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POWERED REVERSE RUNNING OF SCROLL COMPRESSORS

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ABSTRACT

Unlike reciprocating compressors, scroll compressors do not operate properly when run in reverse. If left unprotected, extremely high temperatures, adverse oil flow conditions and unusual pressures can damage components. The mechanisms causing these adverse and potentially damaging conditions are explored. Several methods of preventing compressor damage are detailed.

NOMENCLATURE

\( F_S \) - total sealing force between the contacting flank profiles
\( F_I \) - centrifugal force generated by the eccentricity of the orbiting scroll
\( F_{RG} \) - radial gas force
\( \mu \) - coefficient of friction on the slider block drive flat
\( F_{DR} \) - drive force from the crankshaft
\( F_{TG} \) - tangential gas force
\( F_T \) - scroll tip sealing force
\( F_{TH} \) - axial thrust force
\( F_{AG} \) - axial gas force
\( R_{OR} \) - orbit radius
\( \omega \) - crankshaft angular velocity
\( T_F \) - final temperature (absolute)
\( T_I \) - initial temperature (absolute)
\( P_F \) - final pressure (absolute)
\( P_I \) - initial pressure (absolute)
\( \gamma \) - polytropic exponent

INTRODUCTION

This paper will focus on the powered reverse running characteristics of the low side hermetic scroll compressor. These typically range in capacities from 2 to 15 tons. They are primarily applied in residential and small commercial air conditioning systems. The term “powered reverse running” is used to distinguish the reverse running that occurs when the compressor motor is running in reverse, from that which occurs because of the pressure differential at shutdown. The latter, which poses its own set of design challenges, will not be considered in detail, in the current paper.

The potential for powered reverse running comes primarily from three-phase induction motors that are commonly used to power compressors. It is well known that for this type of motor the phase order determines the rotational direction of the rotor. Since proper phasing can be easily confused it is easy to improperly connect or miswire the motor. Inexpensive handheld devices for determining the proper phasing are available but are not always used. Many service technicians are used to dealing with “recips”, which can operate in forward or reverse direction. Because of this, there is a lack of awareness of the potential damage that can occur from miswiring the compressor.

Among other things, the significant increase in noise and the fact that the compressor is not pumping makes the miswired condition easy to detect. Even so, once a compressor is miswired it is possible for it to go undetected for days or even weeks. This may occur, for example, in heat pump applications where the electric strip heaters will still provide heat, even though the heat pump portion of the system is not providing any benefit. This field problem
has led manufacturers to adopt various design strategies to protect their compressors from this potentially damaging running condition.

A less likely possibility for reverse running is one that occurs for single-phase motors. In this instance, the rotor must have a certain amount of rotational speed in the reverse direction before power is applied. This can occur during a momentary loss of power to the compressor motor (e.g. power flickers during thunderstorms). Since the pressure differential across the scrolls can quickly drive the crankshaft in reverse, when power is reapplied the compressor may continue to run backwards. When this occurs, the motor will only run for a short amount of time before the motor protector will stop the motor. Since the compressor will restart in the forward direction, the potential for damage is less significant.

COMPRESSION PROCESS

The typical scroll compressor configuration is that of a fixed and orbiting scroll. The flanks of the fixed and orbiting scrolls contact at lines along the height of the flanks forming pockets. The orbiting scroll is driven in an orbital motion via the crankshaft. During normal operation, gas is drawn into two symmetric pockets at the periphery of the scrolls. As the shaft continues to rotate, the pockets move radially inward decreasing in volume and compressing the gas (Figure 1). When the pockets reach center, they merge and the gas is discharged to the system. If the crankshaft is driven in the opposite direction, the sequence is reversed. Gas is drawn in from discharge and moved radially outward and expanded. It is normal in scroll compressors to incorporate a discharge check valve, whose primary function, in most designs, is to prevent reverse rotation at shutdown. The significance of this will be detailed in the following paragraphs.

Figure 1: Scroll compression process
The loads generated on the scrolls can be broken into tangential, radial and axial components. The sums of the forces in each direction are shown below. Figures 2 and 3 illustrate these forces.

Radial:
\[ F_s = F_r - F_{RG} \pm \mu F_{DR} \]  \hspace{1cm} (1)

Tangential:
\[ F_{TG} = F_{DR} \]  \hspace{1cm} (2)

Axial:
\[ F_T = F_{TH} - F_{AG} \]  \hspace{1cm} (3)

Figure 2: Radial and tangential forces

Figure 3: Axial forces

It can be shown that the gas forces generated during the compression process are functions of the pressure difference between suction and discharge \([1,2,3]\). For reverse running, the pressure differential is reversed. The gas forces now act in the opposite direction to those of normal running.

In the radial direction the gas force now increases the flank contact force produced by the centrifugal force. This results in increased friction between the contacting flanks with an attendant increase in frictional heating. Another result that is obvious to even a casual observer is the marked increase in the noise generated by the compressor which is due, at least in part, to the increased flank loading.

In the axial direction a similar situation occurs. The axial gas force normally acts to separate the tips of the scroll wraps. To prevent separation and subsequent tip leakage some type of axial compliance mechanism is used. This is achieved by gas biasing the orbiting or fixed scroll, or by the use of tip seals. In either case, thrust and tip forces are generated. For reverse running the axial gas force now acts to bring the scrolls together. For gas biased scrolls, the thrust force produced by the gas biasing would also be reversed due to the pressure reversal across the scroll wraps. This would tend to separate the tips. In reality however, other factors such as seal design may affect the gas biasing thrust force during reverse running. In any case, it is reasonable to assume that sufficient tip sealing is maintained, during reverse running, such that the compressor acts effectively as a vacuum pump.

As cited earlier, a discharge check valve is employed to limit reverse rotation at compressor shutdown. This severely restricts the flow of gas from discharge to suction during reverse running. With this loss of flow,
convective heat transfer is reduced to the point that heat can no longer effectively be removed from the scrolls (or from the motor for that matter). With the primary means of heat transfer impeded, excessive temperatures can be seen in the scrolls. In addition, when the outermost pockets open to suction the relatively high pressure gas in the compressor housing will flow into the pockets and be compressed at a high pressure ratio. This will generate significantly high temperatures which will contribute to, or even dominate, the heat produced in the compressor. This effect can be illustrated with the application of Equation 4. For R-22 it is reasonable to expect pressure ratios between suction and discharge of around 12 during reverse running. For refrigerant gas with an initial temperature of 24°C (75°F) the final temperature would be on the order of 177°C (350°F) assuming a polytropic exponent of 1.2. This can be verified through the use of Equation 4.

\[ \frac{T_F}{T_I} = \left( \frac{P_F}{P_I} \right)^{\frac{\gamma - 1}{\gamma}} \]  

Eventually enough heat will be transferred to the motor protector to stop the compressor. This may not occur however until temperatures two to three times above normal are seen in the compressor.

OIL FLOW

Of significant importance during reverse running is the ability of the lubrication system to continue to supply oil to the bearings. Failure to do so would certainly lead to bearing failure in a matter of minutes. The types of centrifugal oil pumps currently used in scroll compressors typically operate equally or nearly equally well in both directions. Therefore, oil flow to the bearings tends to not be affected significantly. Since the tangential gas force now acts on the opposite side of the crankshaft pin, the location of the load on the journal is shifted. As shown below (Figure 4), this shift does not place the load in closer proximity to the oil feed hole, which could restrict lubrication. If the oil groove in the journal is of the helical type, during reverse rotation the helix is in the wrong orientation for dispersing oil and flushing contaminates from the bearing. However, this does not appear to have a significantly detrimental effect.

**Figure 4: Crankcase journal**

Also of concern is the potential for pumping oil out of the compressor, through the suction tube. Though the mechanisms that may cause this will vary from manufacturer to manufacturer, the end result is the same. That is: The negligible refrigerant flow through the cooling system coils will prevent the oil that leaves the compressor from returning efficiently. This could eventually lead to failure of the compressor bearings due to loss of lubrication.

PROTECTION METHODS

The treatise above assumes that, other than the standard motor protector, no means have been used to protect the compressor during reverse running. As noted earlier, the primary concern is the heat generated in the
scrolls and the damage it may cause to the scrolls themselves or other components within the compressor. To prevent damage caused by this abusive running condition it is necessary to devise a protection scheme. A variety of protection strategies can be used. These may include:

1. automatic miswire correction
2. stopping the compressor
3. robust design which prevents damage
4. allowing the compressor to run in reverse, with a device that eliminates or reduces harmful effects

Automatic miswire correction can be accomplished with the use of a phase corrector. This device will deliver the proper phasing to the compressor regardless of the phasing delivered to the condenser unit. These would typically be wired into the control circuit of the system. From a design and application perspective this is a very attractive method. Not only does this eliminate the potential for miswiring the compressor, it also eliminates the service call to correct the miswire. One drawback, however, is that the phase corrector has to be properly wired to the compressor. Since the original equipment manufacturer would normally perform this function there should not be a problem. However, the potential for miswiring replacement compressors would still exist. Furthermore, their high cost may be difficult to justify, particularly to low tonnage systems which typically have a small profit margin. A device similar to the phase corrector is the phase lockout. This device detects the miswire and prevents the compressor from running. Like the phase corrector the phase lockout is relatively easy to apply. Unfortunately a service call would now be required to correct the problem. Although less expensive than phase correctors, the cost of phase lockouts may still be difficult to justify.

One-way mechanical brakes are currently being used in some single-phase compressors to prevent reverse rotation at shutdown. This concept can be adopted for stopping miswired three-phase compressors. However, because of the higher locked rotor torque produced by three-phase motors, a brake on a three-phase compressor would need to be more robust than its single-phase cousin. Another method of stopping the compressor is with the use of an electronic temperature sensor, in contact with the fixed scroll. One disclosed technique uses an auxiliary winding to provide low voltage power to the sensor(s). When high temperatures are experienced the sensor(s) would then actuate an internal line break, which would stop the motor [4]. This particular device has the benefit of not requiring an additional hermetic terminal or additional wiring in the system.

Two methods, which allow the compressor to run miswired while limiting harmful effects, are the suction to discharge check valve [5], and the solenoid discharge check valve [6]. The suction to discharge check valve allows gas to flow from the suction side of the compressor into the discharge chamber upstream of the discharge check valve. By doing so the pressure ratio is reduced and flow is established through the scrolls. Respectively these act to reduce the heat that is generated and to remove heat via convection. This in turn allows heat removed from the scrolls to be directed onto the motor protector, stopping the compressor before excessively high temperatures are generated. The solenoid discharge check valve is designed to open whenever the motor is energized, even if the motor is miswired. This will again provide flow through the scrolls and protect the compressor from damage. It is interesting to note that a cooling system operating in this mode will act as a heat pump, albeit an inefficient one.

CONCLUSIONS

The inability of scroll compressors to operate properly when run in reverse is a limitation that is inherent to their geometry. Several protection methods, some of which are currently being used in the field, were detailed. Of these methods, some will protect the compressor from damage indefinitely, while others will likely only prolong the time it takes for damage to occur. The importance of proper system labeling and adequate service technician training should not be underestimated. It is felt that these two factors alone would have significant, cost effective benefits to both the manufacturer and end user of the product.

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REFERENCES


