

MP-04 : THERMAL MODELLING

Basic Thermal Concepts

A thermal model is a mathematical method of dynamically predicting the temperature of an object. The accuracy of the model is a function of its algorithm and the accuracy of the values used for the object's thermal capacitance, thermal resistance to its surroundings, and heat generated in or removed from the object.

Thermal capacitance of an object is the energy required to change its temperature by 1°C if no heat is exchanged with its surroundings (adiabatic process). Since energy (Joules) is the product of power and time, thermal capacitance is measured in Watt•seconds per °C. Thermal resistance of an object is the temperature difference that will cause 1 Watt to flow between it and its surroundings and is expressed in °C per Watt. The product of thermal capacitance and thermal resistance is a thermal time constant.

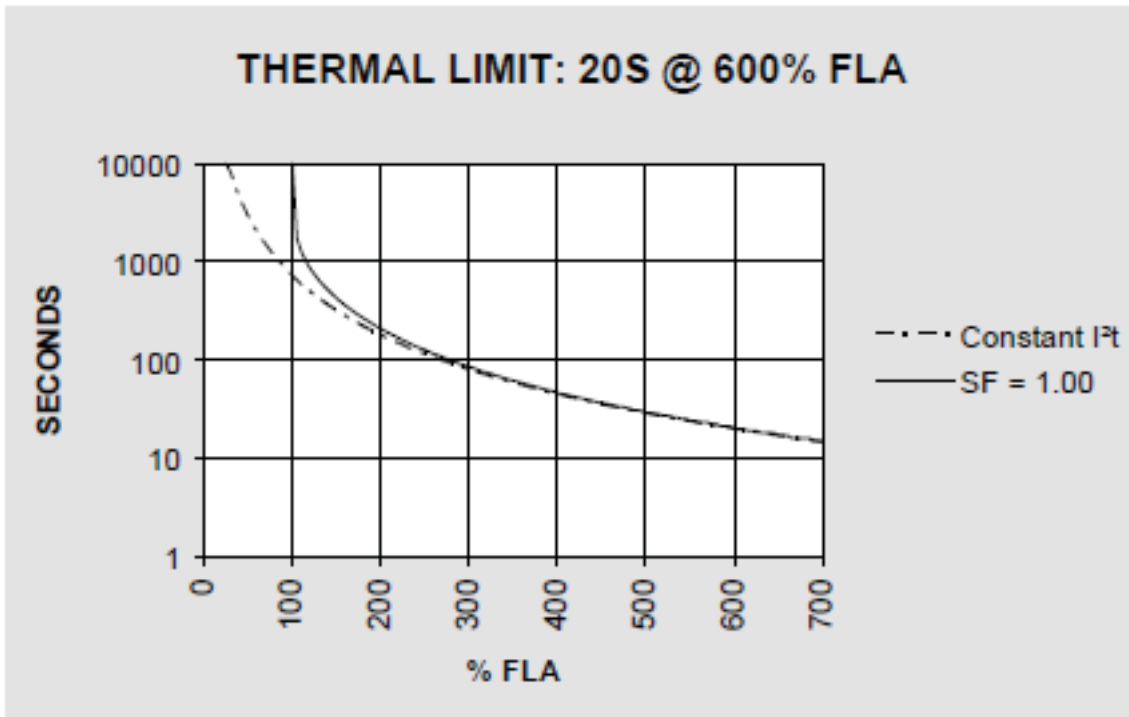
The product of power input and thermal resistance is a temperature rise. At any instant, temperature tends exponentially toward the sum of ambient temperature and the temperature rise. Temperature will be increasing if the temperature rise is greater than the temperature difference between the object and its surroundings. Conversely, an object's temperature will be decreasing if the temperature rise is less than the temperature difference between the object and its surroundings. In all cases, the rate of change of temperature depends on the thermal time constant and the magnitude of the excursion remaining. If power input and ambient temperature remain constant, temperature will change 63% of the remaining excursion in one time constant.

Values of thermal capacitance and thermal resistance are not readily available for an electric motor; however, they are related to its locked-rotor characteristic and to its service factor respectively so that a motor protection relay can determine the motor's thermal time constant. Thermal power input is the only other information required to thermally model the motor. Thermal power input is the difference between the electrical power input to a motor and the mechanical power delivered to its shaft. Unfortunately, this value is not readily available and current measurements must be used to estimate heat generated in a motor. Fortunately, I^2 is a good measure of instantaneous heat generated in a motor and its integral (I^2t) is a measure of the thermal energy input. A good thermal model uses all of this information to determine accumulated thermal energy as a percentage of the thermal energy required to cause a rated temperature rise. This value is called used thermal capacity—it is percent I^2t .

MP-04 : THERMAL MODELLING

I^2t

Allowable locked-rotor time and locked-rotor current plotted on a time-current graph is one point on a motor's thermal-damage curve. Since I^2 is proportional to the power converted to heat in a motor, locked-rotor I^2t is proportional to the quantity of heat (energy) required to cause a rated temperature rise in the motor. The time required to generate the same quantity of heat at other values of current can be determined by equating I^2t at these values to the locked-rotor value:



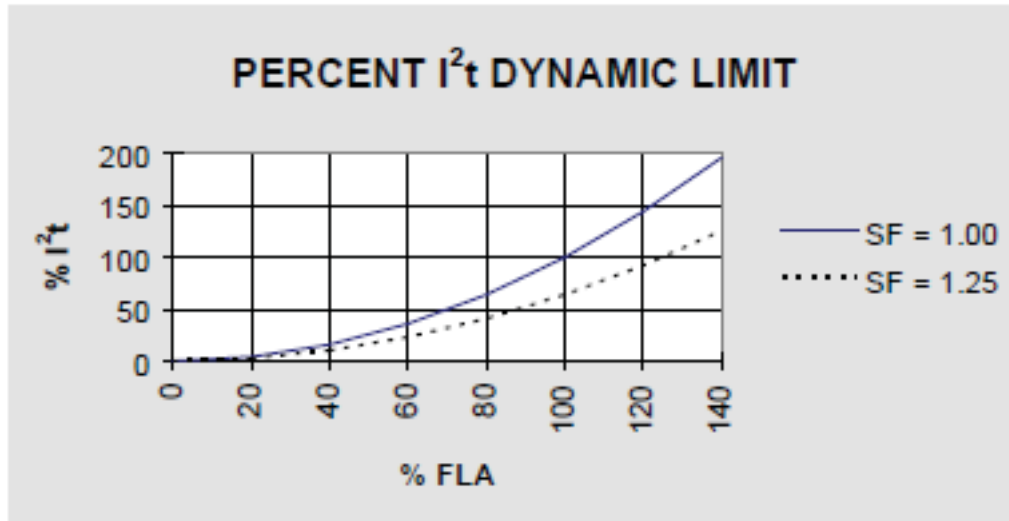
The graph of constant I^2t is a constant-energy plot. It shows the time required for any motor current to cause a rated temperature rise if no heat is lost to the surroundings. The motor's damage curve and the constant- I^2t curve diverge at low current because the motor's cooling system is designed to dissipate the heat generated at 100% FLA. At high current levels, the constant- I^2t curve and the motor's thermal-damage curve converge because the motor's cooling is insignificant with respect to the heat generated in the motor. In this range, the time required for a trip to occur is much less than the thermal time constant of the motor.

MP-04 : THERMAL MODELLING

MPU-32 and MPS Thermal Model

Since a thermal-damage curve and its associated constant I^2t curve are close together above 300% FLA, electronic overload relays that simply calculate a time-to-trip based on current can provide protection for a cold, locked-rotor start. When motor current is less than 200% FLA, motor cooling is effective and the process is not adiabatic. Consequently, the algorithms used in these relays are usually incapable of tracking used thermal capacity of a running motor. This type of thermal modelling is inadequate because the time-to-trip for an overload is the same whether the motor has been operating at rated conditions or at no load. A characteristic of these relays is that they return $\%I^2t$ to a fixed value during running conditions.

The MPU-32 and MPS thermal model uses basic thermal concepts to determine used thermal capacity. The algorithm is continuous for all values of current and $\%I^2t$ always tends toward a final value that is a function of motor current and service factor. The following graph shows this limit for the current range in which a motor spends most of its time:



Unused thermal capacity determines the time-to-trip for overloads above the minimum current capable of causing I^2t to reach 100%. The higher $\%I^2t$ is when an overload is initiated, the faster the trip will occur. For overloads in the range where motor cooling is insignificant, time-to-trip is directly proportional to unused thermal capacity. For overloads where motor cooling is significant, time-to-trip is proportionally larger than unused thermal capacity. This thermal modelling technique allows the MPU-32 and MPS to continuously provide protection through starting, running, overload, and cooling cycles.