1998

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ABSTRACT

Higher compressor efficiencies can be obtained through the use of capacity modulation. One technique to modulate capacity involves reversing the rotation of the compressor mechanism by reversing the rotation of the drive motor. In the reverse direction, a portion of the total available displacement is disabled, lowering the capacity. This technique raises questions as to which method of motor reversal is most efficient. Electronically commutated motors can be made to reverse direction through their control circuitry. Reversing rotation on a three phase induction motor is accomplished by interchanging two of the phase leads. Single phase induction motors can employ several techniques to reverse direction. Several methods to reverse the direction of rotation of a single phase induction motor are discussed and the merits and shortcomings of each design approach is assessed.

INTRODUCTION

The need to change the direction of rotation in single phase induction motors is well established. In open frame motors, applications such as fans and hoists have long used reversible motors to meet the requirements of their applications. In a reciprocating compressor using a three phase induction motor, special lubrication techniques are often devised to allow the motor to rotate in either direction. The rotation of a three phase motor is dependent on the relationship between the phase voltages which can vary from source to source. Single phase hermetic motors with a standard connection rotate in only one direction. Compressor designers can take advantage of this feature and employ unidirectional lubrication systems.

To meet competitive and mandated energy efficiency requirements, compressor capacity modulation is often employed to reduce the power consumption of the unit during non-peak usage. The capacity can be modulated by changing the speed of the compressor motor. Motors with multiple pole configurations or electronically commutated motors such as variable speed induction, brushless DC, or switched reluctance are typically applied for variable speed. However, the cost of the motor and / or required electronic control package can be prohibitive. There are also power losses associated with electronics that can offset efficiency gains made by modulating the capacity.

An inexpensive method of obtaining capacity modulation involves the use of a one-way clutch to disable a portion of the compressor's total displacement in one direction of rotation. In a reciprocating compressor, this can be accomplished by disabling a piston. In rotary and scroll compressors, multiple compression chambers can be used. In the reverse rotation, a chamber can be disabled to lower the compressor's output.

Regardless of the compressor technology used, maximum motor efficiency is desired to pick up even greater efficiency gains for the total system. Permanent split capacitor motors (PSC) offer higher efficiency than other types of single phase motors. Several techniques for reversing the direction of a PSC motor are documented. However, certain techniques can be advantageous when used in a hermetic compressor.

REVERSAL TECHNIQUES

Hermetic PSC motors are normally connected to provide only one direction of rotation. The direction of rotation is determined by the physical and electrical displacement of the auxiliary (aux or sometimes referred to as start) winding in relationship to the main (or run) winding. To reverse rotation without physically changing the location of the winding, the electrical relationship must be changed. This is accomplished by changing the electrical phase relationship between the windings by 180°.

Auxiliary Polarity Reversal

Figure 1 is a connection diagram for a standard PSC motor. In this and all subsequent illustrations, connections external to the compressor are shown to the right of the dotted line. To obtain the 180° phase change, the magnetic polarity of the aux winding can be reversed. This is accomplished by connecting the aux lead normally connected to Line 1 to Line 2 and connecting the Line 2 lead to Line 1. Figure 2 shows the switching requirements to reverse the polarity of the aux winding. For standard rotation, the auxiliary leads are connected to the "A" terminals. For reverse rotation, the aux leads are connected to the "B" terminals.

An obvious disadvantage to reversing the aux winding polarity in this manner is the additional lead wire that must be connected through the compressor housing. Additional leads in open motors are only disadvantageous for cost. In hermetic motors, limiting the number of connections made from the high pressure interior of the compressor to atmospheric pressure outside the compressor will improve reliability.

The motor performance will be identical in both directions of rotation which is not ideal for the reversing compressor application. It is expected that the compressor torque requirement will be reduced when operating in the reverse direction because of the reduced capacity. Since induction motors operate at peak efficiency at only one load point, the motor performance must be compromised at one of the load points or the motor can be designed to provide reasonable, but not optimal, efficiency at both compressor loads.

Tapped Main Winding

Another technique for PSC motor reversal involves a unique connection scheme. The aux winding is connected to (or tapped into) the electrical center of the main winding. A schematic representation of this technique appears in Figure 3. For standard rotation, the auxiliary lead and run capacitor are connected to Line 1 (terminal "A"). For reversed rotation, the aux lead and capacitor are connected to Line 2 (terminal "B").

This technique has an advantage over the scheme in Figure 2 as it requires only three power leads to be connected through the compressor housing like a standard PSC motor. As with the connection in Figure 2., the motor performance is the same in both directions so performance must be compromised in one or both directions. Additional internal connections can be required in the motor windings. If there is a series connection between the poles of the main winding, it is a simple matter to tap the aux winding in to this connection. However, if parallel main connections are used, winding taps must be pulled from the center of the poles and connected to the aux winding adding cost to the motor.

The electrical relationship between the main and aux differs from a standard motor because of the location of the connection. A standard motor can not be re-connected in this manner and provide the same performance. The aux winding must be modified to maintain the same starting and running performance of the standard motor. Table 1 compares the performance of a motor with a standard connection to the same motor with a tapped main winding connection. Note the reduction in break down and locked rotor torque.

Exchanging the Main and Auxiliary Winding

A common technique to reverse direction of rotation in open frame motors involves exchanging the magnetic roles of the main and auxiliary windings. To switch rotation, the main winding acts as the auxiliary winding and the auxiliary performs as the main winding. The connection scheme for this type of motor is shown in Figure 4. Forward rotation is obtained by connecting Line 1 to terminal "A". Rotation is reversed by connecting Line 1 to terminal "B". This method requires only three lead wires through the compressor housing and the internal connection scheme of the motor is identical to a standard PSC motor.

This method is common in devices such as hoists, garage door openers, and automatic gates which require equal torque in both directions. To provide the equal torque, identical windings are applied in the main and aux. PSC motors with equal main and aux windings usually have lower efficiency than standard PSC motors. Space for windings is limited and the magnetic relationship between identical windings is not ideal. In the applications mentioned above, efficiency is not an important performance consideration, but high efficiency is desired in a compressor.

The reversible compressor application will require lower torque in the direction of lower capacity. This design parameter can be used to an advantage with this connection scheme and the efficiency of the motor improved. In the reverse direction, when the aux is acting as the main winding, there is a lower torque requirement. A smaller cross section of winding can be used to carry the necessary current. This allows a larger cross section of wire to be used for the higher torque (and current) requirements of the forward direction of rotation. The unequal windings can be optimized to provide high efficiency in both directions.

In a standard PSC motor, the auxiliary winding carries very little current at locked rotor. With this connection, the aux winding will carry the locked rotor current in the reversed direction. The aux wire cross section of a standard PSC motor is too small to carry locked rotor current; a special aux winding with larger wire is required. In some applications, a larger run capacitor or a start capacitor must be applied to achieve the required starting torques. Both of these factors will contribute to higher motor cost.

APPLICATION OF THE REVERSIBLE MOTOR

Induction motors are classified as either "reversing" or "reversible". A reversing motor can change direction without being brought to rest. A reversible motor must be stopped then restarted in the opposite direction. Reversing motors have adequate starting torque to overcome the rotor and load inertia to decelerate the system to 0 RPM then accelerate the inertia in the opposite direction. PSC induction motors are poor reversing motors because of poor starting characteristics. Without start assistance, such as a start capacitor and relay or positive temperature coefficient (PTC) device, the PSC motor is almost always classified as only reversible. Motors which are classified as only reversible must not be applied in a reversing application. If the motor is not capable of reversing the load, it will continue to run in the same direction with poor efficiency and torque characteristics.

To overcome the poor reversing abilities of the PSC motor, a delay circuit must be incorporated into the direction switching circuitry. The motor must be brought to a full stop before the motor is started in the opposite direction. The compressor designer can take advantage of the delay by allowing the system to equalize before the motor is started in the other direction which can reduce the locked rotor torque requirement.

CONCLUSIONS

Table 2 summarizes the motor reversal techniques discussed. Each should be considered for performance, number of leads required, and cost. While each method will allow bidirectional operation, the last technique described, exchanging the main and aux windings, requires only three leads and allows performance optimization in both directions of the reversing compressor application. The other methods require a performance compromise in one or both directions. Since PSC motors are not normally reversing, a delay switch should be incorporated to allow the motor to come to a complete stop before the direction is reversed.

REFERENCES

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	STANDARD CONNECTION	TAPPED MAIN WINDING
LOAD TORQUE	44.5 oz-ft	44.5 oz-ft
RPM	2926	2927
LINE AMPS	5.86	6.44
LINE WATTS	1336	1345
BREAK DOWN TORQUE	128.4 oz-ft	123.3 oz-ft
LOCKED ROTOR TORQUE	9.2 oz-ft	5.1 oz-ft
LOCKED ROTOR AMPS	40.6	41.5
%EFFICIENCY	86.5	86.0
POWER FACTOR	.94	.87

Table 1. Performance Comparison: Standard Connection vs. Tapped Main Winding

Technique	# Power Leads	Motor Connections	Motor Performance
Aux Polarity Reversal	4	Additional lead wire required	Compromise in one or both directions.
Tapped Main Winding	3	Taps and additional connections required	Compromise in one or both directions.
Exchange Main and Aux	3	Same as standard PSC motor	Good performance in both directions.

Table 2. Summary of Motor Reversal Techniques

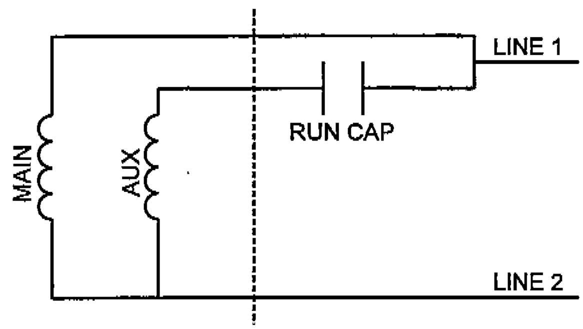

Figure 1. Standard PSC Motor Connection

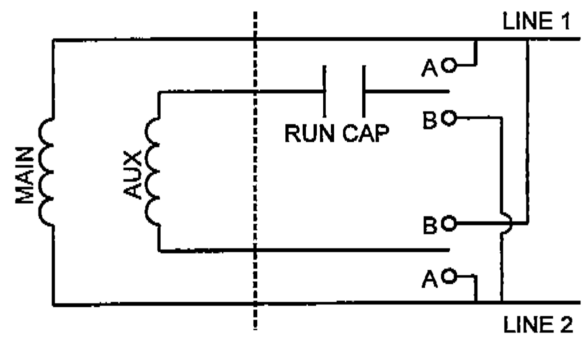

Figure 2. Auxiliary Winding Polarity Reversal Connection

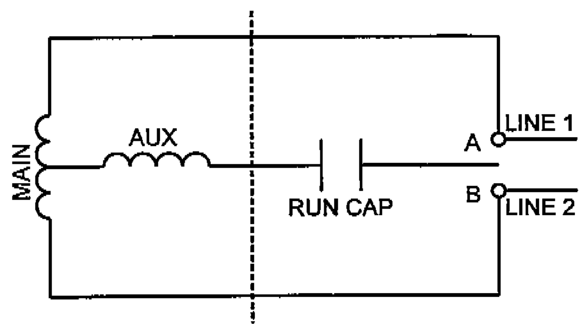

Figure 3. Tapped Main Winding Connection

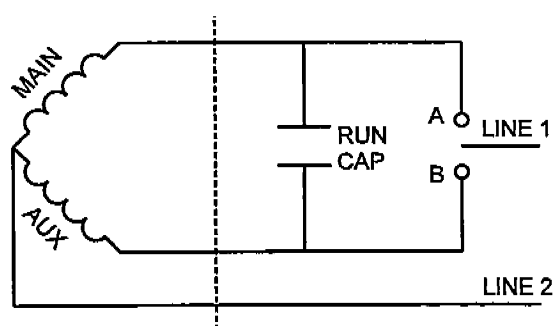

Figure 4. Exchanging Main and Aux Functions to Reverse Direction