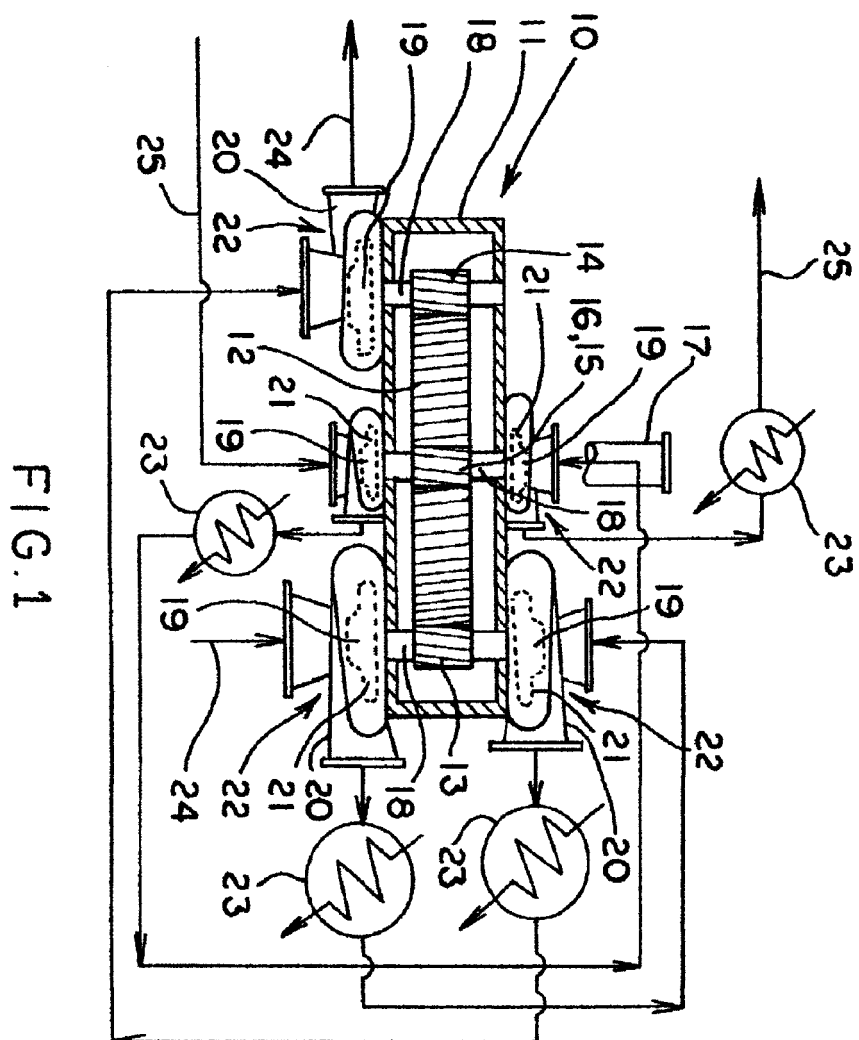
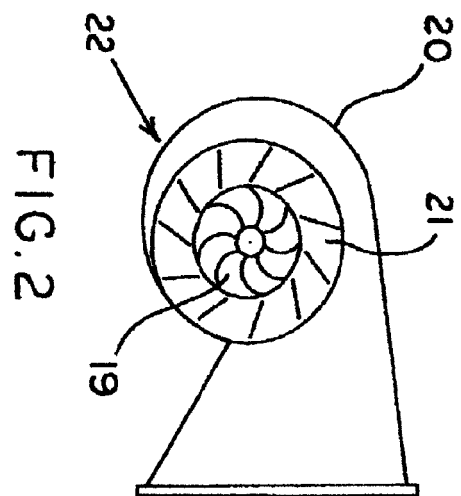
11. A method according to any of claims 7 to 10 wherein the compressor includes an electric motor (M) to drive the compressor, a single motor size being defined for each compressor size.

12. A method according to any of claims 7 to 11 wherein the compressor having a given compressor size (A, B, C, D, E) is capable of providing a range of output flowrates wherein the ratio between the highest flowrate (D) in the range and the lowest flowrate (A) is between 1.2 and 1.6.

13. A method according to any of claims 7 to 12 wherein the compressor includes an electric motor (M) to drive the compressor, only first and second motor sizes being defined for each compressor size (A,B,C,D,E), the first motor size corresponding to 50Hz electricity and the second motor size corresponding to 60 Hz electricity and the motor being chosen from the group comprising the first and second sizes only.

14. A method according to claim 13 wherein the coupling (17C) between the motor (M) and the bull gear (12) is customized for a specific out put pressure and output flowrate.

15. A method according to claim 6 to 14 wherein the impellers (19) and/or the diffusers (21) and/or the inlet guide nozzles are customized for a specific output pressure and output flowrate.



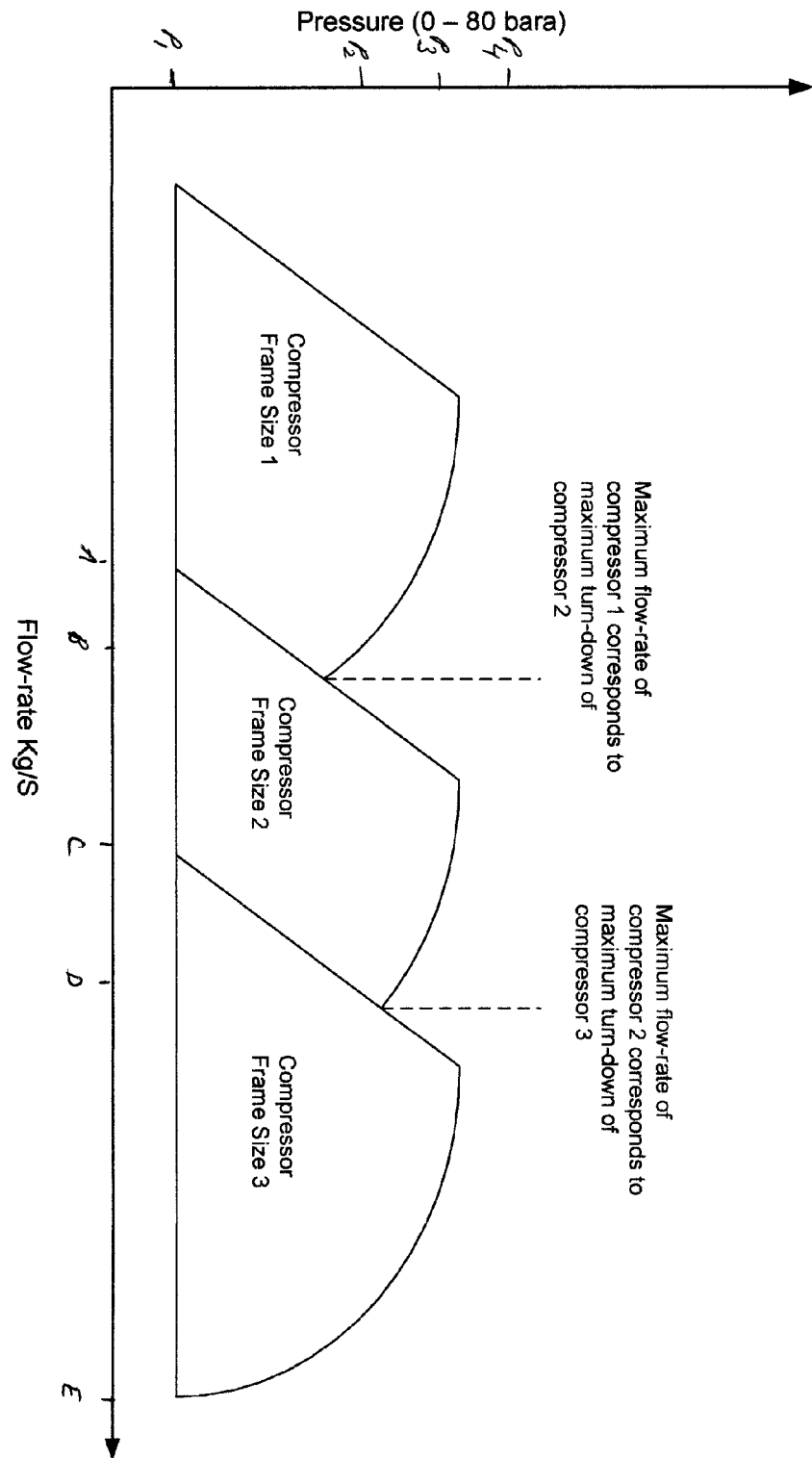


FIG. 3

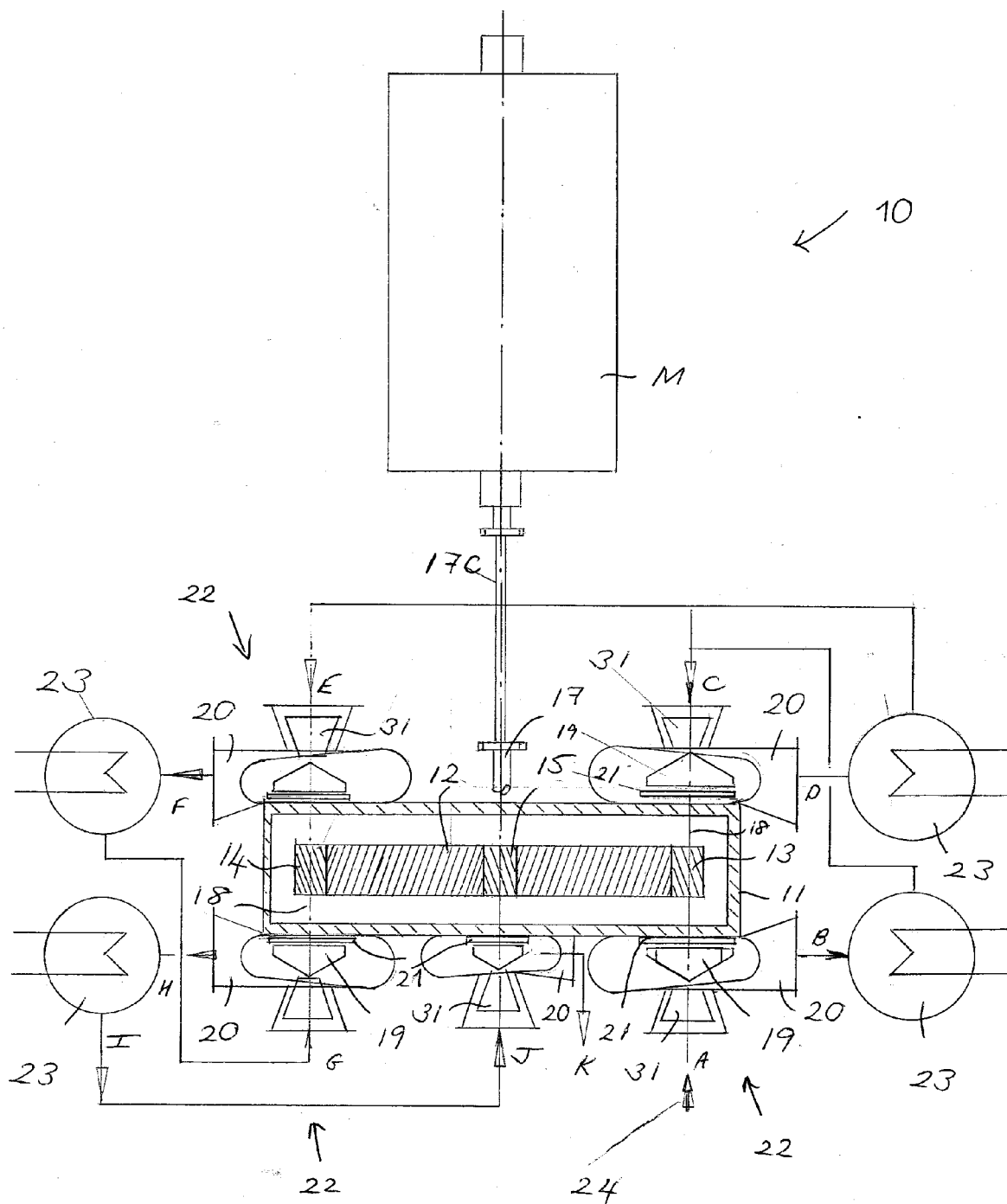


FIG. 4



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EUROPEAN SEARCH REPORT

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