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(54) MINIMISING POWER CONSUMPTION OF OIL-LUBRICATED ROTARY COMPRESSORS

(71) We, HOKUETSU KOGYO KABUSHIKI KAISHA, a Japanese Corporation, of No. 113-1, Ohtakeshinden, Oaza, Bunsui-cho, Nishikanbara-gun, Niigata-ken, Japan, do hereby declare this invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed to be particularly described in and by the following statement:—

The present invention relates to minimising power consumption of an oil-lubricated rotary compressor during unloaded operation in which a rotor or rotors of the compressor is or are rotated within a corresponding compression chamber or chambers in the absence of suction air.

There are two types of unloaders used for rotary compressors, such as screw or vane-type compressors. More specifically, loading or unloading valves are widely used for controlling flow rate of suction air and are generally divided into two categories namely, the suction throttle-type and the suction port shifting-type.

As is well known, compressors of the suction port shifting type require high accuracy for the dimensions of their shifting parts, because these parts directly contact screw rotors or vanes, as the case may be which are rotating at a high speed. In addition, their structures and systems are so complicated that their production cost is considerably high. Therefore, this type of unloading mechanism is scarcely used for compressors of general application which are required to work under various conditions.

On the other hand, the suction throttle type unloader can provide a simple and tough compressor arrangement structure, and its production cost is much lower. Moreover, an unloader of this type is suitable for almost all working conditions. For these reasons, majority of rotary compressors employ this type of unloader. However, it has a serious drawback in that power consumption during unloaded operation of the compressor does not decrease to less than 50 to 70% of that under normal or fully loaded operation.

It is, therefore, a primary object of the present invention to provide a method and system used with an oil-lubricated rotary compressor of suction throttle type for minimizing power consumption of the compressor during unloaded operation.

The present invention is based on our discovery that a major cause for waste of power during unloaded operation comes from back pressure exerted on a rotor or rotors by lubricating oil and compressed or discharged air which remain in the final compression chamber and discharge chamber of the compressor. Due to the existence of this back pressure, the lubricating oil as well as the compressed air is repeatedly subjected to suction and discharge, thus causing excessive waste of power, oil-hammer action and wear of moving parts. These effects are not so seriously detrimental to the power consumption of a compressor if it is of a small size and driven by an internal combustion engine. This is because in an internal combustion engine, the power output can be easily controlled by regulating the rate of fuel supply thereto. However, the problem of power consumption becomes serious when the compressor is driven by an AC motor which rotates at a constant speed for both the loaded and unloaded operation.

Power consumption of an oil-lubricated rotary compressor during unloaded operation, in which at least one rotor of the compressor is rotated in the absence of suction air, may be minimized by forcibly removing lubricating oil and discharged air both remaining in a discharge chamber of the compressor during unloaded operation to eliminate back pressure in said discharge chamber and the final compression chamber of the compressor

independently of the running speed of the compressor. This forced removal of the mixture of the oil and air may be performed by pumping the mixture into an air reservoir.

The flow rate of lubricating oil which is circulated between an air reservoir and at least one compression chamber may be concurrently restricted through said discharge chamber during unloaded operation of the compressor, because during this operation, the compressor runs idle in the absence of suction air and its moving parts do not generate appreciable heat. More specifically, the compressor does not require oil for cooling the air being compressed but merely for lubrication. By reducing the quantity of oil injected into the compressor during unloaded operation, it is possible therefore to save a considerable amount of power which might otherwise be consumed to drive an oil pump and to move excessive oil. The predetermined level is preferably less than 50% of the level during the normal or loaded operation.

During unloaded operation of the compressor, it is found unnecessary to separate oil content from the air in the air reservoir because no air is discharged, and it is also unnecessary to recover the oil removed from the air by oil separators because the quantity of the oil being injected into the compressor is reduced as mentioned previously. For power saving purposes, therefore, it is advantageous to stop recovery of the oil and to reserve the latter in an oil sump.

The three above mentioned operating methods are concerned with the power saving during unloaded operation, while the following fourth operating method is directed to power saving during loaded operation:—

In an oil-lubricated compressor utilising the three above-mentioned operating methods, it is unnecessary during full load operation to recover lubricating oil and discharged air from the discharge chamber, and, as such, it is reasonable and advantageous to save power by closing the inlet and outlet flows of the oil recovery pump during the particular operation. Accordingly, back pressure which might otherwise be exerted on the recovery pump is materially eliminated, and at the same time power to be consumed to drive the pump is reduced for the fully loaded operation.

The oil circulating means or oil pump which feeds lubricating oil to the moving parts during fully loaded operation may be used to discharge the mixture of oil and discharged air, which remains in the discharge chamber, into the air reservoir during unloaded operation. That is, another oil recovery pump can be dispensed with, because the lubricating oil can be sucked into the compressor by the difference between the high pressure in the air reservoir and the reduced pressure in the compression chamber or chambers.

According to another aspect of the present invention, these is provided an oil-lubricated rotary air compressor including a suction chamber, an unloading valve for permitting suction air to be introduced into the suction chamber during loaded operation of the compressor and for blocking the introduction of the suction air during unloaded operation of the compressor, a compression chamber communicating with said suction chamber, a rotor mounted within the compression chamber for compressing introduced air and for discharging compressed air therefrom, said rotor being adapted to be rotated by a motor or a prime mover, detecting means for detecting the pressure of the discharged air and adapted to produce a loading signal and an unloading signal, actuating means responsive to said signals for actuating said unloading valve, a discharge chamber communicating with the compression chamber, an air reservoir communicating with said discharge chamber, oil-circulating means for circulating lubrication oil between said air reservoir and said compression chamber through said discharge chamber to ensure smooth rotation of said rotor and cooling of the compressed air, a first check valve for permitting the discharged air and the lubrication oil in said discharge chamber to flow into said reservoir when the pressure in the former is above the pressure in the latter and for blocking said flow of the discharged air and the lubrication oil when the former pressure is below the latter pressure, conduit means providing communication between said discharge chamber and said air reservoir, recovering means disposed intermediate the ends of said conduit means for forcibly transferring, during unloaded operation, into said air reservoir the discharged air and the lubrication oil remaining in said discharge chamber to eliminate back pressure in said discharge chamber and said compression chamber, and valve means disposed in said conduit means for opening said conduit means during unloaded operation and for closing the same under loaded operation, said valve means being responsive to said signals from said detecting means.

Embodiments of the present invention will now be described, by way of example with reference to the accompanying drawings, in which:—

Figure 1 is a diagrammatical view showing an oil-lubricated two-stage rotary compressor of screw type provided with a lubricating and unloading system; and

Figure 2 is a view similar to Figure 1 showing another embodiment of the present invention.

For simplicity of disclosure, construction arrangements of the preferred oil-lubricated

rotary compressor 11 equipped with the lubricating and unloading system 10 will be described together with the operations thereof.

Under the normal and fully loaded operation of the compressor 11, working fluid, i.e. air, is sucked in a conventional manner through an air cleaner 12 and suction ports 13 into a suction chamber 14, when an unloading valve comprising a movable valve member 15 is open. This suction air is then introduced into a first compression chamber 16 for the first stage compression, within which a first screw-type rotor 17 is mounted. The rotor 17 is driven by an AC motor 18 so as to compress the introduced suction air and to discharge compressed air therefrom. This compressed air is further compressed in a second compression chamber 19, within which second screw-type rotor 21 coupled with rotor 17 is mounted. The air which has thus been compressed in two stages is discharged into a discharge chamber 22 and is permitted to flow into an air reservoir 23 by a check valve 24 which prevents air from passing from reservoir 23 back into chamber 22 when a pressure reversal occurs.

In this meanwhile, lubricating oil is circulated by oil-circulating means in the form of an oil pump 25 between the bottom of the air reservoir 23 and the two compression chambers 16 and 19 thereby to ensure smooth rotation of the two coupled rotors 17 and 21 and cooling of the air being compressed and discharged. The lubricating oil is also fed to other moving parts or elements of the compressor 11, but the description of this lubrication will be omitted here. This oil pump 25 is advantageously driven by the AC motor 18 in a coaxial relationship with the rotors 17 and 21. The oil is thus injected by the oil pump 25 into the compression chambers 16 and 19 and is mixed with the compressed air. After having performed the lubricating and cooling operations, the lubricating oil now mixed in droplets form with the compressed air is conveyed through the discharge chamber 22 into the air reservoir 23. In this reservoir 23, larger droplets of the oil collect in the bottom, as illustrated at 26, while smaller droplets pass over a partition 27 and are trapped by an oil separator 28 to collect in a sump 29. In these ways, the oil is separated from the air and is stored in the bottom 26 and in the oil sump 29. The separated air is stored in the reservoir 23 for subsequent supply through a valve 31.

During this normal, or fully loaded operation, a detector 32 for detecting the pressure of air discharged from the compressor 11 produces a loading signal which, when the reservoir 23 is not fully charged, effects contamination of normal operation. Detection of the working conditions may be carried out in terms of the pressure of either the discharged air or the suction air. For this purpose, the detector 32 is provided with an inlet port 32*a* at the air reservoir 23. The loading signal, which may be pneumatic, electric or mechanical, is passed *via* a line 33 to actuating means 34, whereby the valve-member 15 is actuated pneumatically, electro-magnetically or mechanically to be kept open. With the unloading valve kept open during the loading operation, the suction air is introduced continuously into the compression chambers 16 and 19, as has been explained above.

The loading signal is also passed *via* a line 35 to a valve 36 so as to open a fluid conduit 37. When the fluid conduit 37 is opened in this fashion under the fully loaded operation, lubrication oil which has been stored at the oil sump 29 is passed into the suction chamber 14 and accordingly into the compression chambers 16 and 19 due to the difference between the high pressure in the air reservoir 23 and the negative pressure in the suction chamber 14. The valve 36 may also be of pneumatic, electro-magnetic or mechanical type.

In an oil-circulating passage 38 of the oil pump 25, there is provided a control valve 39 which is also responsive through a line 41 to that loading signal to be kept fully open. This oil control valve 39 may be of lift type or of slide type, but is opened in response to the loading signal to permit a regulated supply of lubricating oil to be injected into the compression chambers 16 and 19. The valve 39 is of the pneumatic type in this embodiment, but may be of another type, such as the electro-magnetic or mechanical type. In the oil-circulating passage 38, an oil cooler 42 is provided to cool the lubricating oil passing therethrough.

When, on the other hand, the pressure in the air reservoir 23 rises as a result of operation of the compressor 11 and exceeds a predetermined level, then the detector 32 stops producing the loading signal and passes an unloading signal, indicating that the reservoir 23 is fully charged and thus initiates an unloading operation of compressor 11. This unloading signal is delivered through the line 33 to the actuating means 34, thereby closing the unloading valve by moving valve-member 15 to the left as viewed in Figure 1 so that it is seated around the suction ports 13 and, accordingly, the supply of inlet air is cut-off so that the rotors 17 and 21 rotate in the absence of inlet air.

During unloaded operation, back pressure which might be exerted on the rotors 17 and 21 is forcibly removed from the final or second compression chamber 19 and the discharge chamber 22. For this purpose, the system 10 includes a conduit 43 providing fluid communication between the discharge chamber 22 and the air reservoir 23, recover-

ing means in the form of an oil and air extraction pump 44 disposed in conduit 43, and two valves 45 and 46 disposed in conduit 43. The oil and air pump 44 is rotated by the AC motor 18 in a coaxial relationship with the oil circulating pump 25 and forcibly feeding, into the air reservoir 23, the mixture of discharged air and lubricating oil remaining in the discharge chamber 22. This action is, however, effected only when the two valves 45 and 46 are opened in response to the unloading signal passed *via* lines 47 and 48, respectively. For convenience the detector 32 is shown separately at the right hand side as well as at the left hand side of Figure 1. During the fully loaded operation, on the contrary, the check valves 45 and 46 are pneumatically, electromagnetically or mechanically shut by the loading signal so as to eliminate back pressure which might be exerted on the oil recovery pump 44 through its inlet 44*a* and outlet 44*b*. As a result, the existence and rotation of the pump 44 does not cause the AC motor 18 to waste unnecessary power. In this instance, the forced removal of the oil and air mixture is accompanied by closing of the check valve 24 due to the pressure difference between the discharge chamber 22 and the air reservoir 23.

The unloading signal is also supplied to the control valve 39 so as to cause the flow rate of the lubricating oil to be reduced to a predetermined level, preferably, to less than 50% of the flow rate during the loaded operation. In this way the power required to pump excessive and unnecessary oil can be saved, and the compressor 11 itself need not consume unnecessary power to move the excess oil even if the running speed of the compressor is constant as is the case when an AC motor is employed.

The unloading signal is further delivered to the valve 36 to close the fluid conduit 37, thus blocking the recovery of the lubricating oil stored in the oil sump 29. This also contributes to reduction of power consumption during the unloaded operation.

Turning now to Figure 2, like reference characters indicate like parts and elements shown and described with reference to Figure 1, and, as such, a detailed explanation thereof will be omitted. In this second embodiment, the oil and air extraction pump as indicated at 44 in Figure 1 is omitted and oil pump 25 serves a dual purpose, i.e. to circulate the lubricating oil under the loaded operation and to recover the oil and air mixture in the discharge chamber 22 under the unloaded operation. Here, it should be noted that construction, arrangement and operation of the system 10′ other than those as will be described hereinafter are similar to those as enumerated with reference to Figure 1, and accordingly are also omitted.

When the compressor 11 is working under the normal, or fully loaded operation, valves 51 and 52 are opened by the loading signal supplied respectively through lines 54 and 48′. In this meanwhile, other valves 45, 46 and 53 are kept closed by the same signal fed respectively, through lines 47′, 48′ and 54. As a result, the lubricating oil is forced by the common oil pump 25′ to the moving parts of the compressor 11 from the bottom 26 of the air reservoir 23 through the oil cooler 42, the valves 51 and 52, and the line 38.

When, on the other hand, the unloaded operation is effected, the valves 45, 46 and 53 are opened by the unloading signal while the valves 51 and 52 are closed. Then, the lubricating oil is introduced for lubricating and cooling purposes into the air compressors 16 and 19 through a bypass conduit (not numbered) including the valve 53. This introduction of the lubrication oil is performed automatically, in other words, by the difference between the high pressure in the air reservoir 23 and the negative pressure in the compression chambers 16 and 19. This is because the negative pressure is produced by forcibly transferring into the air reservoir 23 the back pressure which might otherwise accumulate in the discharge chamber 22, *via*, the oil and air mixture return passage including the valves 45 and 46 and the oil pump 25′.

In this embodiment, the control valve 39 as used in the oil-circulating passage may be the same as that of the first embodiment of Figure 1, but may be replaced by another flow-restricting means, if desired. Such restricting means is, for example, an orifice 39′ disposed in the conduit 43, or merely the conduit 43 if by itself it restricts the oil flow.

In these ways, power consumption of the compressor under the unloaded operation can also be reduced to a minimum with use of a single common oil pump. Those valves 51, 52 and 53 may also be of pneumatic, electro-magnetic or mechanical type.

As has been described in detail, the two systems 10 and 10′ minimize power consumption of the oil-lubricated rotary pump by forcedly releasing or removing the discharged air and the lubrication oil remaining in the final compression chamber and in the discharge chamber. Further reduction of power consumption is achieved during the operation of the unloading mechanism by restricting the quantity of oil supply to the moving parts of the compressor, and by stopping recovery of the stored oil in the oil sump, both for preventing excessive oil from entering the compression chamber or chambers.

In addition to the above effects, power consumption during the normal or fully

loaded operation is also reduced by eliminating back pressure on the oil and air extraction pump, and the power consumption and manufacturing cost is reduced by employing a common oil pump for two purposes to dispense with the recovery pump.

In the case of a compressor, according to the invention, of the single-stage type, the power consumption under unloaded operation has been measured as 70% of the consumption at fully loaded operation of the compressor when not provided with a lubricating and unloading system as described above. In the case of a two-stage compressor, on the other hand, the values are, respectively, 50% and 18%.

WHAT WE CLAIM IS:—

1. An oil-lubricated rotary air compressor including a suction chamber. an unloading valve for permitting suction air to be introduced into the suction chamber during loaded operation of the compressor and for blocking the introduction of the suction air during unloaded operation of the compressor, a compression chamber communicating with said suction chamber. a rotor mounted within the compression chamber for compressing introduced air and for discharging compressed air therefrom said rotor being adapted to be rotated by a motor or a prime mover, detecting means for detecting the pressure of the discharged air and adapted to produce a loading signal and an unloading signal, actuating means responsive to said signals for actuating said unloading valve, a discharge chamber communicating with the compression chamber, an air reservoir communicating with said discharge chamber, oil-circulating means for circulating lubrication oil between said air reservoir and said compression chamber through said discharge chamber to ensure smooth rotation of said rotor and cooling of the compressed air, a first check valve for permitting the discharged air and the lubrication oil in said discharge chamber to flow into said air reservoir when the pressure in the former is above the pressure in the latter and for blocking said flow of the discharged air and the lubrication oil when the former pressure is below the latter pressure, conduit means providing communication between said discharge chamber and said air reservoir, recovering means disposed intermediate the ends of said conduit means for forcibly transferring, during unloaded operation, into said air reservoir, the discharged air and the lubrication oil remaining in said discharge chamber to eliminate back pressure in said discharge chamber and said compression chamber, and valve means disposed in said conduit means for opening said conduit means during unloaded operation and for closing the same under loaded operation, said valve means being responsive to said signals from said detecting means.

2. A compressor according to Claim 1, wherein said recovering means includes a pump driven by said prime mover or motor in a coaxial relationship with said oil-circulating means.

3. A compressor according to Claim 1 or 2, wherein said valve means includes second and third check valves disposed respectively between said discharge chamber and the inlet of said recovering means and between said air reservoir and the outlet of said recovering means for closing said conduit means at the inlet and outlet of said recovering means during loaded operation to eliminate back pressure exerted on said recovering means.

4. A compressor according to Claim 1, wherein said recovering means includes valve means responsive to the signals of said detecting means for providing a circulating passage for said oil-circulating means during loaded operation and for blocking said circulating passage under the unloaded operation to communicate said conduit means with said oil-circulating means and to provide a bypass passage between said air reservoir and said compression chamber.

5. A compressor according to Claim 4 including orifice means disposed in said bypass conduit for restricting, to a predetermined level, the flow rate of the lubricating oil therethrough.

6. A compressor according to Claim 5, wherein said predetermined level is less than 50% of the flow rate during the loaded operation.

7. A compressor according to Claim 1, further comprising control means disposed in the circulating passage of said oil-circulating means and responsive to the signals of said detecting means for restricting, to a predetermined level, the flow rate of the lubricating oil to pass through said circulating passage during unloaded operation.

8. A compressor according to Claim 7, wherein said predetermined level is less 50% of the flow rate during loaded operation.

9. A compressor according to Claim 1, wherein said detecting means has an inlet port opening into said air reservoir.

10. A compressor according to Claim 1, further including an oil separator disposed within said air reservoir for separating lubricating oil content from a mixture of air and lubricating oil discharged into said air reservoir; a sump disposed within said air reservoir for retaining therein the separated lubricating oil content; second conduit means communicating with said suction chamber and said sump, and second valve means disposed in said second conduit means

loaded operation is also reduced by eliminating back pressure on the oil and air extraction pump, and the power consumption and manufacturing cost is reduced by employing a common oil pump for two purposes to dispense with the recovery pump.

In the case of a compressor, according to the invention, of the single-stage type, the power consumption under unloaded operation has been measured as 70% of the consumption at fully loaded operation of the compressor when not provided with a lubricating and unloading system as described above. In the case of a two-stage compressor, on the other hand, the values are, respectively, 50% and 18%.

WHAT WE CLAIM IS:—

1. An oil-lubricated rotary air compressor including a suction chamber, an unloading valve for permitting suction air to be introduced into the suction chamber during loaded operation of the compressor and for blocking the introduction of the suction air during unloaded operation of the compressor, a compression chamber communicating with said suction chamber, a rotor mounted within the compression chamber for compressing introduced air and for discharging compressed air therefrom said rotor being adapted to be rotated by a motor or a prime mover, detecting means for detecting the pressure of the discharged air and adapted to produce a loading signal and an unloading signal, actuating means responsive to said signals for actuating said unloading valve, a discharge chamber communicating with the compression chamber, an air reservoir communicating with said discharge chamber, oil-circulating means for circulating lubrication oil between said air reservoir and said compression chamber through said discharge chamber to ensure smooth rotation of said rotor and cooling of the compressed air, a first check valve for permitting the discharged air and the lubrication oil in said discharge chamber to flow into said air reservoir when the pressure in the former is above the pressure in the latter and for blocking said flow of the discharged air and the lubrication oil when the former pressure is below the latter pressure, conduit means providing communication between said discharge chamber and said air reservoir, recovering means disposed intermediate the ends of said conduit means for forcibly transferring, during unloaded operation, into said air reservoir, the discharged air and the lubrication oil remaining in said discharge chamber to eliminate back pressure in said discharge chamber and said compression chamber, and valve means disposed in said conduit means for opening said conduit means during unloaded operation and for closing the same under loaded operation, said valve means being responsive to said signals from said detecting means.

2. A compressor according to Claim 1, wherein said recovering means includes a pump driven by said prime mover or motor in a coaxial relationship with said oil-circulating means.

3. A compressor according to Claim 1 or 2, wherein said valve means includes second and third check valves disposed respectively between said discharge chamber and the inlet of said recovering means and between said air reservoir and the outlet of said recovering means for closing said conduit means at the inlet and outlet of said recovering means during loaded operation to eliminate back pressure exerted on said recovering means.

4. A compressor according to Claim 1, wherein said recovering means includes valve means responsive to the signals of said detecting means for providing a circulating passage for said oil-circulating means during loaded operation and for blocking said circulating passage under the unloaded operation to communicate said conduit means with said oil-circulating means and to provide a bypass passage between said air reservoir and said compression chamber.

5. A compressor according to Claim 4 including orifice means disposed in said bypass conduit for restricting, to a predetermined level, the flow rate of the lubricating oil therethrough.

6. A compressor according to Claim 5, wherein said predetermined level is less than 50% of the flow rate during the loaded operation.

7. A compressor according to Claim 1, further comprising control means disposed in the circulating passage of said oil-circulating means and responsive to the signals of said detecting means for restricting, to a predetermined level, the flow rate of the lubricating oil to pass through said circulating passage during unloaded operation.

8. A compressor according to Claim 7, wherein said predetermined level is less 50% of the flow rate during loaded operation.

9. A compressor according to Claim 1, wherein said detecting means has an inlet port opening into said air reservoir.

10. A compressor according to Claim 1, further including an oil separator disposed within said air reservoir for separating lubricating oil content from a mixture of air and lubricating oil discharged into said air reservoir; a sump disposed within said air reservoir for retaining therein the separated lubricating oil content; second conduit means communicating with said suction chamber and said sump, and second valve means disposed in said second conduit means

and responsive to the signals of said detecting means for opening said second conduit means during loaded operation to introduce said separated lubricating oil content into said suction chamber and for closing said second conduit means during unloaded operation to block the introduction of said separated lubricating oil content.

11. A compressor substantially as hereinbefore described with reference to Figure 1 or Figure 2 of the accompanying drawings.

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