permissible temperature rise. e.g fans, pumps. 15

Intermittent Rating- The output of Motor can given for a specified short-time (say 1 hour, 1/2 hour, 1/4 hour) without exceeding the permissible temperature rise. e.g. mixies.

Heating and cooling curves:-

* In many of the industrial applications, electric motors are widely used.
* During the operation of motor, various losses are occur such as copper loss, iron loss and windage loss etc.
* Due to these losses, heat is produced inside the machine. This increases the temperature of the motor.
* The Temperature when reaches beyond the ambient value, a part of heat produced starts flowing to the surrounding medium
* Assume a motor as a homogeneous body with uniform temperature gradient. The heat which is generated at all points has same temperature.
* The points at which heat is dissipated to the cooling medium are also at same temperature.
* The heat dissipation is proportional to the difference of the temperatures of the body and surrounding medium.
* If cooling is not provided then motor can not dissipate heat to surrounding medium. This will increase temperature to a very high value.

Heating curves :-

* Consider a homogeneous machine, developing heat internally at a uniform rate and gives it to the surroundings proportional to temperature rise.

* It will obeys exponential law.

let

W - Loss taking Place in a machine in W

G - Mass of the Machine in kg

S - specific heat in watt-sec/kg°c

θ - Rise in temperature above ambient Temperature in °c

θ_F - Final temperature rise with continuous load in°c

A - Area of cooling surface in m^2

λ - Rate of heat dissipation in watts/sq.m/°c

Let us consider the small time interval 'dt' in which temperature rise of the Machine is 'dθ'.

Total losses in machine during time interval $dt = W.dt$

Heat dissipation from surface during the same time interval $= A\lambda\theta.dt$

Additional heat stored in the Machine $= G.sd\theta$

$\therefore$ Heat Developed = Heat Absorbed + Heat Dissipated

$$W \cdot dt = G \cdot S \cdot d\theta + A\lambda\theta \cdot dt \longrightarrow (1)$$

$$\therefore \; W \cdot dt - A\lambda\theta \cdot dt = G \cdot S \cdot d\theta$$

$$(W - A\lambda\theta)dt = G \cdot S \cdot d\theta$$

$$\frac{dt}{G \cdot S} = \frac{d\theta}{W - A\lambda\theta}$$

$$\frac{dt}{\left(\frac{G S}{A\lambda}\right)} = \frac{d\theta}{\left(\frac{W}{A\lambda} - \theta\right)} \longrightarrow (2)$$

When final temperature is reached, there is No heat absorbed. The heat which is generated is totally dissippated.

$$\therefore \; W \cdot dt = A\lambda\theta_F \cdot dt$$

$$W = A\lambda\theta_F$$

$$\theta_F = \frac{W}{A\lambda} \longrightarrow (3)$$

sub (3) in (2) we get

$$\frac{dt}{\left(\frac{G \cdot S}{A\lambda}\right)} = \frac{d\theta}{\theta_F - \theta} \longrightarrow (4)$$

by integrating eq (4)

$$\int \frac{dt}{\left(\frac{GS}{A\lambda}\right)} = \int \frac{d\theta}{\theta_F - \theta}$$

$$\frac{A\lambda}{GS} \cdot t = -\ln(\theta_F - \theta) + K \longrightarrow (5)$$

where K = constant of integration

To find out value of K, let us use initial condition

At $t = 0, \theta = \theta_1$

$$0 = -\ln(\theta_F - \theta_1) + K$$

$$K = +\ln(\theta_F - \theta_1) \longrightarrow (6)$$

sub (6) in (5)

$$\frac{A\lambda}{G \cdot S} \cdot t = -\ln(\theta_F - \theta) + \ln(\theta_F - \theta_1)$$

$$\frac{A\lambda}{G \cdot S} \cdot t = \ln_e\left(\frac{\theta_F - \theta_1}{\theta_F - \theta}\right) \Rightarrow e^{\left(\frac{A\lambda t}{G S}\right)} = \frac{\theta_F - \theta_1}{\theta_F - \theta}$$

(18)

$$\therefore \quad e^{\frac{A\lambda}{GS}\cdot t} = \frac{\theta_F - \theta_1}{\theta_F - \theta}$$

$$\theta_F - \theta = (\theta_F - \theta_1)\, e^{-\frac{A\lambda}{GS}\cdot t}$$

$$\theta = \theta_F - (\theta_F - \theta_1)\, e^{-\frac{A\lambda}{GS}\cdot t} \rightarrow (7)$$

The term $GS/A\lambda$ is called heating time constant of the machine and is denoted by τ.

$$\theta = \theta_F - (\theta_F - \theta_1)\, e^{-t/\tau} \rightarrow (8)$$

If the machine is started from ambient temperature $\theta_1 = 0°C$.

$$\therefore \quad \theta = \theta_F (1 - e^{-t/\tau}) \rightarrow (9)$$

let us consider $t = \tau$ then

$$\theta = \theta_F(1 - e^{-1}) = \theta_F\left(1 - \frac{1}{e}\right)$$

$$\theta = 0.632\, \theta_F$$

|||ly
$t = 2\tau$, $\theta = 0.865\theta_F$
$t = 3\tau$, $\theta = 0.95\theta_F$
$t = 4\tau$, $\theta = 0.982\theta_F$

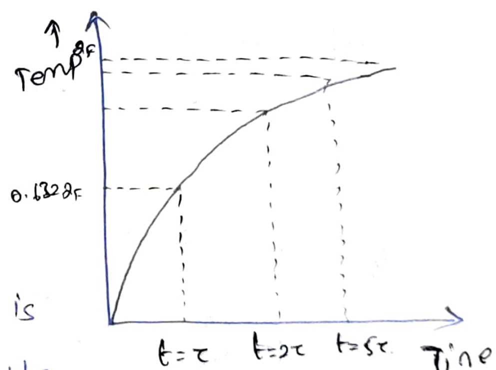

Fig: Heating time curve.

* Final Temperature (θ_F) is reached only after infinite time.

Cooling curve:-

* If the machine is switched off from the supply or when the load is reduced, the machine cools.
* If machine is switched off, there is No heat generation and all the heat stored in the machine is dissipated to surroundings.

$\therefore \quad W \cdot dt + GS\, d\theta = A\lambda\theta \cdot dt \rightarrow (10)$

$(A\lambda\theta - W)\,dt = GS\, d\theta$

$$\frac{GS}{A\lambda'}\, d\theta = \left(\theta - \frac{W}{A\lambda'}\right) dt \rightarrow (11)$$

Here $d\theta$ is decrease in temperature so multiply by $-$ve

$$-\frac{GS}{A\lambda'}\, d\theta = \left(\theta - \frac{W}{A\lambda'}\right) dt \Rightarrow -\frac{d\theta}{\left(\theta - \frac{W}{A\lambda'}\right)} = \frac{dt}{\left(\frac{GS}{A\lambda'}\right)}$$

$$-\int \frac{d\theta}{\left(\theta - \frac{W}{A\lambda'}\right)} = \int \frac{dt}{\left(\frac{GS}{A\lambda'}\right)} \rightarrow (12)$$

From eq (3)

$$\theta_F' = \frac{W}{A\lambda'} \rightarrow (13)$$

sub (13) in (12)

$$-\int \frac{d\theta}{(\theta - \theta_F')} = \frac{A\lambda'}{GS} \int dt$$

$$-\ln(\theta - \theta_F') = \frac{A\lambda'}{GS} \cdot t + K$$

$$\ln(\theta - \theta_F') = -\frac{A\lambda'}{GS} \cdot t + K \rightarrow (14)$$

At $t = 0, \theta = \theta_0$ in eq (14)

$$\ln(\theta_0 - \theta_F') = K \rightarrow (15)$$

sub eq (15) in (14)

$$\ln(\theta - \theta_F') = -\frac{A\lambda'}{GS} \cdot t + \ln(\theta_0 - \theta_F')$$

$$\ln\left(\frac{\theta - \theta_F'}{\theta_0 - \theta_F'}\right) = -\frac{A\lambda'}{GS}\, t$$

$$\frac{\theta - \theta_F'}{\theta_0 - \theta_F'} = e^{-\frac{A\lambda'}{GS} \cdot t} \qquad \left[\because \tau' = \frac{GS}{A\lambda'}\right]$$

$$\theta = \theta_F' + (\theta_0 - \theta_F')\, e^{-t/\tau'} \rightarrow (16)$$

If $\theta_F' = 0$ i.e after cooling

$$\theta = \theta_0\, e^{-t/\tau'} \rightarrow (17)$$

$t = \tau'$, $\theta = 0.367\theta_0$.

* cooling time constant is defined as the time required to cool is 0.367 times the initial temperature rise above

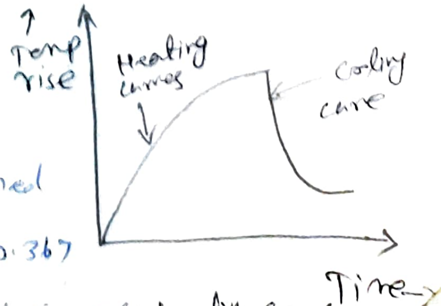

Fig. heating & cooling curve