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An Application Selection Procedure for Hermetic Overloads with Two Heater Construction

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AN APPLICATION SELECTION PROCEDURE FOR HERMETIC OVERLOADS WITH TWO-HEATER CONSTRUCTION

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ABSTRACT

Texas Instruments has recently introduced to the marketplace a line of hermetic overloads which have two-heater circuits, one in series with the start winding, and one in series with the main winding. The selection of a protector for application testing is more complicated than that of the conventional single heater protectors. This paper will serve to show in detail the selection procedure which has been developed and the reasons why this procedure will afford good results. It will deal in general terms with the required test conditions that the protector must pass, the relative influence of start winding, main winding, current, winding temperatures and rates-of-rise in motors, and gas temperatures for each of these selected test conditions. It will illustrate through a theoretical example the procedure to follow using the actual application curves which have been developed for this family of devices. These devices are particularly well suited for application to compressors intended for heat pumps and residential air conditioning split systems.

INTRODUCTION

Industry practice for the protection of central residential air conditioning compressor motors from 1-3/4 - 5 H.P. was to use either a pilot circuit system consisting of a thermostat located in the compressor and a current sensing thermal overload located externally, or a hermetically sealed line break protector.

The selection of the thermostat and supplementary overload combination is relatively simple in that you select the thermostat temperature to limit the winding temperature on running overload and you select the supplementary overload trip time for locked rotor protection. The two devices can be chosen independent of each other.

With line break protectors, since one device protects for both conditions, the selection is somewhat more complicated since the trip point on running overload and on locked rotor are not independent. The line break devices are located in the common line of the compressor load electrically and on the windings of the compressor motor physically. A method of using application curves for the selection of these devices to select for the proper short trip time on the locked rotor conditions is in use. The devices are tested under constant current at room ambient and measure the trip time for different amperages. To establish ultimate trip curves for selection of a protector under running overload conditions, a constant current is applied to the devices and the ambient temperature is increased until the device opens. This is done with a very slow rate-of-rise in order to determine the maximum current that the device can hold at a particular ambient temperature without tripping.

In response to the increasing industry need for a protection system which affords a greater degree of sensitivity to a wide variety of fault conditions, the 5HM and 6HM protectors which have two heaters were developed. The two heaters are located electrically in series with the main winding and the start winding, respectively. The line current passes through the bimetal disc. See Fig. 1.

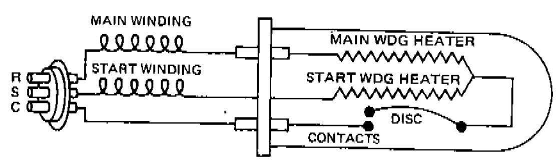

FIG. 1

In addition to locked rotor, running overload and loss-of-charge protection provided by single heater line break hermetic protectors, these devices provide protection against such fault conditions as welded start relay, capacitor failure, light load, high voltage and failed outdoor fan. They also allow the compressor motor designer to design his motor closer to the application requirements and thus achieve an overall cost savings. The selection of these devices, however, now becomes more difficult as the relative influence of the two heaters must be accounted for under a wide range of fault conditions. It is to this problem that the application selection procedure outlined in the paper addresses itself.

GENERAL APPROACH

The general approach in establishing the application selection procedure was to study the main winding and start winding currents and winding temperature under various fault conditions and the relative contribution of heat input that they create in the device under these fault conditions. It was then determined whether or not each contribution was significant to the raising of the temperature of the device to a trip point.

In Fig. 2 the various fault conditions are illustrated in terms of their relative contribution of heat to the device. In addition to the two basic fault conditions of running overload and locked rotor, the fault conditions of loss of refrigerant charge and welded relay are illustrated. The welded relay protection refers to CSCR compressors where very high rates-of-rise occur in the start winding if the potential relay contacts weld and leave the start capacitor in the circuit. Welded relay protection is a protection feature afforded by these two-heater protectors which was not available with the line break devices previously on the market.

In each case, the ambient temperature condition, that is the room ambient, provides a constant heat input to the device. Under a running overload, the location or winding temperature provides the majority of heat input to the device. The main winding current passing through the device is the second largest contributing factor, whereas the start winding current in the start winding heater is the smallest.

Comparing this to the loss-of-charge condition, we see that the main winding current influence becomes very small, whereas the start winding influence increases as does the location or effective winding temperature. This occurs because the main winding current has greatly reduced under this condition due to the fact that the compressor is essentially working against no load and, since it runs at a faster speed, the start winding current increases, and due to the sensitivity of the start winding heater, adds significant amounts of heat to the device. These fault conditions are relatively slow rates-of-rise conditions. Hence, the winding temperature is the predominant heat input to the device because the heat has sufficient time to transfer from the windings to the protector.

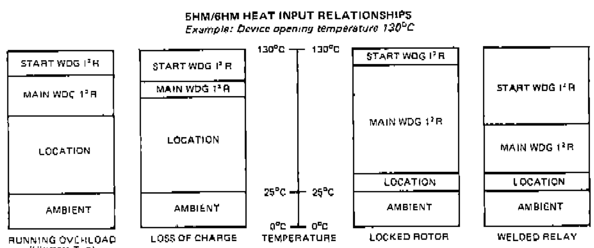

FIG. 2

The locked rotor and welded relay in contrast are fault conditions in which the windings exhibit very rapid rates of temperature rise and high current levels. In these instances, the winding temperature does not have sufficient time to transfer thoroughly to the device so we must depend entirely on the I^2R heating taking place in the device. Under the locked rotor condition, we can see that by far the main winding current is the dominant heat input factor to the device. The start winding current is relatively low under these conditions and does not contribute significantly to the tripping of the overload. Conversely, under welded relay conditions, the start winding current increases dramatically and then becomes the significant heat input to the device. The construction of these devices is such that the start winding heater is made of high resistance heater material and is very sensitive to changes in start winding current. The bimetal disc is also a resistant member sensing line current as well as location temperature. The main winding heater is the element which connects the main winding to the bimetal disc. It is a low resistance element and has no appreciable effect on the trip time under locked rotor conditions.

DELTA T CONCEPT

To aid in our selection procedure, the delta T concept has been designed. The theory is that each element in the device raises the temperature of the bimetal disc a certain delta in temperature by its I^2R heating. It is the bimetal disc which must be raised to a calibrated temperature by collecting the heat inputs of the elements around it and adding to it the I^2R heating in the disc itself. One can effectively measure the delta T or disc temperature rise contributed by each element by passing current through it and measuring the rise in temperature in the disc for different levels of current and drawing a curve of delta T vs. current. Separate curves can be utilized for the start winding heater, the main winding heater and then by combining the derating delta T effect of each, the resultant for various conditions can be found. The basic equation, which applies only to slow rates-of-rise conditions, is:

$$\text{Device open temperature} = \Delta T_{mw} + \Delta T_{sw} + \text{E.P.A.}$$

E.P.A. = Effective protector ambient (location temperature of protector)

ΔT_{mw} = Delta temperature by main winding current

ΔT_{sw} = Delta temperature by start winding current

APPLICATION EXAMPLE

A theoretical example using typical values of current and winding temperature for a 3 H.P. air conditioning compressor to illustrate the application procedure is presented here. In the example there are four fault conditions to be protected. They are listed in the table below with the start current, line current, and effective protector ambient (EPA) and the expected protector performance in each case.

COMPRESSOR DATA

COMPRESSOR CONDITION	START WINDING CURRENT	LINE CURRENT	PROTECTOR PERFORMANCE
Welded relay	34 amps	50 amps	Trip in 8 seconds
Locked rotor	3 amps	94 amps	Trip in 8 seconds
Max load must hold	5 amps	28 amps	Trip in 8 seconds
Running overload	5 amps	32 amps	Trip at 66°C E.P.A.
Loss of charge	6.5 amps	14 amps	Trip at 100°C E.P.A.

The protector performance is the result of tests by the compressor motor designer which have shown him that if these performance criteria met that, he would limit his winding temperature under these fault conditions to acceptable levels. Significant in the data is the comparison of currents under the welded relay and locked rotor condition. The start winding current on the welded relay is over ten times the locked rotor current, whereas the total line current is almost 50% less. The required protector performance under these widely varying conditions is identical; the protector must trip in 8 seconds. Now compare the loss-of-charge condition to the overload condition. In each case, the winding temperature must be protected to a safe level. However, in the loss-of-charge condition, the line current has dropped over 50%, whereas the start winding current has increased only 30%. Let us proceed to select the various elements of the overload protector which will meet these requirements.

SELECT START WINDING HEATER

Selection of the start winding heater is the first element which will be selected. It is extremely critical that this element be chosen carefully with respect to the welded relay condition. Under this condition, the extremely high rate-of-rise in the start winding requires a very quick trip of the overload protector to prevent damage to the start winding. In addition, since the heater element is a very high resistance element, caution must be taken that the heater does not burn out under these conditions. It is recommended that a trip time of less than 6 seconds under these conditions not be attempted as it may, in fact, result in heater burn-out. The principle mode of transfer of heat from the start winding heater to the disc under this condition is radiant heat. The start winding heater becomes incandescent under this condition and it takes a finite time to transfer this heat to the bimetal disc. Close control must be maintained of the positioning of the start winding heater to the disc to ensure that this heat is transferred consistently. The line current passing through the main winding heater and the bimetal disc is insignificant in the protection of the motor under these conditions. That is to say, with 50 amps going through the main winding heater and disc, the change in the disc temperature in 8 seconds is negligible. Therefore, use only the start winding current of 34 amps and the short time trip curve of the start winding heater to select the element which affords protection under this fault condition. Referring to Fig. 3, the -8 heater is selected which trips the device in 8 seconds at 34 amps.

SHORT TIME CURVE
5HM START WINDING HEATER

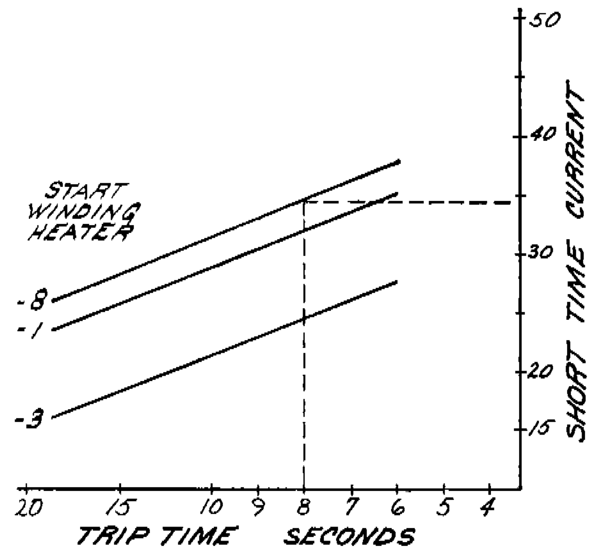

FIG. 3

SELECTION OF THE BIMETAL DISC

To specify the bimetal disc, we refer to the locked rotor condition where the primary influence for the trip of the overload protector is the high line current passing through the disc. Under this condition, the locked rotor current in the start winding is dropped to only 3 amps, hence, the effect of the start winding heater is essentially negligible. Also, the effect of the main winding heater is essentially negligible since in this particular device the resistance of the main winding heater is relatively low and does not generate sufficient heat under these conditions to significantly affect the trip time of a device; hence, we may make our selection for locked rotor protection solely on the basis of the bimetal disc. In Fig. 4 we see the trip time vs. current curve for bimetal disc with various resistivities.

Entering the table at 94 amps, we can see that the F50 bimetal disc will trip in 8 seconds. The initial selections have been made on curves made with a 130°C opening temperature devices for time trips since it is a nominal opening temperature. If in the selection of the device for running overload, or loss-of-charge, we find that we must adjust this opening temperature, the effect on the time to trip under the rapid rate-of-rise conditions will be minimal.

5HM SHORT TIME CURVE
BIMETAL DISC

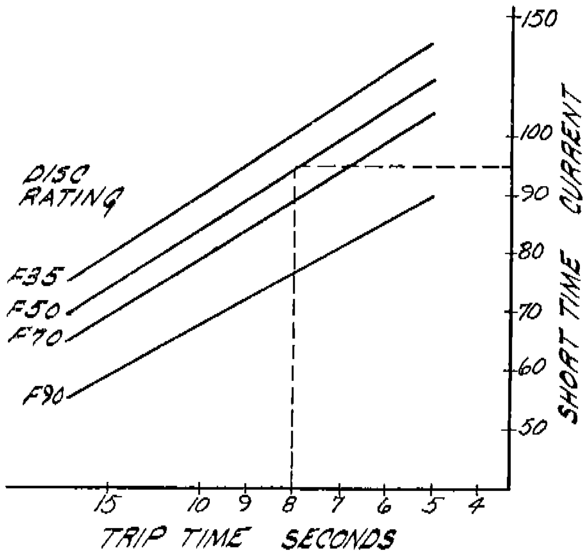

FIG. 4

<u>SELECTION OF THE MAIN WINDING HEATER AND THE MINIMUM OPENING TEMPERATURE</u>

One characteristic of the device is that it must not trip under a maximum load condition on the compressor where the winding temperatures have not reached an unsafe level. Under these conditions, we must take into account the derating effect of the start winding heater and the bimetal disc that we have selected plus the main winding heater. For this selection, make the assumption that the difference between the line current and the main winding current going through the main winding heater is not significant. Use the line current through the main winding heater and disc to determine the derating effect of that combination. Using 28 amps and entering the curve, select the -7 main winding heater and find that the delta T is 38°C (Fig. 5). The -7 main winding was chosen vs. the -1 because it will allow a lower device opening temperature which is preferrable for loss-of-charge protection.

Through measurements on the compressor, it has been determined that the effective protector ambient that the protector is exposed to under this condition is 62°C. This includes the effect of the room ambient, the winding temperature on one side of the protector and the Freon on the other side. In addition to this delta T, we must add the delta T created by the 5 amps in the start winding. Referring to the delta T curve for the start winding heater which was selected previously, we find that 5 amps creates a delta T of 18° (Fig. 6). Adding these three heat inputs together, it is seen that the minimum opening temperature that could be allowed and still not trip the overload under this max load condition is 118°C.

<u>EPA</u> +	<u>main wdg Δ T</u> +	<u>st wdg Δ T</u>	=	<u>open temp</u>
62°C +	28°C +	18°C	=	118°C

Therefore, to allow a safety factor to prevent nuisance tripping, 125°C is chosen as a minimum opening temperature to which the disc should be calibrated.

5HM ULTIMATE TRIP CURVE
F50 BIMETAL DISC

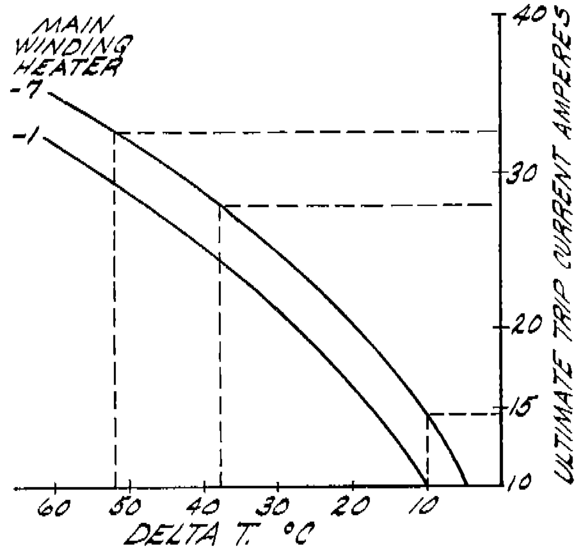

FIG. 5

5HM ULTIMATE TRIP CURVE
START WINDING HEATER

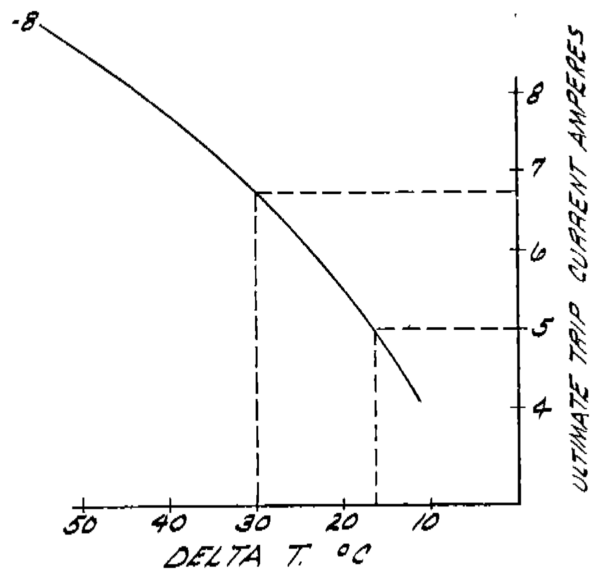

FIG. 6

SELECT THE MAXIMUM OPENING TEMPERATURE

This is done by referring to the running overload data. Having selected the three resistive elements in the device, we check to see whether or not the device will, in fact, trip and at what temperature it must be calibrated. To do this, enter the curve for the main winding heater and disc combination we have selected with 32 amps as listed in the compressor data table for running overload, and find that the delta T is 51°C. The delta T for the start winding current has not changed, it is still 18°C. However, the effective protector ambient has increased to 66°C due to the higher winding temperature created by the higher winding current. Adding these three elements together, it is seen that we should not allow an opening temperature greater than 135°C or the winding temperature will exceed the specified limit.

$$\frac{EPA}{66^\circ C} + \frac{\text{main wdg}\,\Delta T}{51^\circ C} + \frac{\text{st wdg}\,\Delta T}{18^\circ C} = \frac{\text{open temp}}{135^\circ C}$$

CHECK FOR LOSS-OF-CHARGE PROTECTION

Under a loss-of-charge fault condition, the start winding current increases. The line current is reduced, but the effective protector ambient has increased. This is because the refrigerant charge is no longer cooling the motor and is also not reducing the effective protector ambient condition of the protector as it was in the case of running overload and max load. Entering the delta T curve for the start winding heater, we find that 6.5 amps increases the delta T to 30°C. The influence of the line current on the ultimate trip curve for the disc and main winding heater combination is now reduced to 10°C. Adding these together to the EPA of 100°C, indicates that a device calibrated to 140°C will limit the winding temperature to the specified level.

$$\frac{EPA}{100^\circ C} + \frac{\text{main wdg}\,\Delta T}{10^\circ C} + \frac{\text{st wdg}\,\Delta T}{30^\circ C} = \frac{\text{open temp}}{140^\circ C}$$

Since the maximum temperature of the device already selected is 135°C, under conditions of loss-of-charge, the device will trip well before the maximum allowed winding temperature is reached. We have then theoretically made a successful application.

SUMMARY

The device now would be tested in the compressor application for verification of its tripping parameters. In the event that the results are not in agreement with our selection, some adjustment must be made in the parameters. Using the same rationale we have in selecting the protector, various elements in the protector can be adjusted to correct the trip conditions for a specific fault condition and calculate their impact on the other fault conditions. The procedure used here is only precisely appropriate for the particular design of protectors that have been discussed, that is, the 5HM and 6HM devices. However, the basic philosophy in deriving this procedure is applicable to all motor protection devices. That is, to understand the relative importance of various heat input contributions for various fault conditions, and then to work through a logical sequence of selection of the device parameters. One element that requires some judgement initially is the estimation of the effective protector ambient since it is made up of a combination of winding temperature and refrigerant gas temperature which may be quite wide in their values. The judgement as to the actual impact on the bimetal disc requires some experience before the selection of that value is accurate.

ADDENDUM

The use of these devices in addition to providing welded relay protection has also added additional benefit for heat pumps where light load conditions are a problem to protect. The heat inputs under a light load condition is quite similar to the loss-of-charge condition in that the density of refrigerant gas is significantly reduced. The load on the compressor is small and the cooling effect of the gas is reduced; hence, there is a possibility of overheating of the motor windings with quite low line current. Under these conditions, however, the start winding current will increase and the added delta T provided by the start winding heater can provide sufficient input signal to trip the device before the windings overheat. This condition may be substituted for the loss-of-charge condition or added to it and the application procedure outlined in this paper would be essentially the same.