Sizing Circuit Breakers for Self-Regulating Heat Tracers

Introduction

Circuit breaker sizing for S/R tracers is quite easily accomplished by using the specification sheet data or CompuTrace® heat tracing design software. However, sometimes an engineer or designer asks "What is the technical basis for sizing data and the resulting design values?" This ThermoTip is intended to show the technical basis on how circuit breaker sizing is accomplished. Key factors in proper sizing are: (1) the specified start-up temperature, (2) the circuit breaker type and ampacity rating, (3) the specific S/R tracer start-up characteristic, and (4) the total length of heat tracer connected to the circuit breaker.

Resistance Characteristic

Since a self-regulating heat tracer has a PTC (positive temperature coefficient) resistance characteristic, resistance increases with temperature. An example of heat tracer effective resistance as a function of tracer (not pipe) temperature is shown in Figure 1. This example is for a freeze protection heat tracer.

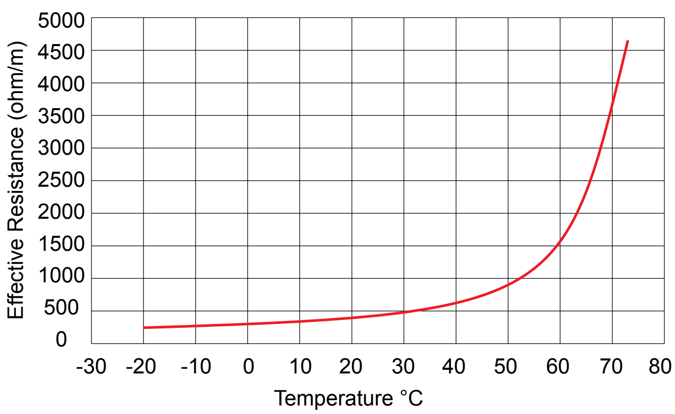

Fig.1: Effective Resistance vs. Tracer Temperature

Note that the resistance of this freeze protection heat tracer gradually increases from -20° C to 30° C. The typical tracer operating temperature range is between 40° C to 60° C. After 60° C the heat tracer starts to exhibit significant increase in resistance as it approaches its "shut-off" temperature near 80° C.

Start-up Current Characteristic

This resistance change with tracer temperature produces the start-up current characteristic of an S/R tracer. An illustrative example of an S/R tracer start-up current characteristic is shown in Figure 2.

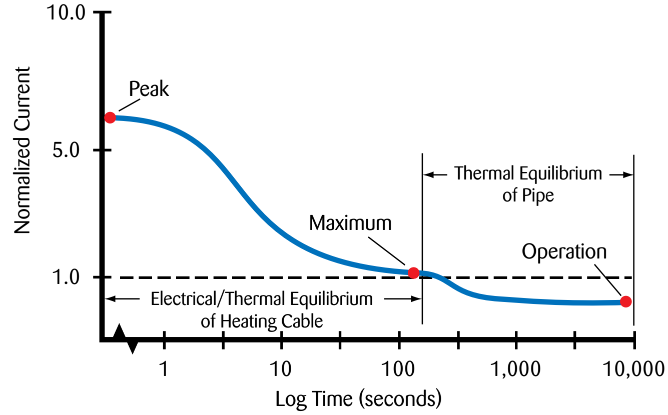

Fig. 2: Self-Regulating Tracer Start-Up Current Response

The start-up current response can be described by three current values:

Peak – the current that occurs just after energization when the tracer temperature is the same as the pipe temperature (during system start-up)

Maximum Current – the current level after the heat tracer has attained its equilibrium temperature above the pipe temperature (usually 300 seconds after energization)

Operating Current – the current level when the pipe has attained its operating temperature or design maintain temperature (several hours after energization depending on the pipe size and fluid contained)

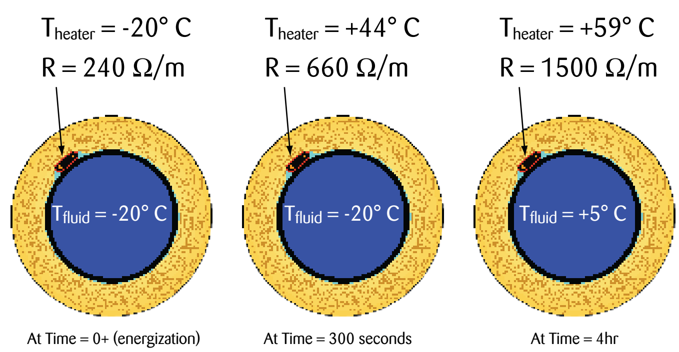

Fig. 3a **Fig. 3b** **Fig. 3c**

Pipe and Tracer Temperature During Start-up

Tracer and pipe temperature for these three current levels are shown in Figure 3.

Fig. 3(a) shows the pipe and tracer at energization. The pipe and tracer are at the same temperature of -20° C. In this example the tracer resistance is 240 Ω/m. The current for this resistance is *PEAK current*.
Fig. 3(b) shows the pipe and tracer after 300 seconds. At this time the pipe has not changed temperature, but the heat tracer has come to its equilibrium temperature of 44° C above the -20° C pipe temperature. The tracer resistance at 44° C is 660 Ω/m. This results in *MAXIMUM current*.

Fig 3(c) shows the pipe at an operating temperature of 5° C. To attain this pipe temperature may have taken several hours depending on the pipe size. The tracer temperature is now 59° C and has a resistance of 1500 Ω/m. The current from this resistance level is *OPERATING current*.

For this example tracer effective resistance is shown as both a function of start-up time and tracer temperature in Figure 4.

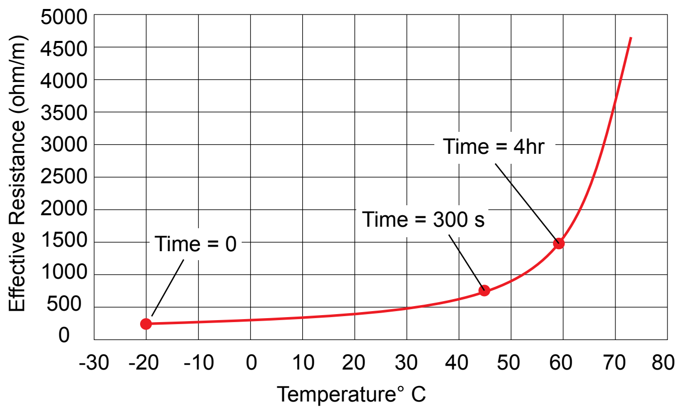

Fig.4: Effective Resistance vs. Tracer Temperature & Time

This is the basis for the typical start up current response shown in Figure 2. When sizing the circuit breaker, the start-up current response of the tracer must not intersect the (minimum) circuit breaker trip curve.

Circuit Breaker Characteristics
Circuit breaker trip curves are typically shown on log-log graphs with multiples of the rated current as a function of time. At 1000 seconds the multiple of rated current is at or near unity. An example of a typical North American circuit breaker response curve is shown in Figure 5.

Note that for this typical North American circuit breaker, the minimum trip curve allows a peak current of 10 times the CB rating. That means for a 20 A breaker a peak current of 200 A would be allowed and not cause a breaker trip. However, after 10 seconds the load current must be under 1.2 times the CB rating or in the case of a 20 A breaker, 24 A.

Circuit breaker trip characteristics are not all the same. Two other common international circuit breaker trip characteristics are Type C and Type B. The trip curves for these two types of circuit breakers are shown in Figure 6(a) and 6(b).

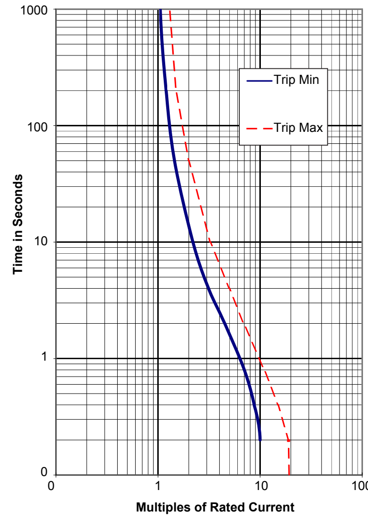

Fig. 5: Typical North American Breaker Trip Curve

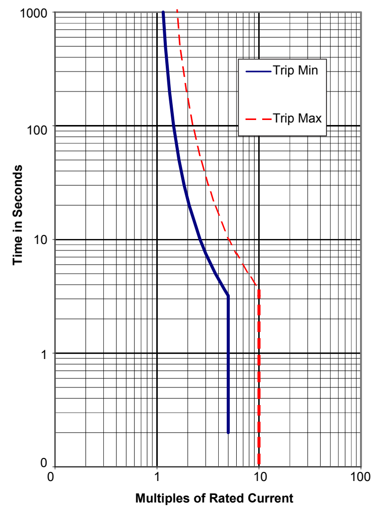

Fig. 6a: Typical IEC Type C Breaker Trip Curve

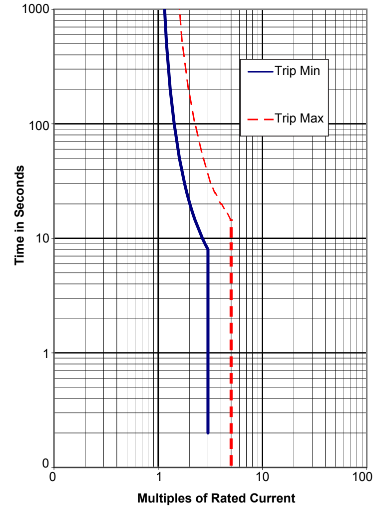

Fig. 6b: Typical IEC Type B Breaker Trip Curve

Other than a lower allowable peak current, the international Type C response curve in Figure 6(a) is quite similar to that of the typical North American circuit breaker. The allowable peak current for the Type B circuit breaker is much lower with a 2.0 multiplier. Thus, when sizing S/R heat load for a circuit breaker, it is important to specify the breaker class or type in addition to its ampacity rating.

The Circuit Breaker Sizing Process

As stated previously the circuit breaker ampacity must be sized so that the tracer start-up current response is under the minimum trip current curve. Or alternatively for a specified circuit breaker, the length of the cable must be sized such that the resulting tracer current response is under the trip curve. For many S/R tracer options, if the *maximum current* value (current at 300 seconds) is equal or lower than the circuit breaker rating, the tracer start-up current response is under the breaker trip curve (there is no intersection). Figure 7 shows an example. Note that the tracer start-up curve is under the breaker trip curve at all points. This could be a case where the S/R tracer *maximum current* at 300 sec is just under 20 A and the breaker rating is 20 A.

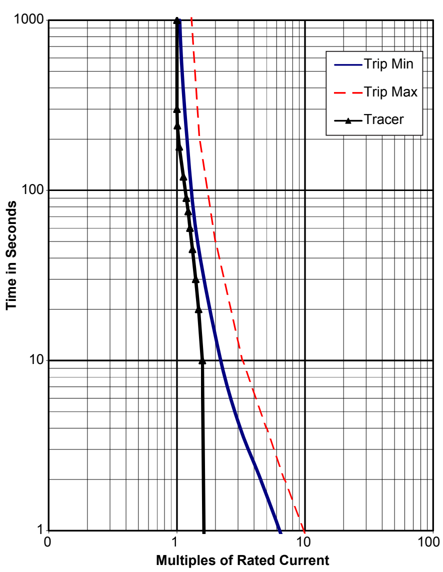

Fig. 7: Typical North American Breaker Trip Curve Maximum Amps - at 100% Loading

There are cases when the tracer *maximum current* and breaker rating are the same and the tracer start-up current intersects the breaker trip curve. Examples are shown in Figure 8(a) and 8(b). For the QO breaker example the intersection occurred in the first 10 seconds. For the Type B breaker the intersection occurred at time 0+ with peak current.

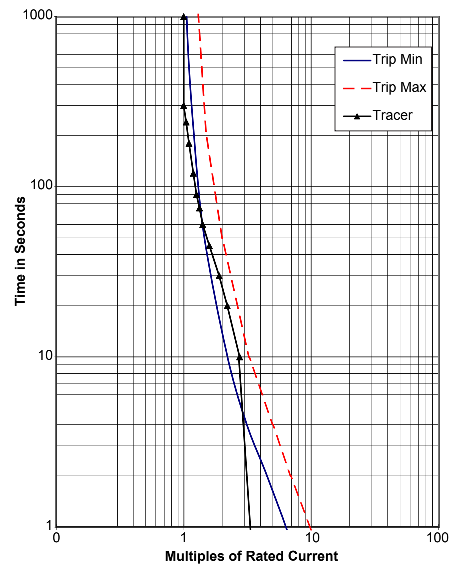

Fig. 8a: Typical North American Breaker Trip Curve

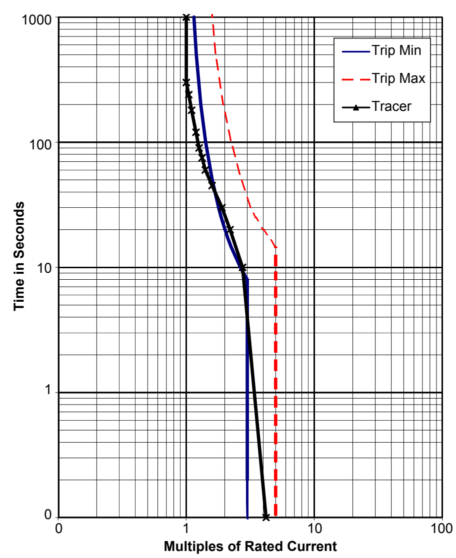

Fig. 8b: Typical IEC Type B Breaker Trip Curve

Sizing Circuit Breakers for Self-Regulating Heat Tracers

To prevent the breaker tripping, both start-up current curves must be shifted to the left so there is no intersection. This shift can be quantified as percentage of the breaker rating. The resulting percentage value is used to de-rate the effective breaker ampacity or circuit length on 100 % loading. This is shown in Figure 9(a) and 9(b).

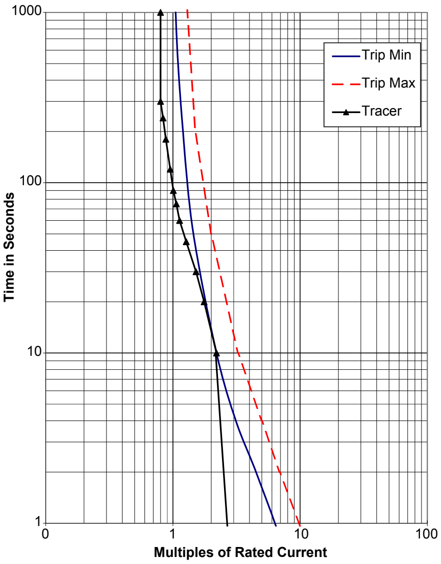

Fig. 9a: Typical North American Breaker Trip Curve Maximum Amps - at 80% Loading

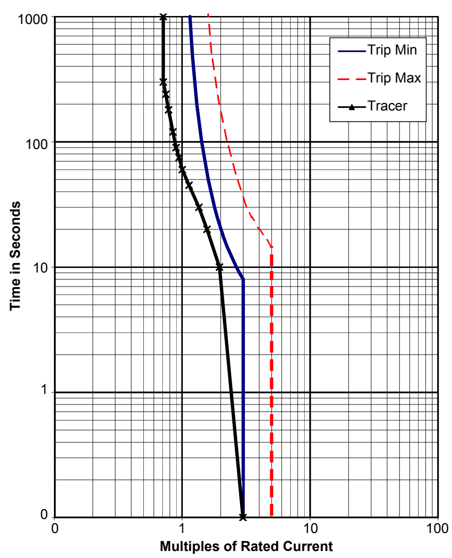

Fig. 9b: Typical IEC Type B Breaker Trip Curve Maximum Amps - at 70% Loading

To avoid an intersection the tracer start-up curve had to be shifted left to 80% of the breaker rating in Figure 9(a) and to 70% of the breaker rating in Figure 9(b). For the North American breaker example, the intersection occurred in the first 10 seconds. For the IEC Type B breaker, the intersection occurred at time 0+ with peak current. If both breakers in these examples had a 20 A rating, the allowable *maximum current* would be 16 A and 14 A, respectively, not 20 A.

So now the question is, "How is *maximum current* established?". Previously, *maximum current* was defined as:

Maximum Current – the current level after the heat tracer has attained its equilibrium temperature above the pipe temperature (usually 300 seconds after energization).

This is the steady-state current for the S/R cable at the specified start-up temperature at the top or maximum end of the manufacturing power output tolerance. Refer to the top line indicated as Max in Figure 10 for an example.

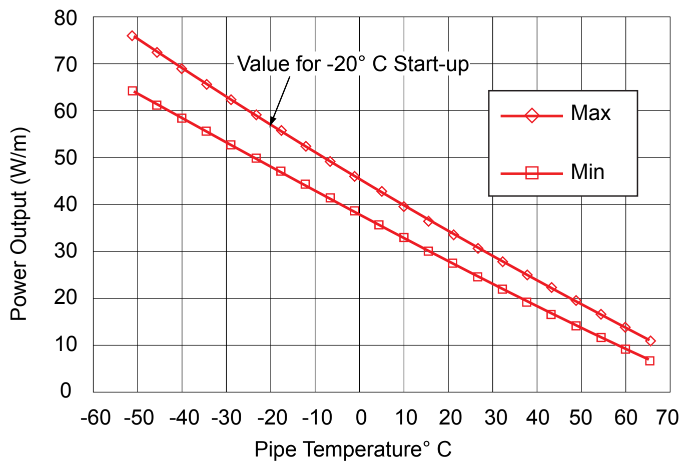

Fig. 10: Max/Min Power Output as a Function of Pipe Temperature

The minimum power output curve, bottom line indicated as Min, is used for design to make up the pipe heat loss. With the self-regulating slope characteristic, the lower the pipe temperature the higher the power and resulting current. This is why circuit breaker sizing data is shown for various start-up temperatures. To be conservative the maximum power output curve or tolerance is used for the *maximum current* value in circuit breaker sizing.

Here is an example of circuit breaker sizing using the basic steps outlined in the preceding discussion.

Given:

- A 240 Vac operating voltage
- A specified North American circuit breaker with an rating of 20 A
- Start-up temperature of -20° C
- A S/R freeze protection tracer with 33 W/m at 10° C (a 10-2 type cable)

What is the maximum length of tracer that can be applied to the specified North American circuit breaker for the above conditions?

Step 1 - When the S/R 10-2 normalized current response is applied to the North American circuit breaker minimum trip curve the offset or loading factor is found to be 80%. (Refer to Fig. 9a)

Step 2 - The specified ampacity for the North American circuit breaker is 20 A. The effective ampacity to avoid tripping with the 80% loading factor is 16 A.

Step 3 - For a start-up at -20° C the maximum power output of the S/R 10-2 heating cable is 57 W/m. At 240 Vac the corresponding maximum current is 0.24 A/m. Refer to Fig. 10.

Step 4 - By dividing the maximum current of 0.24 A/m into the effective ampacity of the 20 A North American circuit breaker of 16 A, the resulting length is 67 m. This is the maximum length of the S/R 10-2 cable that can be applied to the 20 A North American circuit breaker for a -20° C start-up.

Summary

The sizing of a circuit breaker with an S/R tracer depends on a number of factors: (1) start-up temperature, (2) tracer start-up current characteristic, (3) circuit breaker type, and (4) circuit breaker ampacity. This ThermoTip has shown how circuit breaker sizing or establishing a maximum circuit length for a given circuit breaker is accomplished. While this process may seem somewhat complex, Thermon's CompuTrace® design program quickly and easily performs these basic steps according to the user input values for circuit breaker type and ampacity rating found under the SETTINGS tab of the program. Note that Maximum Current in CompuTrace output should not be used for sizing circuit breakers. The circuit breaker sizing tables found on Thermon specification sheets for self-regulating tracers are also based on these basic steps.

In conclusion, use Thermon's CompuTrace design program or the tracer specification sheets for determining maximum tracer circuit lengths.