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AN IMPROVED METHOD FOR SELECTING THERMAL OVERLOADS TO PROVIDE HALF VOLTAGE PROTECTION

John R. D'Entremont, Marketing Supervisor
Texas Instruments Incorporated, Motor Controls Department
Attleboro, Massachusetts

ABSTRACT

A condition of half normal voltage imposed on a refrigerator compressor will result in overheating of the motor if the condition persists for an extended time. The line current and heating of the compressor shell are similar to the conditions which exist under peak loading. A thermal overload which allows compressor operation under peak conditions and still prevents overheating when half normal voltage is imposed must be selected carefully. This paper will describe an application technique which has been successfully used to select a proper rating in a systematic manner using existing application curves in a unique way. The paper will illustrate this technique with a theoretical example.

INTRODUCTION

There are infrequent occurrences in the field when the line voltage drops to a point significantly below the level of which a refrigerator is designed to operate. This would be due to an extreme malfunction of the power distribution system caused by a lightning storm for example.

The mechanisms of such a malfunction and number of occurrences are beyond the scope of this paper. The fact is that there is a critical range of voltage which will cause overheating of many refrigerator compressor motors, to the point of permanently damaging the insulation system if the thermal protector is not sized properly to function in that range.

This critical range of voltage extends from the point at which the motor is self-protected due to its own impedance, to the point just below that at which the current starting relay picks up and allows the compressor to run. This range of voltage is typically 40% to 70% of the normal operating line voltage. An example of this range for a 115V compressor is shown in Figure 1.

Thermal protectors, such as the KLIXON MRA type phenolic, dome mounted motor protector respond to current and shell temperature. (Picture 3/4" M.P.)

Since in the 40%-70% voltage range, the compressor is on locked rotor the current and heating rate are directly proportional to the voltage. In addition, the cur-
rent relay has not picked-up and only the main winding is in circuit, resulting in a very low rate of temperature rise. From the viewpoint of the thermal protector, the lowest voltage which causes objectionable overheating provides the least current signal and is, therefore, the most critical application test point. Also, this level of current is frequently very close to the line current draw under peak loading such as on a pull-down when it is not desirable for the thermal overload to cutout. In a pull-down, the compressor motor is being cooled by a flow of refrigerant. The resultant shell temperature is likely to be different from that which occurs for the same current when the compressor is on locked rotor. A careful consideration of these currents and temperatures and selection of the overload characteristics will result in full achievement of the protection goals.

GENERAL APPROACH

It is general industry practice to select a KLIXON Thermal Protector using the application information described as Short Time curves and Ultimate Trip curves. The Short Time curve (see Figure 3) is developed by measuring the trip time of a particular thermal protector, bimetal disc, heater and opening temperature combination when a constant current is applied. The series of trip points taken at room ambient defines the response of the device in the range of 2 to 30 seconds. This curve is used to predict the ability of a specific rating to protect a compressor motor under conditions of locked rotor with nominal line voltage (+15%) applied.

The ambient temperature is increased very slowly until the protector trips. The protector is fitted with thermocouples and heat sinks to simulate an actual installation and the temperature at trip is recorded and this temperature is called the Effective Protector Ambient (E.P.A.). The current is decreased and a new higher ambient is required to trip the device. A series of such points form a what is known as the Ultimate Trip curve. This curve is used to predict response of the thermal protector under conditions of heavy compressor loading such as a pull-down or a running overload which exhibits a very slow rate of temperature rise. (see Figure 4)

The heating rate of a motor, subject to voltage equal to 40%-60% of the normal range, is very similar to the heating rate of a compressor under running overload. It follows, therefore, that despite the fact that the motor is actually in a locked rotor condition that the Ultimate Trip curves should be used to predict the response of a particular protector rating under this condition. (see Figure 5)
One can then plot on a conventional x-y graph of current vs. Effective Protector Ambient (E.P.A.), the critical must trip and must hold points.

The E.P.A. is determined by testing the compressor under peak load and recording temperature of thermocouples located between protector and shell, and on protector case opposite to shell and averaging the values. The same method can be used to find the E.P.A. under half voltage conditions.

The critical points with respect to the must hold condition is the point of peak current in the pull-down cycle with the associated E.P.A. and the point of peak E.P.A. and the associated current. The peak current and the peak E.P.A. may not occur simultaneously in the pull-down cycle. (see Figure 6)

The next step is to find a protector rating which has the proper slope in this area to provide the desired results. In order to better insure that the desired results are obtained over the full range of device operating temperature it is necessary to plot the Ultimate Trip curve of the device at the minimum and maximum opening temperature. The following section will describe a method useful in plotting the band of ultimate trip. (see Figure 7)

**K_t METHOD**

The ultimate trip current is related to the resistance of the thermal protector, the heat dissipation rates and the difference between the device opening temperature and the Effective Protector Ambient of the thermal protector. The following equation describes this relationship.

\[ I^2 K_t = T_o - T_a \]

where:
- \( I \) = current through protector
- \( K_t \) = resistance and heat dissipation constant of the thermal protector
- \( T_o \) = device open temperature
- \( T_a \) = Effective Protector Ambient (E.P.A.)

The \( K_t \) is determined for each combination of bimetal disc and heater and is in tabular form. In addition, the ultimate trip current at an E.P.A. of 71°C for each combination is also calculated for device opening temperatures of 105°C, 120°C and 135°C and is included in the \( K_t \) table.

The equation and the table can be used to develop the ultimate trip plot in the
following manner. Select disc, heater
open temperature and record $K_t$ from table.

<table>
<thead>
<tr>
<th>DISC TYPE</th>
<th>HEATER NUMBER</th>
<th>NOMINAL OPEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kt TABLE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

APPLICATION FOR TYPE AI DISC

<table>
<thead>
<tr>
<th>HTR</th>
<th>DISC</th>
<th>Kd</th>
<th>Kh</th>
<th>TOTAL $K_t$</th>
<th>ULTIMATE TRIP AMPS A 71°C EPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.370</td>
<td>.006</td>
<td>.376</td>
<td>9.586</td>
<td>11.508, 13.152</td>
</tr>
<tr>
<td>10</td>
<td>.370</td>
<td>.175</td>
<td>.545</td>
<td>7.898</td>
<td>9.482, 10.837</td>
</tr>
<tr>
<td>18</td>
<td>.370</td>
<td>.222</td>
<td>.592</td>
<td>7.578</td>
<td>9.008, 10.386</td>
</tr>
<tr>
<td>20</td>
<td>.370</td>
<td>.288</td>
<td>.638</td>
<td>7.300</td>
<td>8.764, 10.016</td>
</tr>
<tr>
<td>22</td>
<td>.370</td>
<td>.412</td>
<td>.780</td>
<td>6.594</td>
<td>7.916, 9.047</td>
</tr>
<tr>
<td>30</td>
<td>.370</td>
<td>1.331</td>
<td>1.701</td>
<td>4.471</td>
<td>5.367, 6.134</td>
</tr>
</tbody>
</table>

Select several values of current which
bracket the critical range and solve fol­lowing equation for E.P.A. ($T_a$)

$$T_a = T_0 - I^2 K_t$$

$T_n$ = nominal opening temperature

The value of this approach will be illus­trated in the next section which discusses
a specific example.

APPLICATION EXAMPLE - A

In this example, the peak pull-down cur­rent is actually higher than the minimum
locked rotor current. The values are rec­orded in Table 1 and plotted on Figure 8.

Table 1

<table>
<thead>
<tr>
<th>CONDITION</th>
<th>CURRENT</th>
<th>E.P.A.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak amps pull-down</td>
<td>6</td>
<td>70°C</td>
</tr>
<tr>
<td>Peak E.P.A.-pull-down</td>
<td>4,8</td>
<td>80°C</td>
</tr>
<tr>
<td>Minimum amps - L.R.</td>
<td>5.2</td>
<td>90°C</td>
</tr>
</tbody>
</table>

The first selection can be made by scan­ning $K_t$ tables and picking out rating
which has Ultimate Trip slightly higher
than 6 amps at 71°C. The type Ai disc
set at 135°C with No. 36 heater is rated
at 6.134 amps Ultimate Trip at 71°C so
we can plot this out after solving equa­tion $T_a = T_0 - I^2 K_t$ and filling in the table.

<table>
<thead>
<tr>
<th>DISC TYPE</th>
<th>HEATER NUMBER</th>
<th>NOMINAL OPEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ai</td>
<td>36</td>
<td>135°C</td>
</tr>
</tbody>
</table>

It becomes obvious from Figure 9 that the
minimum protector will trip on pull-down
and the maximum protector will not trip
at the minimum locked rotor current. The
plot also suggests that a protector with a steeper slope in this area will meet the requirements and this can be achieved with a lower opening temperature device. We then select a protector with 22 heater Ai disc set $105^\circ C$ which has an Ultimate Trip rating of 6.594 amps at $71^\circ C$. (See Kt table)

<table>
<thead>
<tr>
<th>DISC</th>
<th>HEATER</th>
<th>OPEN</th>
<th>$K_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ai</td>
<td>-22</td>
<td>105°C</td>
<td>.782</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CURRENT</th>
<th>E.P.A. °C</th>
<th>E.P.A. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = 110°C</td>
<td>97.5</td>
<td>87.5</td>
</tr>
<tr>
<td>T = 100°C</td>
<td>90.5</td>
<td>80.5</td>
</tr>
<tr>
<td>T = 82°C</td>
<td>82</td>
<td>72</td>
</tr>
<tr>
<td>T = 72°C</td>
<td>72</td>
<td>62</td>
</tr>
</tbody>
</table>

The protector selected would then be tested with a minimum open device on pull-down and the maximum open device on locked rotor. Adjustments may have to be made if our estimation of the E.P.A. were not exact. The protector would also be tested to meet other criteria such as rated-voltage locked rotor and running overload.

**APPLICATION EXAMPLE - B**

Example A illustrates a case where the must hold current is higher than the minimum locked rotor current but the E.P.A. is lower at the must hold point. In Figure 11 & 12, another example is shown where the E.P.A.'s are equal and the must trip current is slightly higher than the must hold current. In this case, the 36Ai set $135^\circ C$ is the proper protector and the 22Ai set $105^\circ C$ is unsatisfactory.

**CURRENT vs. E.P.A.**

- **MIN./MAX. PROTECTOR TEMP 22 Ai set 105°C NOMINAL EXAMPLE "B"**
- **MIN./MAX. PROTECTOR TEMP 36 Ai set 135°C NOMINAL**

**SUMMARY**

The approach illustrated requires that the application engineer determine the maximum current and associated E.P.A. and maximum E.P.A. and associated current on a refrigerator pull-down test. It also requires that he determine the minimum voltage, current and associated E.P.A. that causes objectionable motor overheating. He, then selects an overload which has the proper slope in the critical area by plotting the curve of the minimum and maximum open temperature Ultimate Trip curves and observing the relationship between the critical must hold and must trip points. The selection is then verified by actual tests.

The determination of the maximum allowable motor temperature under minimum applied voltage should take into consideration the relative infrequency of this fault condition. This philosophy should allow higher temperatures than those permitted under more frequent fault conditions.
ADDENDUM

Many applications are such that the must trip current on minimum locked rotor is sufficiently higher than the must hold current on pull-down that this type of rigorous attention to the thermal overload selection need not be taken. It is, however, valuable in cases where those two currents are very close. It may, in fact, allow one to make a successful application in circumstances that previously appeared unsuited. The alternatives to the successful application of the thermal overload would generally result in additional cost. The on-winding protector is a good technical solution, however, the installation cost and inherently long off-time on running overload trips are drawbacks. Supplementary low voltage cut outs can also be applied but also add substantial cost to the control system.

The technique described in the paper is also applicable to Room Air Conditioning compressors where the maximum load, minimum voltage running condition can be substituted for the pull-down condition described in this paper.