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# MECHANICAL TESTING OF HERMETIC MOTOR SYSTEMS

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## ABSTRACT

Following is a discussion of two testing procedures that can be performed on hermetic motors to ensure mechanical compatability with the compressor system. The first details a plug reversal procedure which utilizes forced refrigerant flow to maintain a predetermined motor temperature and to simulate the mechanical impingement of oil and gas flow onto the stator windings. The second test is useful for determining the magnitude of unbalanced magnetic forces in the motor at start greater than the compressor stiffness can absorb. Both tests are applicable to single and polyphase motors of all voltages utilized in across-the-line or increment (step) starting procedures.

## INTRODUCTION

The OEM user of a motor specifies the general characteristics of a motor such as frame size, torque requirement, maximum amp draw. When the prototypes are received from the motor manufacturer, the motors are usually tested in a manner which typically verifies the required electrical characteristics, and, so far as the motors are tested in the final configuration, provides small assurances regarding system compatability. Electrical stress tests provide a performance map of the motor when operated under adverse conditions (e.g. running at high load with the motor at an undervoltage condition, and low load with the motor at an overvoltage condition.) However, little knowledge is gained concerning the mechanical ability of the motor to withstand operating and system stresses. The operating stresses of the motor are the result of mechanical movement of the coil heads due to thermal expansion differences within the motor and to magnetic forces induced from the winding currents. The system introduces stresses resulting from the operating temperatures of the motor (which is dependent on the operating conditions of the compressor and the amount and type of cooling utilized), chemical properties of the refrigerant and refrigeration oils used, and frequency that the motor is started.

To this extent, two additional tests are detailed which will aid in determining the mechanical integrity of a motor under application requirements. The first procedure described is a plug reversal test. Plug reversal testing is a well known method for checking the design and quality of manufacture of a motor. Unfortunately, motor manufacturers do not usually perform this test on large motors (50HP and above). In addition, when a plug reversal test is performed, the motor manufacturer is generally unable to simulate the system environment that the motor will witness. The other testing method involves starting the motor part wind or across-the-line with a bearing support on one side only. Through this test the amount of inherent motor magnetic unbalance at start can be determined.

## PLUG REVERSAL

Plug reversal is a test that accelerates the breakdown of a motor due to the interaction of heat, adverse chemical environment, and mechanical stress. The principle element of the test is a rapid reversal of the stator magnetic field while the motor is maintained at a high temperature. Due to the mechanical and temperature stresses the varnish, insulation system, and the method of winding can be evaluated.

Since each reversal exceeds the worst case start possible (i.e. each reversal simulates a locked rotor condition with transients caused by inrush currents and back EMF generated by opposite rotation of the rotor), this test provides a rough measure to determine the life of the motor in the field. By dividing the number of reversals the motor achieved in the test by the maximum number of field starts permitted per hour, the minimum number of probable field usage hours is obtained.

## Preparation of Motor

The sample motor is visually inspected for defects or mechanical damage. The motor is then electrically checked by performing the following tests:

1. Electrical resistance of the windings is measured and compared to the manufacturer's specification. After every 20,000 cycles (where a cycle represents two reversals) the resistance is measured, temperature corrected, and compared to the original measurement.
2. The meg-ohms of the motor is measured by megger and recorded. This test is repeated every 150,000 cycles.
3. The motor is high-potted. If there is any question concerning the integrity of the motor during the test, it is high-potted again. If the insulation system of the test motor is to be used in various voltage applications, then the high potential voltage is to be twice the larger voltage application plus 1000.
4. The motor rotor is tested on a V-block growler to ensure that there are no broken or open bars within the rotor.

## Fixture and Rigging

The stator is installed into the compressor motor housing or into a specially designed test housing. The rotor is supported by a shaft held by bearings. This is a free spinning shaft with no loads other than the shaft and rotor inertia and the weight of the rotor. In applications where the rotor is held only on one end, it is appropriate to also support the rotor in a similar fashion. Figure 1 illustrates the rotor bolt down method for a single bearing support. Particular care must be taken to ensure that there is minimal axial mismatch between the rotor and stator (less then 1/16″) and also that an equal air gap around the rotor and stator is achieved. Failure to do either would introduce additional forces into the test due to unbalanced magnetic attraction.

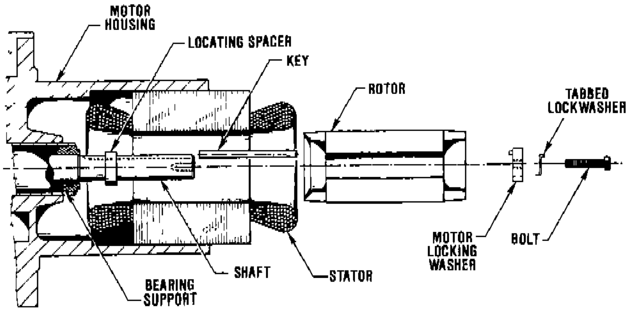

Figure 1: Bolt down of a Singulary Supported Rotor

The motor and housing support is then piped into a refrigerant cycle to supply the basic cooling of the motor and to simulate oil and gas impingement onto the stator windings. In Figure 2 it can be seen that the test motor and housing acts as an evaporator in a conventional air conditioning system.

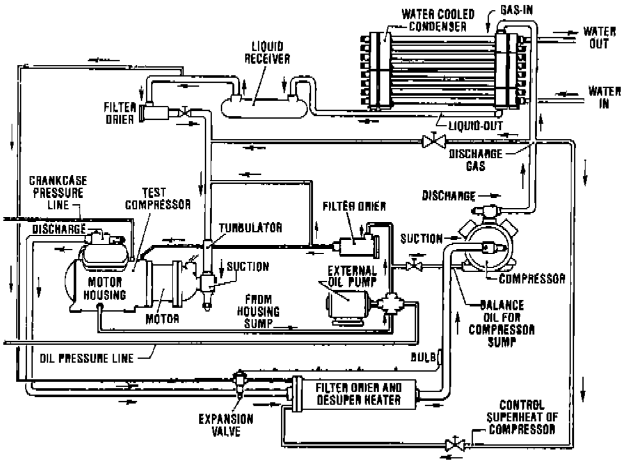

Figure 2: Plug Reversal Piping Schematic

Liquid from the receiver and gaseous refrigerant discharge flow from the compressor are controlled to maintain a predetermined temperature in the test motor. Additional plumbing is used to control the compressor suction and discharge temperatures. The motor is connected via a motorized timer to two sets of contactors. The timer should allow for adjustments to the time units used between reversals. See Figure 3 for a wiring schematic of the incoming power to the motor.

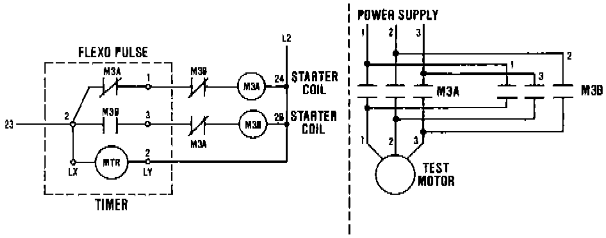

Figure 3: Plug Reversal Power Supply Schematic

### Procedure

The motor is run in one direction until the refrigeration cycle is balanced and the test temperature is achieved. The minimum test temperature of the motor should be no less than what will be experienced in the field. See Figure 4 for typical testing temperatures. Once the motor temperature is achieved, as measured by the internal motor sensors (e.g. thermocouples), the reversal process can begin. The test motor is run in alternate directions for five seconds in each direction for the first 10,000 cycles. After 10,000 cycles the motor is run in alternate directions for two seconds in each direction. To eliminate the possibility of electrical transients induced by the reversal of the electrical field, the test motor is de-energized .2 to .5 seconds between each direction change. After the motor has reached the 100,000 cycle range, the ambient temperature of the motor is raised to introduce additional temperature stresses. Each day of testing includes a three to four hour period in which the motor is de-energized. This part of the test will enable the motor to be thermal-cycled from hot to cool, then back to hot.

**Figure 4: Plug Reversal Testing Temperatures**

| C'out Temp. of mtr. installed in normal serv. | 105°C | 115°C | 125°C | 135°C | 150°C |
|---|---|---|---|---|---|
| *1st 100,000 cyc. | -120 | 120 -130 | 130 -140 | 140 -150 | 155 -165 |
| *Subseq. cycles | 140 -150 | 150 -160 | 160 -170 | 170 -180 | 185 -195 |

* Test temps. in degrees C and sensed by highest reading sensor/thermocouple on test .

Besides the variables noted above, there are variations in the plug reversal procedure which can be changed to promote a more stressful test. The test voltage can be under or over the normal application voltage of the motor to see if any detrimental effects are noted. For situations in which the motor will be utilized in part wind applications, a more stressful test may result if the motor is tested with part wind connections. For example, the first step inrush on a wye-wye wound motor is about 60-65% of the total inrush current. The same coils would experience only 50% of the total inrush current when both windings are connected across-the-line (neglecting transients). In the part wind start mode, since one winding group would be energized while the other was not, this would lead to greater relative coil head movement due to thermal expansion differences and to magnetic force differences in the coil.

### Completion of Plug Reversal Testing

The test is discontinued when one or more of the following occurs:

1. The motor fails under ground-fault or blown circuit breaker.
2. The motor draws exceedingly high amps.
3. The electrical resistance of the motor changes by more than 15% from the beginning of the test. This is an indication of an insulation breakdown of the magnet wire in the coil head. The damage may not yet be enough to cause overheating or a short to ground (e.g. the stator body).
4. The motor temperature cannot be stabilized at the desired temperature. This is indicative of an overheating condition due to external problems such as amount of coolant flow, voltage and current variations of the incoming power, change in test stand torque requirements, or problems relating to motor design or insulation breakdown.
5. Undue vibration or noise is being generated as the test proceeds.
6. There is a problem with the test stand unrelated to the motor but needing attention (e.g. refrigerant leak, bearing failure, compressor failure).

If the test is stopped due to items 2 through 6, the motor should be removed from the housing and electrically and visually inspected to determine if the test should resume. If possible, the test is continued until the motor experiences some type of electrical failure. Utilizing ground-fault in the safety circuit will ensure that the motor comes off-line as soon as a short to ground occurs. Besides limiting the amount of contamination to the test stand, ground-fault protection will also help to ensure that the initial cause of failure will not be obliterated before the motor comes off-line.

### Inspection and Interpretation

Through inspection of the motor, it is possible to determine if the failure was caused by an insulation failure, or was initiated by a mechanical problem. Examples of mechanical problems which can induce failures are improper air gap, mishandling of the stator, and the passage of metal components. Improper air gap usually results in a slot insulation failure with heavy rotor to stator contact in the vicinity of the burn. Damage to the stator caused by improper motor handling results in an isolated zone of failure, and generally occurs in the stator head. Failures caused by the passage of metal components (e.g. parts of a filter) produce an abrasive looking damage zone in the stator head closest to the inlet port.

Once mechanical problems have been eliminated as the cause of failure, it is necessary to identify which part of the motor insulation system failed. The insulation sytem of a motor is comprised of slot liners to isolate the magnet wire from the stator body, slot collars which protect the magnet wire as it exits the stator body, phase separators, and magnet wire insulation. The type of insulation which failed is evident by the location, or locations, of the burn. A failure in the coil head has to connect to ground before the ground-fault will detect it. Therefore, caution must be exercised when deciding on which area failed first. By careful analysis of the burn area (sometimes resulting in dissection of the stator). it is possible to determine if the insulation failure was a result of improper insertion (i.e. misassembly of the stator by the motor manufacturer).

By process of elimination, the cause of failure is either due to mechanical movement of the coil heads (failure of this type is usually experienced in the slot collar) or to basic incompatibilities of some portion of the insulation system with the environment it was exposed to (in this case all similar insulation would exhibit an even degradation).

## SIDE-PULL TESTING

This test is to determine whether any unbalanced magnetic forces exist in the start mode which would cause the rotor to deflect. This procedure is specifically applicable for those motor applications in which the rotor is bearing supported on one side only. From extensive testing it has been found that most motors do not have any significant magnetic unbalances in the run or across-the-line start configurations. However, in increment (part wind) starts, many large HP motors (50HP and above) do exhibit significant side-pull tendencies. In applications in which the rotor is singularly supported, it has been found that the side-pull effect on the rotor and the shaft has been enough to pull the free end of the rotor into contact with the stator. Over repeated starts, the individual stator laminations can be driven into the slots, and the stator shorted. There are several reasons for this type of phenomenon:

1. Unbalanced magnetic forces in the stator due to the sequencing of in-rush currents.
2. The stiffness of the shaft and bearing support being too small to absorb the unbalanced forces.
3. The lack of testing by motor manufacturers to discover and correct the problem. Since the majority of large HP motor applications utilize bearing supports on both sides of the rotor, this concern has never been a design issue.

If a rotor to stator contact problem is discovered, the solution is to stiffen the assembly (make rotor shaft greater in diameter, provide more and stiffer bearing supports on the shaft), or to insist that the motor manufacturer construct a motor which is magnetically balanced in start and run modes. The manufacturer can accomplish this by changing any of several variables such as the type of winding, the number of slots spanned by each coil group, or the order in which the coils are grouped and electrically connected. In applications which utilize supports on both ends, the rotor to stator contact would not occur. However, two items must be kept in mind:

1. If there is an unbalanced force, the bearings must take this radial load. Generally, the magnitude of the force is low when compared to other forces which are present, and the duration of the force is short if the unbalance is only present during start. However, this is a real force which should be considered when sizing the rotor support bearings.
2. In so far as the magnetic unbalance represents an electrical unbalance in the motor windings, this is an indication of internal stresses which could hasten mechanical breakdown of the insulation system.

### Fixture and Rigging

The purpose of the side-pull test is to evaluate the motor and compressor as a system. To this extent, the standard compressor body should be utilized as the motor housing. Since magnetic forces are a function of current, it is desirable to test the motor under the worst case current draw: namely, locked rotor inrush currents. This can be mechanically achieved by welding the shaft to other compressor members, or by designing a locking mechanism that will prevent rotation. This will expose the stator to lock rotor amperage when the motor is energized. The rotor is to be held onto the shaft by a bolt and washer assembly torqued into the shaft (see Figure 1 for illustration of bolt down). The stator is mounted around the rotor in the normal fashion. Care must be used to ensure that an acceptable air gap is achieved (normally the high and low air gap measurements are within 10%). The greater the air gap variance, the larger the unbalanced forces. The motor end cover on the free end is to be left off (since the shaft is locked from rotation, no oil or refrigerant flow will occur).

The normal electrical connections are made to all motor lead wires. However, in the case of part wind testing, one motor starter will be jumped out. This aids in two ways: 1) The motor can easily be tested across the line by removing the jumper on the deleted starter; and 2) in the case of interconnected stator windings, the field experience during start is duplicated. If a motor is to be started part wind and across-the-line, it is useful to do testing in both modes to ensure no problems exist in either.

## Procedure

The easiest way to determine if a magnetic unbalance exists is to utilize tracing paper as a visual go/no go gage:

1. Insert the tracing paper between the rotor and stator. The paper may need to be trimmed to ensure that no overlap occurs.
2. Energize the motor stator for two to three seconds. For part wind modes the actual amount of transition time between steps should be used if it is greater than three seconds.
3. Remove the tracing paper and check for visual indications of contact. The contact, if any, may be faint lines of individual laminations from a single stator bar, or numerous heavy contacts 360 degrees around the paper. See Figure 5 for a graphical representation of a possible contact pattern.

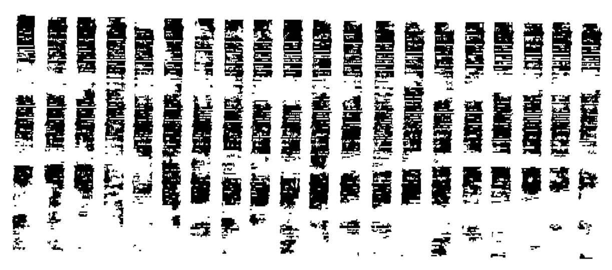

Figure 5: Graphical Representation of Side-pull Contact

4. The test should then be repeated to verify results.
5. If contact is only witnessed in one location, it is useful to rotate the stator (remember, the rotor is mechanically locked) and repeat the test. If the pattern moves with the rotation of the stator, then the striking is a result of a magnetic unbalance in the motor. If the pattern remains stationary it is an indication that the test fixture is at fault. Recheck the air gap, check the bolt down torque on the rotor and stator bolts, and ensure that the bearings are properly seated before proceeding.

## Inspection and Interpretation

Of significance is the location and extent of the contact on the paper. Heavy contact which cuts through the tracing paper represents an immediate and pressing problem. But even light contact indicates a potential field problem. The contact should be limited to the unsupported end of the rotor. If there is contact at the supported end, this could be an indication that the air gap is not correct, the bolt down torque is inadequate, or the stiffness of the assembly at this end is not large enough to overcome the magnetic forces. Generally, for the same motor design (e.g. frame size, winding), method of start, and compressor shaft design, the amount of contact increases as the length of the rotor increases. Hence, no contact area on the paper is not an indication of magnetic balance, but rather an indication that the unbalance is less than the system stiffness can accommodate.

If the amount of unbalance is desired, or if it is important to know how much the air gap is affected, there are additional tests that can be done. Again, depending on the configuration of the compressor, the easiest method utilizes tracing paper. Plastigage of a known thickness is applied to the tracing paper. The paper is then inserted between the rotor and stator and the procedure repeated. The air gap reduction is indicated by the amount of plastigage deformation. Another method would be to utilize strain gages and other types of electrical equipment to record the amount of shaft deformation that occurs during the locked rotor tests. Once the amount of radial rotor movement has been determined, it is then possible to calculate the amount of force required to bend the rotor and shaft assembly. By calculating the stiffness of the shaft and bearing support, and knowing the amount of measured radial movement, one can then determine the magnitude of force required to bend the assembly. (The calculations can be simplified by treating the as assembly cantilever beam supported on one end with the load applied at the center).

## CONCLUSION

When testing motor samples to determine how they will perform in the field, it is important to simulate the variables which are prevalent in the field. In essence, it is necessary to model the testing program to reflect what the motor can be expected to witness in field applications. The plug reversal method presented above represents an improvement over conventional methods of plug reversal testing due to better modeling of the test to field usage:

1. The method utilizes forced refrigerant flow to maintain a predetermined motor temperature. Not only does this duplicate the method in which the motor is actually cooled, but it also simulates the mechanical impingement of oil and gas flow onto the stator windings.
2. The test incorporates a daily cool down period to permit thermal cycling of the motor. The majority of all motors in the field undergo numerous starts and stops, hence, temperature cycling is a normal part of operation.
3. Raising the test temperature to a higher plateau after 100,000 cycles accounts for the uncontrolled field variences which increase the operating temperature of the motor. Some examples of these field variences are breakdown of external electrical connections over time (i.e. loosening of starter contact lugs), seasonal variation in power supply, change in design requirements, or the quality of the system maintenance (i.e. superheats changing over time due to misadjustments of valves, condensers getting clogged).

The side-pull test represents a program where the magnetic characteristics of a motor at start are examined to determine if problems exist. To amplify any irregularities, the worst case current draw was modeled into the test by mechanically locking the rotor from rotation. As a result of this test, the extent of magnetic unbalance (hence, the electrical unbalance in the stator) can be determined.