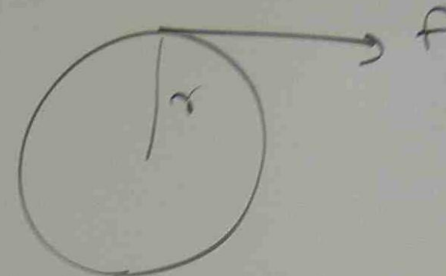
FORCE = $9.8m$



$T = F \times r$

(N)

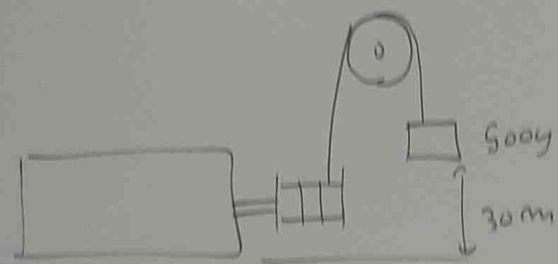
$$\text{POWER} = \frac{\text{WORK DONE}}{\text{TIME}}$$

$$\text{POWER OF MOTOR} = \frac{nT}{9.55}$$

n = SPEED (RPM)

T = TORQUE

① AN ELECTRIC MOTOR LIFT THE MASS OF 500g THROUGH A HEIGHT OF 30 m IN 12 SECONDS. CALCULATE THE POWER DEVELOPED BY THE MOTOR IN KILOWATT AND IN HORSE POWER.



$$F = mg = 500 \times 9.81 \quad N$$

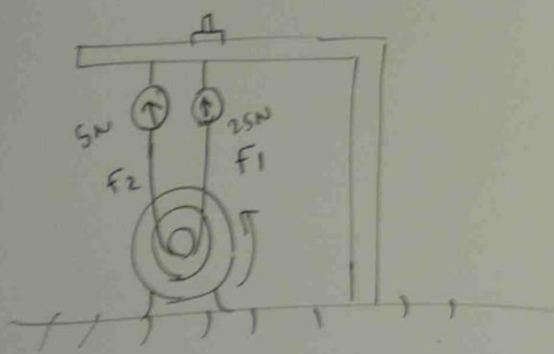
$$W = F \times h = 500 \times 9.81 \times 30 \quad (J)$$

$$P = \frac{W}{t} = \frac{500 \times 9.81 \times 30}{12} = 12250W$$

$$= 12.25kW$$

$$HP = \frac{12250}{746} = 16.4 \, HP$$

(2) DURING A PRONY BRAKE TEST ON ELECTRIC MOTOR, THE SPRING SCALE INDICATES 25 N AND 5 N RESPECTIVELY. CALCULATE THE POWER OUTPUT IF THE MOTOR TURNS AT 1700 RPM AND THE RADIUS OF THE PULLEY IS 0.1m.



$$T = (F_1 - F_2) r$$

$$= (25 - 5) \times 0.1$$

$$= 20 \times 0.1$$

$$= 2 \text{ (N-m)}$$

$$P = \frac{n T}{9.55} = \frac{1700 \times 2}{9.55}$$

$$= 356 \text{ W}$$

KINETIC ENERGY OF LINEAR MOTION

$$KE = \frac{1}{2} m v^2$$

KE = KINETIC ENERGY (J)

m = MASS (kg)

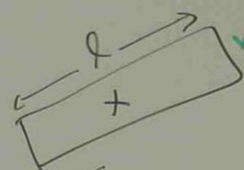
v = VELOCITY (m/s)

KINETIC ENERGY OF ROTATION, MOMENT OF INERTIA

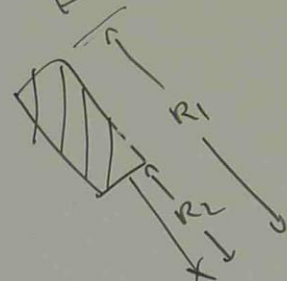
$$I = m r^2$$

$$I = \frac{1}{2} m r^2$$

$$I = \frac{m}{2}\left(R_1^2 + R_2^2\right)$$



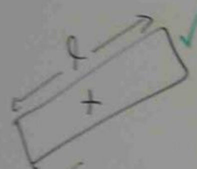
$$I = \frac{m l^2}{12}$$



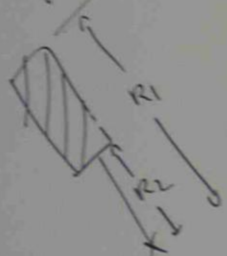
$$I = \frac{m}{3}\left(R_1^2 + R_2^2 + R_1 R_2\right)$$

Pb A FLYWHEEL HAVING THE SHAPE GIVEN IN FIGURE COMPOSES OF A RING SUPPORTED BY A RECTANGULAR HUB. THE RING AND HUB RESPECTIVELY HAVE A MASS OF 80 kg AND 20 kg. CALCULATE THE MOMENT OF INERTIA OF THE FLYWHEEL.

$$I = \frac{m}{2}\left(R_1^2 + R_2^2\right)$$



$$I = \frac{m l^2}{12}$$



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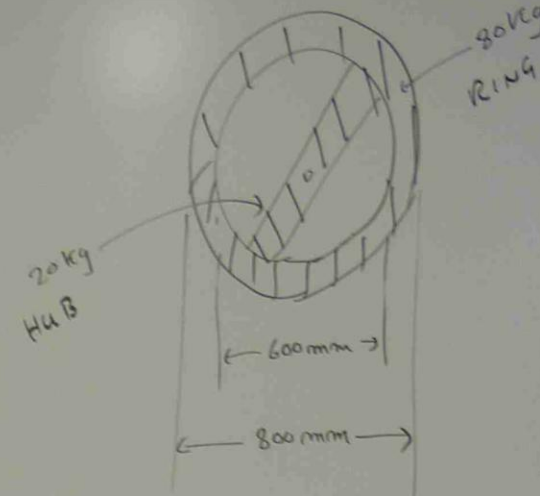
Pb/ A FLYWHEEL HAVING THE SHAPE GIVEN IN FIGURE COMPOSES OF A RING SUPPORTED BY A RECTANGULAR HUB. THE RING AND HUB RESPECTIVELY HAVE A MASS OF 80kg AND 20kg. CALCULATE THE MOMENT OF INERTIA OF THE FLYWHEEL.



RING

$$I_1 = \frac{m}{2}\left(R_1^2 + R_2^2\right)$$

$$= \frac{80}{2}\left[\left(\frac{800\times10^{-3}}{2}\right)^2 + \left(\frac{600\times10^{-3}}{2}\right)^2\right]$$

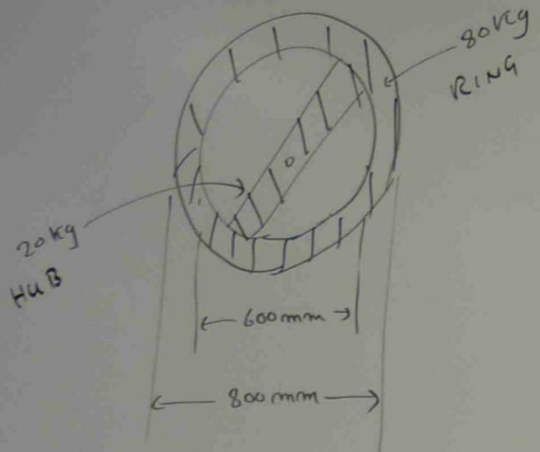
$$= 10 \text{ kg-m}^2$$

HUB

$$I_2 = \frac{m l^2}{12} = \frac{20\times\left(600\times10^{-3}\right)^2}{12}$$

$$= 0.6 \text{ kg-m}^2$$

$$I_T = I_1 + I_2 = 10 + 0.6 = 10.6 \text{ kg-m}^2$$



RING

$$I_1 = \frac{m}{2}\left(R_1^2 + R_2^2\right)$$

$$= \frac{80}{2}\left[\left(\frac{800\times10^{-3}}{2}\right)^2 + \left(\frac{600\times10^{-3}}{2}\right)^2\right]$$

$$= 10 \text{ kg-m}^2$$

HUB

$$I_2 = \frac{m l^2}{12} = \frac{20\times(600\times10^{-3})^2}{12}$$

$$= 0.6 \text{ kg-m}^2$$

$$I_T = I_1 + I_2 = 10 + 0.6 = 10.6 \text{ kg-m}^2$$

TORQUE, INERTIA AND CHANGE OF SPEED

$$\Delta n = \frac{9.55\, T\, \Delta t}{I}$$

Δn = CHANGE OF SPEED (RPM)

T = TORQUE (N-m)

Δt = TIME TAKEN FOR CHANGE (sec)

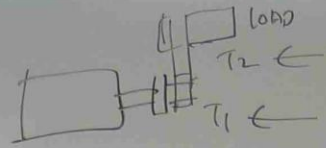
I = MOMENT OF INERTIA (kg-m^2)

pb THE FLY WHEEL HAVING MOMENT OF INERTIA 10.6 kg-m^2 IN PREVIOUS PROBLEM TURNS AT 60 RPM. BY APPLYING THE TORQUE 20 N-m, THE SPEED IS INCREASED TO 600 RPM. HOW LONG MUST THE TORQUE BE APPLIED?

$$\Delta n = 600 - 60 = 540 \text{ RPM}$$

$$\Delta n = \frac{9.55\, T\, \Delta t}{I} \rightarrow 540 = \frac{9.55\times 20\times \Delta t}{10.6}$$

$$\Delta t = \frac{540\times10.6}{9.55\times20} = 30 \text{ sec}$$



$$\Delta n = \frac{9.55\,(T_m - T_L)\,\Delta t}{I}$$

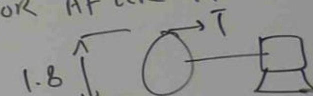
pb

A LARGE REEL OF PAPER INSTALLED AT THE END OF A PAPER MACHINE HAS A DIAMETER OF 1.8 m. A LENGTH OF 5.6 m AND A MOMENT OF INERTIA 4 500 kg – m². IT IS DRIVEN BY A DIRECTLY COUPLED VARIABLE SPEED DC MOTOR TURNING AT 120RPM. THE PAPER IS KEPT UNDER A CONSTANT TENSION OF 6000 N.

(a) CALCULATE THE POWER OF THE MOTOR WHEN THE REEL TURNS AT A CONSTANT SPEED 120 RPM.

(b) IF THE SPEED HAS TO BE RAISED FROM 120 RPM TO 160 RPM IN 5 SECONDS, CALCULATE THE TORQUE THAT MOTOR MUST BE DEVELOPING DURING THIS INTERVAL

(c) CALCULATE THE POWER OF THE MOTOR AFTER IT HAS REACHED THE DESIRED SPEED OF 160 RPM



(a) $T = F r = 6000 \times \frac{1.8}{2} = 5400\,N\text{-}m$

$$P = \frac{nT}{9.55} = \frac{120 \times 5400}{9.55} = 67850\,W = 67.85\,kW$$

(b) $$\Delta n = \frac{9.55\, T\, \Delta t}{I} \rightarrow (160-120) = \frac{9.55 \times (T_m - T_L) \times 5}{4500}$$

$$40 = \frac{9.55(T_m - 5400) \times 5}{4500}$$

$$T_m = 9170\ N\text{-}m$$

(c) $$P = \frac{nT}{9.55} = \frac{160 \times 9170}{9.55}$$

$$= 153600\,W$$

$$= 15.36\,kW$$

HEAT DISSIPATED BY MOTOR

HEAT TRANSFER BY CONDUCTION

HEAT TRANSFER BY CONVECTION

HEAT TRANSFER BY RADIATION

HEAT TRANSFER BY CONDUCTION => $P = \frac{\lambda A (T_1 - T_2)}{d}$

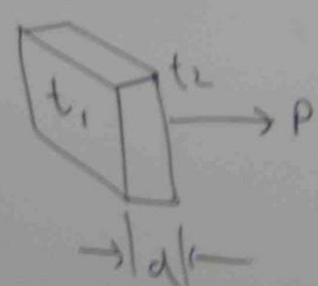
P = POWER OF HEAT TRANSMITTED (W)

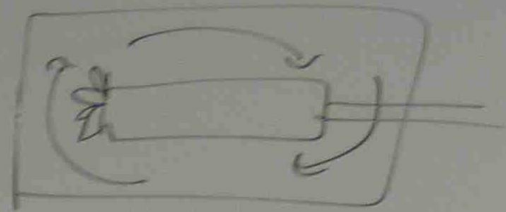
λ = THERMAL CONDUCTIVITY OF BODY (W/m °C)

A = SURFACE AREA OF BODY (m^2)

$T_1 - T_2$ = DIFFERENCE IN TEMPERATURE BETWEEN OPPOSITE FACES

d = THICKNESS OF THE BODY (m)





HEAT TRANSFER BY CONVECTION = $3A\,(T_1 - T_2)^{1.25}$
P

HEAT TAKEN AWAY BY BLOWER = $1280\,V\,(T_1 - T_2)$

V = VOLUME OF COOLING AIR cm^3/sec

HEAT TRANSFER BY RADIATION = $KA\,(T_1^4 - T_2^4)$

$T_1 = 273 + t\,(C)$
(°K)

ABSOLUTE TEMPERATURE

pb A TOTALLY ENCLOSED MOTOR HAS AN EXTERNAL SURFACE AREA OF $1.2\,m^2$. WHEN IT OPERATES AT FULL LOAD, THE SURFACE TEMPERATURE RISES TO 60°C IN AN AMBIENT OF 20°C. CALCULATE HEAT LOSS BY NATURAL CONVECTION.

$$P = 3A\,(T_1 - T_2)^{1.25}$$

$$= 3 \times 1.2\,(60 - 20)^{1.25} = 362\,W$$

/sec

---

pb A FAN RATED AT 3.75 KW BLOWS $240\,m^3/min$ OF AIR THROUGH A 750 KW MOTOR TO CARRY AWAY THE HEAT. IF THE INLET TEMPERATURE IS 22°C AND THE OUTLET TEMPERATURE IS 31°C. ESTIMATE THE LOSSES IN THE MOTOR.

$$P = 1280\,V\,(T_1 - T_2)$$

$$= 1280 \times \frac{240}{60} \times (31 - 22)$$

$$= 46000\,W = 46\,kW$$

PD

THE MOTOR IN ABOVE QUESTION IS COATED WITH A NON METALLIC ENAMEL CALCULATE THE HEAT LOSS BY RADIATION. KNOWING THAT ALL SURROUNDING OBJECTS ARE AT AN AMBIENT TEMPERATURE OF 20°C

$K = 5 \times 10^{-3}$, $A = 1.2\,m^2$

$$P = KA\left(T_1^4 - T_2^4\right)$$

$$= 5 \times 10^{-3} \times 1.2\left((60+273)^4 - (20+273)^4\right)$$

$$= 5 \times 10^{-3} \times 1.2\left(333^4 - 293^4\right)$$

$$= 296\,W$$

POWER LOSSES IN MOTOR

MECHANICAL LOSS

WINDAGE LOSS

- BEARING
- BRUSH
- COMMUTATOR
- SLIP RING

FRICTION LOSS.

ELECTRICAL LOSS

- CONDUCTOR
- BRUSH
- IRON LOSS

$$p = 1000\, J^2 \rho / \beta$$

p = SPECIFIC CONDUCTOR POWER LOSS

W/kg

J = CURRENT DENSITY (A/mm^2)

β = DENSITY OF CONDUCTOR

ρ = RESISTIVITY (nΩ-m)

AN AC MACHINE TURNING AT 875 RPM CARRIES THE ROTOR WINDING WHOSE TOTAL WEIGHT IS 40 kg. THE CURRENT DENSITY IS $5\,A/mm^2$ AND OPERATING TEMPERATURE IS $80^\circ C$. TOTAL IRON LOSSES ARE 1100W

$\rho = 21.3\ n\Omega - m$, $\beta = 8890$

CALCULATE (a) THE COPPER LOSSES

(b) THE MECHANICAL DRAG (N-m) DUE TO IRON LOSSES.

(a) $$P = 1000\,\rho\,J^2/\beta$$

$$= \frac{1000 \times 21.3 \times (5)^2}{8890}$$

$$= 60\ W/kg$$

TOTAL POWER LOSS = $60\ W/kg \times 40\,kg = 2400W$

(b) $$P = \frac{nT}{9.55} \Rightarrow 1100 = \frac{875 \times T}{9.55} \rightarrow T = \frac{1100 \times 9.55}{875}$$

$$= 12\ N\text{-}m$$

TEMPERATURE RISE AND LIFE EXPECTANCY OF ELECTRIC EQUIPMENTS

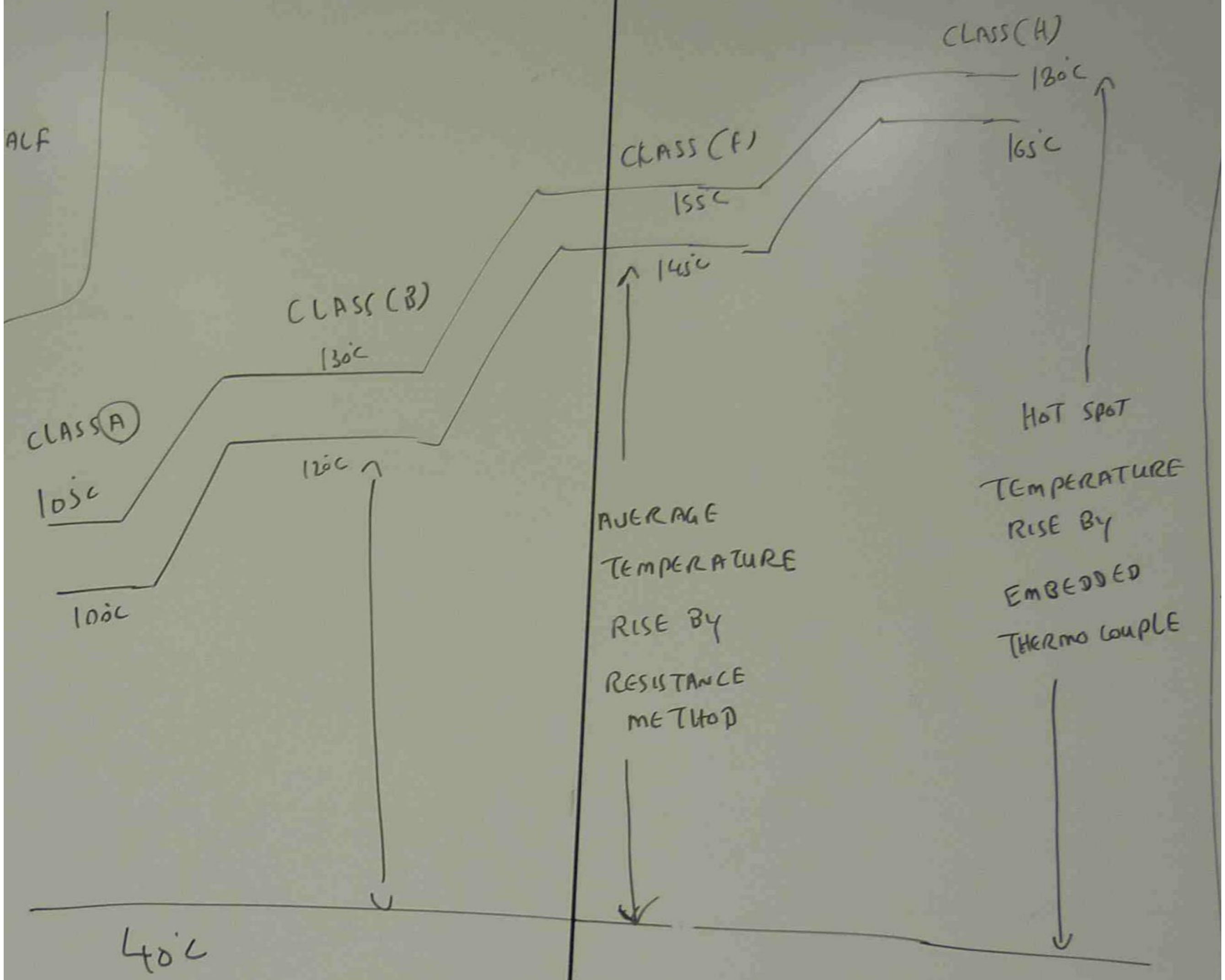
USEFUL LIFE OF ELECTRICAL EQUIPMENTS REDUCES BY HALF EVERY TIME THE TEMPERATURE IS INCREASED BY 10°C.

THERMAL CLASSIFICATION OF INSULATORS

CLASS (A) 105°C	COTTON, SILK, PAPER
CLASS (B) 130°C	GLASS, ASBESTOS WITHOUT BONDING
CLASS (F) 155°C	GLASS, FIBRE, ASBESTOS WITHOUT BONDING
CLASS (H) 180°C	FIBRE, MICA, ASBESTOS BONDING

MODIFIED CLASSES – N (200°C)
R (220°C)
S (240°C)

C (ABOUT 240°C)



ALF
CLASS(H)
180°C
165°C
CLASS (F)
155°C
145°C
CLASS (B)
130°C
CLASS A
105°C
120°C
100°C
AVERAGE TEMPERATURE RISE BY RESISTANCE METHOD
HOT SPOT TEMPERATURE RISE BY EMBEDDED THERMO COUPLE
40°C

$$t_2 = \frac{R_2}{R_1}(234 + t_1) - 234$$

t_2 = AVERAGE TEMPERATURE OF WINDING WHEN HOT (°C)

R_2 = HOT RESISTANCE OF WINDING (Ω)

R_1 = COLD RESISTANCE OF WINDING (Ω)

t_1 = TEMPERATURE OF WINDING WHEN COLD

---

pb A 75 kW MOTOR INSULATED CLASS F OPERATES AT FULL LOAD IN AN AMBIENT TEMPERATURE OF 32°C. IF THE HOT SPOT TEMPERATURE IS 125°C, DOES THE MOTOR MEET THE TEMPERATURE STANDARD?

HOT SPOT TEMPERATURE RISE = 125 − 32 = 93°C

CLASS (F) ACCEPTABLE TEMPERATURE RISE = 155 − 40
= 115°C

HOT SPOT TEMPERATURE RISE < CLASS (F) ACCEPTABLE TEMPERATURE RISE

IT MEETS THE STANDARD.

pb

AN AC MOTOR THAT HAS BEEN IDLE FOR SEVERAL DAYS IN AN AMBIENT TEMPERATURE OF 19°C IS FOUND TO HAVE A FIELD RESISTANCE OF 22Ω. THE MOTOR THEN OPERATES AT FULL LOAD AND WHEN THE TEMPERATURES HAVE STABILIZED, THE FIELD RESISTANCE IS FOUND TO BE 30Ω. THE CORRESPONDING AMBIENT TEMPERATURE IS 24°C. IF THE MOTOR IS BUILT WITH CLASS B INSULATION, CALCULATE THE FOLLOWINGS.

(a) THE AVERAGE TEMPERATURE OF THE WINDING AT FULL LOAD

(b) THE FULL LOAD TEMPERATURE RISE BY THE RESISTANCE METHOD.

(c) WHETHER THE MOTOR MEETS THE TEMPERATURE STANDARDS.

$t_1 = 19°C$, $R_1 = 22\Omega$, $R_2 = 30\Omega$

(a)

$$t_2 = \frac{R_2}{R_1}(234 + t_1) - 234$$

$$= \frac{30}{22}(234 + 19) - 234$$

$$= 111°C$$

$t_a =$ AMBIENT TEMPERATURE

(b)

AVERAGE TEMPERATURE RISE $= t_2 - t_a = 111 - 24 = 87°C$

CLASS (B) INSULATION, ACCEPTABLE TEMPERATURE RISE $= 120 - 40 = 80°C$

(c)

MOTOR ACTUAL TEMPERATURE RISE (87°C) > CLASS (B) INSULATION ACCEPTABLE TEMPERATURE RISE (80°C)

MOTOR DOES NOT MEET THE TEMPERATURE STANDARD

$$t_2 = \frac{R_2}{R_1}(234 + t_1) - 234$$

t_2 = AVERAGE TEMPERATURE OF WINDING WHEN HOT (°C)

R_2 = HOT RESISTANCE OF WINDING (Ω)

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$t_1 = 19°C \quad , R_1 = 22\Omega \quad , R_2 = 30\Omega$

(a)

$$t_2 = \frac{R_2}{R_1}(234 + t_1) - 234$$

t_a = AMBIENT TEMPERATURE

$$= \frac{30}{22}(234 + 19) - 234$$

$$= 111°C$$

40 (b)

AVERAGE TEMPERATURE RISE $= t_2 - t_a = 111 - 24 = 87°C$

CLASS(B) INSULATION, ACCEPTABLE

TEMPERATURE RISE $= 120 - 40 = 80°C$

(c)

MOTOR ACTUAL TEMPERATURE RISE (87°C) $>$ CLASS (B) INSULATION ACCEPTABLE TEMPERATURE RISE (80°C)

MOTOR DOES NOT MEET THE TEMPERATURE STANDARD

RELATIONSHIP BETWEEN THE SPEED AND SIZE OF A MACHINE

MAXIMUM ALLOWABLE TEMPERATURE RISE ESTABLISHES THE NOMINAL POWER RATING OF A MACHINE, ITS BASIC PHYSICAL SIZE DEPENDS UPON POWER AND SPEED OF ROTATION.

TO GENERATE THE SAME VOLTAGE AT THE HALF SPEED, IT NEEDS TO INCREASE THE SIZE OF ROTOR AND NUMBER OF POLES. THE MACHINE SIZE IS BIGGER.

$$N = \frac{120f}{P}$$

Pb

AN EXCITER OF A 3ϕ ALTERNATOR IS A COMPOUND GENERATOR

IT HAS A RATING OF 10 KW (INPUT), 1150 RPM, 230V, 50A.

IT HAS THE FOLLOWING LOSSES AT FULL LOAD.

BEARING FRICTION LOSS = 40W

BRUSH FRICTION LOSS = 50 W

WINDAGE LOSS = 200 W

TOTAL MECHANICAL LOSS = 290W

IRON LOSS = 420W

COPPER LOSS IN SHUNT FIELD = 120W

CONSTANT LOSS

COPPER LOSS AT FULL LOAD

IN ARMATURE = 500W

IN SERIES FIELD = 25W

IN COMMUTATING WINDING = 70W

TOTAL COPPER LOSS AT FULL LOAD = 595W

VARIABLE LOSS

CALCULATE LOSSES AND EFFICIENCY AT NO LOAD, HALF LOAD AND FULL LOAD.

GENERATOR.

50A.

$$\text{VARIABLE LOSS AT ANY LOAD} = (\text{LOAD RATIO})^2 \times \text{VARIABLE LOSSES AT FULL LOAD}$$

OSS

$$\text{NO LOAD} = \underset{(\text{CONSTANT LOSS})}{\text{TOTAL LOSSES}} = 290 + 420 + 120 = 830\,W$$

$$\text{NO LOAD EFFICIENCY} = \frac{\text{OUTPUT}}{\text{INPUT}} \times 100 = \frac{\text{INPUT} - \text{LOSSES}}{\text{INPUT}} \times 100 = \frac{830 - 830}{830} \times 100 = 0\,\%$$

LE

HALF LOAD

$$\text{VARIABLE LOSS AT } \tfrac{1}{2} \text{ LOAD} = \left(\tfrac{1}{2}\right)^2 \times 595 =$$

$$\text{TOTAL LOSSES AT HALF LOAD} = \text{VARIABLE} + \text{CONSTANT LOSSES}$$

$$= \tfrac{1}{4} \times 595 + 830 = 979\,W$$

$$\tfrac{1}{2}\text{ LOAD EFFICIENCY} = \frac{\tfrac{1}{2} \times 10{,}000 - 979}{\tfrac{1}{2} \times 10{,}000} \times 100 = 83.6\,\%$$

FULL L

TOTAL LOSS

FULL LOAD EFFICIENCY =

FULL LOAD

TOTAL LOSSES = 830 + 595

= 1425W

$\frac{\ldots - 830}{\ldots 30} \times 100 = 0\ \%$

FULL LOAD EFFICIENCY $= \frac{10{,}000 - 1425}{10{,}000} \times 100$

$= 87.5\%$