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(54) **MULTI-STAGE SCREW COMPRESSOR**
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Description

[0001] The invention relates to improvements in the drive of a multi-stage screw compressor using independent electric motors with electronic speed control.

[0002] In a multi-stage screw compressor a single fixed speed driver is currently used to drive the individual stages of the compressor simultaneously through a gearbox. Normally this requires a speed-increasing gear train, as the speed of the driver is considerably less than the drive required by the compressor stages. The speed of each stage has to be matched for best efficiency and to share the work done by each stage. As the gear ratio has to be changed to effect a change in output volume, to enable a range of different output volumes to be provided from a common set of stages, a unique gear-set is needed for each nominal output. When a range of different final delivery pressures is required, this also necessitates, in many cases, a unique gear ratio for each operating pressure.

[0003] A set of compressor stages may be used, running at different speeds, to give a range of output air flows. To obtain an increase in air flow, the speed of all the stages must be increased. Due to the difference in performance characteristics of each stage, the increase in speed of each stage will not be the same. In addition to this, the relative speed of the stages may need to be altered depending on the desired final stage delivery pressure or overall pressure ratio. The basic parameter that determines the relative speed of the stages is the work done in each stage. To obtain the best efficiency, the work has to be balanced equally in each stage.

[0004] The result of this is that, for a given air flow rate and delivery pressure, a specific set of speeds for the various compression stages has to be determined. Having determined the speeds, the appropriate gears must be selected. This imposes a further limitation. Due to the restriction imposed by the need to have whole numbers of gear teeth, the ideal ratio may not be possible.

[0005] A further consideration is that, for series produced machines, the performance of similar compression stages will not be identical due to manufacturing tolerances giving rise to clearance variations. With fixed gear ratios there is no means of compensating for this variation, which may adversely affect the performance of the compressor as the balance of work between the stages will be sub-optimal. Furthermore, if a user wishes to use a compressor at a duty at a distance from the design point, the efficiency of the machine will be reduced or, in extreme cases, overheating of individual stages may occur.

[0006] Another consideration is that, to provide capacity control of a multi-stage compressor, inlet throttling can only be used over a very narrow range of speeds as it effectively increases the pressure ratio across the machine. This again leads to overheating. For this reason multi-stage compressors are usually controlled by total closure of the inlet by a control valve. This provides very

coarse pressure or flow control with poor efficiency. Varying the speed of the drive motor has been used to control some machines to improve efficiency at part load. With a fixed ratio of speeds between the stages this leads to an imbalance of work between the stages which may limit the control range.

[0007] Another example of a two-stage screw compressor where the electric motor of each stage is driven by a variable speed drive is given by the document JP 07-158576 A.

[0008] It is an object of the present invention to overcome these disadvantages.

[0009] According to the invention there is provided a multi-stage screw compressor as set out at claim 1.

[0010] A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which;

Fig. 1 is a schematic representation of the operation of a typical prior art screw compressor; and

Fig. 2 is a schematic representation of a screw compressor according to the present invention.

[0011] A typical prior art two-stage compressor 5 is shown in Fig. 1. Although a two-stage, oil-free machine is shown for clarity, the principles are the same where more stages are involved or where the stages have oil or water injection.

[0012] Each of the two compressor stages 10, 11 consists of a pair of contra-rotating, helically cut fluted rotors supported at each end in rolling bearings in a rigid casing. Each casing is attached to a single gearbox 12. The drive motor 13 is coupled to the input gear in the gearbox 12, which transfers drive to the stages 10, 11 via a pinion on the shafts 12a, 12b of each stage 10, 11.

[0013] Air is drawn through an air filter 14 and inlet control valve 15 into the inlet port of the first stage 10 where it is partially compressed. The partially compressed air from the first stage 10 passes to an intercooler 16, where its temperature is reduced before the air is passed to the inlet of the second stage 11 for further compression. On leaving the second (or final) stage 11 the fully compressed air passes via a check valve 17 to an aftercooler 18 for further cooling, after which it is delivered to the user via air delivery outlet 19.

[0014] In this embodiment the intercooler 16 and aftercooler 18 are each cooled by ambient air being drawn over them by a motor driven fan 20. An alternative is to use water-cooled heat exchangers.

[0015] Fig. 2 shows a compressor 30 according to the present invention. The essential operation is as described above, but differs from the prior art compressor 5 in that independent, variable speed motors 31, 32 drive each stage 10, 11 of the compressor 30 independently, with no mechanical link between the individual motor driven stages 10, 11. The characteristics of the motors 31, 32 are matched to the corresponding compressor stages

10, 11.

[0016] The speed of the motors 31, 32 is controlled by an electronic controller 33. The basic control parameter is the required final air delivery pressure or delivery air flow rate. The speed at which each of the stages 10, 11 is driven is increased to give a greater air flow or is reduced to give a lesser air flow. The maximum rotary speeds are limited to pre-determined levels based on mechanical considerations. The minimum speeds are either pre-determined or are determined by measuring the delivery temperatures of each stage 10, 11. As the speed of the rotors in any stage slows down, the stage becomes less efficient causing the temperature to rise. When this reaches a pre-set maximum value, the compressor 30 is stopped or unloaded via an inlet valve 15.

[0017] To maintain optimum efficiency under all conditions, the speeds of the individual compressor stages 10, 11 are varied to compensate for a variety of factors. These factors include altitude, barometric pressure, ambient temperature and coolant temperature, blocking of filters and wear. Manufacturing variations in the compressor stages 10, 11 are also compensated for.

[0018] This control is achieved by continuously measuring air delivery pressures and temperatures from each stage 10, 11, as well as the input torque and speed to each stage 10, 11. Appropriate measuring devices are used to measure these parameters and transmit signals to the electronic controller 33. The motors 31, 32 may have feedback loops directly to the controller 33. The controller 33 processes the signals and sets the speed of the stages 10, 11 to achieve the desired delivery air flow and pressure. Then, using the measurements previously described, the controller 33 makes small adjustments to the stage speeds to minimise power consumption, balance the work evenly between the various stages and maintain safe operating temperatures.

[0019] Although the description above only refers to air compressors, it should be understood that this invention can also be used for compressors for other gasses.

Claims

1. A multi-stage screw compressor (30) comprising:

two or more compressor stages (10, 11), wherein each compressor stage comprises a pair of rotors for compressing a gas;
two or more variable speed drive means (31, 32), wherein each variable speed drive means (31, 32) is operable to drive a respective compressor stage (10, 11); and
a control unit (33) comprising processing means operable to process signals indicative of operating parameters of the screw compressor (30) and control the speeds of the variable speed drive means (31, 32),

characterised in that:

the screw compressor comprises monitoring devices operable to monitor the torque and speed of each of the variable speed drive means (31, 32),

the control unit (33) is operable to control the speeds of the variable speed drive means (31, 32) so that the screw compressor (30) provides gas at a required flow delivery rate and pressure, and **in that**

the control unit (33) is operable to process signals indicative of the torque and speed of each of the variable speed drive means (31, 32) and to control the speeds of the variable speed drive means (31, 32) so that the power consumption of the screw compressor (3) is substantially minimised.

2. A screw compressor (30) as claimed in claim 1 further comprising monitoring devices for monitoring the delivery temperatures of the gas at each compressor stage (10, 11).
3. A screw compressor (30) as claimed in any one of the preceding claims further comprising at least one monitoring device for monitoring the ambient temperature.
4. A screw compressor (30) as claimed in any one of the preceding claims further comprising cooling means (16) provided between adjacent compressor stages (10, 11) and at least one monitoring device for monitoring the temperature of the gas after passing through the cooling means (16).
5. A screw compressor (30) as claimed in any one of the preceding claims further comprising at least one monitoring device for monitoring the delivery pressure of the gas at each compression stage (10, 11).

Patentansprüche

1. Mehrstufen-Schraubenverdichter (30), umfassend:

zwei oder mehr Verdichterstufen (10, 11), wobei jede Verdichterstufe ein Paar von Rotoren zum Verdichten eines Gases umfasst;
zwei oder mehr Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit, wobei jedes Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit betreibbar ist, um eine jeweilige Verdichterstufe (10, 11) anzutreiben; und
eine Steuer/Regeleinheit (33), welche Verarbeitungsmittel umfasst, die derart betreibbar sind, dass sie Signale verarbeiten, welche Betriebsparameter des Schraubenverdichters (30) anzeigen, sowie derart, dass sie die Geschwindigkeiten des Antriebsmittels (31, 32) mit veränder-

barer Geschwindigkeit steuern/regeln,

dadurch gekennzeichnet, dass:

der Schraubenverdichter Überwachungsvorrichtungen umfasst, welche derart betreibbar sind, dass sie das Drehmoment und die Geschwindigkeit eines jeden der Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit überwachen,

wobei die Steuer/Regeleinheit (33) derart betreibbar ist, dass sie die Geschwindigkeiten der Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit derart steuert/regelt, dass der Schraubenverdichter (30) Gas bei einer geforderten Strömungslieferrate und bei einem geforderten Druck bereitstellt, sowie **dadurch**, dass

die Steuer/Regeleinheit (33) derart betreibbar ist, dass sie Signale verarbeitet, welche das Drehmoment und die Geschwindigkeit eines jeden der Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit anzeigen, sowie derart, dass sie die Geschwindigkeiten der Antriebsmittel (31, 32) mit veränderbarer Geschwindigkeit derart steuert/regelt, dass der Energieverbrauch des Schraubenverdichters (3) im Wesentlichen minimiert ist.

2. Schraubenverdichter (30) nach Anspruch 1, ferner umfassend Überwachungsvorrichtungen zum Überwachen der Liefertemperaturen des Gases bei jeder Verdichterstufe (10, 11).
3. Schraubenverdichter (30) nach einem der vorhergehenden Ansprüche, ferner umfassend wenigstens eine Überwachungsvorrichtung zum Überwachen der Umgebungstemperatur.
4. Schraubenverdichter (30) nach einem der vorhergehenden Ansprüche, ferner umfassend ein Kühlmittel (16), welche zwischen benachbarten Verdichterstufen (10, 11) vorgesehen sind, sowie wenigstens eine Überwachungsvorrichtung zum Überwachen der Temperatur des Gases nach einem Durchgang durch das Kühlmittel (16).
5. Schraubenverdichter (30) nach einem der vorhergehenden Ansprüche, ferner umfassend wenigstens eine Überwachungsvorrichtung zum Überwachen des Lieferdrucks des Gases bei jeder Verdichtungsstufe (10, 11).

Revendications

1. Compresseur à vis à plusieurs étages (30), comprenant :

deux étages de compression, ou plus, (10, 11),

dans lesquels chaque étage de compression comprend une paire de rotors pour comprimer un gaz ;

deux moyens d'entraînement à vitesse variable, ou plus, (31, 32), dans lesquels chaque moyen d'entraînement à vitesse variable (31, 32) peut fonctionner pour entraîner un étage de compression respectif (10, 11) ; et

une unité de commande (33) comprenant un moyen de traitement pouvant fonctionner pour traiter des signaux indicatifs de paramètres de fonctionnement du compresseur à vis (30) et commander les vitesses des moyens d'entraînement à vitesse variable (31, 32),

caractérisé en ce que :

le compresseur à vis comprend des dispositifs de contrôle pouvant fonctionner pour contrôler le couple et la vitesse de chacun des moyens d'entraînement à vitesse variable (31, 32),

l'unité de commande (33) peut fonctionner pour commander les vitesses des moyens d'entraînement à vitesse variable (31, 32) de sorte que le compresseur à vis (30) fournisse un gaz à un débit et une pression d'acheminement nécessaires, et **en ce que**

l'unité de commande (33) peut fonctionner pour traiter des signaux indicatifs du couple et de la vitesse de chacun des moyens d'entraînement à vitesse variable (31, 32) et pour commander les vitesses des moyens d'entraînement à vitesse variable (31, 32) de sorte que la consommation de puissance du compresseur à vis (3) soit sensiblement minimisée.

2. Compresseur à vis (30) selon la revendication 1 comprenant en outre des dispositifs de contrôle destinés à contrôler les températures d'acheminement du gaz au niveau de chaque étage de compression (10, 11).
3. Compresseur à vis (30) selon l'une quelconque des revendications précédentes, comprenant en outre au moins un dispositif de contrôle destiné à contrôler la température ambiante.
4. Compresseur à vis (30) selon l'une quelconque des revendications précédentes, comprenant en outre un moyen de refroidissement (16) disposé entre des étages de compression adjacents (10, 11) et au moins un dispositif de contrôle pour contrôler la température du gaz après son passage à travers le moyen de refroidissement (16).
5. Compresseur à vis (30) selon l'une quelconque des revendications précédentes, comprenant en outre au moins un dispositif de contrôle destiné à contrôler la pression d'acheminement du gaz à, chaque étage de compression (10, 11).



