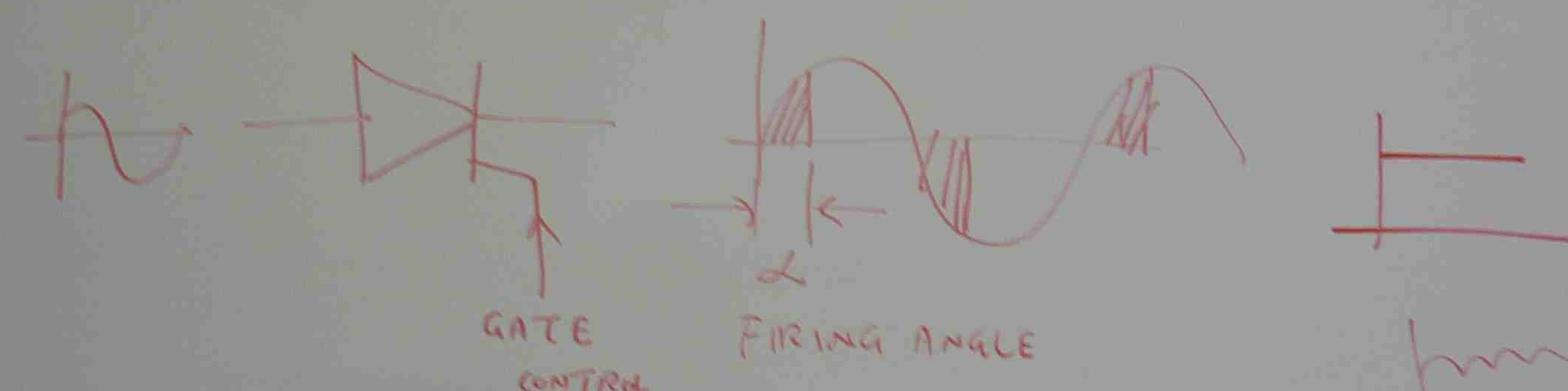
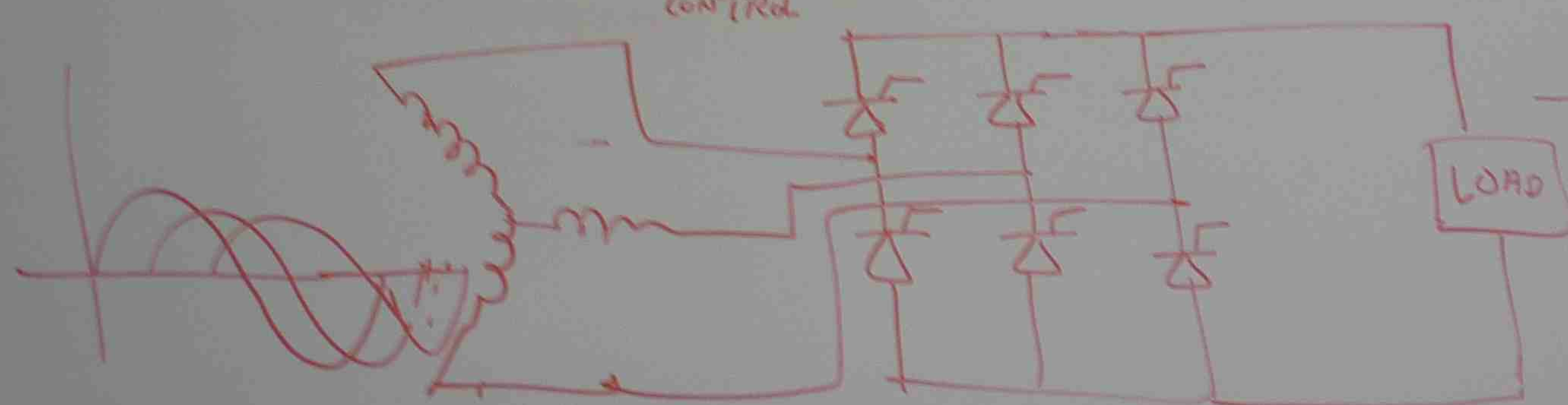
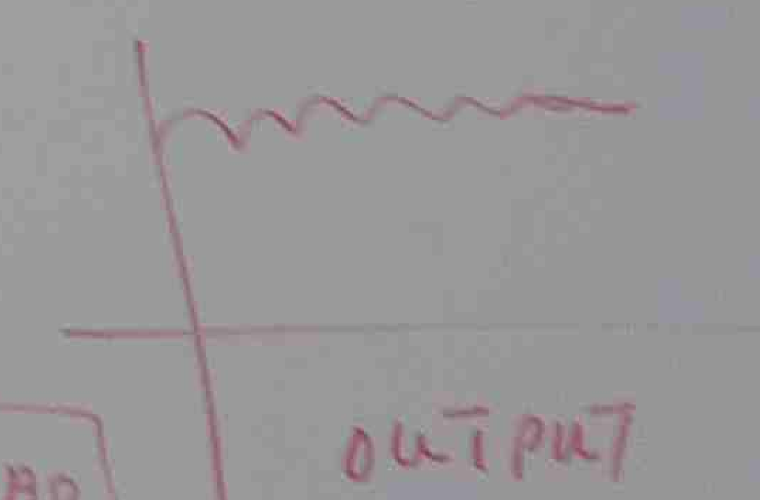
DC MOTOR CONTROL

SCR (SILICON CONTROLLED RECTIFIER)

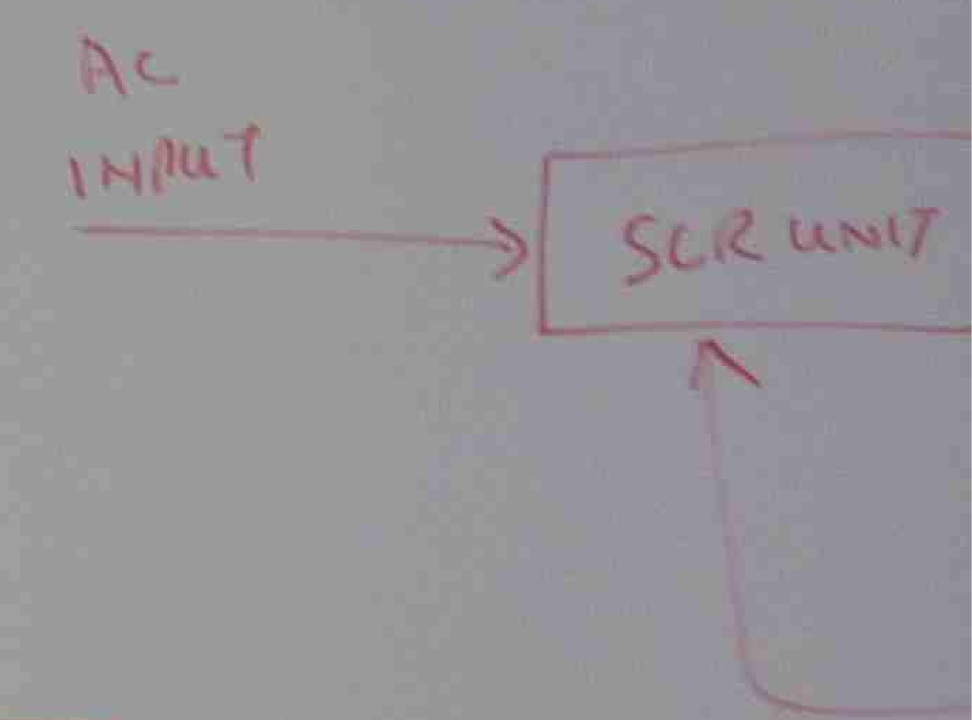
- AC MOTOR SPEED CONTROL
- DC MOTOR SPEED CONTROL







BLOCK DIAGRA

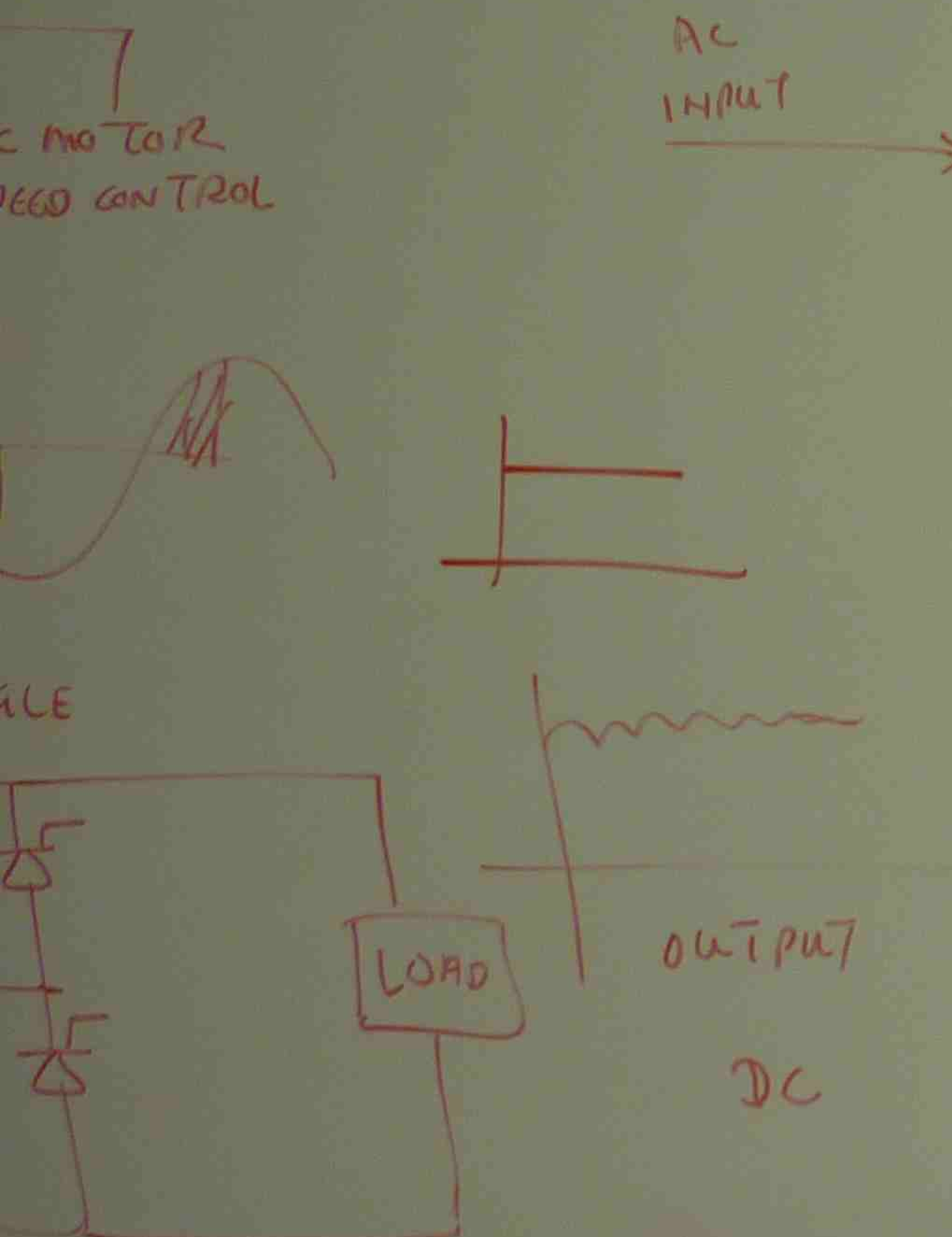


HEA

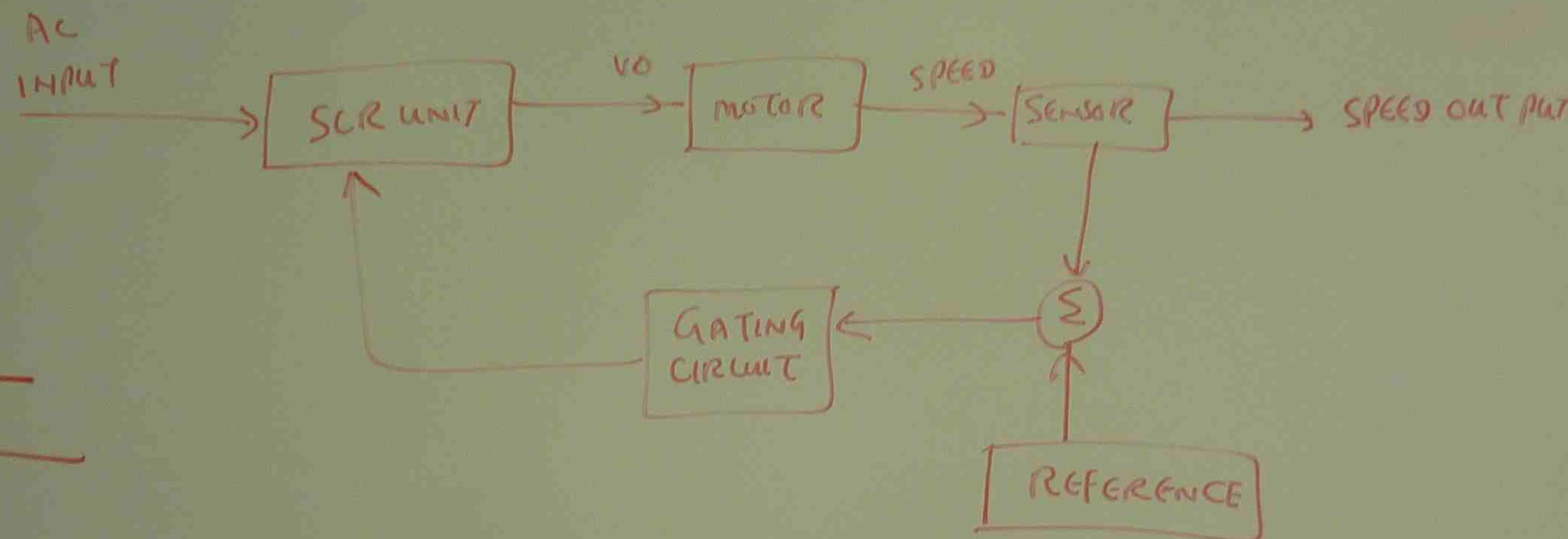
PRODUCED BY
HIGH FREQUENCY
SWITCHING PWM

RECTIFIER)

C MOTOR
SPEED CONTROL



BLOCK DIAGRAM OF SCR CONTROLLED MOTOR



HEATING EFFECT OF RIPPLES

RIPPLE → HEATING

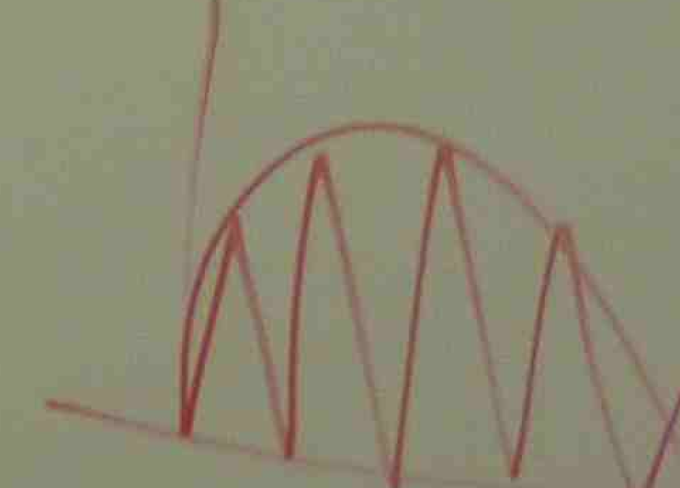
RIPPLE → HARMONIC → NEED TO BE ELIMINATED BY FILTER

RIPPLE → VIBRATION

RIPPLE → DERATE THE MACHINE

RIPPLE → DERATE THE INSULATION

PRODUCED BY HIGH FREQUENCY SWITCHING PWM DRIVES.

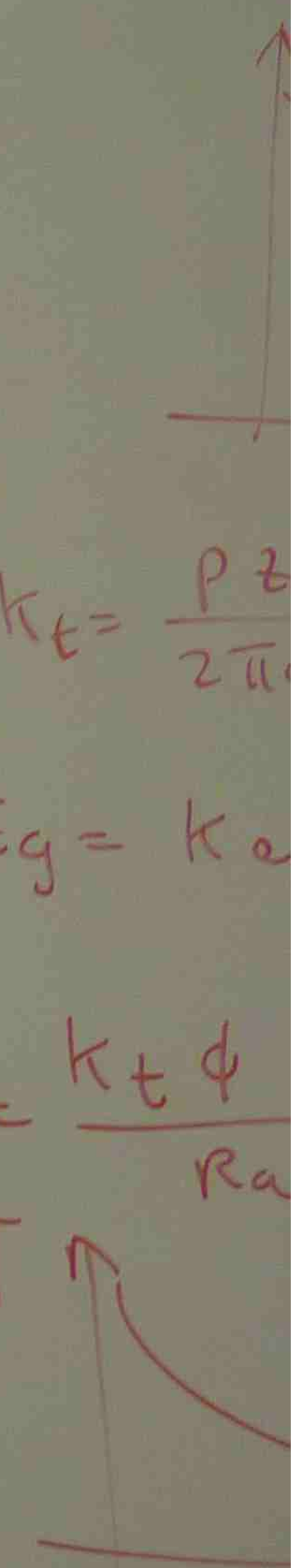


TORQUE

$k_t = \frac{PZ}{2\pi}$

$E_g = K_e$

$T = \frac{k_t \phi}{R_a}$



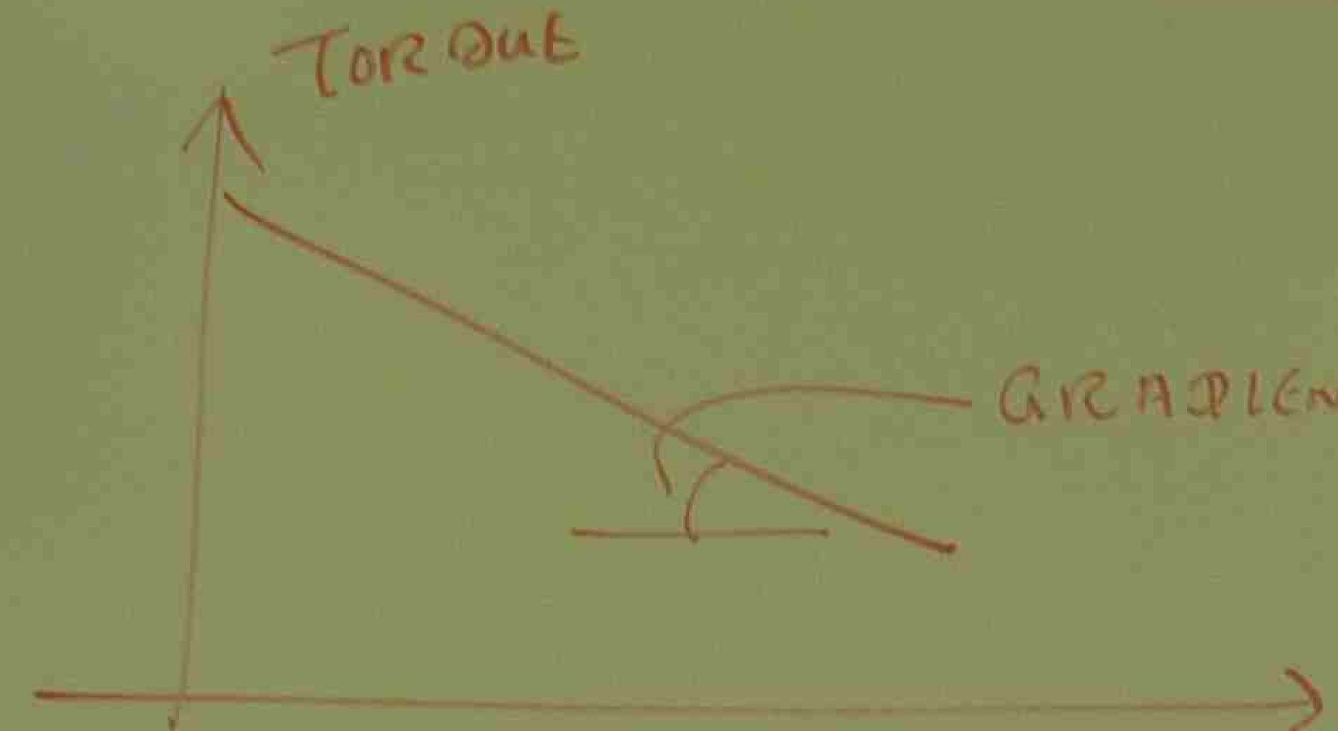
→ SPEED OUTPUT

ENCE

→ NEED TO BE ELIMINATED BY FILTER

TION

TORQUE - SPEED RELATIONSHIP



$$\text{GRADIENT} = \frac{K_e K_t \phi^2}{R_a}$$

$$T = \frac{K_t \phi V_t}{R_a}$$

$$K_t = \frac{PZ}{2\pi a}, \quad K_e = \frac{PZ}{60a}$$

$$E_g = K_e \phi N$$

$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

T = TORQUE, ϕ = FLUX

I_a = ARMATURE CURRENT

P = NO. OF POLES

Z = ARMATURE CONDUCTORS

a = NO. OF ARMATURE PARALLEL PATHS.

N = SPEED

pb. A 4 POLES

OF FLUX

CONDUCTORS.

FUNCTION OF

$T = \frac{K_t}{\ldots}$

$K_t = \frac{PZ}{2\pi a}$

$K_e = \frac{PZ}{60\ldots}$

$T =$

$$T = \frac{K_t \phi V_t}{Ra}$$

$$\frac{K_e K_t \phi^2}{Ra}$$

orque, ϕ = flux

armature current

. of poles

rmature conductors

No. of armature

parallel paths.

speed

---

pb A 4 poles wound armature operating in a field of flux 0.01 webers in wound with 360 armature conductors. Determine the expression of torque as a function of speed if $V_t = 250V$ and $Ra = 0.1\Omega$.

$$T = \frac{K_t \phi V_t}{Ra} - \frac{K_e K_t \phi^2 N}{Ra}$$

$$K_t = \frac{PZ}{2\pi a} = \frac{4 \times 360}{2 \times 3.1416 \times 2}$$

$$= 114.5$$

$a = 2m$ wave

$= 2 \times 1 = 2$

$$K_e = \frac{PZ}{60a} = \frac{4 \times 360}{60 \times 2} = 12$$

$$T = \frac{114.5 \times 0.01 \times 250}{0.1} - \frac{12 \times 114.5 \times (0.01)^2 N}{0.1}$$

$$= 2860 - 1.38N$$

Duty cy

As well as

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the heati

the RMS

pb 2

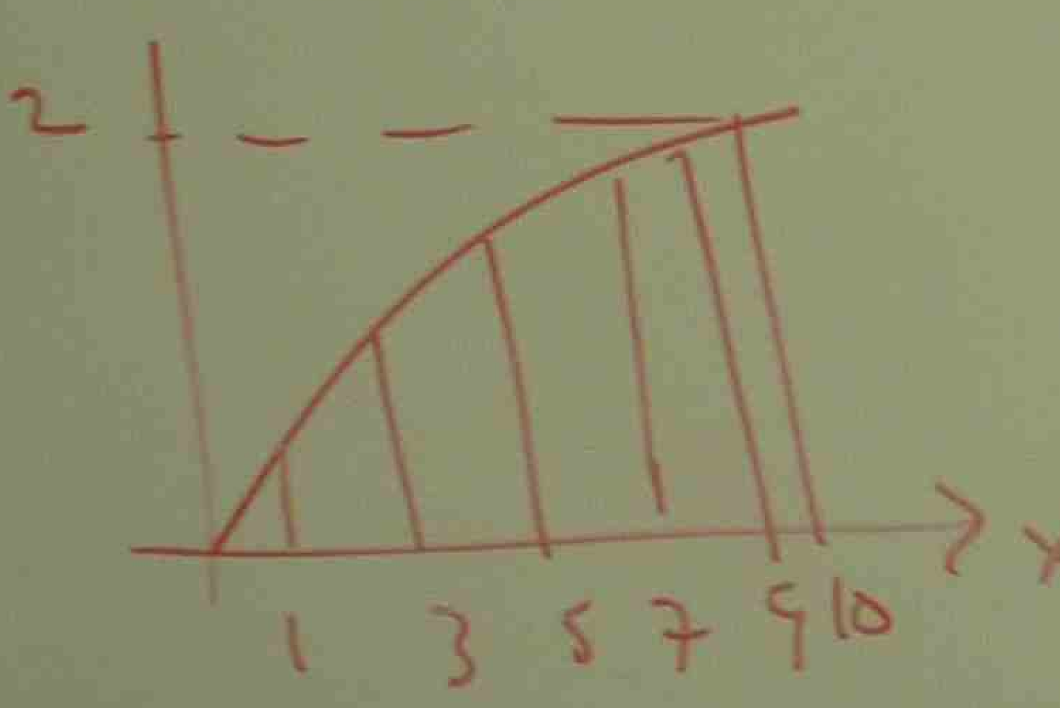
DUTY CYCLE

AS WELL AS SELECTING A MOTOR THAT IS CAPABLE OF DEVELOPING THE SUFFICIENT TORQUE TO DRIVE A LOAD AT THE REQUIRED SPEED, THE MOTOR SO CHOSEN MUST BE ABLE TO PROVIDE THIS TORQUE AND NOT SUFFER ANY UNDUE DAMAGE AS A CONSEQUENCE TO THE HEAT PRODUCED WITHIN THE MACHINE BY THE CURRENTS IN VARIOUS WINDINGS.

THE HEATING EFFECT IS THE FUNCTION OF RM.S

THE RMS VALUE OF THE LOAD MUST BE OBTAINED.

pb



$y = 0.2x$ FIND Rms

$$Rms = \sqrt{\frac{1}{y}\int_0^y y^2\,dx}$$

$y = 10$

$$Rms = \sqrt{\frac{1}{10}\int_0^{10}(0.2x)^2\,dx}$$

$$= \sqrt{\frac{1}{10}\int_0^{10} 0.04\,x^2\,dx}$$

$$= \sqrt{\frac{1}{10}\times 0.04\int_0^{10} x^2\,dx}$$

$$= \sqrt{\frac{1}{10}\times 0.04\times\left[\frac{x^3}{3}\right]_0^{10}}$$

$$= \sqrt{\frac{1}{10}\times 0.04\times\frac{10^3}{3}}$$

$$= 1.153$$

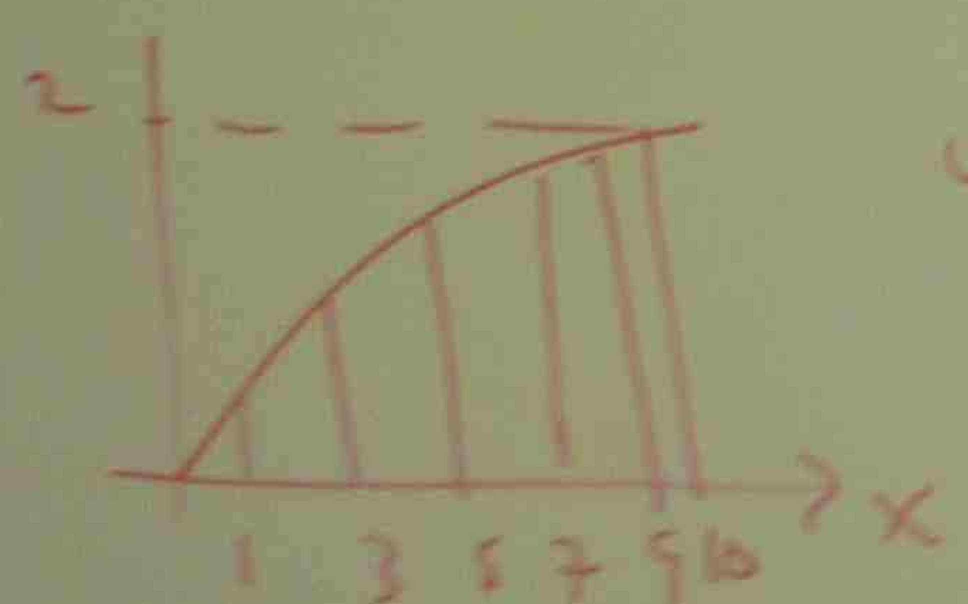
DUTY CYCLE

AS WELL AS SELECTING A MOTOR THAT IS CAPABLE OF DEVELOPING THE SUFFICIENT TORQUE TO DRIVE A LOAD AT THE REQUIRED SPEED, THE MOTOR SO CHOSEN MUST BE ABLE TO PROVIDE THIS TORQUE AND NOT SUFFER ANY UNDUE DAMAGE AS A CONSEQUENCE TO THE HEAT PRODUCED WITHIN THE MACHINE BY THE CURRENTS IN VARIOUS WINDINGS.

THE HEATING EFFECT IS THE FUNCTION OF RM.S

THE RMS VALUE OF THE LOAD MUST BE OBTAINED.

pb



$y = 0.2x$ FIND RMS

$$\text{Rms} = \sqrt{\frac{1}{y_1}\int_0^{y_1} y^2\,dx}$$

$y_1 = 10$

$$\text{Rms} = \sqrt{\frac{1}{10}\int_0^{10} (0.2x)^2\,dx}$$

$$= \sqrt{\frac{1}{10}\int_0^{10} 0.04\,x^2\,dx}$$

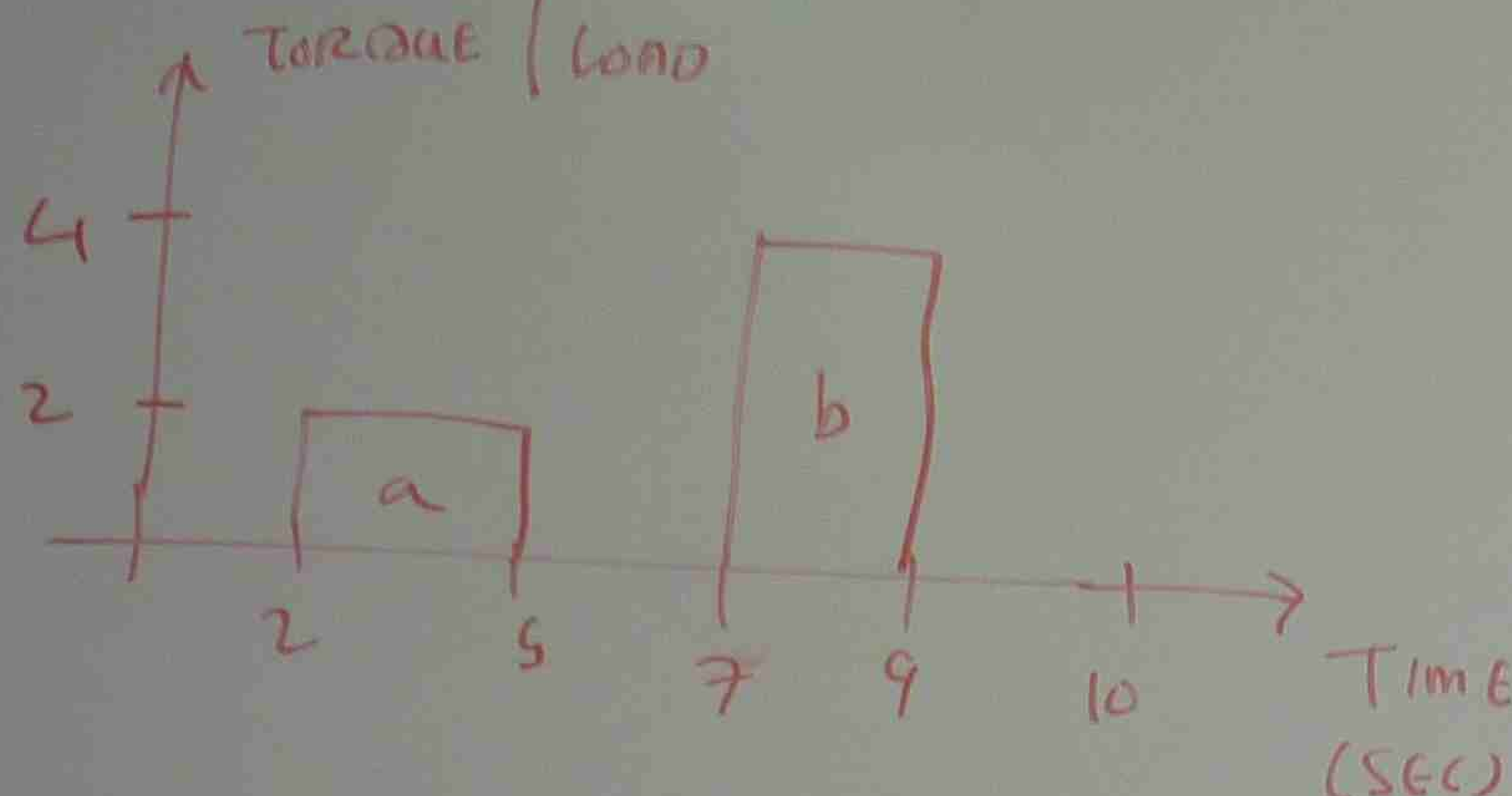
$$= \sqrt{\frac{1}{10}\times 0.04\int_0^{10} x^2\,dx}$$

$$= \sqrt{\frac{1}{10}\times 0.04\times\left[\frac{x^3}{3}\right]_0^{10}}$$

$$= \sqrt{\frac{1}{10}\times 0.04\times\frac{10^3}{3}}$$

$$= 1.153$$

Pb → FIND RMS VALUE OF THE GIVEN GRAPH



SECTION	DURATION	VALUE	AREA
			DURATION × VALUE
a	2 → 5 (5−2=3) 3 sec	2	3×2 = 6
b	7 → 9 (9−7=2) 2 sec	4	4×2 = 8
		TOTAL	14

$$\text{AVERAGE} = \frac{\text{TOTAL AREA}}{\text{TOTAL DURATION}}$$

$$= \frac{14}{10}$$

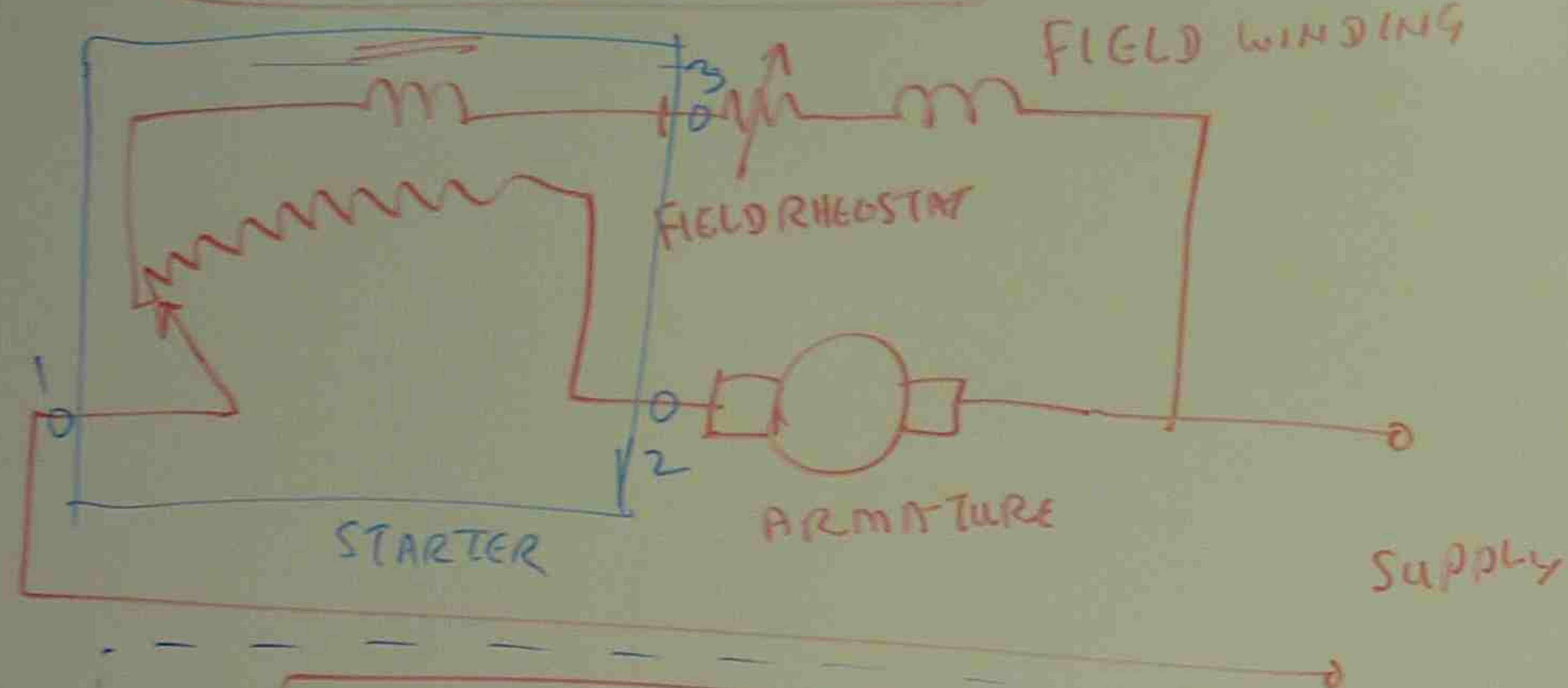
$$= 1.4$$

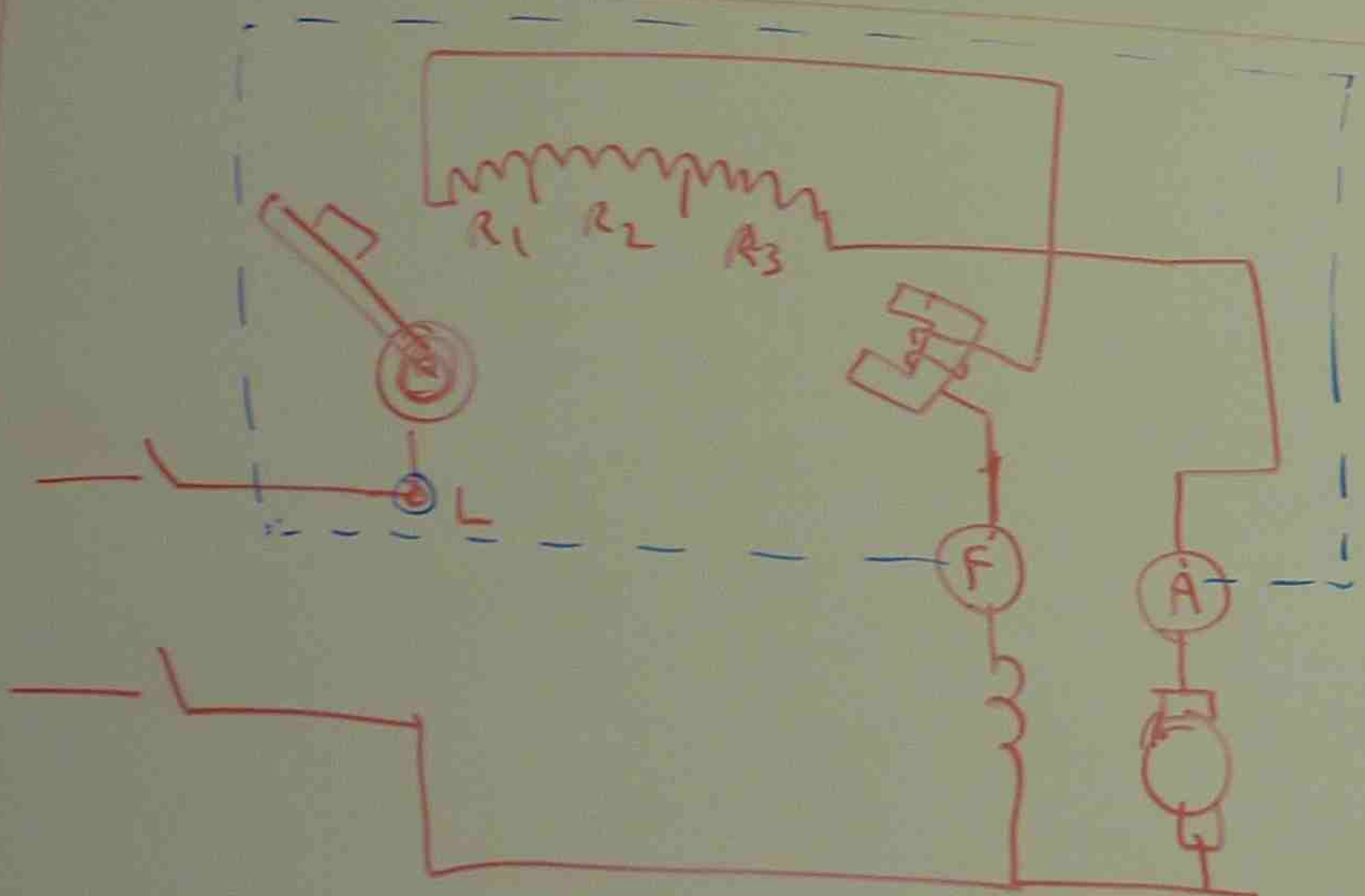
$$\text{RMS} = \sqrt{\text{AVERAGE}}$$

$$= \sqrt{1.4}$$

$$= 1.183$$

DC MOTOR STARTERS





3 POINTS STARTER

$$\left(\frac{I_{max}}{I_{min}}\right)^{n+1} = \frac{V_t}{I_r\,R_a}$$

n = NUMBERS OF STEPS

R_a = ARMATURE RESISTANCE

I_r = FULL LOAD CURRENT

$$\frac{I_s}{I_r} = \frac{R_K}{R_{K+1}}$$

I_s = INITIAL RESISTANCE STEP CURRENT (R_K)

I_r = FINAL RESISTANCE STEP CURRENT (R_{K+1})

t

r Ra

NT (R_K)

RRENT (R_{K+1})

Pb THE RESISTANCE OF THE ARMATURE OF A 240V DC SHUNT MOTOR IS 0.5 Ω. IT IS REQUIRED THAT THE CURRENT AT STARTING BE LIMITED TO 200 % OF FULL LOAD CURRENT AND FULL LOAD CURRENT IS 15 Amp.

DETERMINE (a) TOTAL RESISTANCE OF ARMATURE CIRCUIT AT STARTING

(b) THE NUMBERS OF STUDS ON THE STARTER

(c) RESISTANCE BETWEEN EACH STUD.

$R_a = 0.5\,\Omega$ $\quad V_t = 240V$, $\quad I_r = 15$ Amp

$I_s = 200\%\, I_r = 2 \times 15 = 30$ Amp.

$$\left(\frac{I_{max}}{I_{min}}\right)^{n+1} = \frac{V_t}{I_r R_a}$$

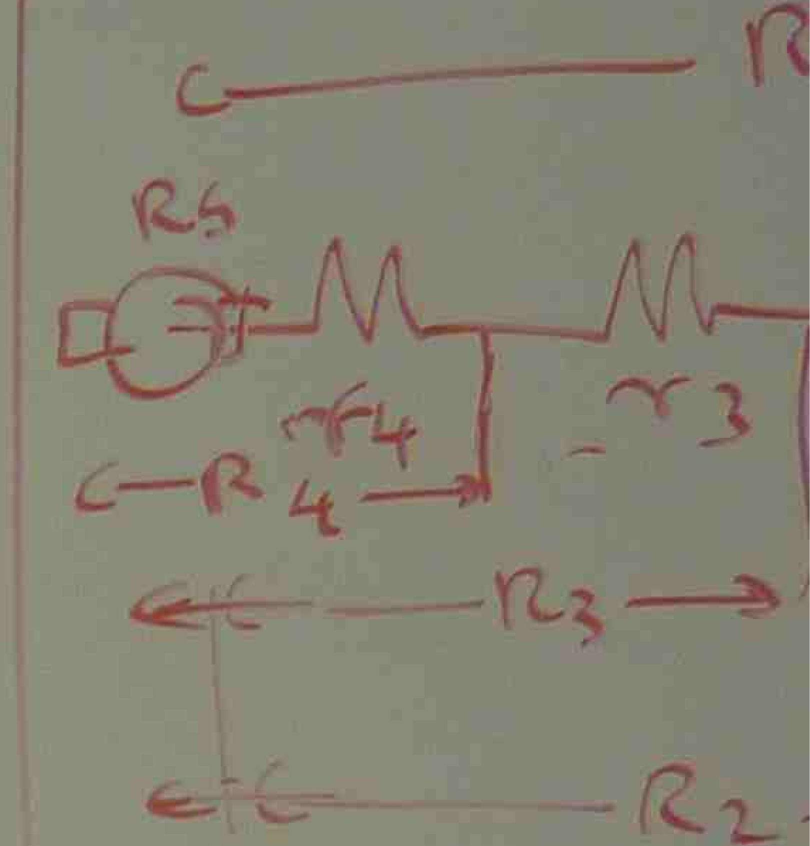
$$\left(\frac{30}{15}\right)^{n+1} = \frac{240}{15 \times 0.5} \rightarrow$$

$$2^{n+1} = 32$$

$$\log 2^{n+1} = \log 32$$

$$(n+1)\log 2 = \log 32$$

$$n = \frac{\log 32}{\log 2}$$



$r_1 = R_1 - R$

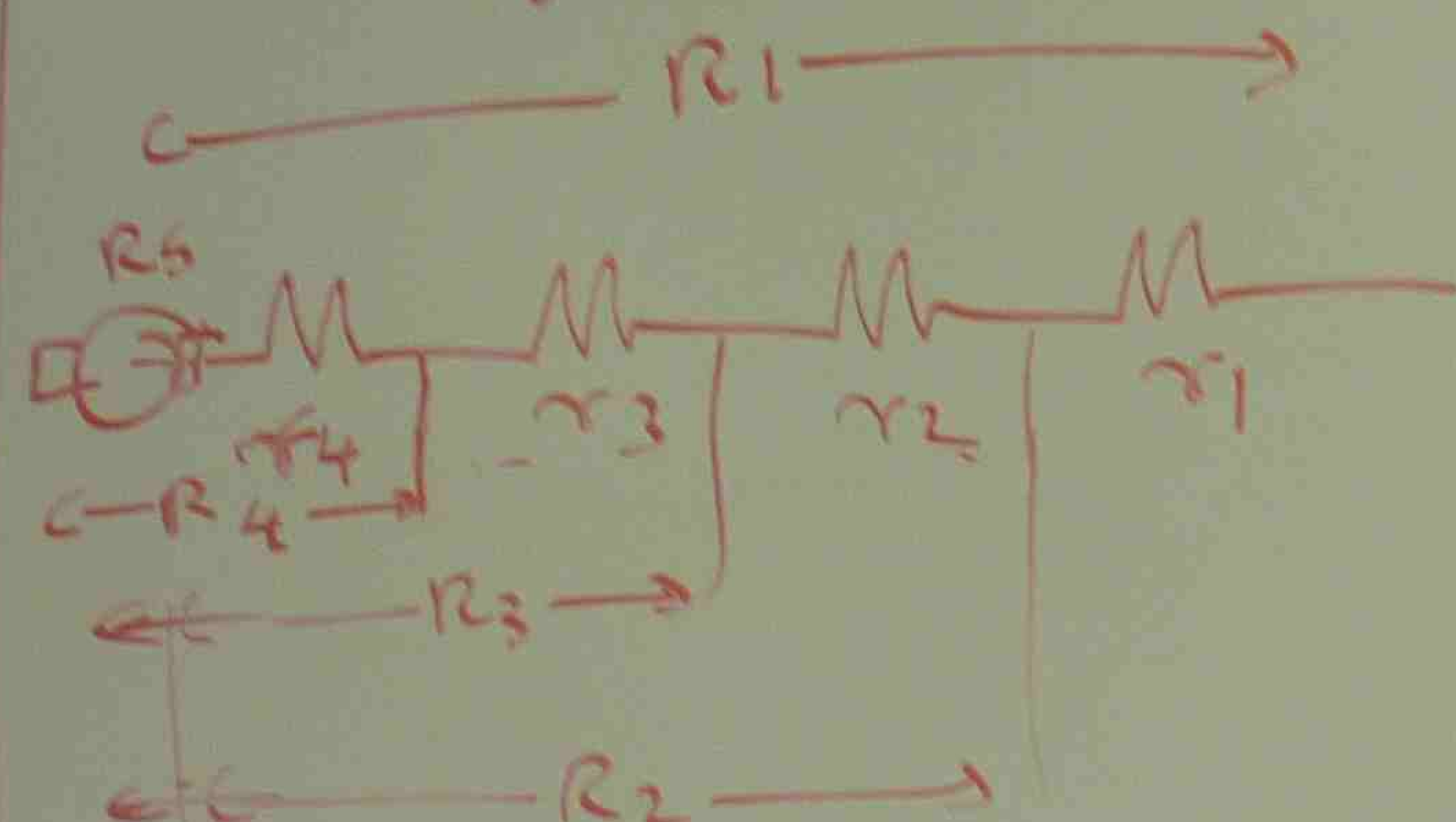
$r_2 = R_2 - R$

$r_3 = R_3 -$

$r_4 = R_4$

MOTOR
TING SE
AD
AT
ER
Amp
30 Amp.
g32
32

$$n = \frac{\log 32}{\log 2} - 1 = 4$$



$r_1 = R_1 - R_2$

$r_2 = R_2 - R_3$

$r_3 = R_3 - R_4$

$r_4 = R_4$

$$\frac{I_s}{I_r} = \frac{R_K}{R_{K+1}}$$

$$\frac{30}{I_s} = \frac{R_K}{R_{K+1}}$$

$$2 = \frac{R_K}{R_{K+1}}$$

$$\boxed{R_1 = \frac{V_t}{I_s}}$$

$$= \frac{240}{30} = 8\,\Omega$$

$$\frac{R_K}{R_{K+1}} = 2$$

$$K = 1 \rightarrow \frac{R_1}{R_{1+1}} = 2$$

$$\frac{R_1}{R_2} = 2$$

$$\frac{8}{R_2} = 2$$

$$R_2 = 8/2 = 4\,\Omega$$

$K = 2$ $\quad \frac{R_2}{R_{2+1}} =$

$\frac{R_2}{R_3} =$

$\frac{4}{R_3}$

$R_3 = \frac{4}{2}$

$K = 3$ $\quad \frac{R}{R_3}$

$\frac{R_3}{R_4}$

$\frac{2}{R_4}$

R_4

$K = 4 = \frac{R_4}{R}$

$$\frac{I_s}{I_r} = \frac{R_K}{R_{K+1}}$$

$$\frac{30}{15} = \frac{R_K}{R_{K+1}}$$

$$2 = \frac{R_K}{R_{K+1}}$$

$$\boxed{R_1 = \frac{V_t}{I_s}}$$

$$= \frac{240}{30} = 8\,\Omega$$

$$\frac{R_K}{R_{K+1}} = 2$$

$$1 \rightarrow \frac{R_1}{R_{1+1}} = 2$$

$$\frac{R_1}{R_2} = 2$$

$$\frac{8}{R_2} = 2$$

$$R_2 = 8/2 = 4\,\Omega$$

$$K = 2 \quad \frac{R_2}{R_{2+1}} = 2$$

$$\frac{R_2}{R_3} = 2$$

$$\frac{4}{R_3} = 2$$

$$R_3 = \frac{4}{2} = 2\,\Omega$$

$$K = 3 \quad \frac{R_3}{R_{3+1}} = 2$$

$$\frac{R_3}{R_4} = 2$$

$$\frac{2}{R_4} = 2$$

$$R_4 = \frac{2}{2} = 1\,\Omega$$

$$K = 4 = \frac{R_4}{R_5} = 2 \rightarrow R_5 = \frac{R_4}{2} = \frac{1}{2} = 0.5$$

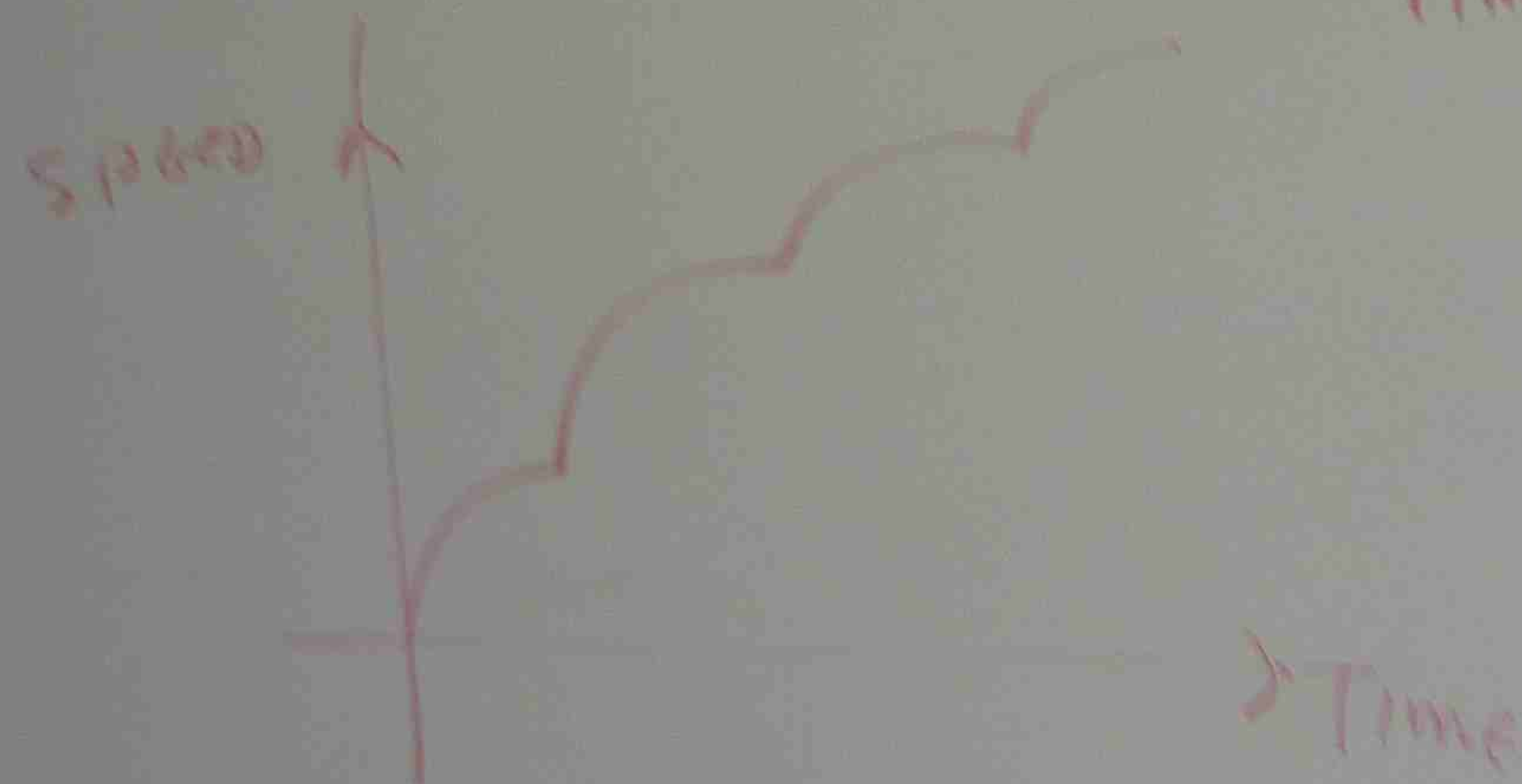
$$r_1 = R_1 - R_2$$
$$= 8 - 4 = 4\,\Omega$$

$$r_2 = R_2 - R_3$$
$$= 4 - 2 = 2\,\Omega$$

$$r_3 = R_3 - R_4$$
$$= 2 - 1 = 1\,\Omega$$

$$r_4 = R_4 - R_5$$
$$= 1 - 0.5 = 0.5\,\Omega$$

ACCERELATION OF DC MOTORS

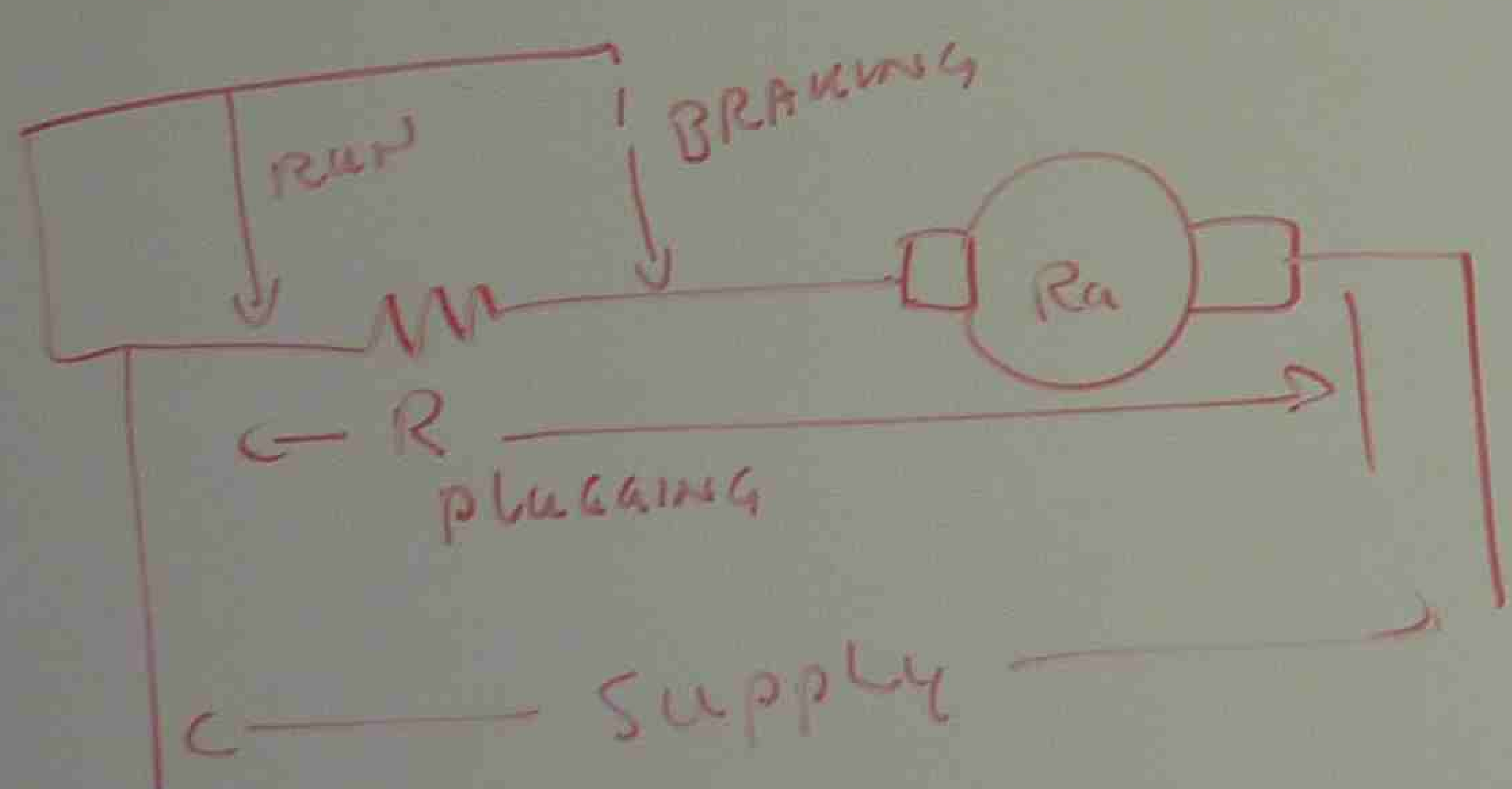


STARTERS

- BACK EMF STARTER
- CURRENT DEPENDENT STARTER
- TIME LIMIT STARTER

Pb

A 240V MOTOR IS REQUIRED TO BE BRAKED BY PLUGGING. IF THE ARMATURE CURRENT AT FULL LOAD IS 100 AMP AND THE ARMATURE RESISTANCE IS 0.1 Ω, CALCULATE THE RESISTANCE OF BRAKING RESISTOR IF THE INITIAL BRAKING CURRENT IS LIMITED TO 150% OF FULL LOAD CURRENT AND BRUSH DROP IS 5 VOLT.



$$R_{PLUGGING} = \frac{V_t - (V_b + E_b)}{I_{br}}$$

V_t = TERMINAL VOLTAGE

I_{br} = BRAKING CURRENT

V_b = BRUSH VOLTAGE DROP

E_b = BACK EMF

$$E_b = V_t - (I_a R_a + V_b)$$

$$= 240 - (100 \times 0.1 + 5)$$

$$= 225 \text{ V}$$

$$I_{br} = 150\% \, I_a$$

$$= 1.5 \times 100 = 150 \text{ Amp}$$

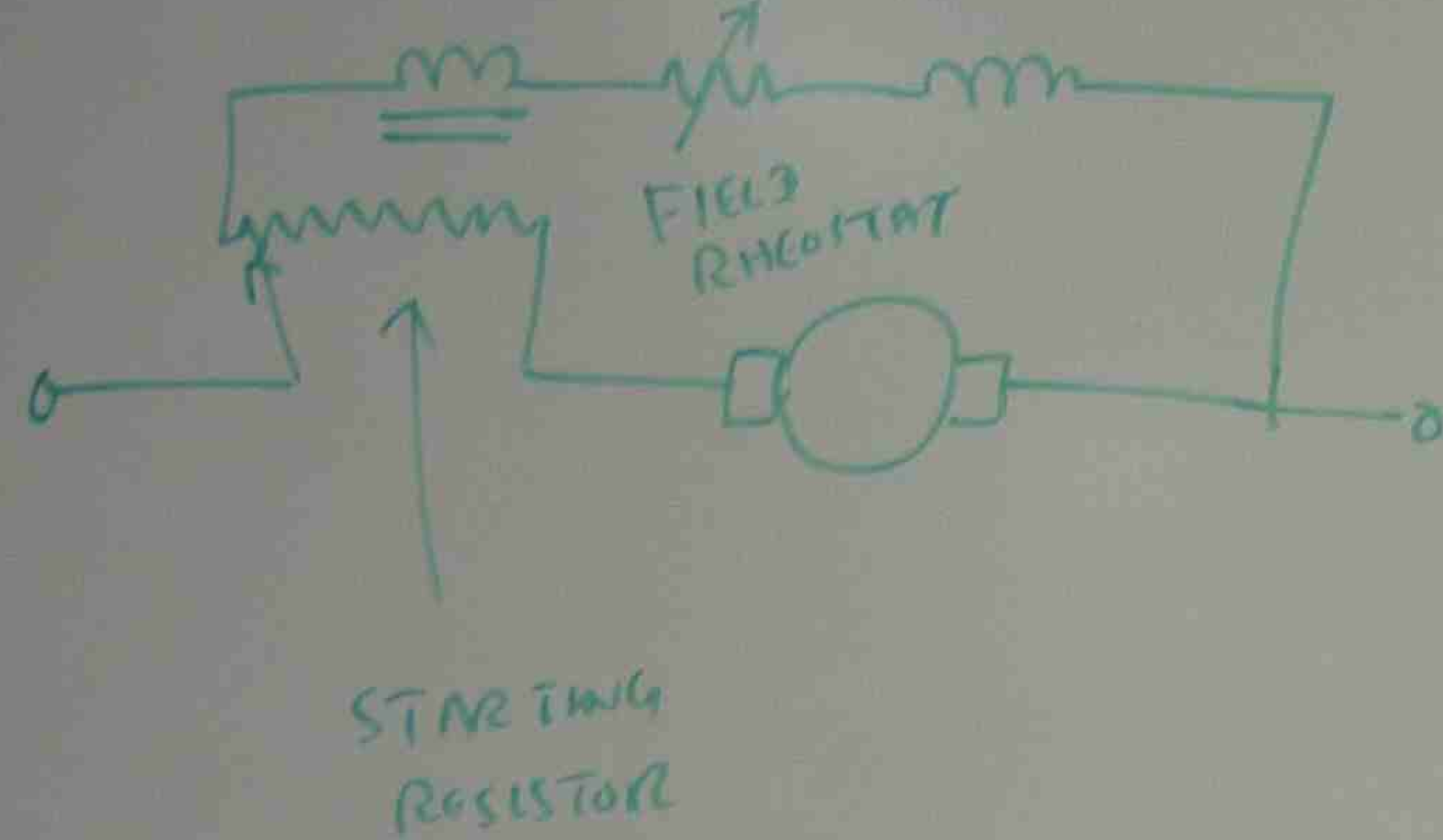
$$R_{PLUGGING} = \frac{V_t - (V_b + E_b)}{I_{br}}$$

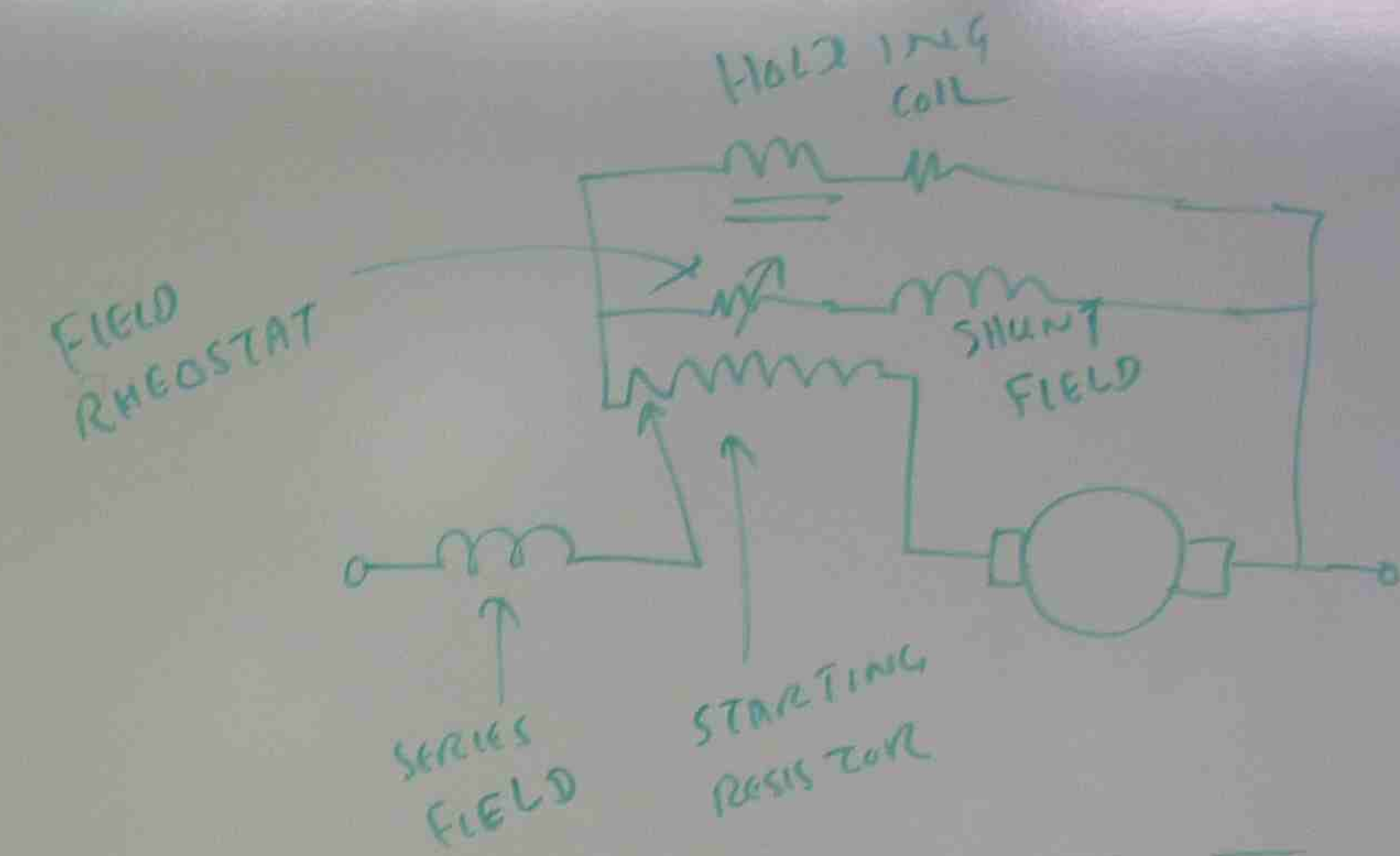
$$= \frac{240 - (5 + 225)}{150}$$

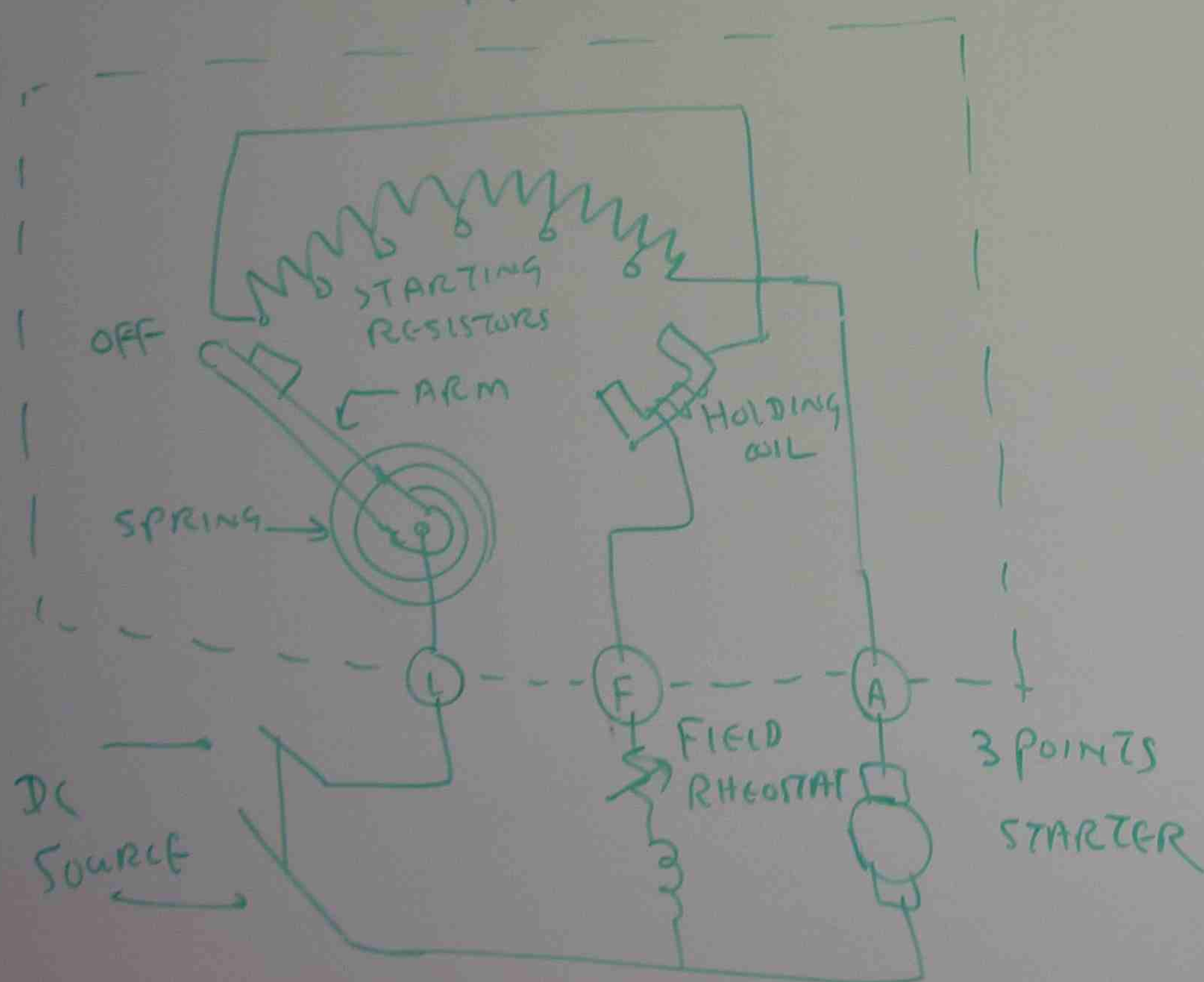
$$= 3.05 \, \Omega$$

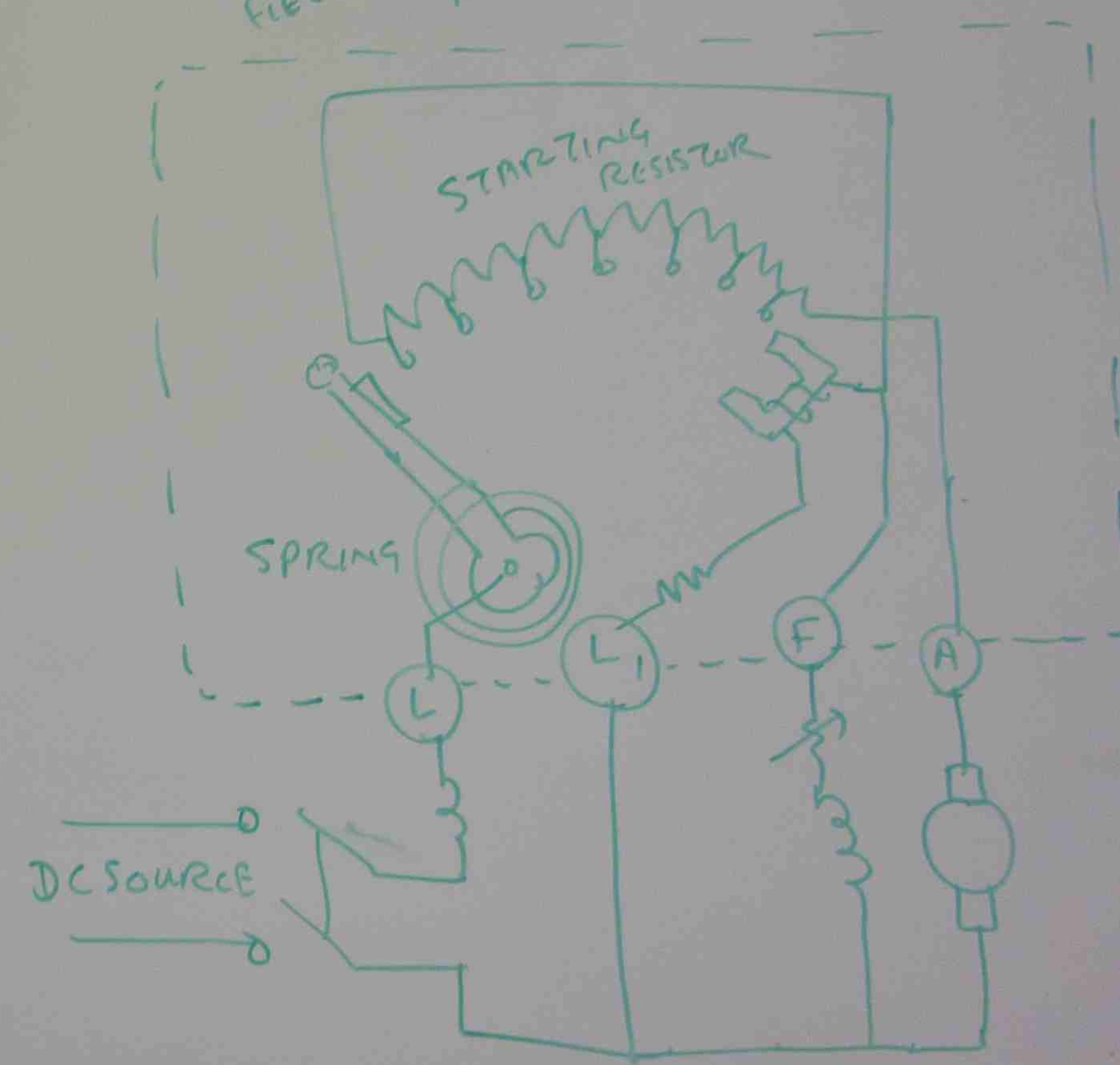
ADDITIONAL RESISTANCE $= 3.05 - 1 = 2.95 \, \Omega$

DC MOTOR STARTERS









pb — A 100 KW 500V DC SHUNT MOTOR HAS AN ARMATURE RESISTANCE 0.2Ω AND FULL LOAD SPEED 920 RPM. IF THE LOAD HAS A TORQUE SPEED CURVE WHICH MAY BE DEFINED BY THE EXPRESSION.

$$T = 100 + 9.2\times10^{-4} N^2$$

AND THE MOTOR ARMATURE PARTICULARS ARE

$Z = 756$ CONDUCTORS, $P = 4$ POLES PAIRS, $a = 8$ PARALLEL PATHS

$\phi = 0.04$ WEBERS.

THE COMBINED INERTIA OF LOAD AND ARMATURE IS $100\ N\text{-}m^2$

CALCULATE (a) STARTER RESISTANCES (b) SPEED AT EACH RESISTANCE STEP (c) TORQUE (CURRENT LIMIT 150%, 90%)

EFFICIENCY = 90%

$$I_{FL} = \frac{100\times1000}{500\times\frac{90}{100}} = 220\ \text{Amp}$$

$$I_{max} = 1.5\times I_{FL} = 1.5\times220 = 330\ \text{Amp}$$

$$I_{min} = 0.9\times I_{FL} = 0.9\times220 = 200\ \text{Amp}.$$

$$R_1 = \frac{V_t}{I_{MAX}} = \frac{500}{330} = 1.51\Omega$$

$$\left(\frac{I_{MAX}}{I_{MIN}}\right)^n = \frac{R_1}{R_a}$$

$$\left(\frac{330}{200}\right)^n = \frac{1.51}{0.2}$$

$$1.65^n = 7.4$$

$$n\log 1.65 = \log 7.4$$

$$n = \frac{\log 7.4}{\log 1.65} = 4$$

$R_2 =$

$=$

$R_3 =$

$R_4 =$

$R_5 =$

L LOAD

dy

$$R_2 = R_1 \times \left(\frac{I_{MIN}}{I_{MAX}}\right)$$

$$= 1.51 \times \left(\frac{200}{330}\right) = 0.42\Omega$$

$$R_3 = R_2 \times \frac{I_{MIN}}{I_{MAX}}$$

$$= 0.42 \times \frac{200}{330} = 0.555\Omega$$

$$R_4 = R_3 \times \frac{I_{MIN}}{I_{MAX}}$$

$$= 0.555 \times \frac{200}{330} = 0.336\Omega$$

$$R_5 = R_4 \times \frac{I_{MIN}}{I_{MAX}}$$

$$= 0.336 \times \frac{200}{330} = 0.2\Omega$$

$$\frac{Eb_1}{Eb_2} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

FULL LOAD

$$E_b = V_t - I_a R_a$$

$$= 500 - 220 \times 0.2$$

$$= 455.4V$$

REF $N = 920 RPM$

$R_1 = 1.51\Omega$

$$Eb_1 = V_t - I_1 \times R_1$$

$$= 500 - 200 \times 1.51 = 198V$$

$$\frac{E_b}{Eb_1} = \frac{\phi N}{\phi N_1} \rightarrow \frac{455.4}{198} = \frac{920}{N_1}$$

$$N_1 = \frac{920 \times 198}{455.4}$$

$$= 400 RPM$$

$R_2 = 0.42\Omega$

$Eb_2 = V_t - I$

$= 500 - 2$

$= 316$

$\frac{E_b}{Eb_2} = \frac{\phi}{\phi}$

$\frac{455.4}{316} =$

$N_2 = 625$

$R_3 = 0.55$

$Eb_3 = V -$

$= 500$

$= 3$

$\frac{E_b}{Eb_3} = \frac{\phi}{\phi}$

$= 148V$

$= \frac{920}{N_1}$

$= \frac{920 \times 148}{455.4}$

$= 400 RPM$

$R_2 = 0.92\Omega$

$E_{b_2} = V_t - I_1 \times R_2$

$= 500 - 200 \times 0.92$

$= 316V$

$\frac{E_b}{E_{b_2}} = \frac{\phi N}{\phi N_2}$

$\frac{455.4}{316} = \frac{920}{N_2}$

$N_2 = 625 RPM$

$R_3 = 0.555\Omega$

$E_{b_3} = V - I_1 R_3$

$= 500 - 200 \times 0.555$

$= 389V$

$\frac{E_b}{E_{b_3}} = \frac{\phi N}{\phi N_3} \rightarrow \frac{455.4}{389} = \frac{920}{N_3}$

$N_3 = 780 RPM$

$R_4 = 0.336\Omega$

$E_{b_4} = V_t - I_1 R_4$

$= 500 - 200 \times 0.336$

$= 455V$

$\frac{E_b}{E_{b_4}} = \frac{\phi N}{\phi N_4}$

$\frac{455.4}{455} = \frac{920}{N_4}$

$N_4 = 860 RPM$

$R_5 = 0.2\Omega$

$E_{b_5} = V_t - I_1 R_5$

$= 500 - 200 \times 0.2$

$= 460V$

$\frac{E_b}{E_{b_5}} = \frac{\phi N}{\phi N_5}$

$\frac{455.4}{460} = \frac{920}{N_5}$

$N_5 \simeq 920 R$

$T = \frac{K_t \phi V_t}{R_a}$

$K_e = \frac{PZ}{60a}$

$K_e = \frac{8 \times 756}{60 \times 8}$

$K_t = \frac{8 \times 756}{2 \times 3.1416 \times}$

$R_4 = 0.336\,\Omega$

$E_{b4} = V_t - I_1 R_4$

$= 500 - 200 \times 0.336$

$= 455\,V$

$\frac{E_b}{E_{b4}} = \frac{\phi N}{\phi N_4}$

$\frac{455.4}{455} = \frac{920}{N_4}$

$N_4 = 860\,RPM$

$R_5 = 0.2\,\Omega$

$E_{b5} = V_t - I_1 R_5$

$= 500 - 200 \times 0.2$

$= 460\,V$

$\frac{E_b}{E_{b5}} = \frac{\phi N}{\phi N_5}$

$\frac{455.4}{460} = \frac{920}{N_5}$

$N_5 \simeq 920\,RPM$

$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$

$K_e = \frac{PZ}{60a}$, $K_t = \frac{PZ}{2\pi a}$

$K_e = \frac{8 \times 756}{60 \times 8} = 12.6$

$K_t = \frac{8 \times 756}{2 \times 3.14 \times 8} = 121$

$T = \frac{121 \times 0.1 \times 500}{0.2} - \frac{12.6 \times 121 \times 0.1^2 \times N}{0.2}$

$T = 1600 - 1.62\,N$

$R_4 = 0.336\Omega$

$E_{b4} = V_t - I_1 R_4$

$= 500 - 200 \times 0.336$

$= 455V$

$$\frac{E_b}{E_{b4}} = \frac{\phi N}{\phi N_4}$$

$$\frac{455.4}{455} = \frac{920}{N_4}$$

$N_4 = 860\,RPM$

$R_5 = 0.2\Omega$

$E_{b5} = V_t - I_1 R_5$

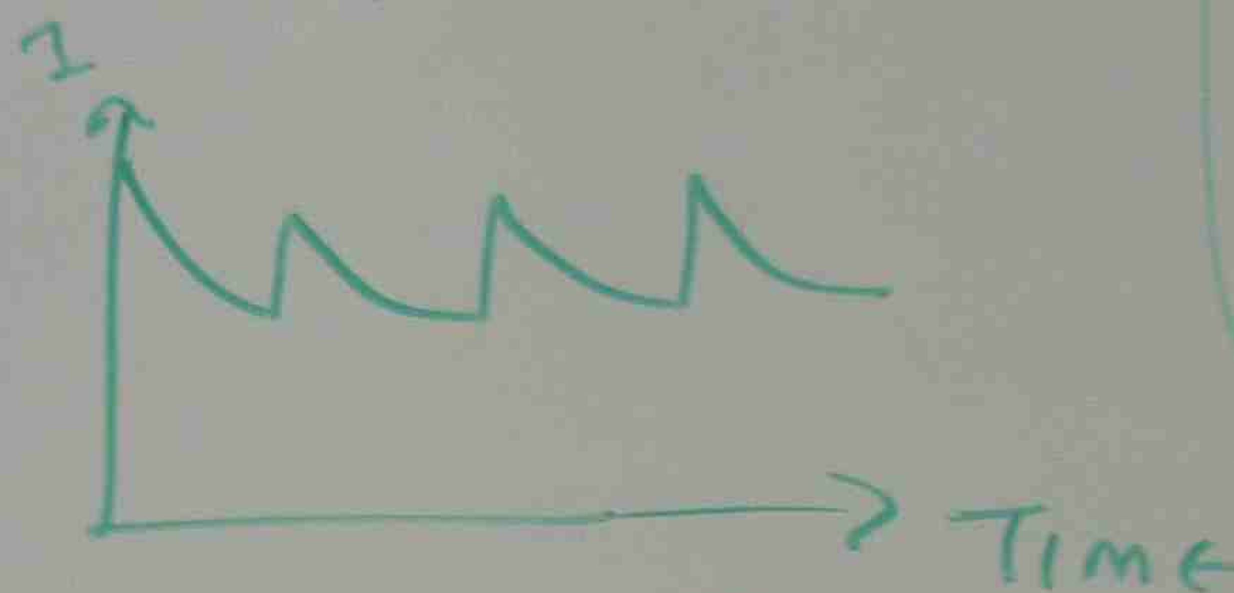
$= 500 - 200 \times 0.2$

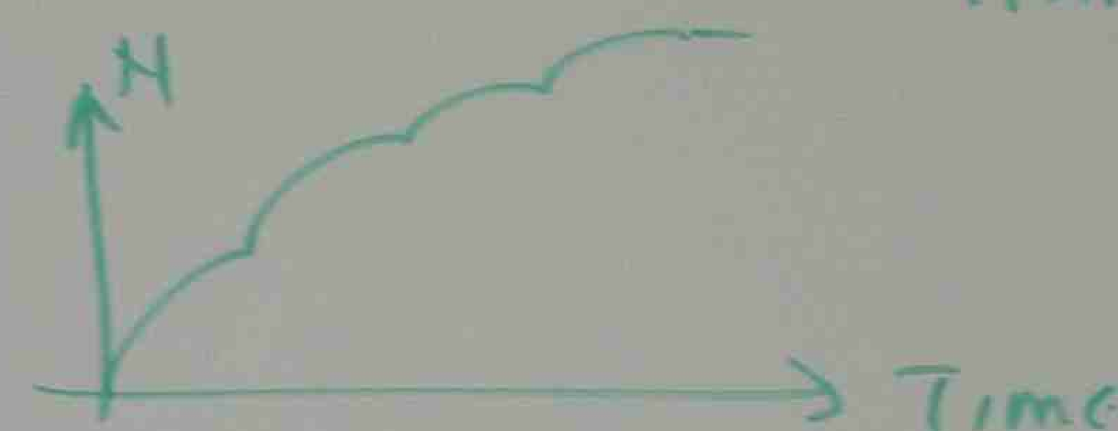
$= 460V$

$$\frac{E_b}{E_{b5}} = \frac{\phi N}{\phi N_5}$$

$$\frac{455.4}{460} = \frac{920}{N_5}$$

$N_5 \simeq 920\,RPM$





$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

$$K_e = \frac{PZ}{60a}, \quad K_t = \frac{PZ}{2\pi a}$$

$$K_e = \frac{8 \times 756}{60 \times 8} = 12.6$$

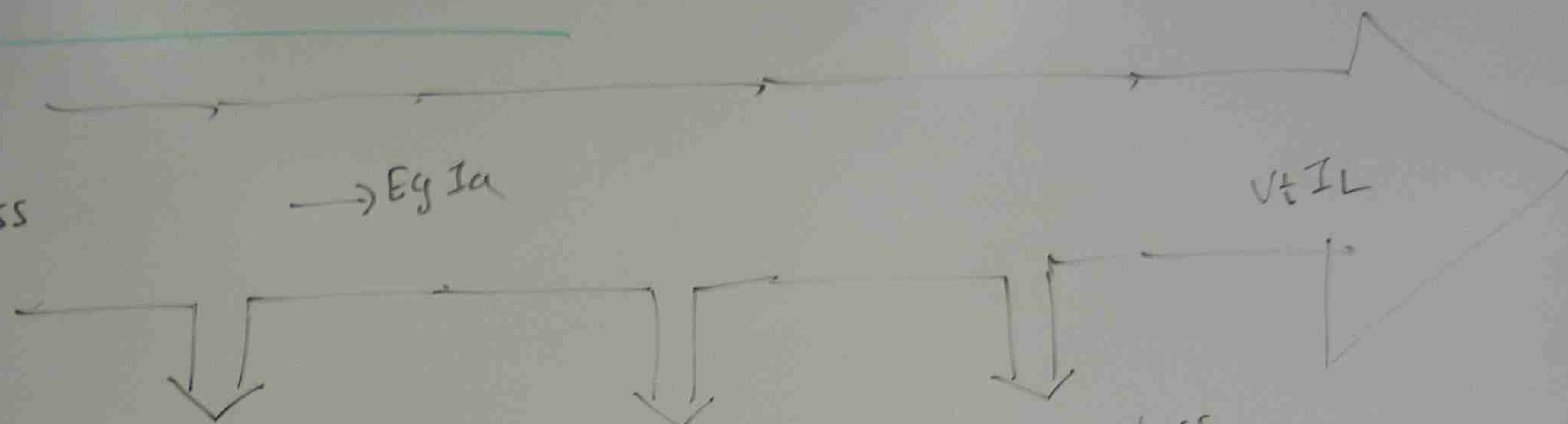
$$K_t = \frac{8 \times 756}{2 \times 3.1416 \times 8} = 121$$

$$T = \frac{121 \times 0.1 \times 500}{0.2} - \frac{12.6 \times 121 \times 0.1^2 \times N}{0.2}$$

$T = 30250 - 76.23\,N$

POWER FLOW DIAGRAM OF DC GENERATOR

MECHANICAL POWER INPUT $= E_g I_a +$ loss



W = ROTATIONAL LOSS

FRICTION, BRUSH

IRON, WIND

HYSTERESIS

ARMATURE COPPER LOSS

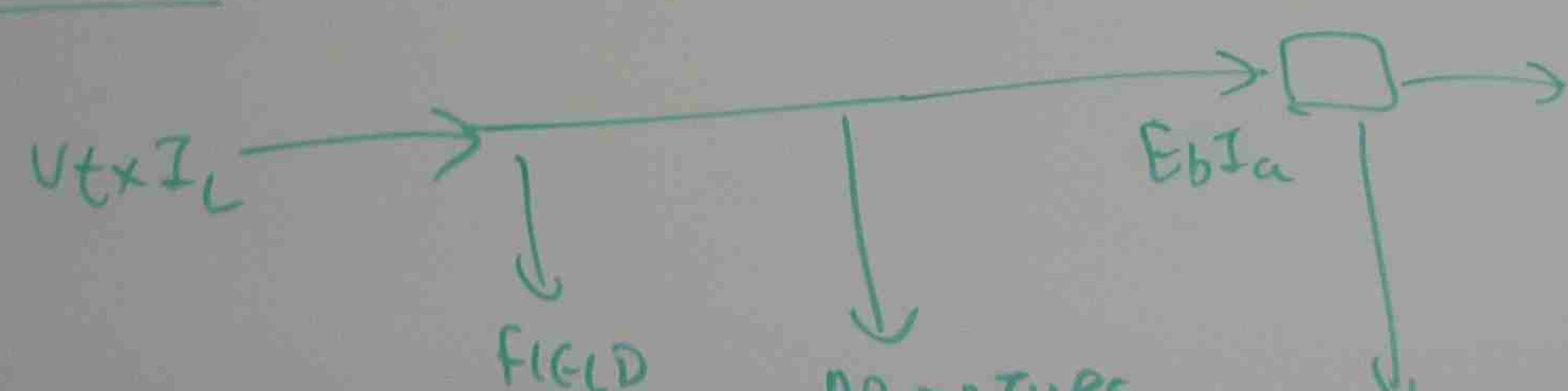
$= I_a^2 R_a$

FIELD LOSS

$V_t \times I_{FIELD}$

$$\text{GENERATOR EFFICIENCY} = \frac{V_t I_L}{E_g I_a + W} \times 100$$

DC motor



$\rightarrow E_b I_a -$ FRICTION LOSS $=$ Hp$\times$746

OUTPUT

FIELD LOSS

$V_t I_f$

ARMATURE LOSS

$I_a^2 R_a$

FRICTION LOSS

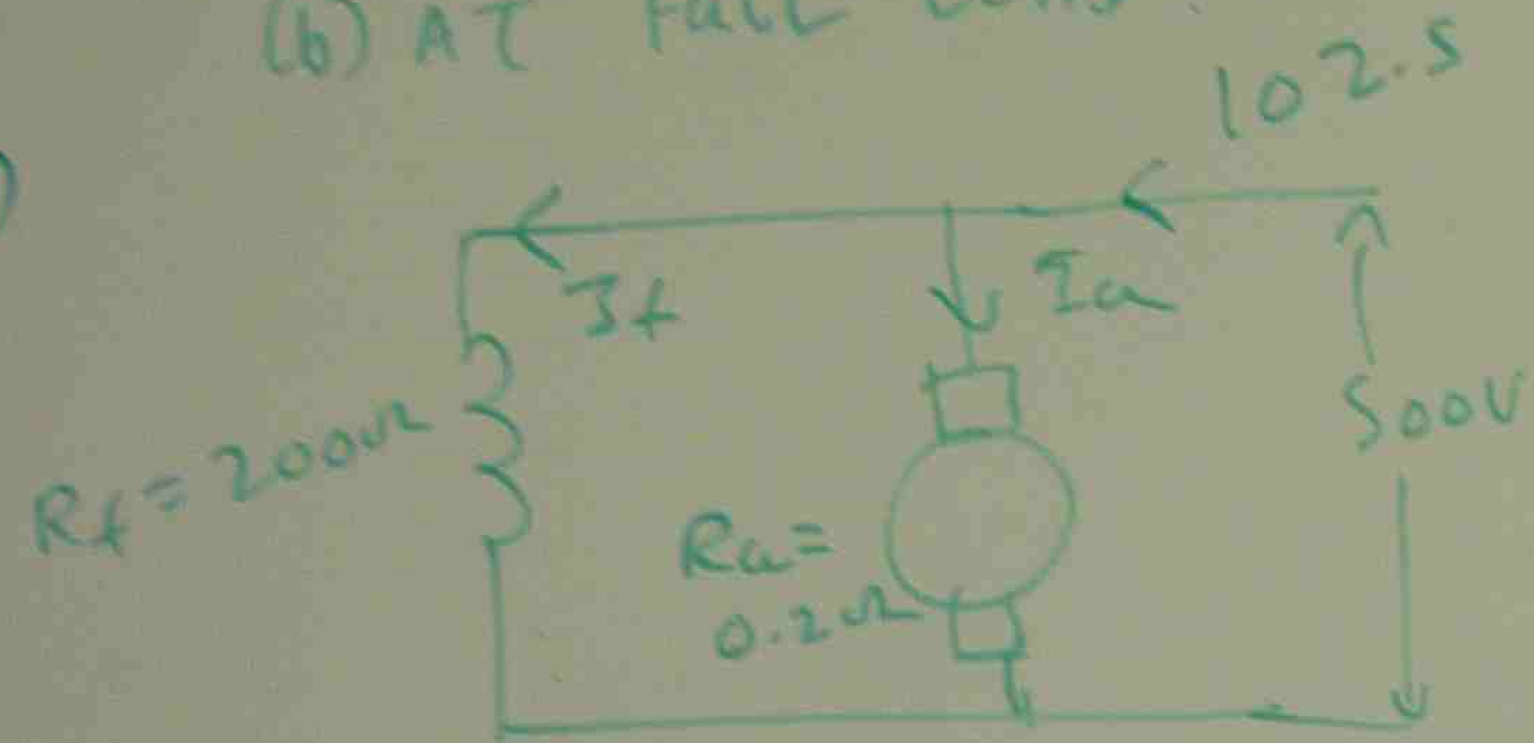
Pb) THE WINDING RESISTANCE OF A 500V, 60KW DC SHUNT MOTOR ARE $R_a = 0.2\Omega$ $R_f = 200\,\Omega$

IF MECHANICAL LOSSES ARE 1.4 KW, DETERMINE THE EFFICIENCY OF THE MACHINE

(a) WHEN THE LINE CURRENT IS 102.5 Amp

(b) AT FULL LOAD

(a)



$$I_f = \frac{500}{200} = 2.5\ A$$

$$I_a = I_L - I_f = 102.5 - 2.5 = 100\ \text{Amp.}$$

$$P_{IN} = V_t \times I_L = 500 \times 102.5 = 51250\ \text{WATT}$$

$$P_{losses} = I_a^2 R_a + I_f^2 R_f + 1400 = 100^2 \times 0.2 + 2.5^2 \times 200 + 1400$$

$$= 4650\,W$$

$$\%\eta = \frac{P_{IN} - P_{loss}}{P_{IN}} \times 100$$

$$= \frac{51250 - 4650}{51250} \times 100$$

$$= 90.93\%.$$

0.2Ω $R_f = 200\ \Omega$

MACHINE

SS x100

SO x100

%

(b) AT FULL LOAD

$$P_{OUT} = 60\,kW = 60{,}000\ W$$

$$P_{OUT} = E_g I_a - W \Rightarrow E_g I_a = P_{OUT} + W$$

$$E_g I_a = 60{,}000 + 1400 = 61400$$

$$E_g = V_t - I_a R_a$$

$$(V_t - I_a R_a) I_a = 61400$$

$$(500 - I_a \times 0.2) I_a = 61400$$

$$500 I_a - 0.2 I_a^2 = 61400$$

$$0.2 I_a^2 - 500 I_a + 61400 = 0$$

$$A x^2 + B x + C = 0$$

$$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

$$I_a = \frac{-(-500) \pm \sqrt{(-500)^2 - 4 \times 0.2 \times 61400}}{2 \times 0.2}$$

$$= 129.5 \text{ (OR) } 2375$$

$$P_{IN} = P_{OUT} + \underset{\text{LOSS}}{\text{ROTATIONAL}} + I_a^2 R_a + I_f^2 R_f$$

$$= 60000 + 1400 + (129.5)^2 \times 0.2 + 2.5^2 \times 200$$

$$= 66000 \text{ WATT}$$

$$\%\eta = \frac{P_{OUT}}{P_{IN}} \times 100$$

$$= \frac{60000}{66000} \times 100 = 90.9\%$$

$R_2 = 0$

E_{b_2}

E_b

E_b

455

31

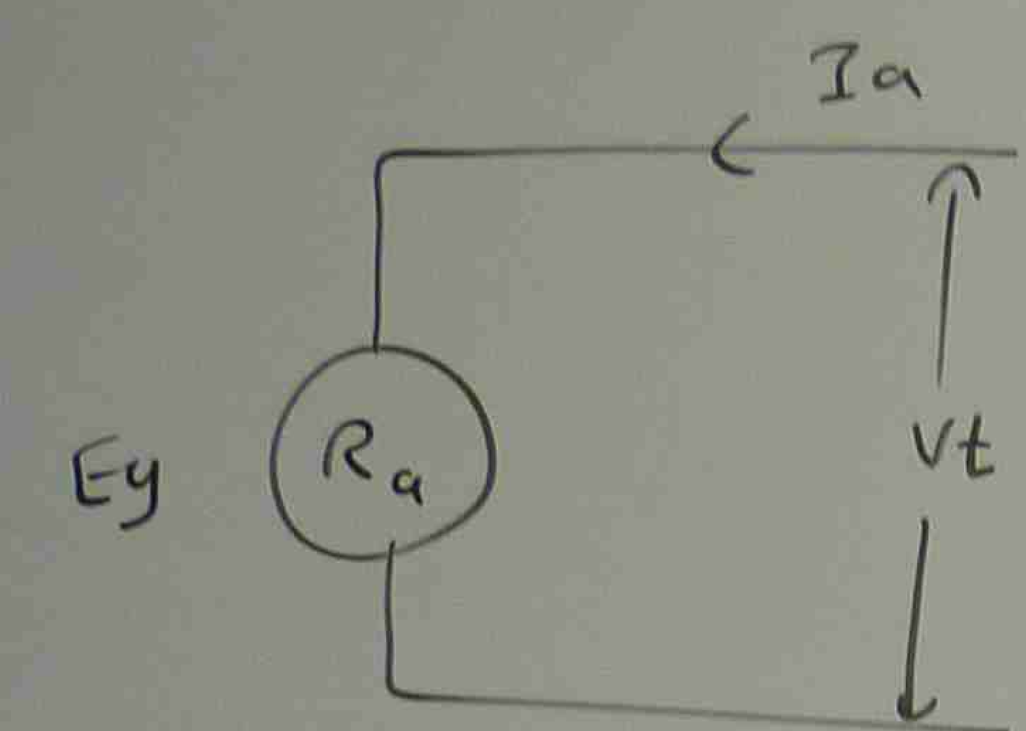
i_3

E_b

E

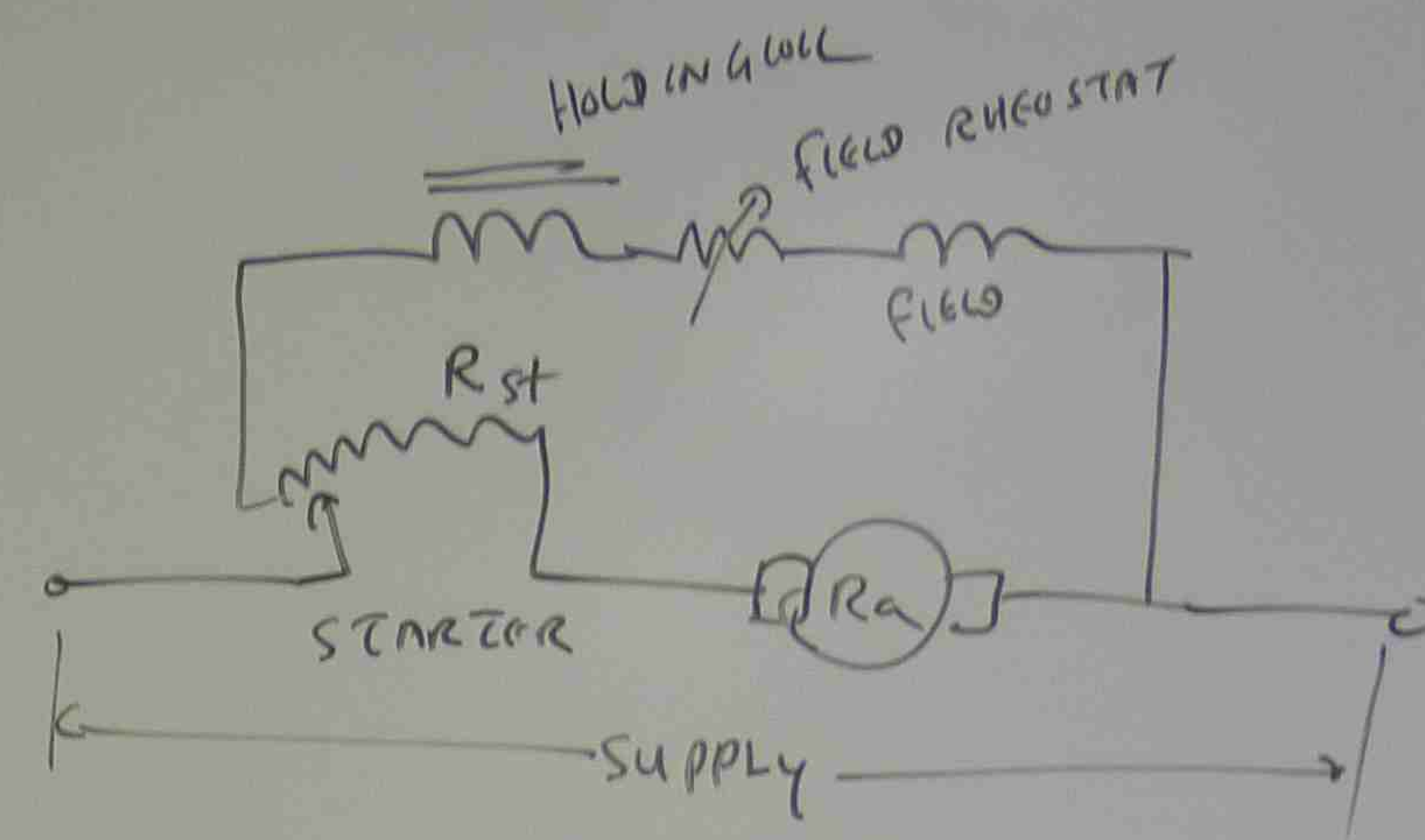
DC MOTOR STARTERS

CIRCUIT ANALYSIS



$$E_g = V_t - I_a R_a$$

$$I_a = \frac{V_t - E_g}{R_a}$$



$$I_a = \frac{V_t - E_g}{R_a + R_{st}}$$

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{a}$$

E_g = BACK EMF

ϕ = FLUX

Z = ARMATURE CONDUCTORS

N = SPEED

P = NO. OF POLES

a = NO. OF ARMATURE PARALLEL PATHS.

AT ST

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RESISTOR

pb THE

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FULL

(a) IF

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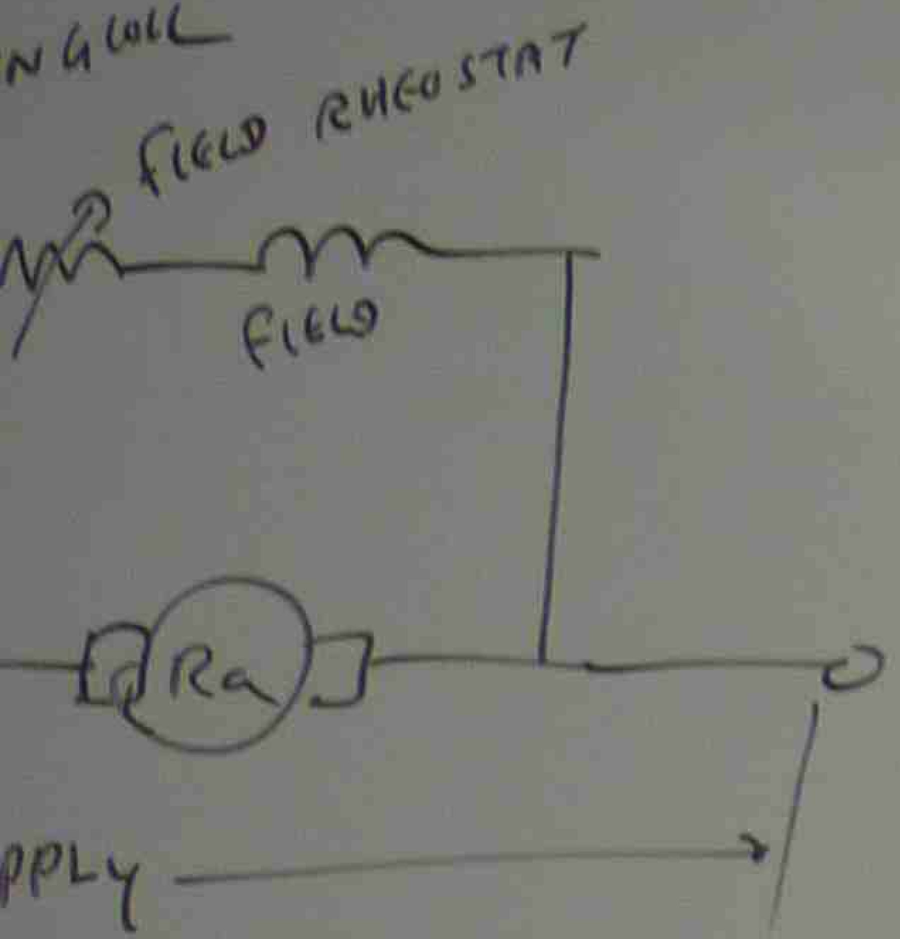
(b) D



$\frac{Eg}{Rst}$

$\times \frac{P}{a}$

f

CONDUCTORS

MATURE PARALLEL PATHS.

AT STARTING TIME, N IS SMALL AS IT STARTS FROM ZERO SPEED.

ACCORDING TO $E_g = \frac{\phi Z N}{60} \times \frac{P}{a}$, E_g IS SMALL.

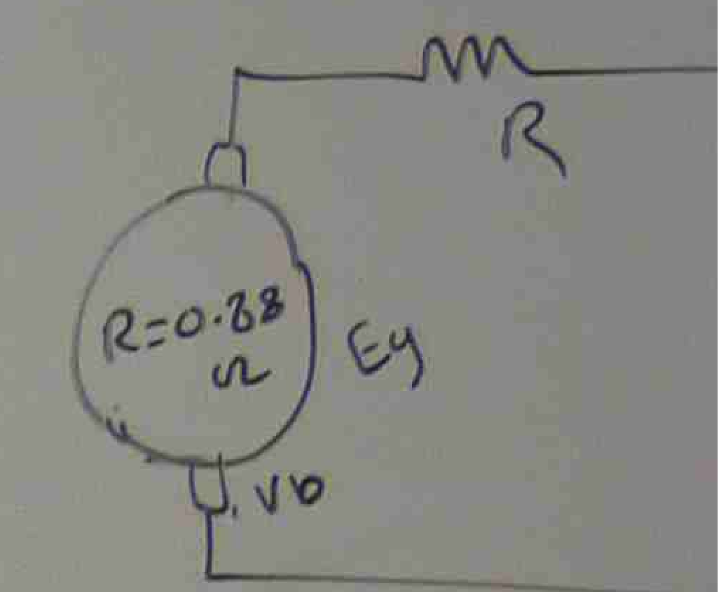
STARTING CURRENT $I_a = \frac{V_t - E_g}{R_a}$ IS LARGE.

LARGE STARTING CURRENT NEEDS TO BE LIMITED BY STARTING RESISTOR.

Pb THE ARMATURE OF A 230V SHUNT MOTOR HAS A RESISTANCE OF 0.88Ω AND TAKES 28.2 AMP AT FULL LOAD.

(a) IF I_a IS NOT TO EXCEED 150% OF NORMAL FULL LOAD CURRENT AT STARTING, CALCULATE STARTING RESISTANCE

(b) DETERMINE I_a IF NO STARTING RESISTANCE IS INSERTED. ASSUME BRUSH DROP 3V.



(a)

$I_{st} = \frac{V_t}{Ra}$

$\frac{150}{100} \times 28.2 = \frac{230-}{0.8}$

$0.88 + R = \frac{22}{15}$

$R = \frac{227 \times}{150 \times}$

(b) $I_{st} = \frac{V_t - (}{R}$

L AS IT STARTS FROM ZERO SPEED.

, E_g IS SMALL.

$\frac{- E_g}{R_a}$ IS LARGE.

S TO BE LIMITED BY STARTING

30V SHUNT MOTOR HAS A

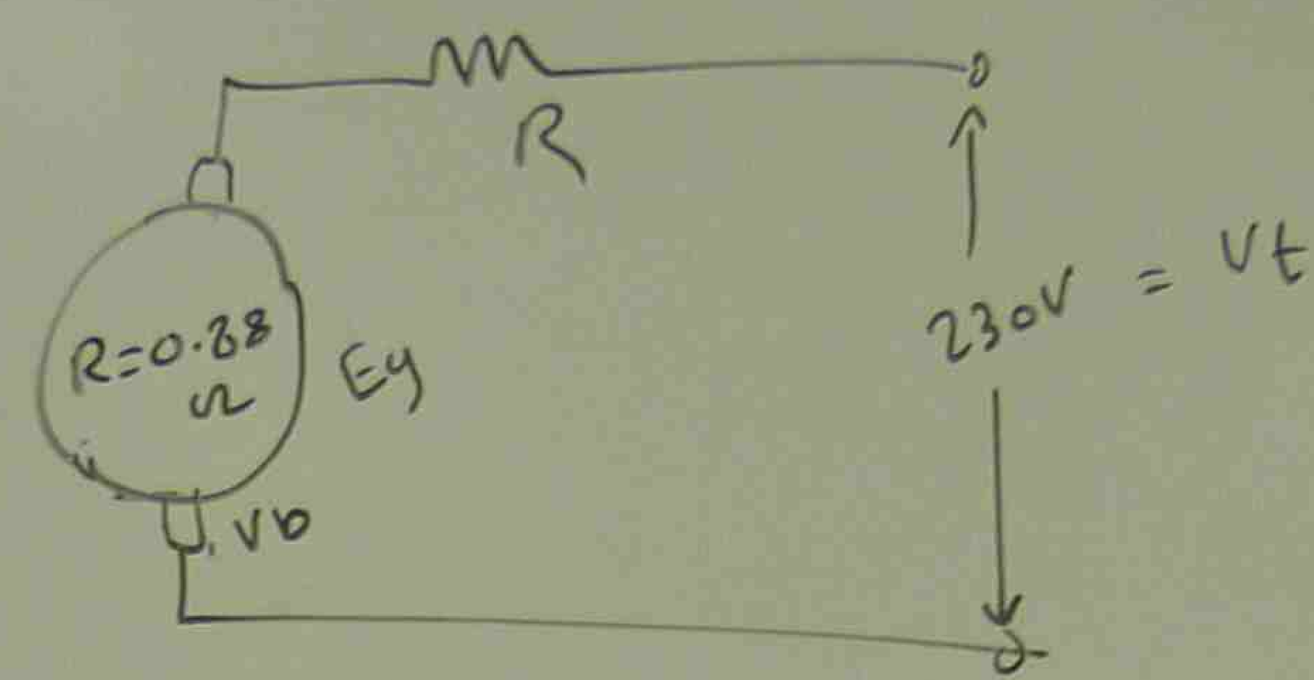
AND TAKES 28.2 Amp AT

CEED 150% of NORMAL FULL

TING , CALCULATE STARTING

NO STARTING RESISTANCE IS

RUSH DROP 3V.



(a)

$$I_{st} = \frac{V_t - (E_g + V_b)}{R_a + R}$$

$$\frac{150}{100} \times 28.2 = \frac{230 - (0 + 3)}{0.88 + R}$$

$$0.88 + R = \frac{227 \times 100}{150 \times 28.2}$$

$$R = \frac{227 \times 100}{150 \times 28.2} - 0.88 = 4.55\,\Omega$$

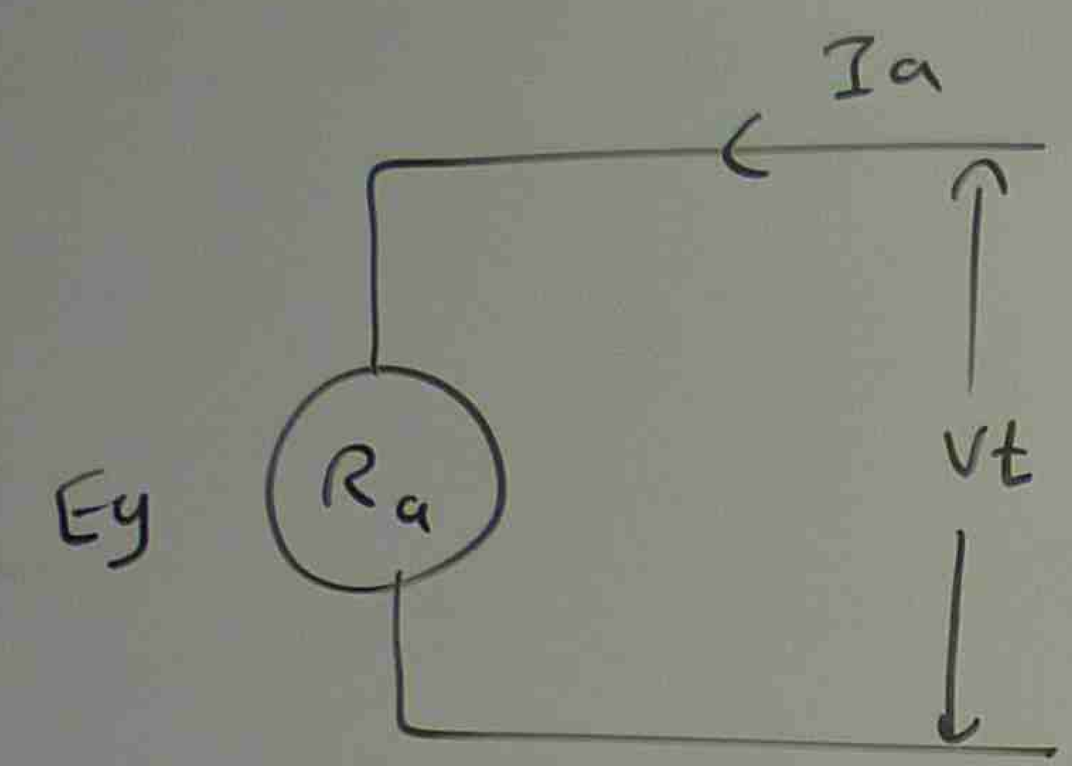
(b)

$$I_{st} = \frac{V_t - (E_g + V_b)}{R_a} = \frac{230 - (0 + 3)}{0.88} = \frac{227}{0.88}$$

$= 277$ Amp.

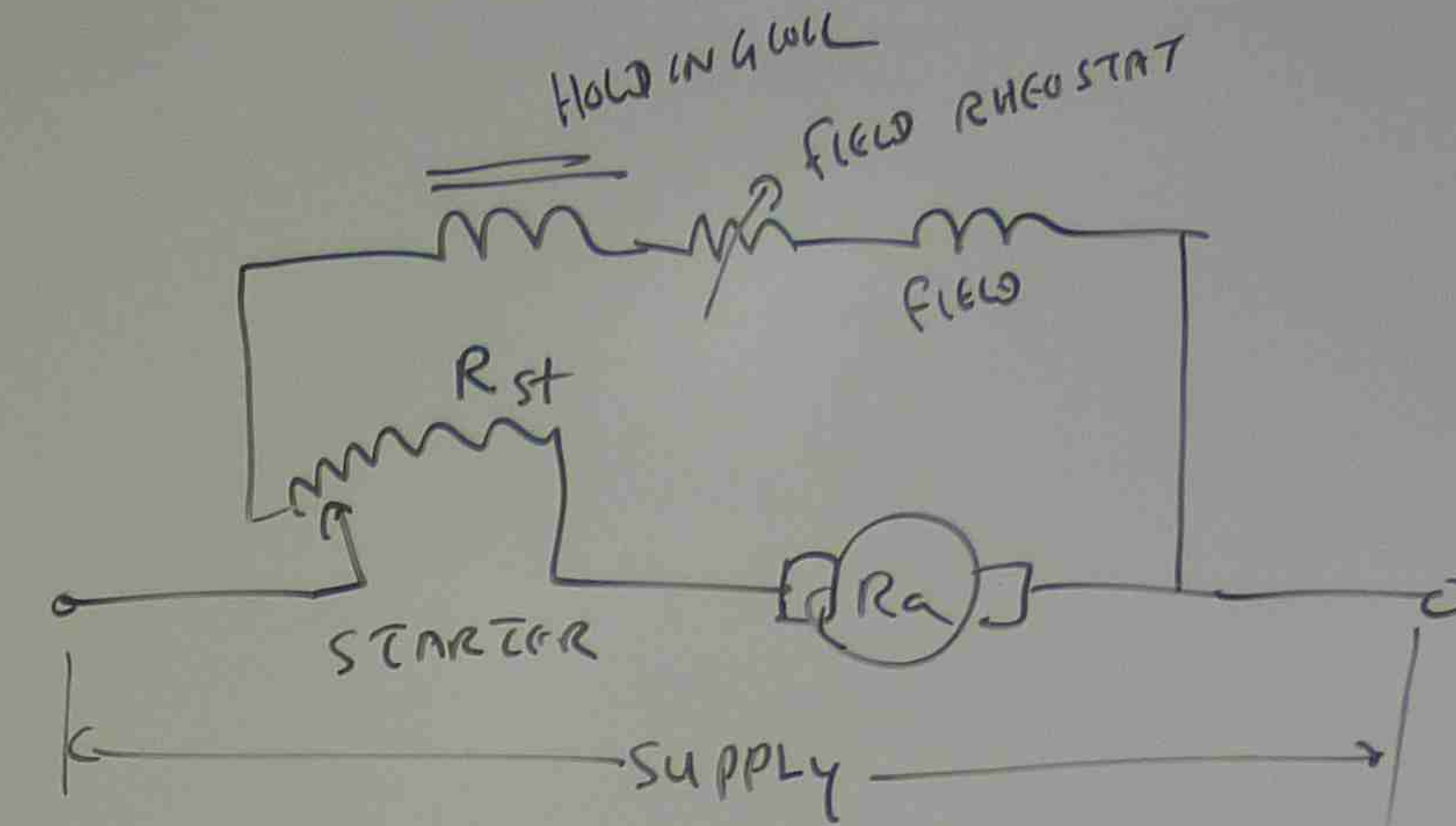
DC MOTOR STARTERS

CIRCUIT ANALYSIS



$$E_g = V_t - I_a R_a$$

$$I_a = \frac{V_t - E_g}{R_a}$$



$$I_a = \frac{V_t - E_g}{R_a + R_{st}}$$

$$E_g = \frac{\phi Z N}{60} \times \frac{P}{a}$$

E_g = BACK EMF

ϕ = FLUX

Z = ARMATURE CONDUCTORS

N = SPEED

P = NO. OF POLES

a = NO. OF ARMATURE PARALLEL PATHS.

AT STAR

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(a) IF

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(b) I

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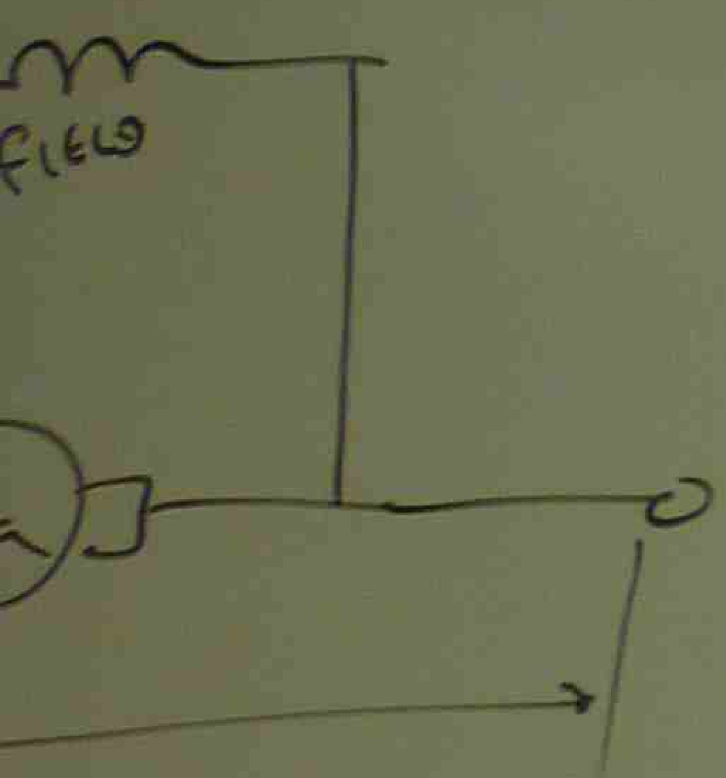
FIELD



DUCTORS

URE PARALLEL PATHS.

AT STARTING TIME, N IS SMALL AS IT STARTS FROM ZERO SPEED.

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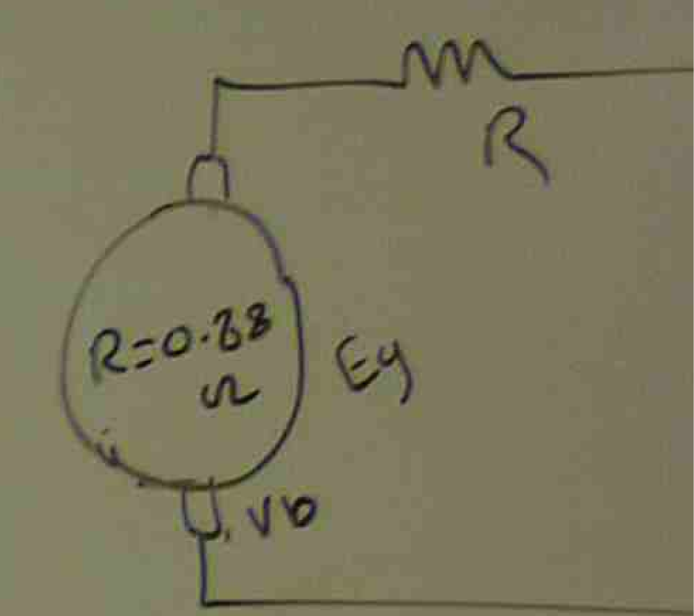
(pb) THE ARMATURE OF A 230V SHUNT MOTOR HAS A RESISTANCE OF 0.88Ω AND TAKES 28.2 Amp AT FULL LOAD.

(a) IF I_a IS NOT TO EXCEED 150% OF NORMAL FULL LOAD CURRENT AT STARTING, CALCULATE STARTING RESISTANCE

(b) DETERMINE I_a IF NO STARTING RESISTANCE IS INSERTED. ASSUME BRUSH DROP 3V.



(a)

$I_{st} = \frac{V_t \ldots}{R \ldots}$

$\frac{150}{100} \times 28.2 = \frac{230 - \ldots}{0. \ldots}$

$0.88 + R = \frac{2 \ldots}{1 \ldots}$

$R = \frac{227 \times \ldots}{150 \times \ldots}$

(b) $I_{st} = \frac{V_t - \ldots}{\ldots}$

IT STARTS FROM ZERO SPEED.

Eg IS SMALL.

IS LARGE.

BE LIMITED BY STARTING

SHUNT MOTOR HAS A

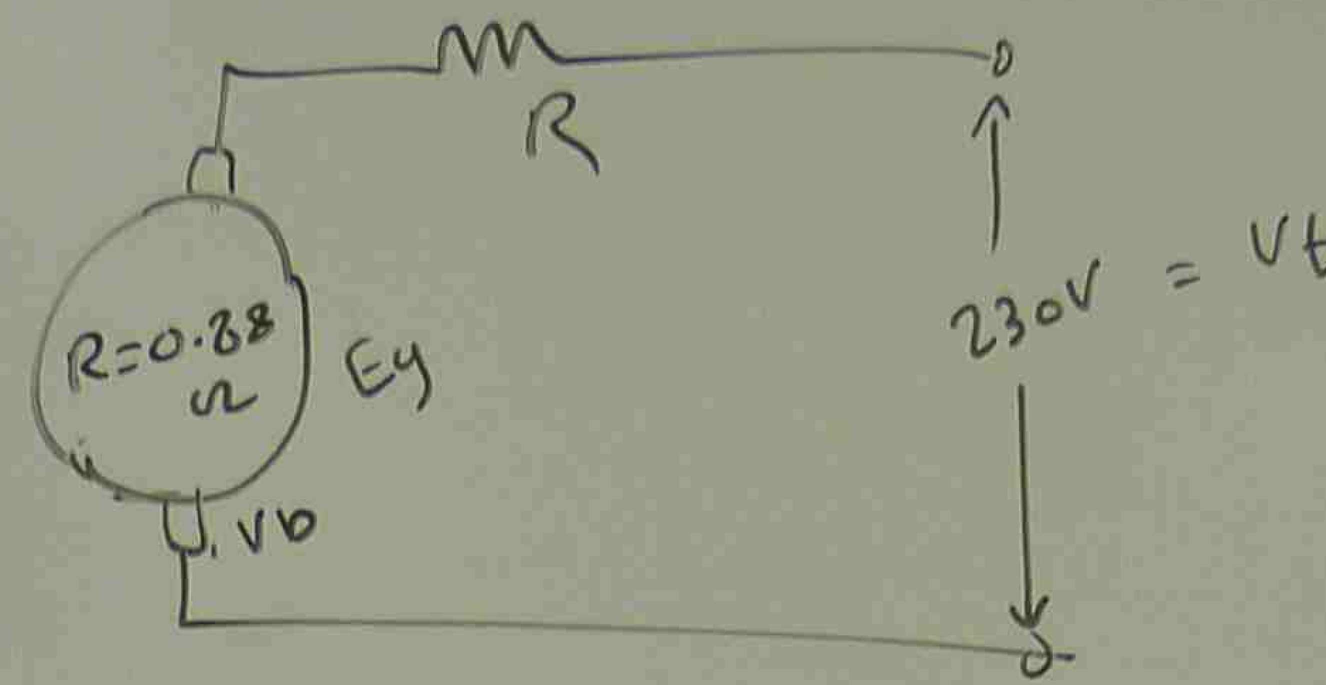
AKES 28.2 Amp AT

150% of NORMAL FULL

, CALCULATE STARTING

TARTING RESISTANCE IS

ROP 3V.



(a)

$$I_{st} = \frac{V_t - (E_g + V_b)}{R_a + R}$$

$$\frac{150}{100} \times 28.2 = \frac{230 - (0+3)}{0.88 + R}$$

$$0.88 + R = \frac{227 \times 100}{150 \times 28.2}$$

$$R = \frac{227 \times 100}{150 \times 28.2} - 0.88 = 4.55\,\Omega$$

(b)

$$I_{st} = \frac{V_t - (E_g + V_b)}{R_a} = \frac{230 - (0+3)}{0.88} = \frac{227}{0.88}$$

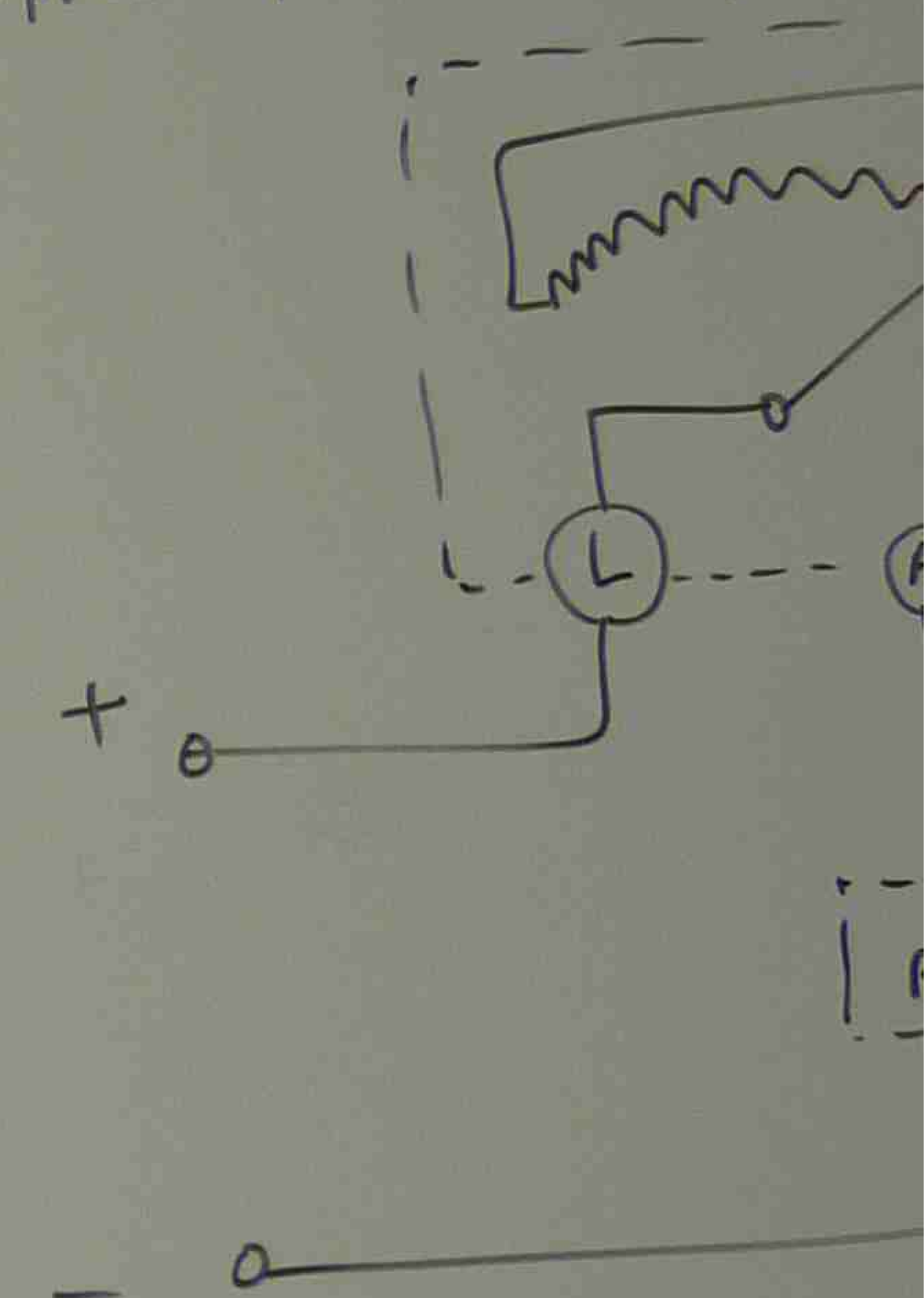
$$= 257 \text{ Amp.}$$

DYNAMIC BRAKING

WHEN THE STOP SWITCH IS

IS DISSIPATED IN DYNAMIC

STOPPED IMMEDIATELY.



$$I_{br} = \frac{E_g - V}{R_{br} + }$$

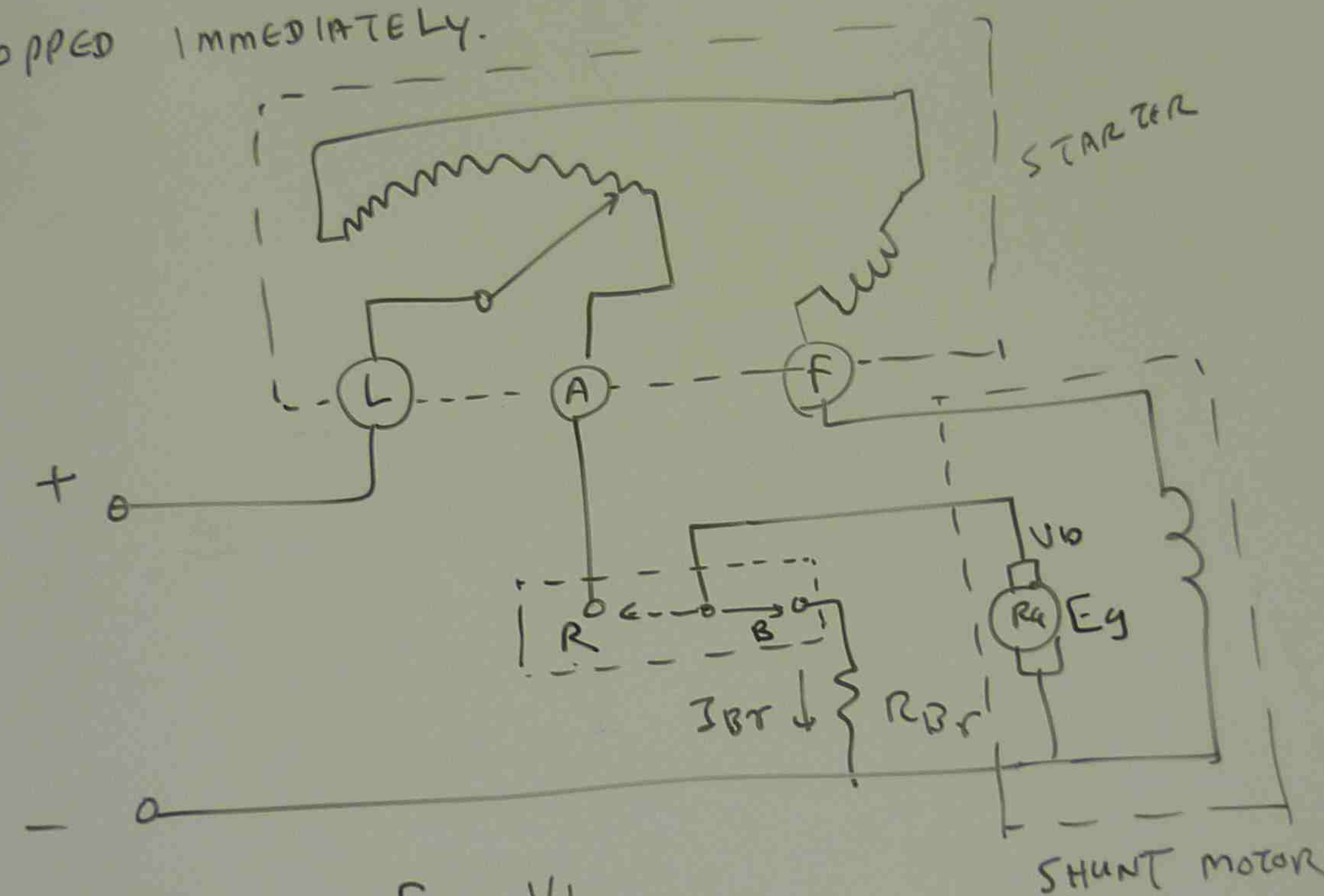
$= 4.55\Omega$

$$\frac{o-(0+3)}{0.88} = \frac{227}{0.88}$$

$= 257$ Amp.

DYNAMIC BRAKING

WHEN THE STOP SWITCH IS PRESSED, THE ENERGY STORED IN MOTOR ARMATURE IS DISSIPATED IN DYNAMIC BRAKING RESISTOR. THEREFORE, THE MOTOR IS STOPPED IMMEDIATELY.



$$I_{br} = \frac{E_g - V_b}{R_{br} + R_a}$$

pb THE BRA
SERIES WOUND
TO BE LIMIT
CALCULATE TH

ASSUME Eg

I_{br}

$E_g =$

$R_a =$

R_b

I_{br}

R_{br}

ORED IN MOTOR ARMATURE
FORE, THE MOTOR IS

R

pb THE BRAKING CURRENT OF A 12.5 KW 230V 58 Amp MOTOR SERIES WOUND, TOTAL ARMATURE AND FIELD RESISTANCE 0.28 Ω IS TO BE LIMITED TO 1.75 TIMES MOTOR FULL LOAD RATING. CALCULATE THE VALUE OF THE DYNAMIC BRAKING RESISTOR.

ASSUME Eg IS 94% OF RATED VOLTAGE AND BRUSH DROP IS 3V.

$I_{br} = 1.75\, I_{FL} = 1.75 \times 58$

$E_g = 0.94 \times 230$ ✓

$R_a = 0.28\,\Omega$ $\qquad V_b = 3V$

$R_{br} = ?$

$$I_{br} = \frac{E_g - V_b}{R_{br} + R_a}$$

$$R_{br} + R_a = \frac{E_g - V_b}{I_{br}}$$

$$R_{br} = \frac{E_g - V_b}{I_{br}} - R_a$$

$$= \frac{0.94 \times 230 - 3}{1.75 \times 58} - 0.28$$

$$= 1.82\,\Omega$$

ACCELERATION

$$t = \frac{\Delta N}{\ldots}$$

t = TIME (

ΔN = CHANGE

I = MOMENT

T = TORQUE

IT IS REQ

SUITABLE PER

THE TORQUE

ACCELERATIN

THE TORQUE

LIMITING RE

THE DAMAG

W 230V 58 Amp MOTOR

IELD RESISTANCE 0.28 Ω IS

FULL LOAD RATING.

BRAKING RESISTOR.

GE AND BRUSH DROP IS 3V.

$$\frac{E_g - V_b}{I_{br}} - R_a$$

$$\frac{.94 \times 230 - 3}{1.75 \times 58} - 0.28$$

$$= 1.82\,\Omega$$

ACCELERATION TIME CONSIDERATION

$$t = \frac{\Delta N\,(2\pi I)}{60\,T} \quad \underline{\underline{sec}}$$

t = TIME (sec)

ΔN = CHANGE IN SPEED (RPM)

I = MOMENT OF INERTIA $N\text{-}m\,s^{-2}$

T = TORQUE (N-m)

IT IS REQUIRED THAT THE MOTOR IS TO HAVE THE SUITABLE PERFORMANCE AT THE STARTING TO ENSURE THAT THE TORQUE PRODUCED BY CHOSEN MOTOR IS CAPABLE OF ACCELERATING THE ASSOCIATED SYSTEM.

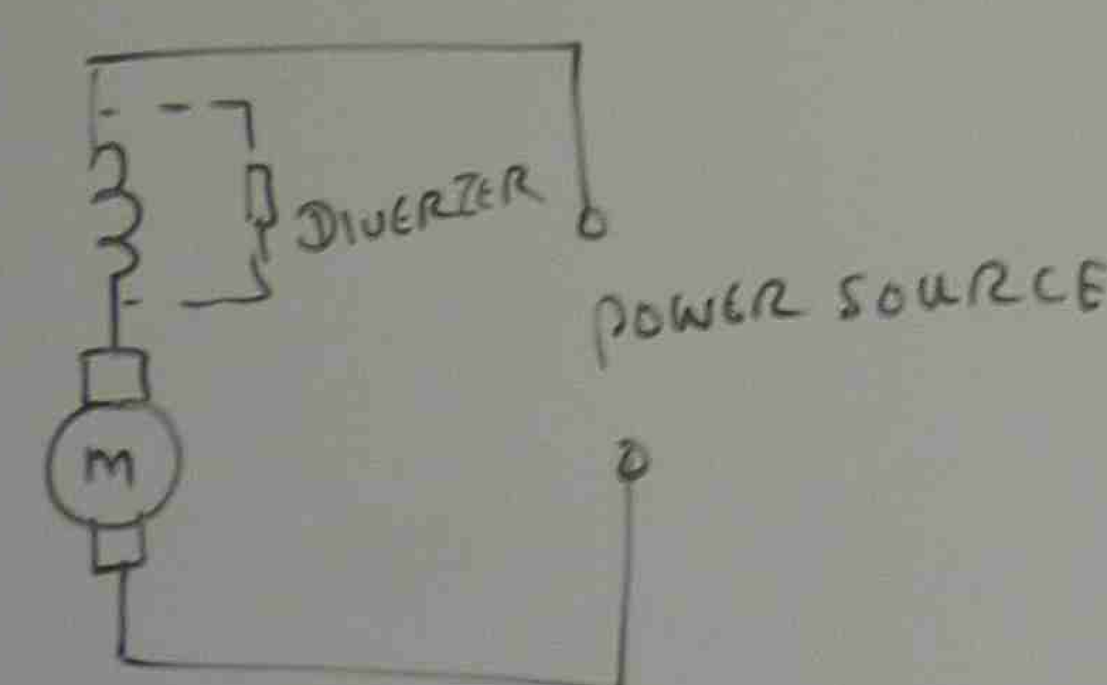
THE TORQUE PRODUCED UNDER THE RESTRICTION OF CURRENT LIMITING RESISTOR MUST HAVE APPROPRIATE VALUE TO PREVENT THE DAMAGE.

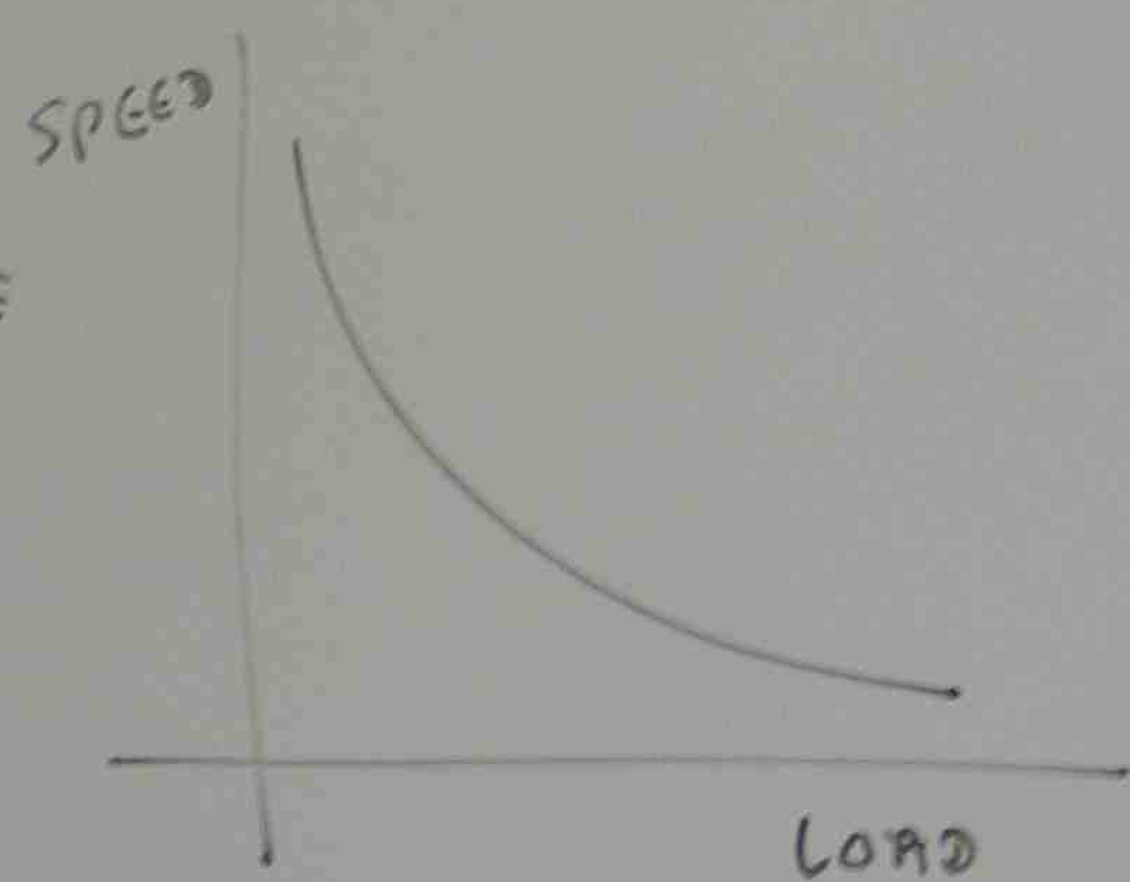
CHARACTERISTICS OF DC MOTORS

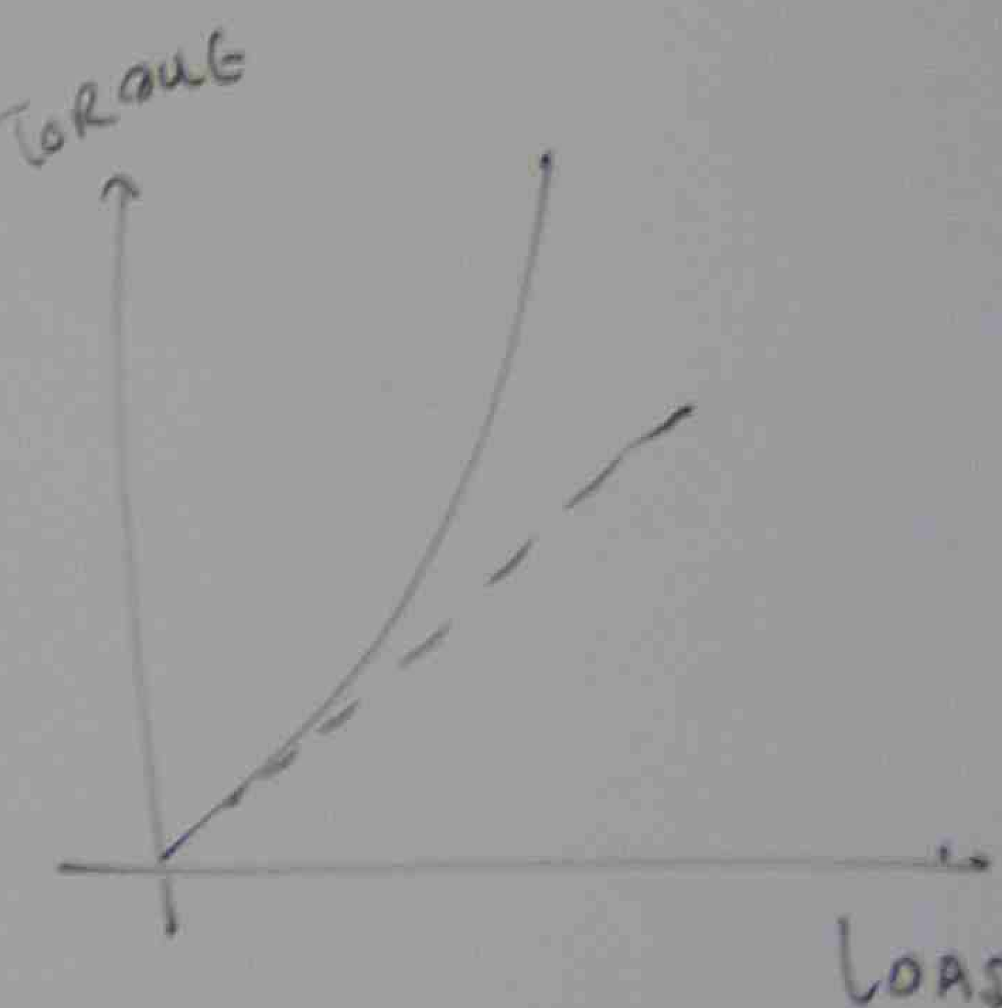
SERIES MOTOR

THE SERIES EXCITED MOTOR IS USED FOR IT'S GOOD STARTING TORQUE CHARACTERISTICS

Eg. TRAMS, ELEVATORS, CRANES, STARTER MOTORS







SHUN

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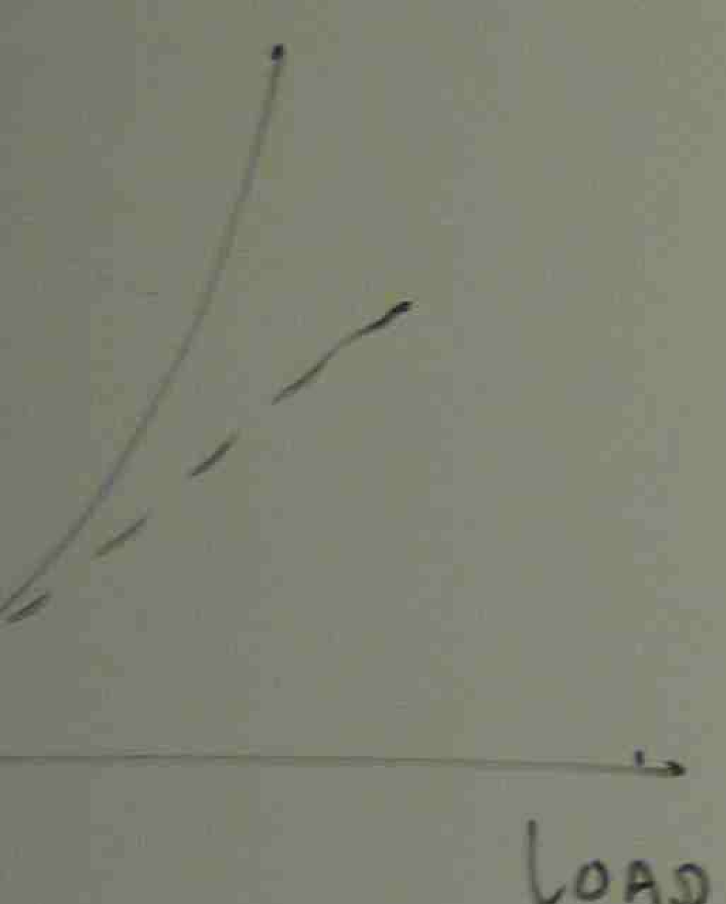
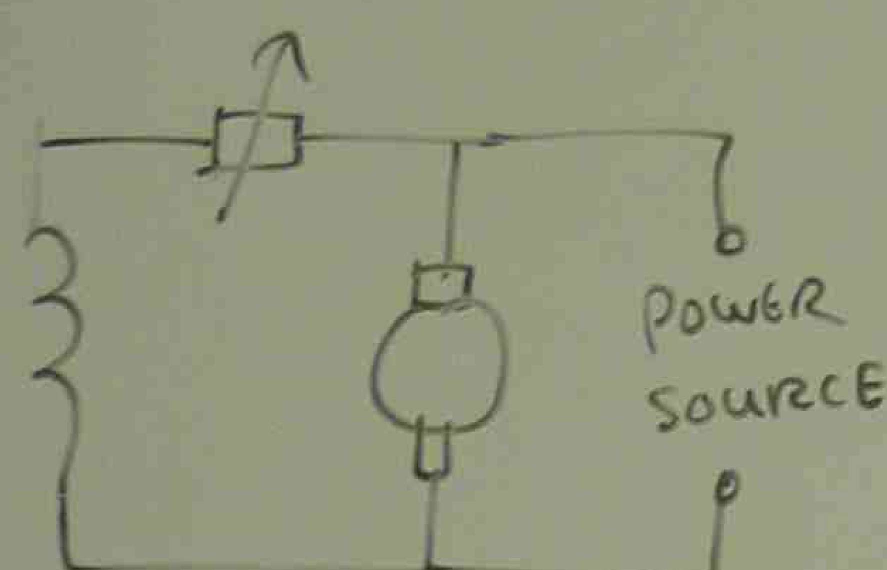
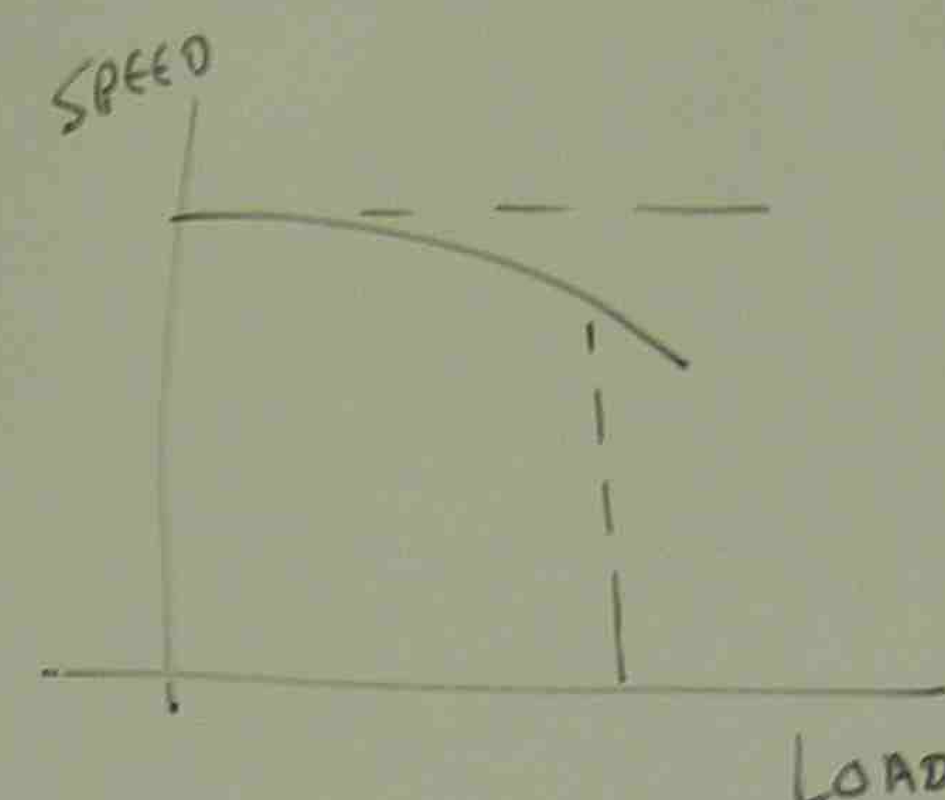
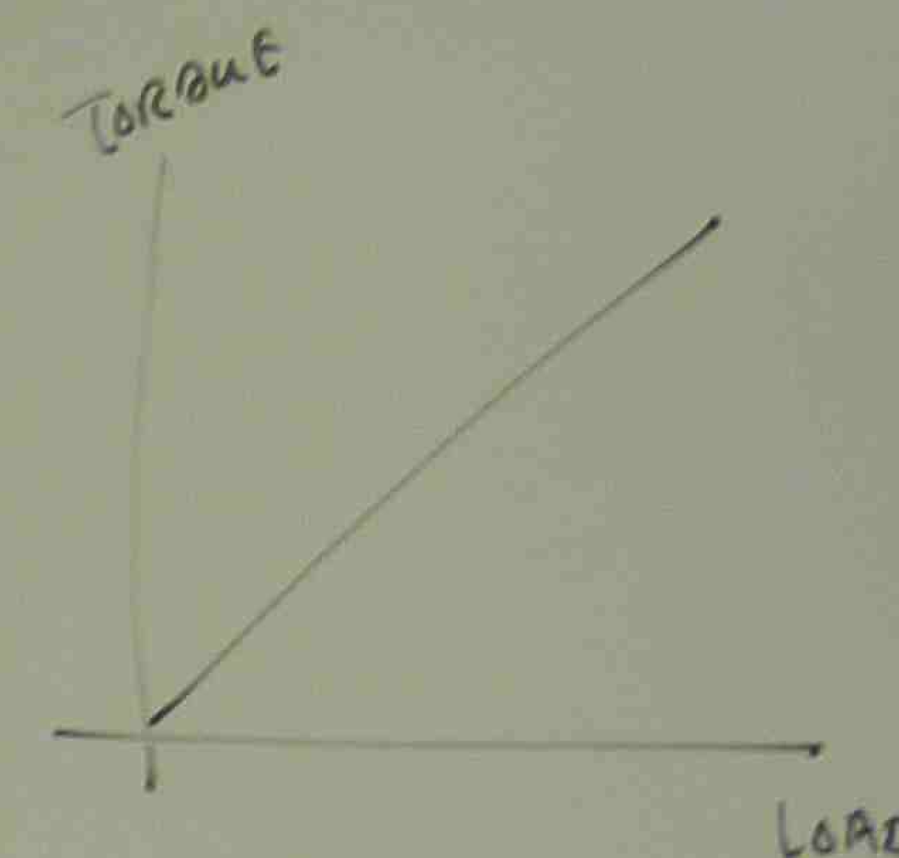


SHUNT MOTOR

THE SHUNT EXCITED MOTOR IS USED FOR IT'S FAIRLY CONSTANT SPEED CHARACTERISTICS

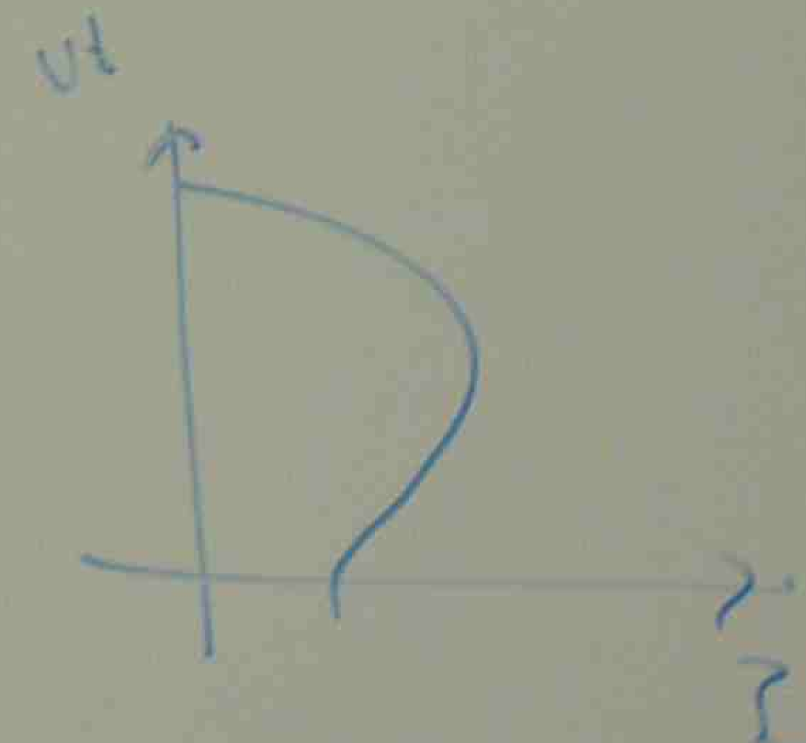






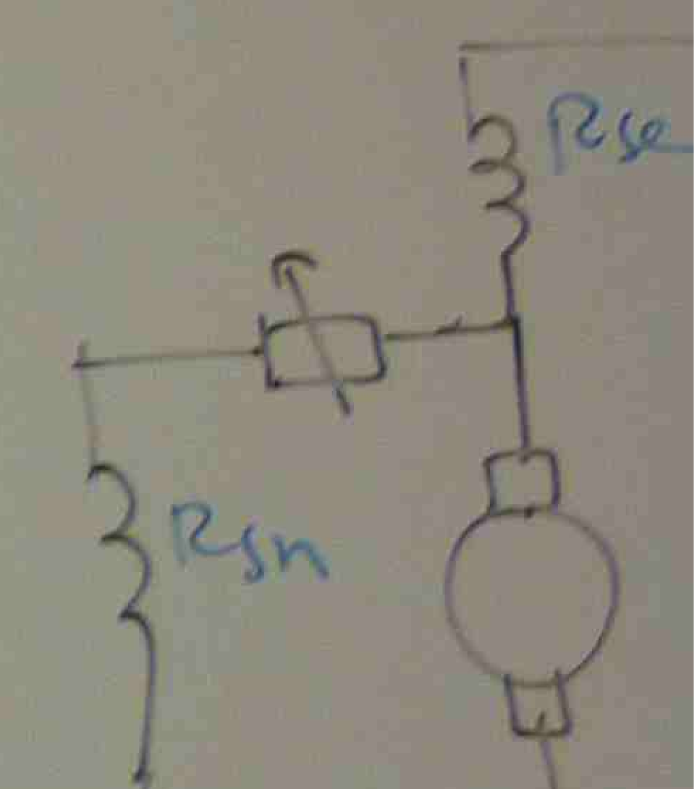
DIFFERENTIAL

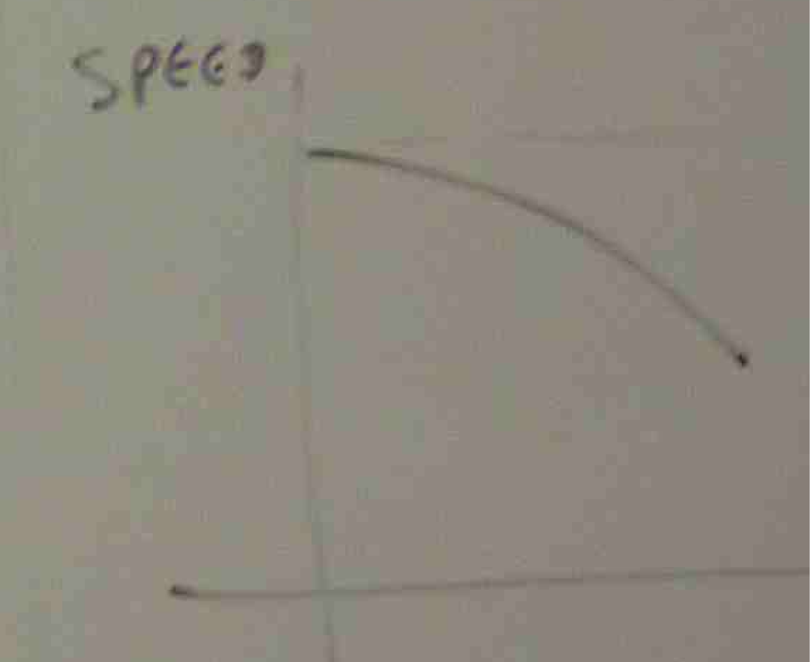
$\phi_{sh} - \phi_{se}$



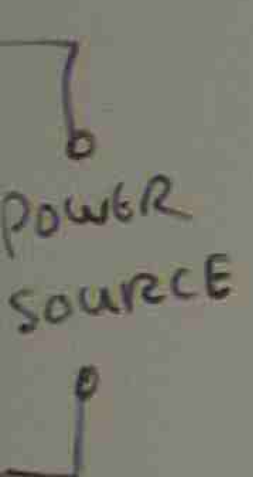
COMPOUND MOTOR

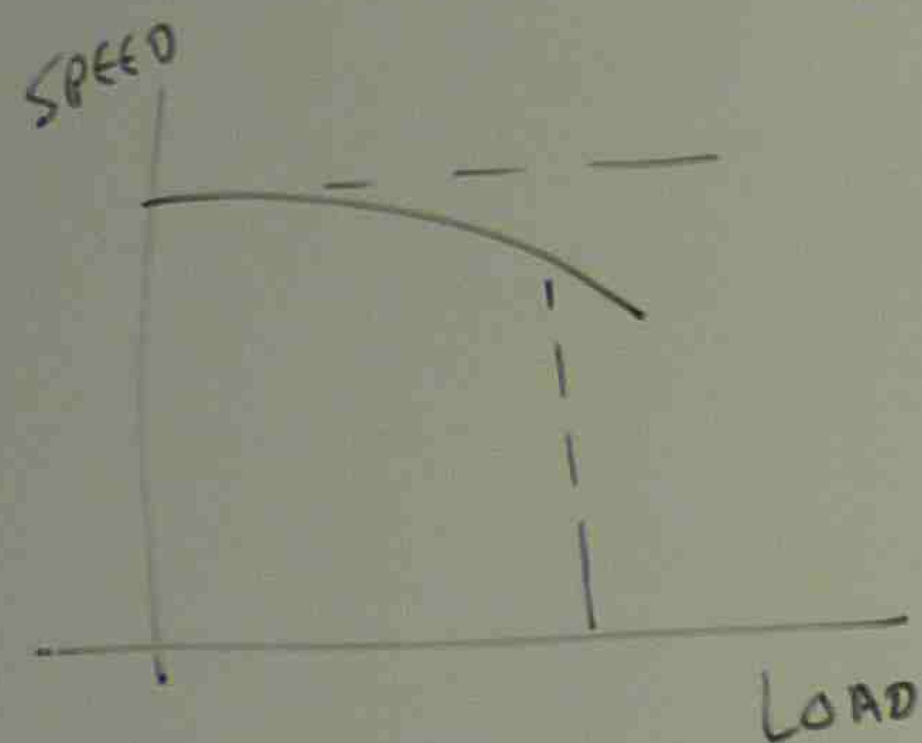
THE CUMULATIV
THE CHARACTERIST
SHUNT MOTORS.
SHEARS, ROLLING

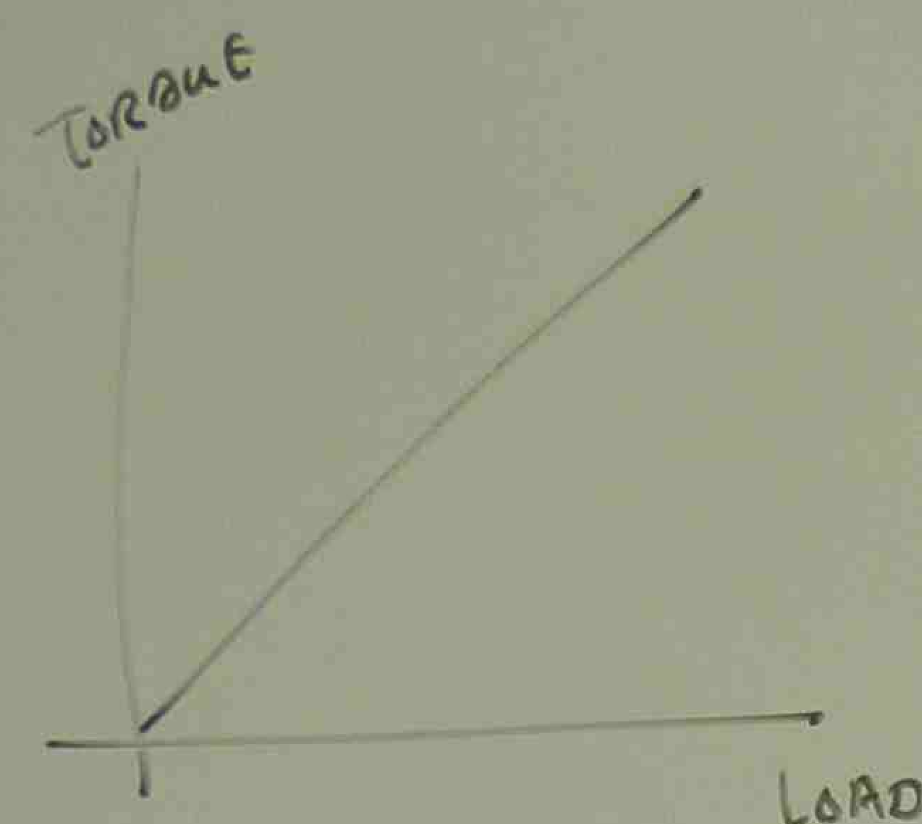




...ITED MOTOR IS USED FOR IT'S FAIRLY
CHARACTERISTICS

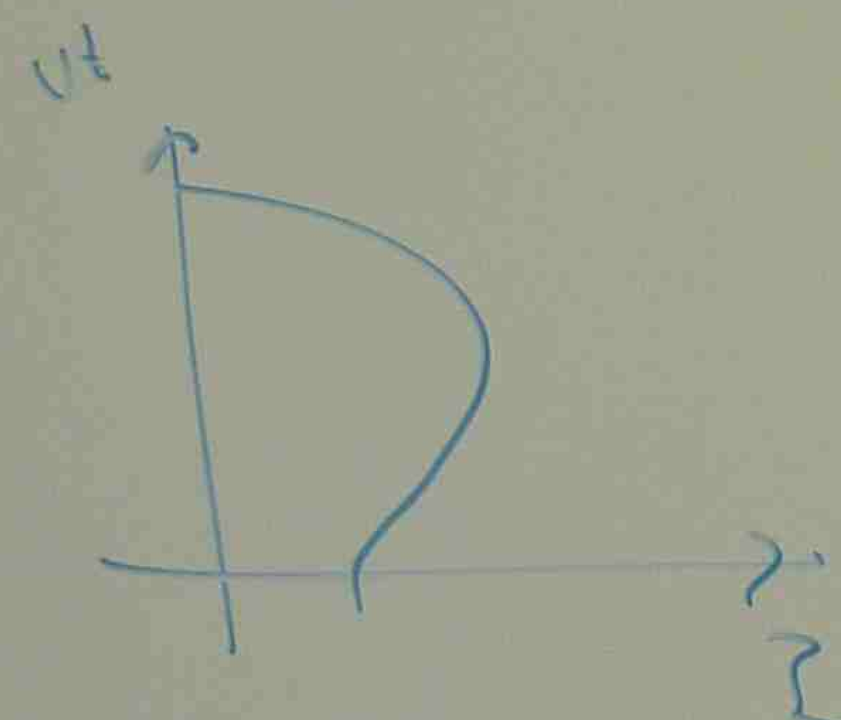






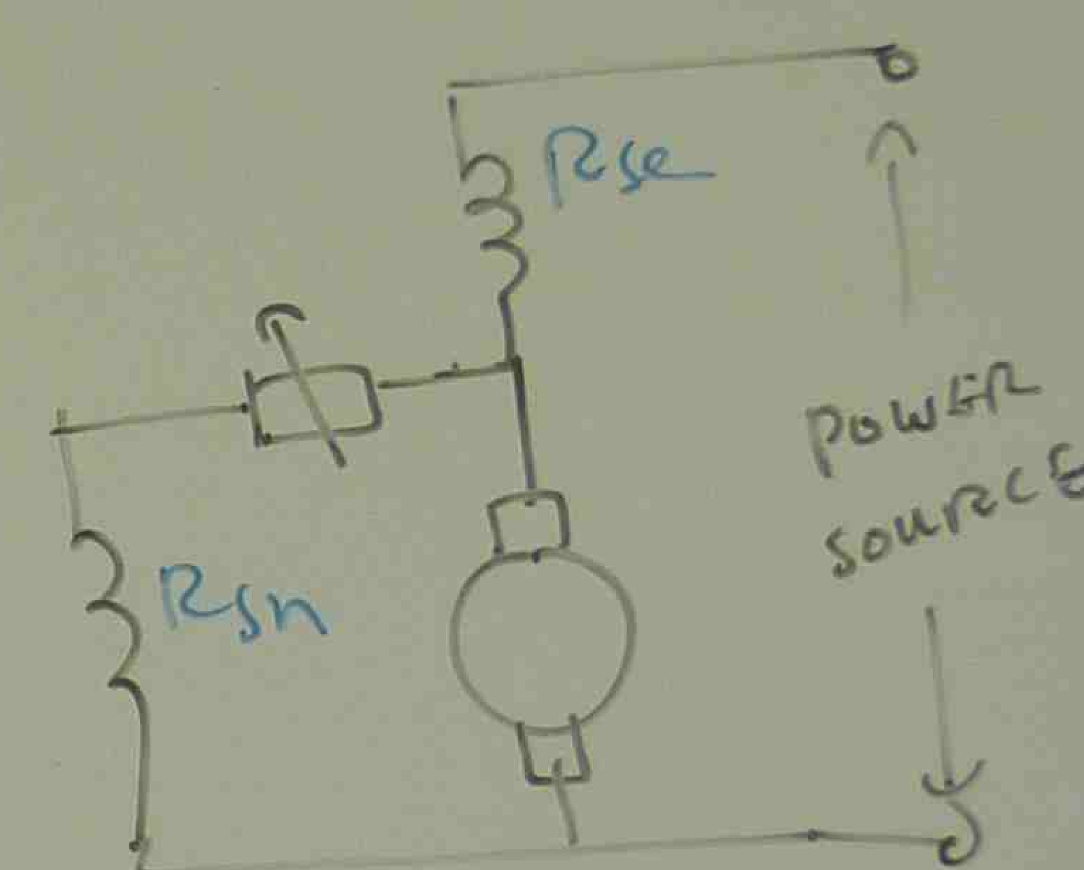
DIFFERENTIAL

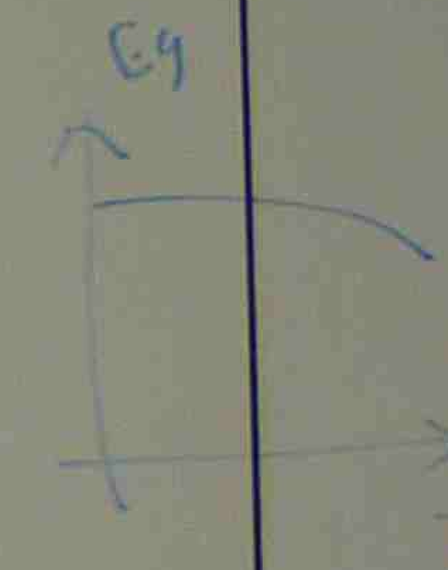
$\phi_{sh} - \phi_{se}$



COMPOUND MOTOR

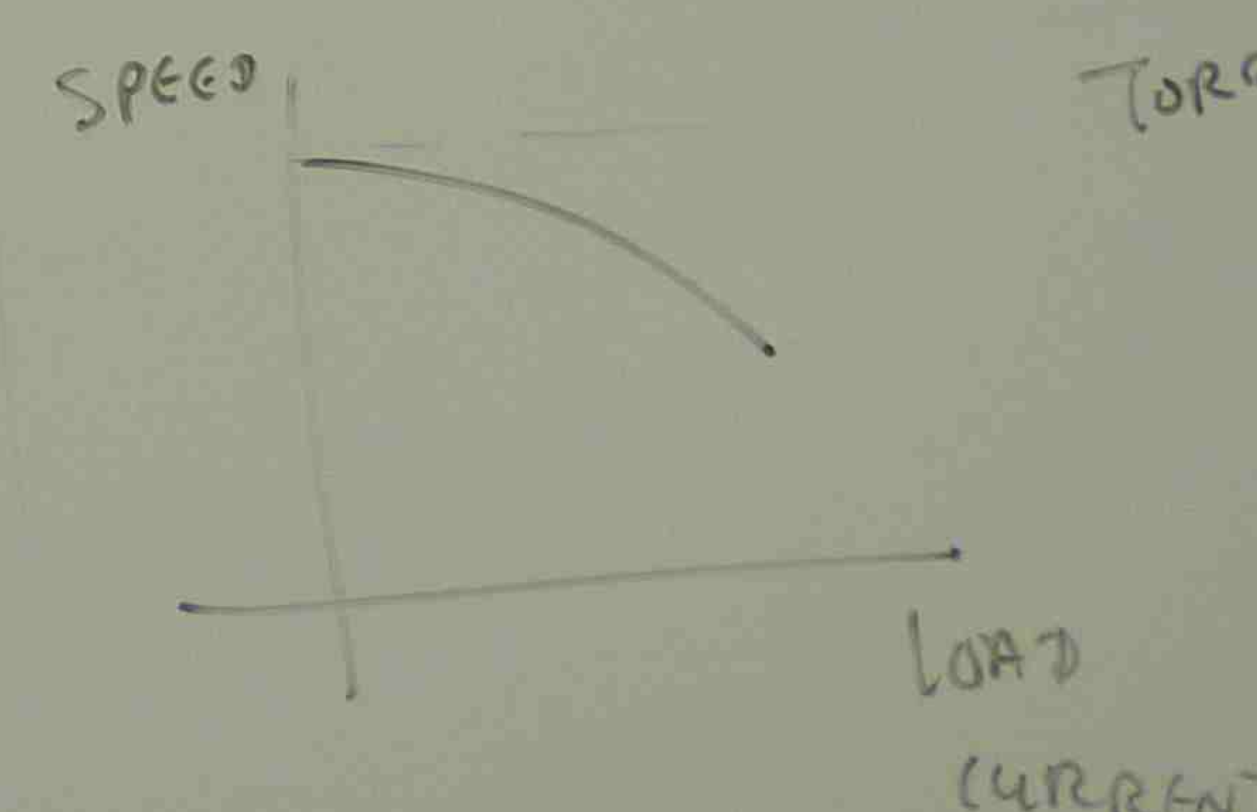
THE CUMULATIVELY COMPOUNDED MOTOR COMBINES THE CHARACTERISTICS OF BOTH THE SERIES AND SHUNT MOTORS. APPLICATIONS ARE PUNCHES, SHEARS, ROLLING MILLS.

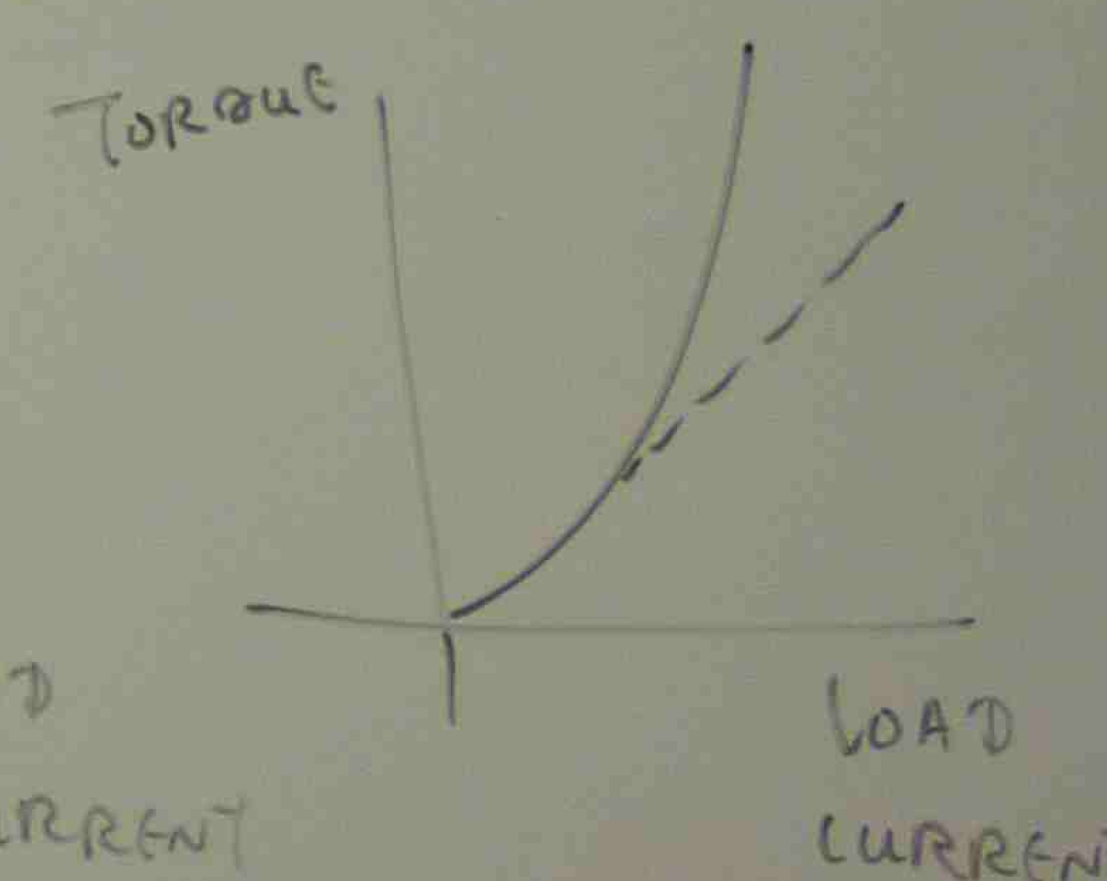




$\phi_{se} \longrightarrow \phi_{sh}$

CUMULATIVE
COMPOUND





WHEN ...
IS D...
STOP...

DC MOTOR SPEED CONTROL

$$E_b = \frac{\phi Z N}{60} \times \frac{P}{a}$$

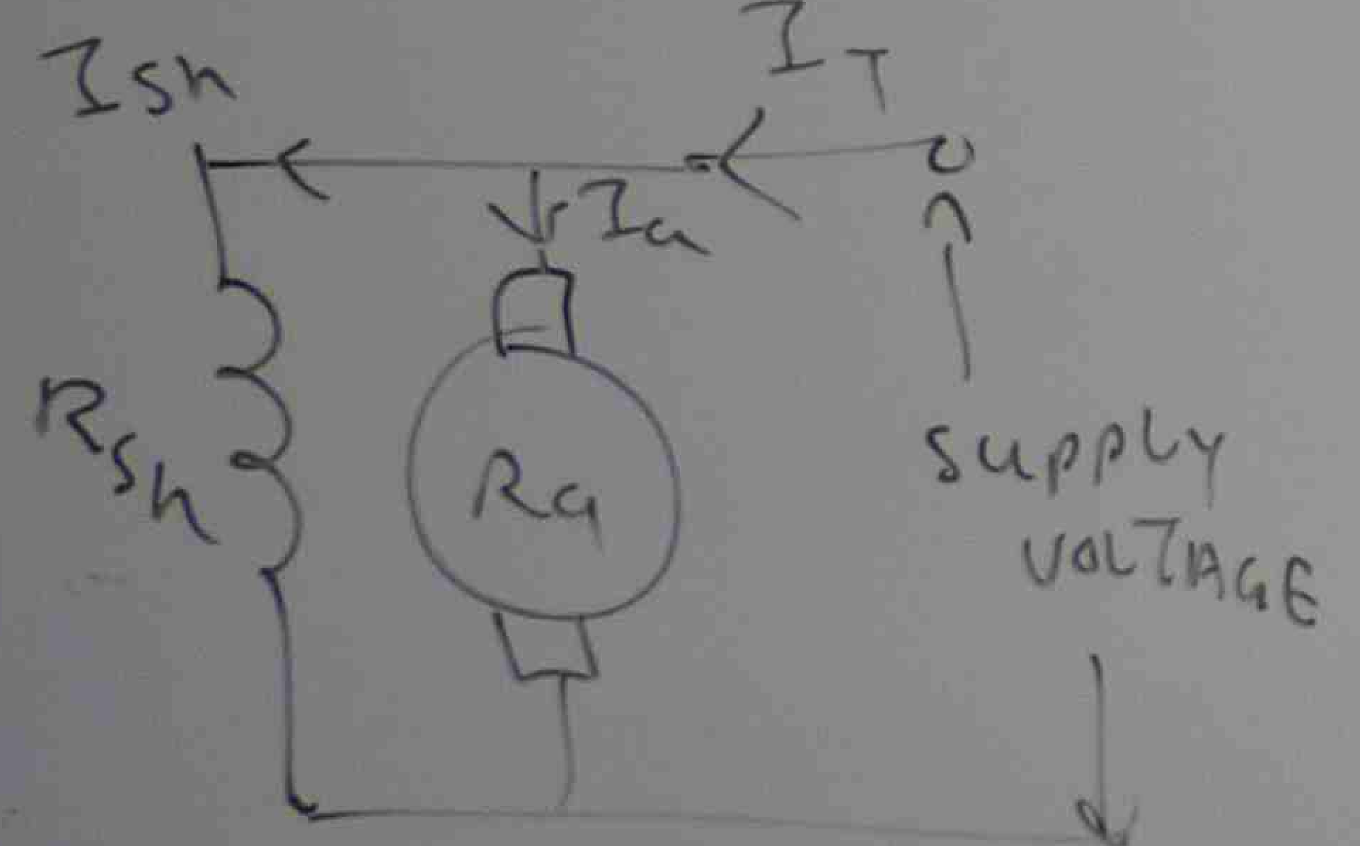
ϕ = FLUX

Z = ARMATURE CONDUCTORS

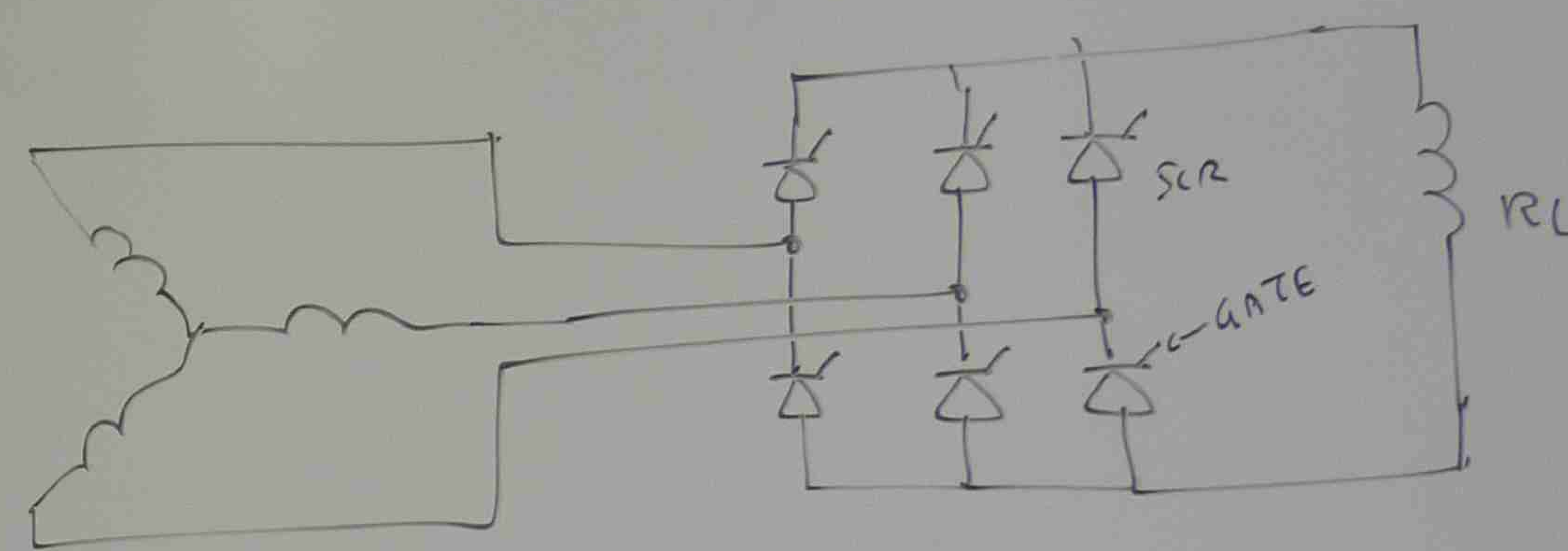
N = SPEED

P = NO. OF POLES

a = NO. OF ARMATURE PARALLEL PATHS

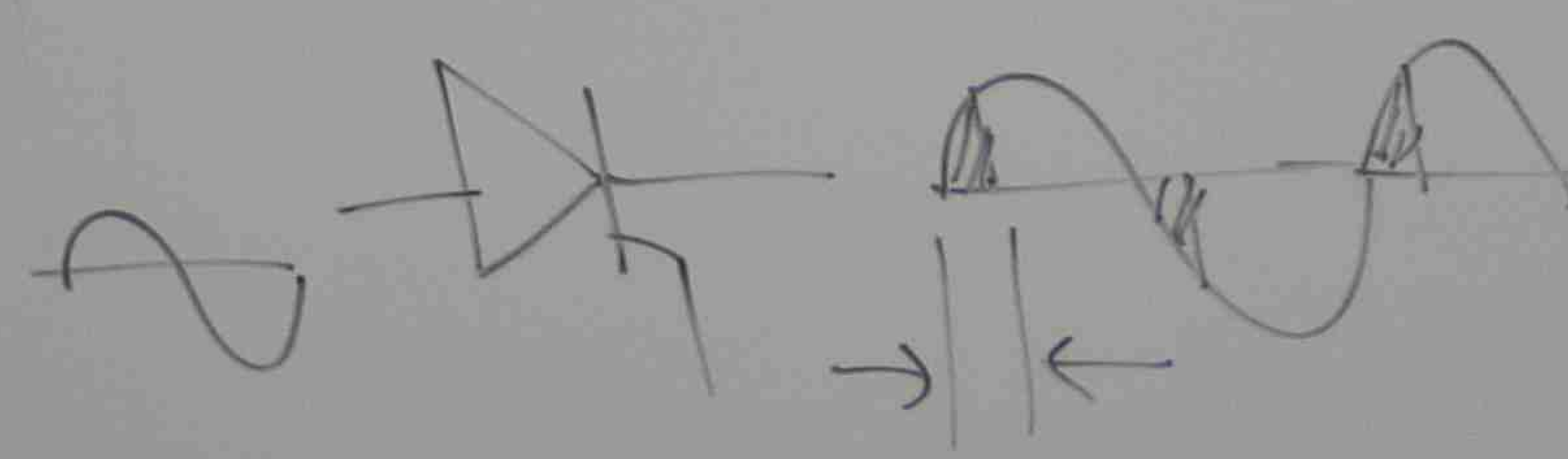


BY ADJUSTING FIELD CURRENT, DC MOTOR SPEED CAN BE CONTROLLED

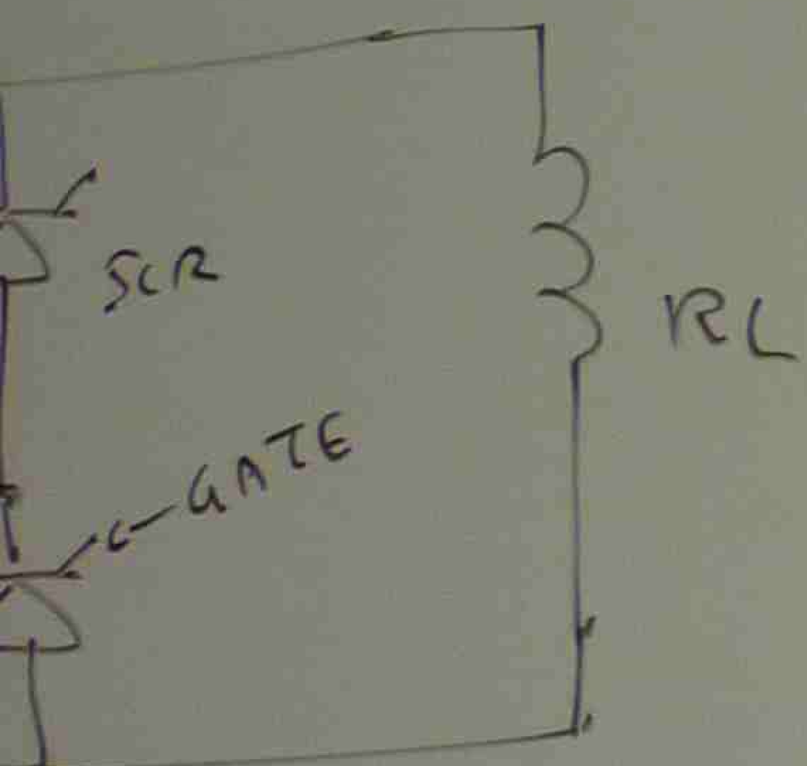


SCR (SILICON CONTROLLED RECTIFIER)

- AC MOTOR SPEED CONTROL
- DC MOTOR SPEED CONTROL



PEED CAN BE CONTROLLED

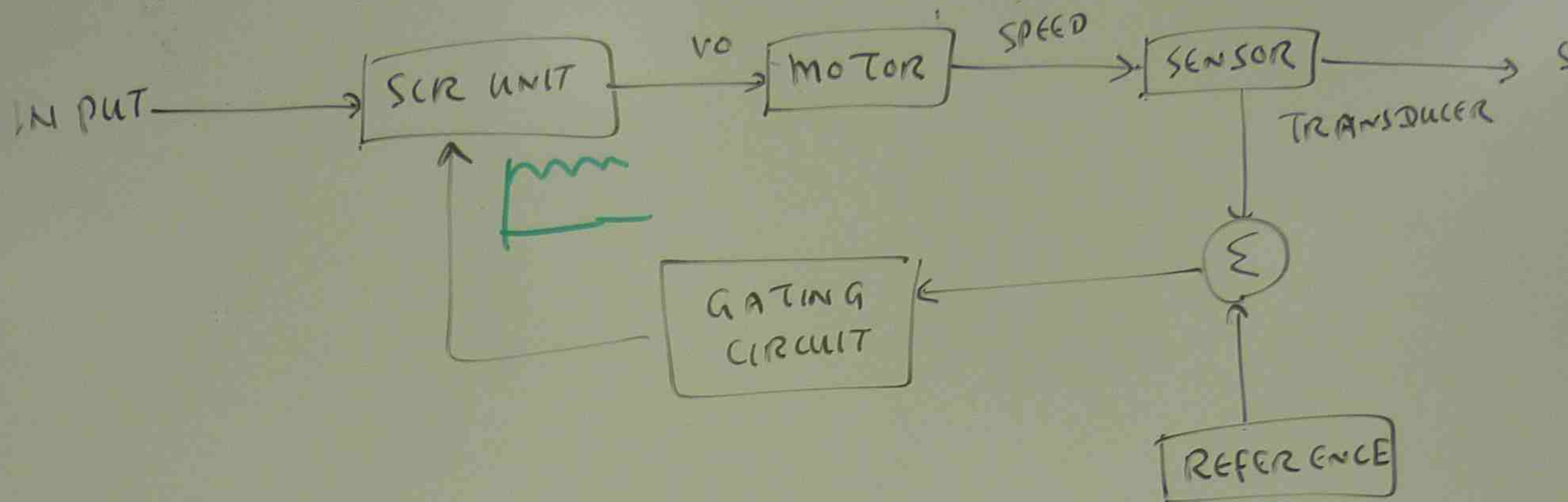


D RECTIFIER)

OR

CONTROL

BLOCK DIAGRAM OF SCR CONTROLLED MOTOR



HEATING EFFECT OF RIPPLE

RIPPLE → HEATING

RIPPLE → HARMONIC → NEED TO BE ELIMINATED BY FILTER

RIPPLE → VIBRATION

RIPPLE → DERATE THE MACHINE

RIPPLE → DERATE INSULATION

PRODUCED BY

HIGH FREQUENCY

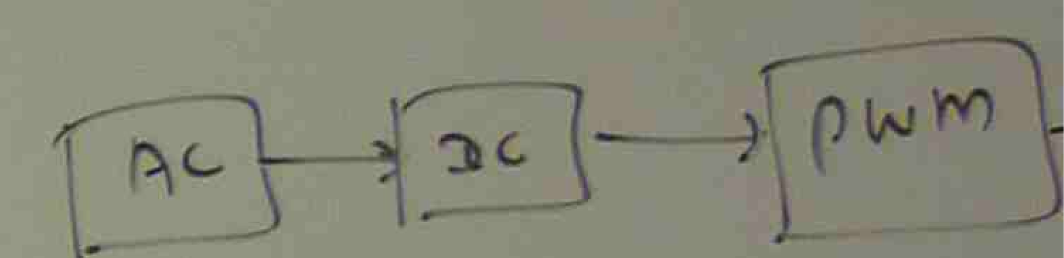
SWITCHING CIRCUITS

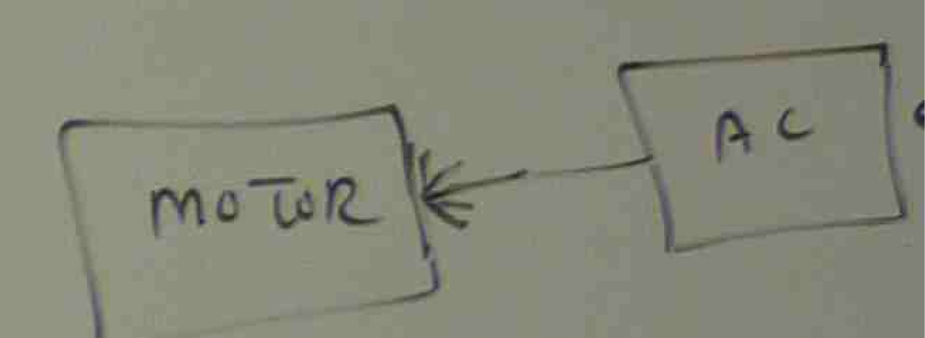
PWM DRIVES

PWM - PULSE WIDTH MODULATION

AC

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

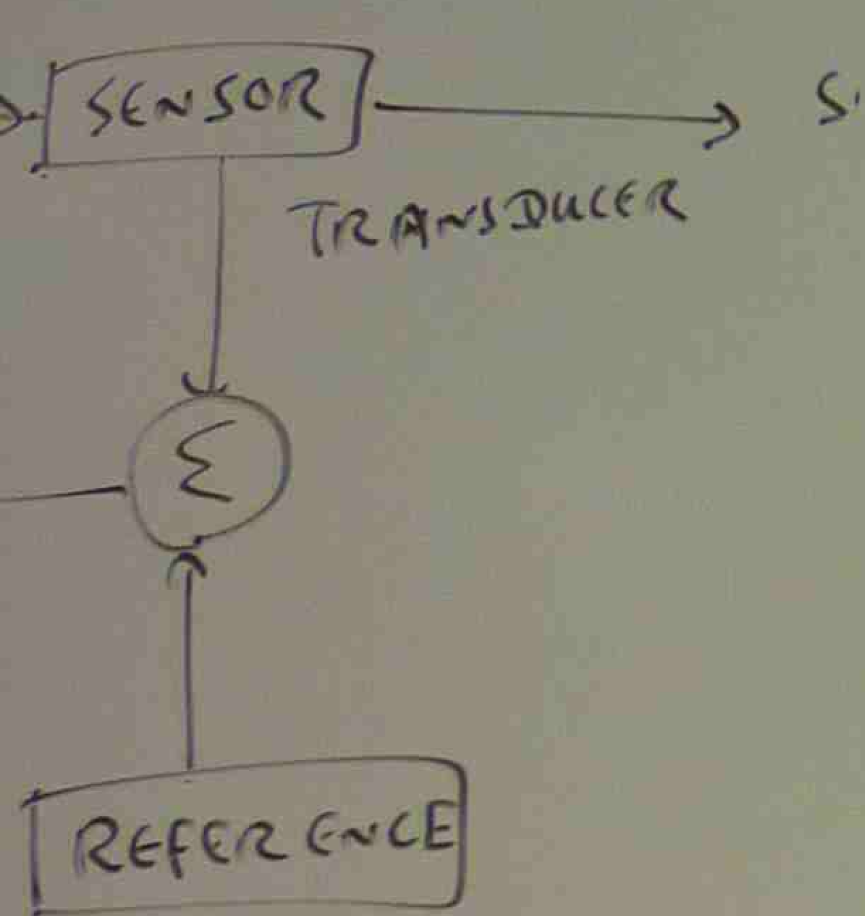




E

MOTOR

TACHO METER

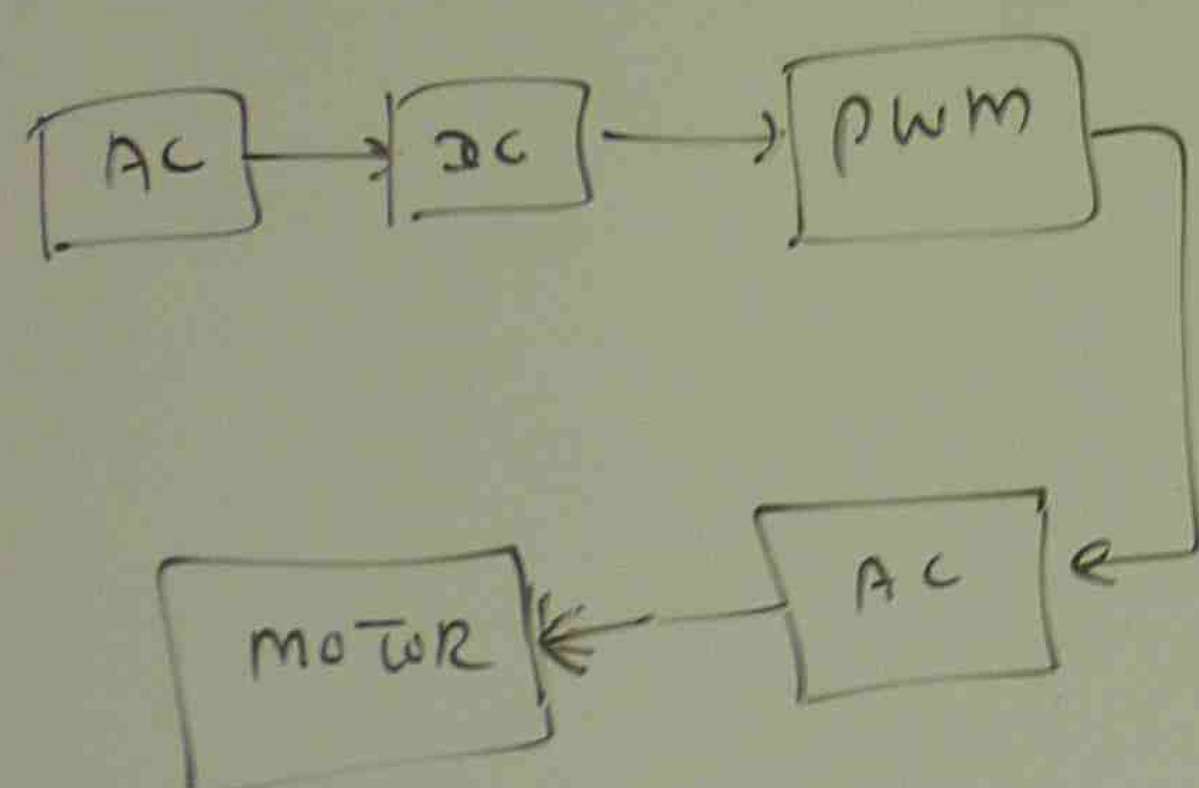


IMINATED

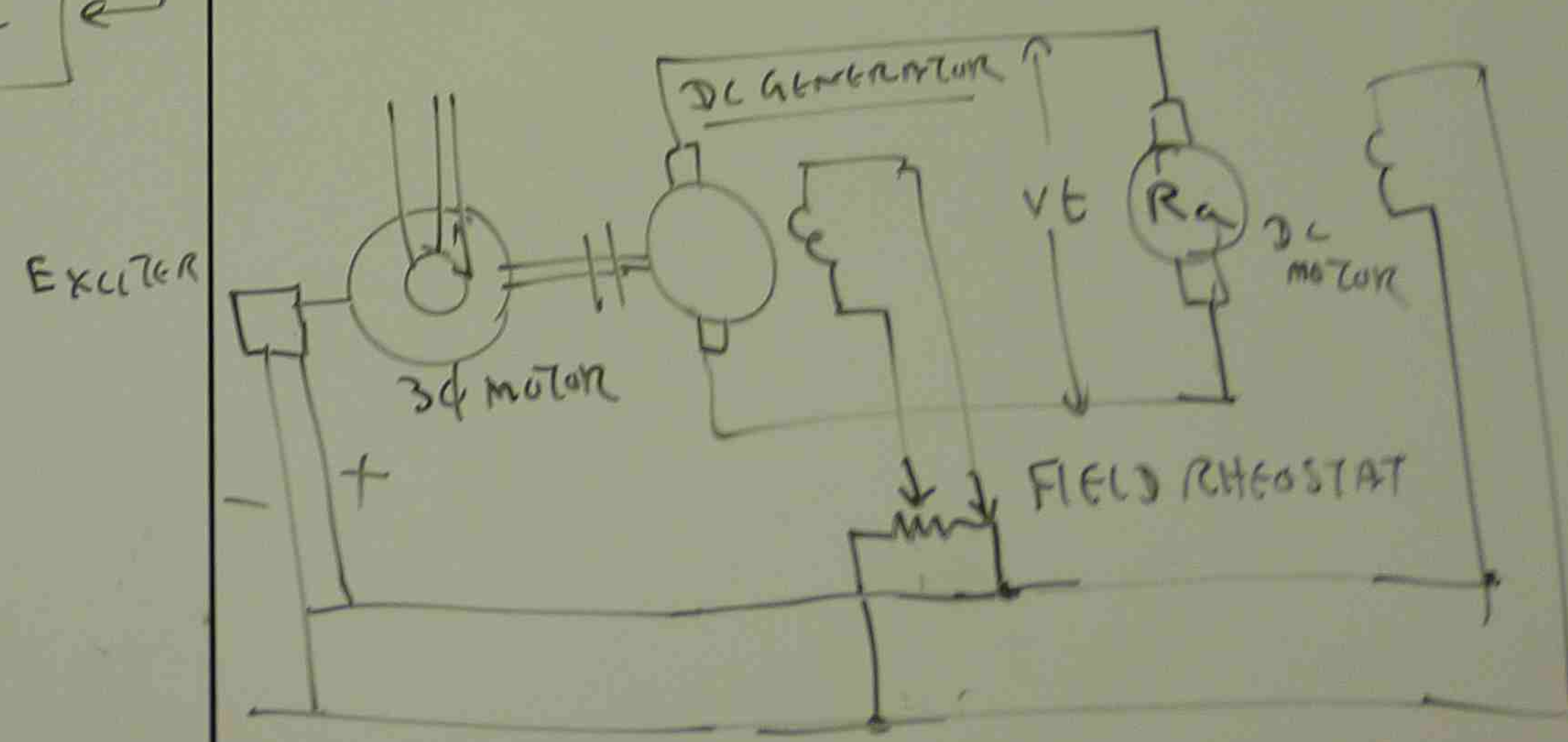
WM - PULSE WIDTH MODULATION

SPEED CONTROL

- AC
  - $N = \frac{120f}{P}$
- DC
  - SHUNT FIELD CURRENT/ FLUX CONTROL
  - ARMATURE CURRENT/ FLUX CONTROL
  - WARD LEONARD CONTROL



WARD LEONARD SYSTEM



EXCITATION BUSBAR

WARD LE

DC GENE

DC MO

DC GENE

BY FI

GENERA

FIELD

GENE

CURR

AN

RD

WARD LEONARD SYSTEM

DC GENERATOR GENERATED VOLTAGE IS SUPPLIED TO DC MOTOR ARMATURE.

DC GENERATOR FIELD EXCITATION IS VARIED BY FIELD RHEOSTAT.

GENERATED VOLTAGE DEPENDS ON DC GENERATOR FIELD EXCITATION.

GENERATED VOLTAGE INDUCES THE VARIABLE CURRENT SUPPLIED TO DC MOTOR ARMATURE AND MOTOR SPEED IS VARIED

DC MOTOR TORQUE-SPEED RELATIONSHIP

$$\boxed{T = k_t \phi I_a}$$

T = TORQUE, (N-m) ϕ = FLUX (wb), I_a = ARMATURE CURRENT (amp)

$$K_t = \frac{PZ}{2\pi a}$$

P = NO. OF POLES

Z = NO. OF CONDUCTORS IN ARMATURE

a = NO. OF ARMATURE PARALLEL PATHS

$$\boxed{E_g = K_e \phi N}$$

E_g = GENERATED VOLTAGE

$$K_e = \frac{PZ}{60a}$$

RELATIONSHIP

I_a = ARMATURE CURRENT (Amp)

F POLES

of CONDUCTORS IN ARMATURE

OF ARMATURE PARALLEL PATHS

NGRATED VOLTAGE

$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

pb A 4 POLE WAVE WOUND ARMATURE OPERATING IN A FIELD OF FLUX 0.01 wb IN WOUND WITH 360 ARMATURE CONDUCTORS.

DETERMINE THE EXPRESSION OF TORQUE AS A FUNCTION OF SPEED IF $V_t = 250V$ AND

$R_a = 0.1\Omega$.

$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$

$$K_t = \frac{PZ}{2\pi a}$$

$a = P\,m$ for LAP

$\quad\; 2\,m$ for WAVE

$$= \frac{4 \times 360}{2 \times 3.1416 \times 2}$$

ASSUME SIMPLEX WAVE

$m = 1$

$= 114.5$

$a = 2 \times m = 2 \times 1 = 2$

$$K_e = \frac{PZ}{60a} = \frac{4 \times 360}{60 \times 2} = 12$$

$$T = \frac{114.5 \times 0.01 \times 250}{0.1} - \frac{12 \times 114.5 \times (0.01)^2 \times N}{0.1}$$

$T = 2800 - 1.38\,N$

NO LOAD $\rightarrow T = 0$

$0 = 2800 - 1.38N$

$1.38N = 2800$

$$N = \frac{2800}{1.38} = 2028 \text{ RPM}$$

DC

Tor

Tor

N

FOR LAP

FOR WAVE

...MPLEX WAVE

$2 \times 1 = 2$

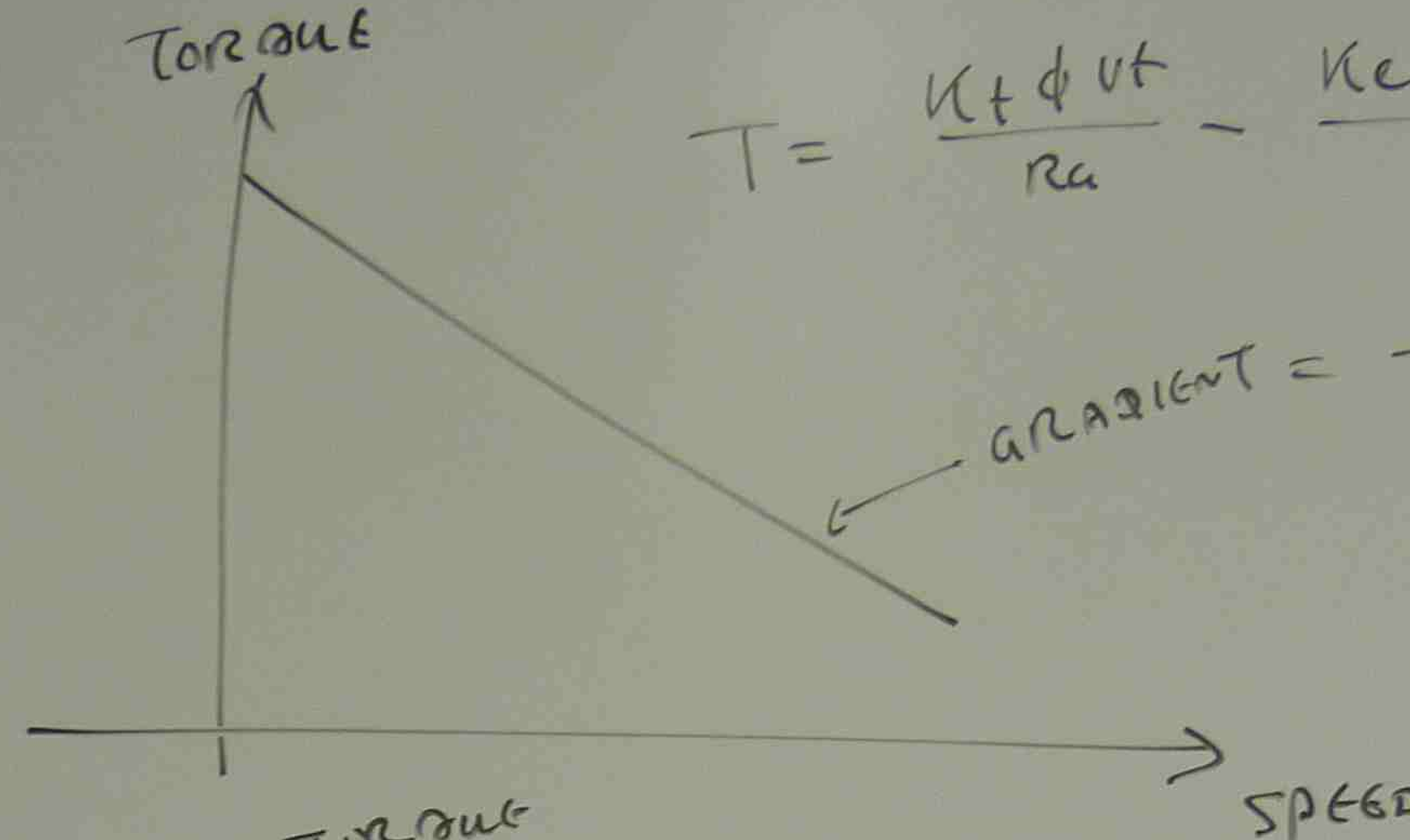
$$\frac{\ldots \times 114.5 \times (0.01)^2 \times N}{0.1}$$

$\ldots 38 N = 2800$

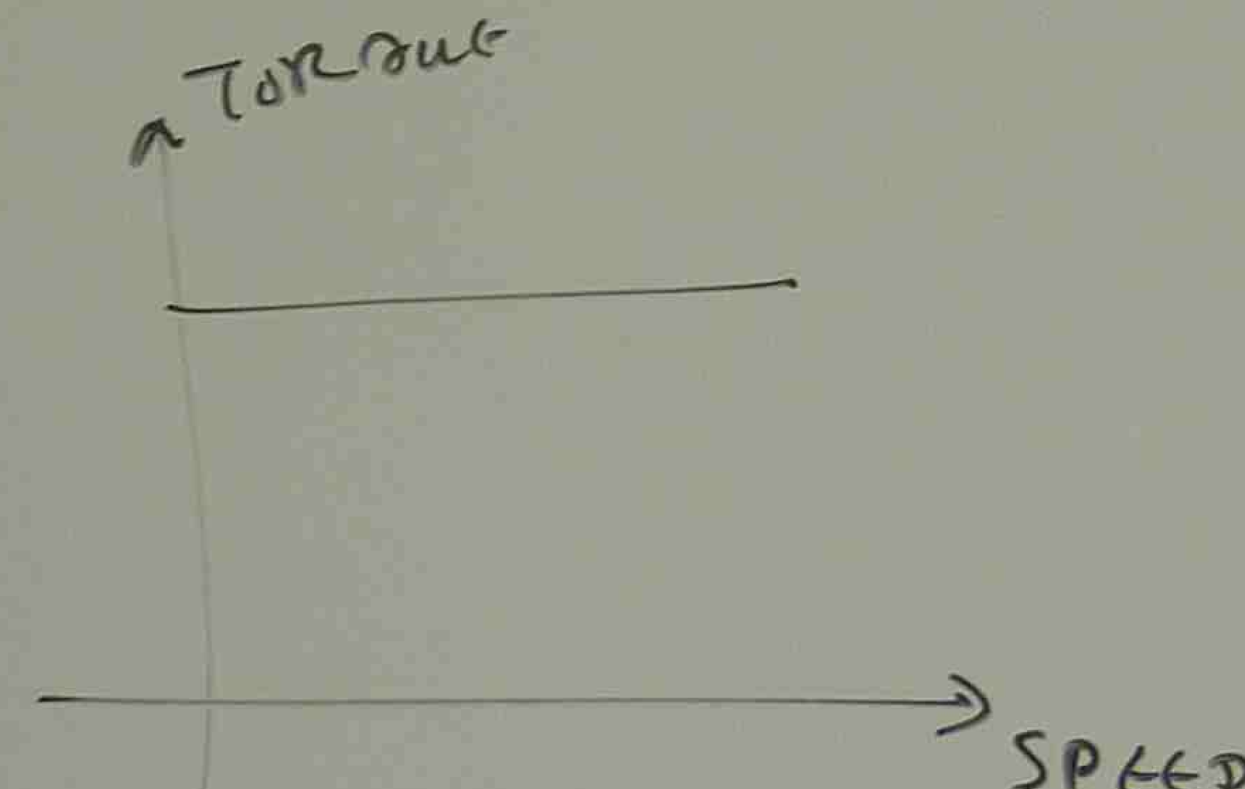
$$N = \frac{2800}{1.38} = 2028 \text{ RPM}$$

DC MOTOR TORQUE & SPEED RELATIONSHIP

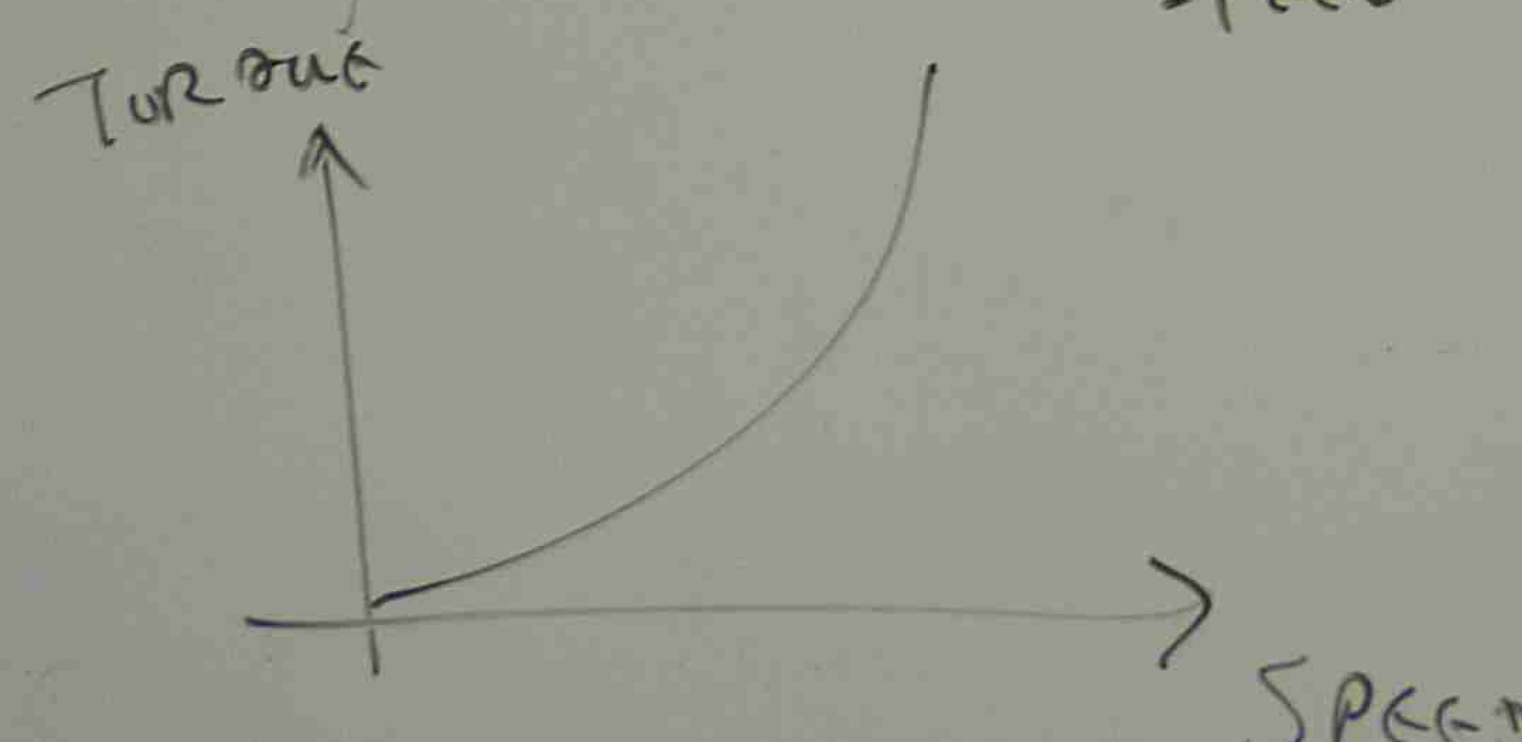
$$T = \frac{K_t \phi V_t}{R_a} - \frac{K_e K_t \phi^2 N}{R_a}$$



$$\text{GRADIENT} = -\frac{K_e K_t \phi^2}{R_a}$$



CONSTANT TORQUE



SERIES MOTOR

MATH THE MOTO...

pb FOR MO...

FOR LOA...

TO MATCH THE...

SPEED IN EACH...

MOTOR & ...

MO...

2860

23...

SPEED RELATIONSHIP

$\dfrac{K_t \phi V_T}{R_a} - \dfrac{K_e K_t \phi^2 N}{R_a}$

GRADIENT $= -\dfrac{K_e K_t \phi^2}{R_a}$

SPEED

CONSTANT TORQUE

SPEED

SERIES MOTOR

SPEED

MATH THE MOTOR AND DRIVE SYSTEM.

~~Pb~~ FOR MOTOR $T = 2860 - 1.38N$

FOR LOAD (i) $T = 50 + 1.25N$

(ii) $T = 50 + 0.625 \times 10^{-4} N^2$

TO MATCH THE MOTOR AND LOAD, CALCULATE THE EQUILIBRIUM SPEED IN EACH INSTANCE.

MOTOR & LOAD $T = 50 + 1.25N$

MOTOR TORQUE = LOAD TORQUE

$2860 - 1.38N = 50 + 1.25N$

$2860 - 50 = 1.38N + 1.25N$

$2.63N = 2810$

$N = \dfrac{2810}{2.63} = 1087$ RPM

MOTOR

2860

0.62

X

X = N

BRIUM

MOTOR & LOAD $T = 50 + 0.625 \times 10^{-4} N^2$

MOTOR TORQUE = LOAD TORQUE

$$2860 - 1.38N = 50 + 0.625 \times 10^{-4} N^2$$

$$0.625 \times 10^{-4} N^2 + 1.38N - 2810 = 0$$

$$A x^2 + B x + C = 0$$

$$X = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

$X = N$, $A = 0.625 \times 10^{-4}$, $B = 1.38$, $C = -2810$

$$N = \frac{-1.38 \pm \sqrt{(1.38)^2 - 4 \times 0.625 \times 10^{-4} \times (-2810)}}{2 \times 0.625 \times 10^{-4}}$$

$$N = \frac{-1.38 \pm 1.622}{1.25 \times 10^{-4}}$$

$$= \frac{-1.38 + 1.622}{1.25 \times 10^{-4}}$$

$$= 1930 \text{ RPM}$$

PL

DPDT SWITCH

$$= \frac{-1.38 \pm 1.622}{1.25\times10^{-4}}$$

$$= \frac{-1.38 + 1.622}{1.25\times10^{-4}}$$

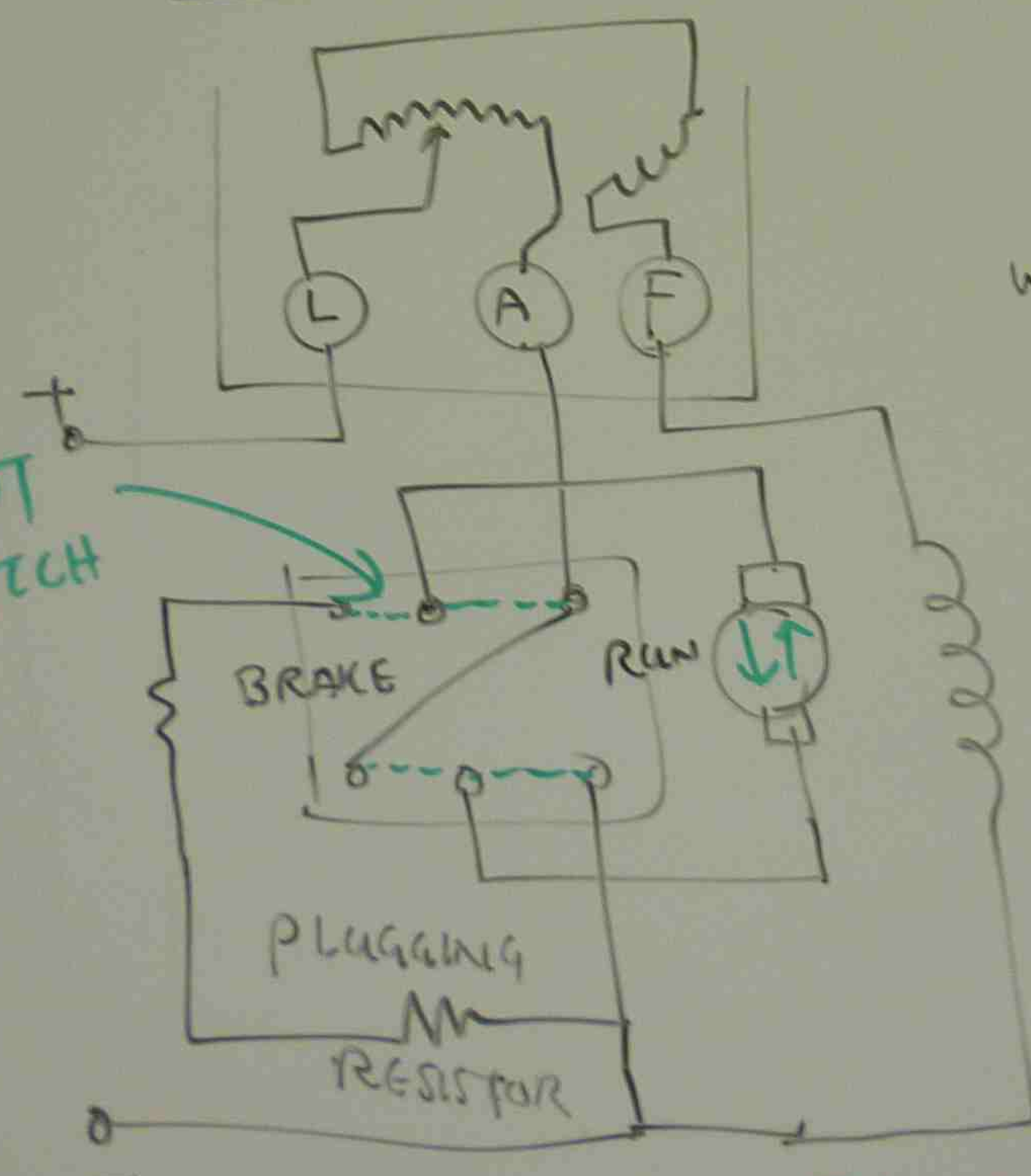
$$= 1930 \text{ RPM}$$

DC MOTOR BRAKING

AC / DC

- PLUGGING
- DYNAMIC BRAKING
- MECHANICAL BRAKE

BRAKING BY PLUGGING

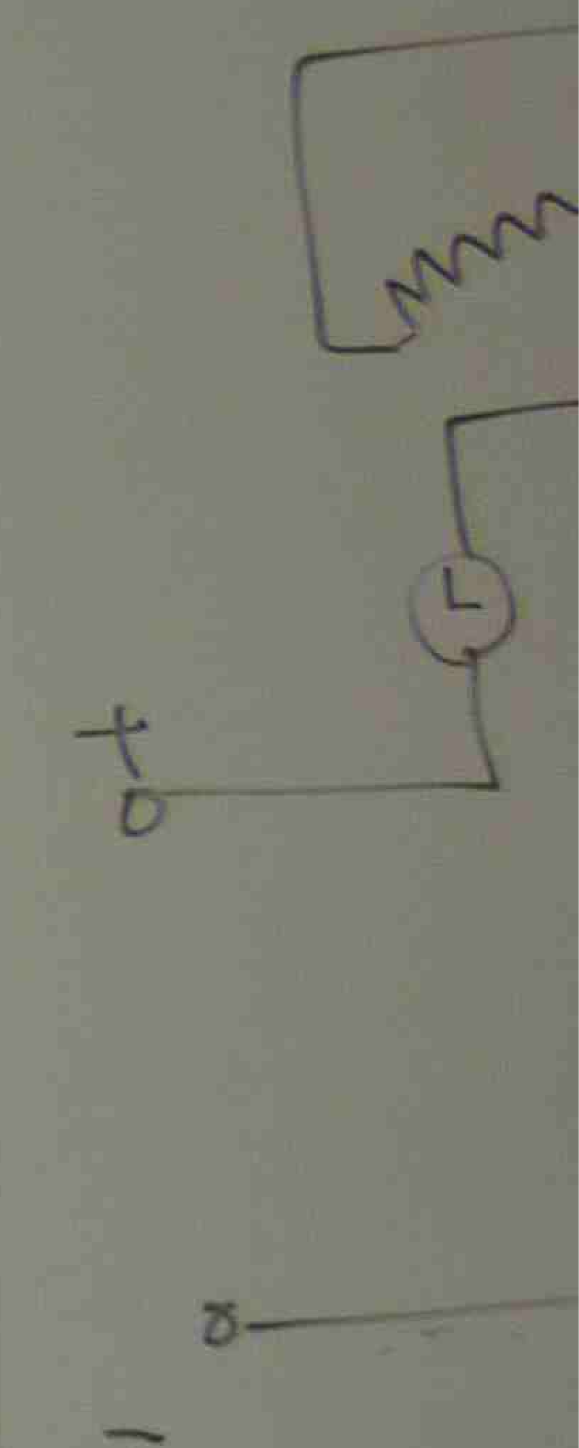


SHUNT MOTOR

WHEN THE STOP SWITCH IS PRESSED, MOTOR TERMIAL CONNECTION IS REVERSED.

REVERSED SUPPLY CANCELS THE MOTOR ROTATIONAL INERTIA AND MOTOR IS STOPPED IMMEDIATLY. THEN MOTOR IS CUT OFF FROM SUPPLY.

BRAKING B



WHEN STO
IS CONNECT
RESISTOR
IS DISS
MOTOR

MECHANICAL
BRAKE

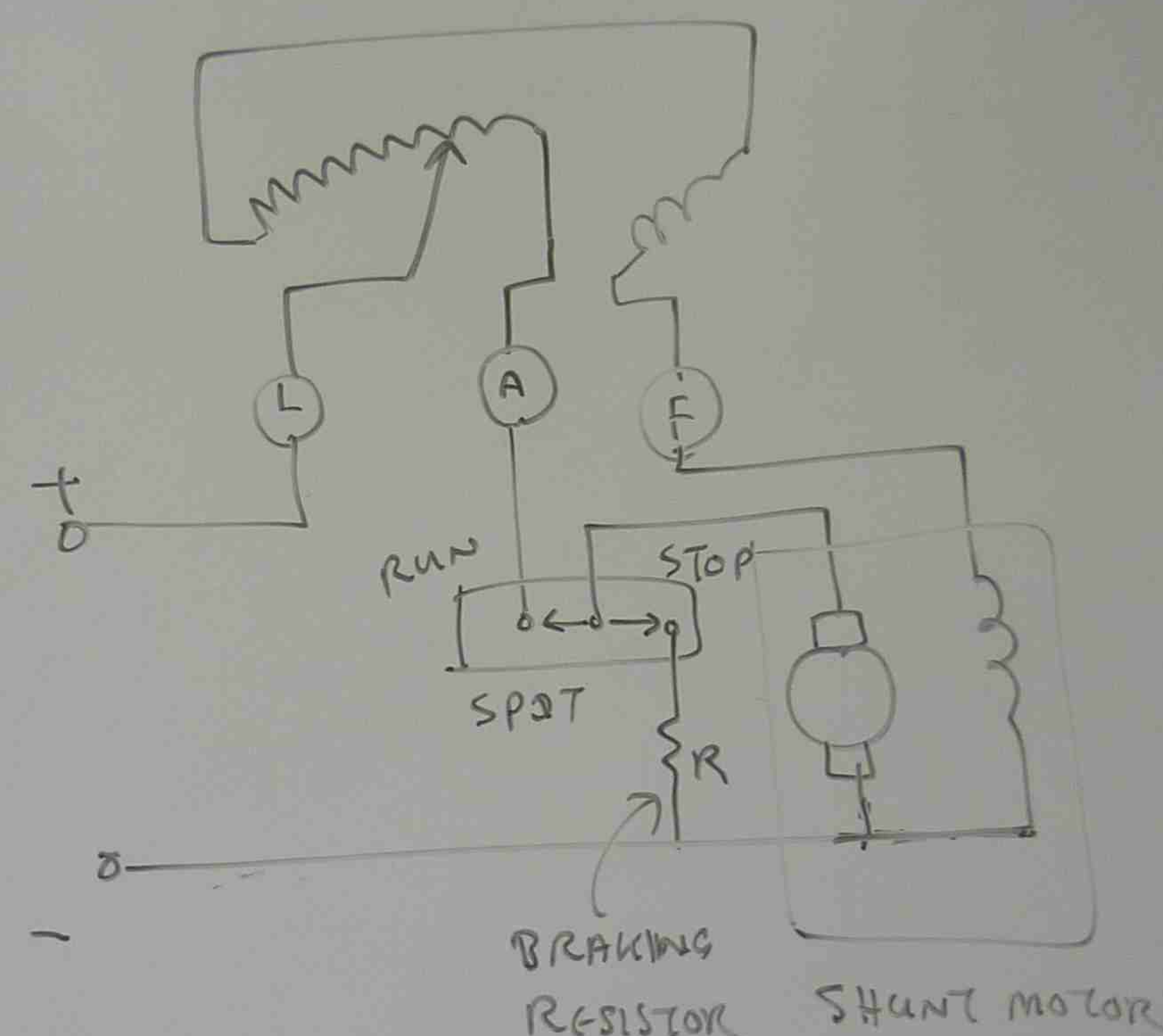
WHEN THE STOP SWITCH IS PRESSED, MOTOR TERMIAL CONNECTION IS REVERSED.

REVERSED SUPPLY CANCELS THE MOTOR ROTATIONAL INERTIA AND MOTOR IS STOPPED IMMEDIATELY.

THEN MOTOR IS CUT OFF

MOTOR FROM SUPPLY.

BRAKING BY DYNAMIC BRAKING



WHEN STOP BUTTON IS PRESSED, MOTOR TERMINAL IS CONNECTED TO EXTERNAL DYNAMIC BRAKING RESISTOR. THE STORED ENERGY IN MOTOR ARMATURE IS DISSIPATED IN DYNAMIC BRAKING RESISTOR AND MOTOR IS STOPPED.