



# **SNS COLLEGE OF TECHNOLOGY**

**(An Autonomous Institution)**



**COIMBATORE-35**

**Accredited by NBA-AICTE and Accredited by NAAC – UGC with A++ Grade  
Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai**

## **DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING**

**COURSE NAME: 2EEB210 / Electrical Machines and Drives**

**II YEAR / IV SEMESTER**

**Unit I – ELECTRICAL MOTORS**

**Topic : HEATING AND COOLING CURVES**



# HEATING AND COOLING CURVES

- A machine can be considered as a homogeneous body developing heat internally at uniform rate and dissipating heat proportionately to its temperature rise,

## RELATION SHIP BETWEEN TEMPERATURE RISE AND TIME

let

|            |                                                                                                                                                            |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $P$        | =heat developed, joules/sec or watts                                                                                                                       |
| $G$        | =weight of active parts of machine, kg                                                                                                                     |
| $h$        | =specific heat per kg per deg cell                                                                                                                         |
| $S$        | = cooling surface, m <sup>2</sup>                                                                                                                          |
| $\lambda$  | = specific heat dissipation (or) emissivity, J per sec per m <sup>2</sup> of<br>Surface per deg cell difference between surface and ambient cooling medium |
| $\theta$   | = temperature rise, deg cell                                                                                                                               |
| $\theta_m$ | =final steady temperature rise, deg cell                                                                                                                   |
| $t$        | =time, sec                                                                                                                                                 |
| $\tau$     | =heating time constant, seconds                                                                                                                            |
| $\tau'$    | =cooling time constant, seconds                                                                                                                            |



# HEATING AND COOLING CURVES

Assume that a machine attains a temperature rise after the lapse of time  $t$  seconds.

In an element of time “ $dt$ ” a small temperature rise “ $d$ ” takes place.

Then,

$$\text{Heat developed} = p \cdot dt$$

$$\text{Heat developed} = Gh \cdot dq$$

$$\text{Heat dissipated} = Sq \cdot dt$$

Therefore, total heat developed = heat stored + heat dissipated



# HEATING AND COOLING CURVES

$$Gh d\theta + S \theta \lambda \cdot dt = p \cdot dt$$

$$\frac{d\theta}{dt} + \theta \cdot \frac{s\lambda}{Gh} = \frac{p}{Gh}$$

This is a differential equation and solution of this equation is,

$$\theta = \frac{P}{s\lambda} + ke^{-(s\lambda / Gh)t}$$

Where k is a constant of integration determined by initial conditions.  
Let the initial temperature rise to be zero at  $t=0$ .

$$\text{Then, } 0 = \frac{P}{s\lambda} + k$$

$$k = \frac{-P}{s\lambda}$$



# HEATING AND COOLING CURVES

Hence, 
$$\theta = \frac{P}{s\lambda} (1 - e^{-\left(\frac{s\lambda}{Gh}\right)t}) \quad \text{----- (1)}$$

When  $t = \infty$ ,  $\theta = \frac{P}{s\lambda} = \theta_m$ , the final steady temperature rise.

Represent  $\frac{P}{s\lambda} = \theta_m$  and  $\frac{Gh}{s\lambda} = \tau$  ----- (2)

Equation 1 can be written as

$$\theta = \theta_m (1 - e^{-1}) \quad \text{----- (3)}$$

Where  $\tau$  is called as heating time constant and it has the dimensions of time.



# HEATING AND COOLING CURVES

## Heating time constant

Heating time constant is defined as the time taken by the machine to attain 0.623 of its final steady temperature rise.

When  $t = \tau$ ,

$$\theta = \theta_m(1 - e^{-1})$$
$$\theta = 0.632\theta_m$$

The heating time constant of the machine is the index of time taken by the machine to attain its final steady temperature rise.

We know that  $\tau = \frac{Gh}{s\lambda}$ , therefore, the time constant is inversely proportional to has a larger value for ventilated machines and thus the value of their heating time constant is small.

The value of heating time constant is larger for poorly ventilated machines with large or totally enclosed machines, the heating time constant may reach several hours or even days.



# HEATING AND COOLING CURVES

When a hot body is cooling due to reduction of the losses developed in it, the temperature time curve is again an exponential function

$$\theta = \theta_f + (\theta_i - \theta_f)e^{-\frac{t}{\tau}} \quad \text{----- (4)}$$

Where,

$\theta_f$  = final temperature drop (the temperature at which whatever heat is generated is dissipated)

$\frac{P}{s\lambda}$  = where,  $\lambda$  is rate of heat dissipation while cooling

$\theta_i$  = the temperature rise above ambient in the body at time  $t=0$

$\tau$  = cooling time constant =  $\frac{Gh}{s\lambda}$

If motor where disconnected from supply during cooling, there would be no losses taking place and hence, final temperature reached will be the ambient temperature.

There fore,  $\theta_f = 0$  and hence equation (4) becomes

$$\theta = \theta_i e^{-\frac{t}{\tau}}$$

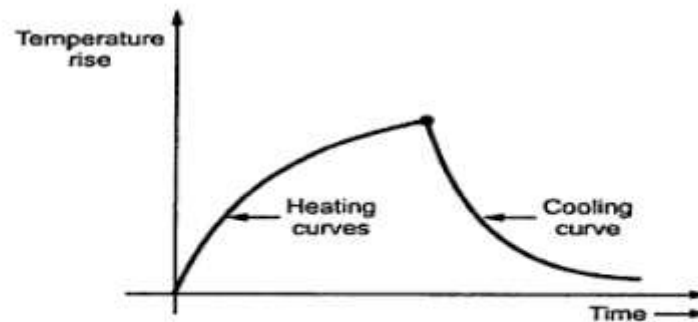


# HEATING AND COOLING CURVES

## Cooling time constant

$$\text{At } t = \tau, \theta = 0.368\theta_i$$

Cooling time constant is, therefore, defined as the time required cooling the machine down to 0.368 times the initial temperature rise above ambient temperature.



*Fig.1.2 Heating and cooling time curves*





KEEP  
LEARNING.

Thank u

SEE YOU IN NEXT CLASS