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Increasing Compressor Reliability with Solid State Motor Starters and Internal Protectors

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SOLID STATE MOTOR STARTERS AND INTERNAL PROTECTORS

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Ever since the invention and proliferation of hermetically sealed compressors in home refrigerators, placement of the compressor motor on the inside of the compressor shell imposed very high demands on motor system reliability. As the result, a modern refrigerator is expected to last 10-15 years without any trouble, as far as the consumer is concerned. Admittedly, a remarkable engineering feat.

Nevertheless, refrigerator manufacturers and their component suppliers have always exerted efforts to further improve this record. There are two major reasons behind this: (1) The desire to reduce in-field breakdowns and the associated repairs, particularly during the warranty (an average warranty call costs about $60). (2) More recently, the distinct possibility of severe "brownouts" that in certain cases can destroy the motor insulation. Such brownouts are expected to be the norm in the foreseeable future. Thus any future system must take this "fact of life" into consideration.

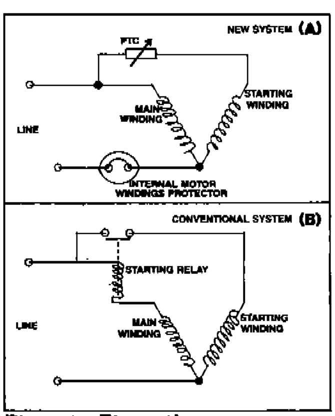

Figure 1a, Figure 1b


Figure 2a

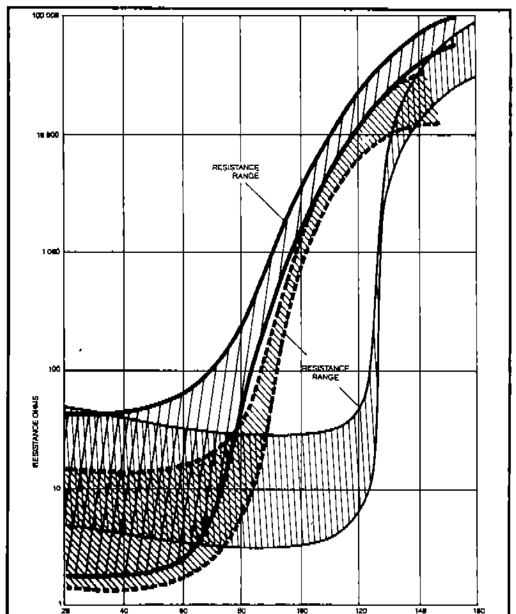

Figure 2b

Nominal Resistance @25 C	Maximum Operating Voltage	Maximum Allowable Voltage	Maximum Current
10Ω	160V	200V	8A
10Ω	200V	250V	10A
33Ω	315V	400V	7A
4.7Ω	160V	200V	12A

Figure 2c

It should be noted that a modern compressor motor is built with carefully selected materials and relatively little reliability improvement can be gained in this area. Motor starting and motor protection methods, on the other hand, have remained virtually unchanged except in larger compressors where internal protection has been practiced successfully for quite some time. It is in this area that the largest reliability gains can be scored through the application of latest semiconductor technology and more reliable winding temperature sensing techniques.

For instance, the use of PTC (positive temperature coefficient) thermistors instead of the electromechanical starting relay together with a glass-enclosed bimetallic motor-winding protector that can be placed within the motor windings to measure the winding temperature directly (unlike conventional protectors mounted on the outside of the compressor shell).

Very briefly, major advantages of this solid-state starting and internal protection system include:

1. For motor starting, all the advantages of a solid-state device versus an electromechanical relay.
2. For motor protection, a very sensitive and quick-acting device since it "looks" directly at the measured variable - the winding temperature - rather than at the temperature of the compressor shell that is a function of compressor motor temperature. Moreover, the internal protector cannot be bypassed (either by a serviceman or a user) thus ensuring better overall system safety.

DEFINING THE NEW SYSTEM

Figure 1a compares the new starting/protection system with a typical conventional system (Figure 1b). Since the availability of PTC devices with sharp switching action is relatively recent, it is well worth while to summarize their properties.

Figure 2a depicts a typical PTC device mounted in a package that goes on the case of a refrigerator compressor. Figure 2b is a generalized plot of PTC resistance versus temperature. Major electrical parameters for a few appliance-type PTC thermistors are given in Figure 2c. It should be pointed out that these parameters are only representative, since production quantities of these devices are generally built to meet some specific application.

In a nut shell, as can be seen from Figure 2b, a PTC thermistor is simply a resistor whose resistance changes rapidly over a certain temperature range between 40°C and 140°C. Note that in a good switching PTC, this resistance range is very large - several orders of magnitude, or from about 10 ohms to 10,000 ohms.

When used as a replacement for an electromechanical relay in a refrigerator compressor, the PTC thermistor operates as follows.

When voltage is applied to a cold PTC, the initial resistance is very low and full rated starting current flows through the starting winding. As the PTC is heated by the starting current to its switching temperature, its resistance rises sharply, effectively switching the starting winding off.

PTC & Internal Protector	Relay & External Protector
Starting	Starting
1. PTC reliably shuts off starting winding, providing reliable protection.	1. Winding stays in the circuit under locked rotor condition until shut off by protector.
2. No contacts—unlimited life.	2. Cycles with protector.
3. No RFI generation—no contacts.	3. Radio noise from contacts.
4. When used with run capacitor, can get resistance start capability efficiency of a PSC motor.	4. No comparison.
5. Two-wire start winding can be avoided because PTC shuts off winding. Use all forward turns.	5. Two-wire start winding may be necessary. Use forward and reverse turns.
6. No pull-in and drop-out currents that can cause problems.	6. Specific pull-in and drop-out current values result in relay chatter at low voltage.
7. Allows protector to sense only main winding current, does not need rapid trip on locked rotor to protect the start winding.	7. Depending on voltage and motor conditions, relay may not pick up or may not drop out, causing start winding burnout.
Low-voltage conditions	Low-voltage conditions
On-winding device that senses winding temperature directly.	Possibility of damage to the windings because of slow response.
High load current	High load current
If components are properly chosen, *nuisance trips* can be eliminated.	*Nuisance trips* are commonplace.
Oil/freon breakdown	Oil/freon breakdown
Improved protection since protector senses actual winding temperature.	Protector does not sense winding temperature, it looks at the heater temperature in the protector.
Loss of charge	Loss of charge
Low current with loss of charge, motor runs free. Internal protection offers quick response.	External protection will not protect.

Figure 3.

As Figure 3 indicates, the advantages in replacing an electromechanical relay with a solid-state PTC thermistor are clearly defined. Thus they include almost limitless life; clean, chatter-free operation; reliable shutting off of the starting winding; total absence of either mechanical or electrical noise (RFI, or radio frequency interference); no chance of contact welding; immune to shock and vibration, as well as to line-voltage variations.

The case is just as clear cut with the internal protector. While here an externally-mounted temperature-and-current sensitive bimetal switch is replaced with an internally-mounted temperature and-current sensitive bimetal switch, there are important, reliability-contributing differences between the conventional (external) and the new (internal) approaches.

Referring to Figure 4a, the new internal motor-winding protector can be placed - in fact, it has been designed for placement within the windings of a motor-directly among the motor windings. In part this has been made possible by its sealed glass case, i.e., an electrically insulated enclosure. As was mentioned earlier, the internal protector cannot be bypassed, thus providing better safety.

As can be seen from the Figure 4b sketch of a thermoprotector, the heart of each protector is a bimetal blade, prestressed to provide snap action. The glass enclosure provides reliable hermeticity for maximum thermal response and arc suppression.

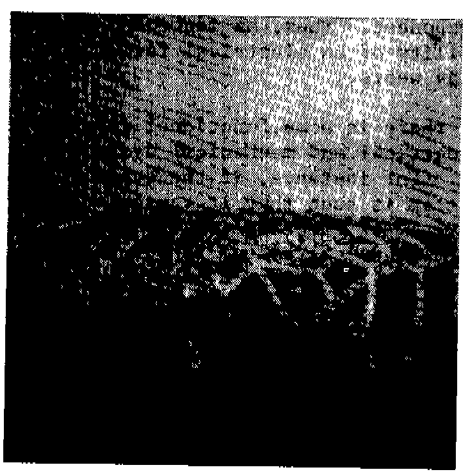

FIGURE 4A

The unique glass enclosure is shock-resistant and is self-insulating, eliminating the need for secondary insulation. The kind of glass that is used for the enclosure has the ability to withstand extreme pressures, and high mechanical and thermal shock.

These major specifications partially explain the reason why these thermoprotectors are being used for internal protection of refrigeration compressor motors, i.e., in an application that requires ultimate reliability. Fault conditions producing excessive current and/or heat in the motor windings will trip the contacts open. Contact-opening temperatures may be varied to maintain the motor winding temperatures under the desired limits during cycling conditions. The motor will resume normal operation once the fault condition is removed.

The devices are designed for line-break protection on small, fractional horsepower motors with locked rotor ratings up to 40 amps or as pilot-duty protection when mounted on the windings and in series with the magnetic motor contactor coil.

From the refrigerator manufacturer's point of view, however, what really counts is the degree of protection and product safety provided by a protector.

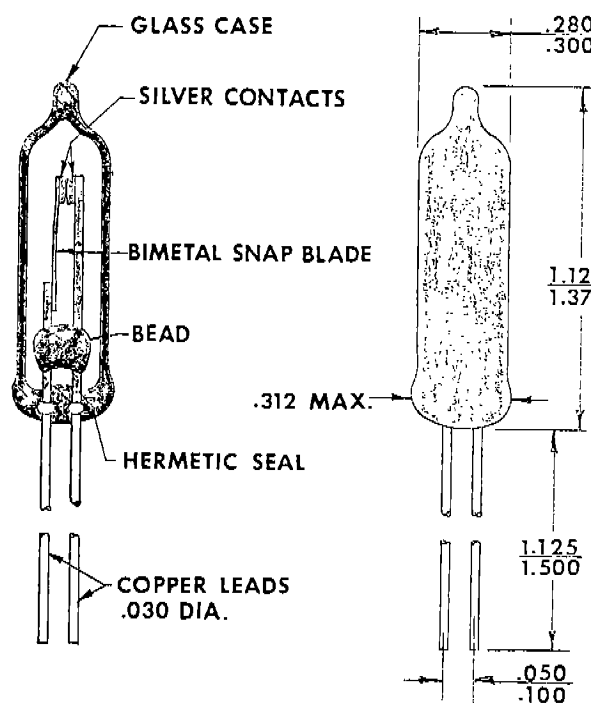

FIGURE 4B

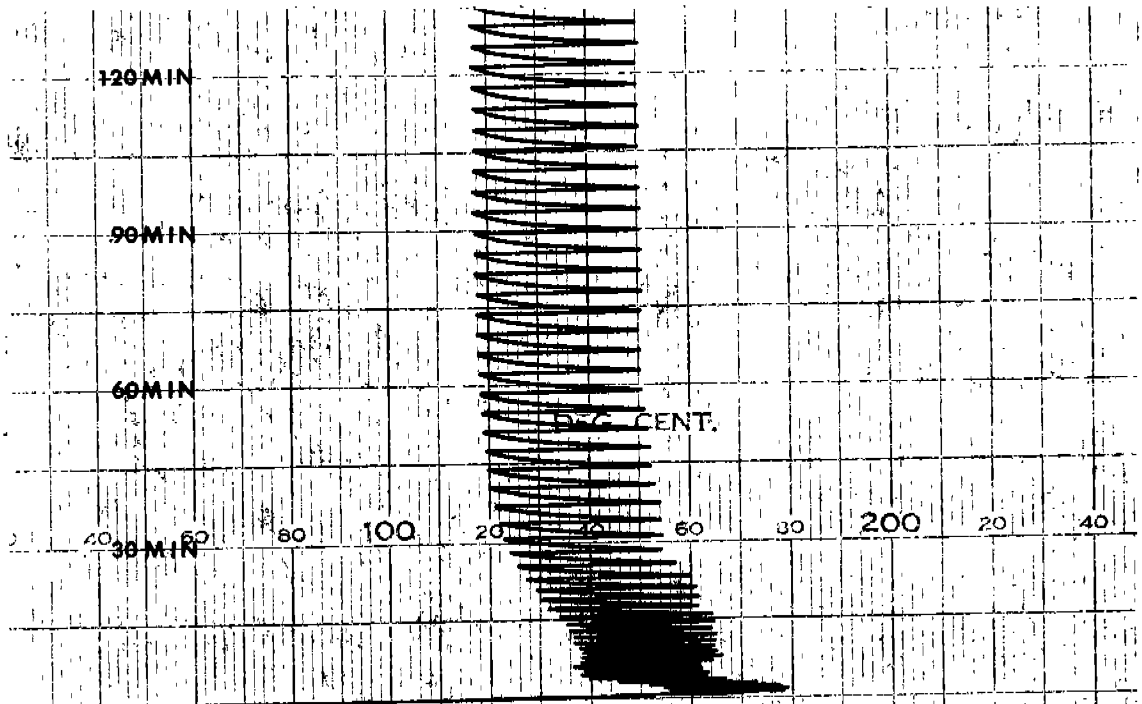

FIGURE 5 SL PROTECTOR IN 1/3 H.P. SPLIT PHASE COMPRESSOR MOTOR LOCKED ROTOR I_{COLD} = 29 AMPS

Figure 5 illustrates how a glass-enclosed, mounted-on-the-windings hermetic thermoprotector is cycling on and off during a locked rotor condition. The protector trip point was 120°C, so that the protector kept cycling for 2 hours, keeping the windings at the reasonable temperature of between 100°C and 120°C. It may be noted from this graph that, due to the clean snap action of the prestressed bimetal blade, no contact chatter has been observed.

COMPONENT RELIABILITY IS THE KEY

When approaching the subject of reliability of such a product as a home refrigerator, it should be understood that there are two distinct aspects to the problem:

1. Customer satisfaction due to the elimination of early failures in the life of the appliance, i.e., sometime before 10 years.
2. Cost of warranty repairs.

Poor reliability of a home refrigerator has a direct economic impact on the manufacturer: a direct, out-of-pocket expense in the case of an early (in-warranty) failure or a long-range loss of business due to mounting customer dissatisfaction with after-warranty failures. An ideal situation would be to ensure operating system reliability for life of the appliance as determined by factors other than the ability to operate (styling, size, damage in transfer,etc).

According to data gathered by a major European compressor manufacturer (Figure 6), in-field failures follow a definite trend. That is, electrical failures as a percentage become more significant with time, while mechanical defects are eliminated in the first year of use. The reason for this is partly due to the fact that the electromechanical relay is a wearing component. Thus, as mentioned earlier, the probability of an electrical failure rises as the relay wears.

Of course, there is some functional dependence between electrical and mechanical systems in a compressor. For instance, if the starting/protection system is such that it causes too many nuisance trips, or erroneous starts, this will subject the mechanical system to an undue stress that may eventually lead to a mechanical failure. Or an excessive friction in the system may cause the motor to run overloaded all the time, leading to an early electrical failure.

Assuming, however, that a division into mechanical and electrical failures is possible, let us concentrate on the electrical system possible with the new PTC/internal protector system.

Most advantages of a solid-state device such as a PTC thermistor versus an electromechanical relay have been detailed previously. There are several aspects, however, that are more subtle.

To begin with, in a starting failure in a compressor that uses an electromechanical relay, the starting winding will be kept under voltage until the motor protector breaks the circuit.

In systems that use PTC thermistors as a starting device, the starting winding will always be switched off a few seconds after a starting attempt, regardless of whether or not the motor actually starts: Starting current flowing through a PTC causes a rapid rise in the device temperature and the subsequent high resistance. Thus a PTC thermistor offers an extremely reliable protection against this particular failure mode.

Furthermore, the use of the new PTC/internal protector system permits the use of a single-wire starting winding, rather than the conventional two-wire approach. And the new system affords a double protection for that winding - a PTC and an internal protector that acts much quicker than the conventional metallic-enclosed protector mounted on the outside of a compressor case.

On the basis of data from 300,000 compressors that use the new system (data from the same European compressor manufacturer), there was both a reduction in failures as well as shift in the nature of failures. As is shown in Figure 7, the percentage of electrical defects was reduced drastically, compared to mechanical defects.

Overall failure rate was reduced substantially. This reduction, multiplied by the cost of a warranty repair call amounts to a considerable sum. Obviously, a certain amount of customer satisfaction should also be included in the overall economic benefit. (It should be reminded that in this reliability gain was made with a highly reliable product to begin with!)

The reliability gain was achieved through a rigorous cooperative program between quality control and development departments. In fact, the QC department was involved in the development of the new PTC/internal protector system from the beginning.

Extensive component life and reliability tests have been conducted during the development period. Close relationship with vendors of PTC's and thermoprotectors has been maintained to make sure that component makers clearly understand the QC requirements that would ensure the required reliability of the overall system.

Many reliability and economic factors have been taken into consideration during the development period. Component count reduction, for instance, was an important factor. That is, in the case of replacing a starting relay with a PTC thermistor, there is a reduction in the number of different relay types with a single PTC type. This greatly simplifies both the inventory and in-field replacement.

The utilization of an internal protector further simplifies life for a refrigerator manufacturer by permitting the use of a single protector for a variety of compressors. This again implies inventory cost savings.

No discussions of reliability would be complete without some mention of the initial system cost. On the basis of actual in-field experience, it can be stated that the initial cost of the new, system of the future, PTC/internal protector, is quite competitive.

It should be pointed out that full benefits will be realized only when a PTC and the internal protector are used as a system. Various attempts to go half way - replacing a starting relay with a PTC but leaving an external protector intact - were not successful. A major reason for this was the necessity to match the characteristics of an external protector to the rest of the system very closely. A PTC in conjunction with an internal protector, on the other hand, is very forgiving since both devices span a wide range of compressor characteristics.

In conclusion, one may look upon the PTC/internal protector combination as a system that reduces life-cycle costs while taking care of a variety of adverse conditions safely and reliably. Such conditions include the almost certain possibility of brownouts; locked-rotor situations due to whatever cause; loss of charge; and an ever-increasing emphasis on overall product safety.

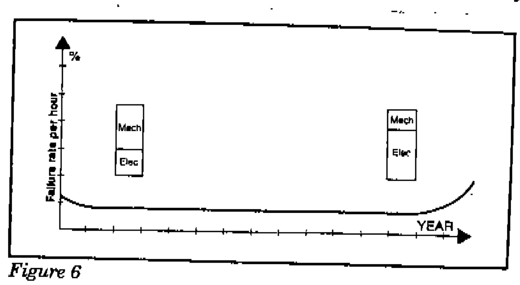

Figure 6

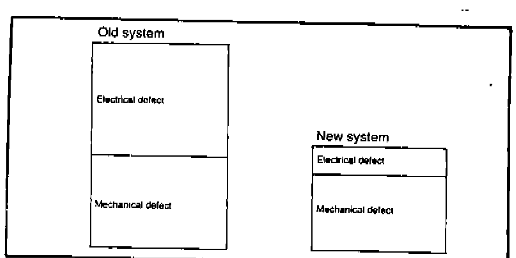

Figure 7