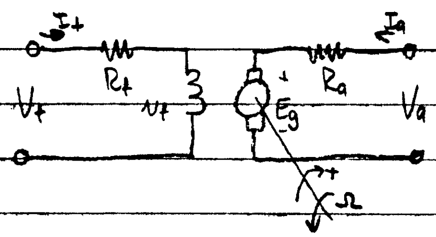
DC MACHINE BASICS

- KEEP UNITS STRAIGHT!
- BASIC D.C. MACHINE MODEL



$E_g = K_v \Phi \Omega$ $\quad K_v$ = VOLTAGE CONSTANT (≈ # SERIES TURNS/SECT.)

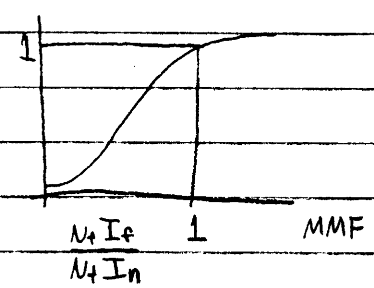
$T = K_T \Phi I_a$ $\quad K_T$ = TORQUE CONSTANT = K_v IN SI UNITS.

$P = T\Omega$

- TO SOLVE PROBLEMS, WE MUST KNOW RELATIONSHIP BETWEEN Φ AND I_f.

USE SATURATION (MAGNETIZATION) CURVE, A NORMALIZED VERSION OF B-H CURVE.

$$\frac{E_g}{E_n} = \frac{K_v \Phi}{E_n/\Omega}$$



THEY MUST TELL YOU THE NORMALIZATION VALUES TO GET NUMERICAL ANSWERS.

DC GENERATORS

SEPRATE EXCITATION

- FIELD CURRENT COMES FROM SOMEPLACE OTHER THAN GEN. ITSELF.
- USE SIMPLE RELATIONSHIPS & MODEL.

EX: S.E. DC GEN RATED 10KW, 240V, 2800 RPM FOR 15HP INPUT. NO LOAD $V_{out} = 260V$.

ARMATURE RESISTANCE:

$$I_{a,LOAD} = \frac{10KW}{240V} = 41.6A$$

$$R_a = \frac{E_g - V_a}{I_{a,LOAD}} = \frac{260-240}{41.6} = .48\Omega$$

MECHANICAL LOSSES:

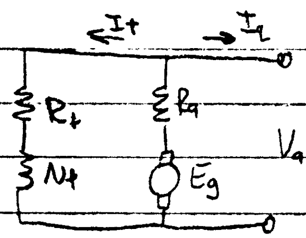
$$P_{IN} = P_{OUT} + I_a^2 R_a + P_M$$

$$15HP \times \frac{746w}{HP} = 10{,}000 + 41.6^2 \cdot .48 + P_M$$

$$P_M = 359\,w.$$

SELF EXCITED GENERATORS.

- FIELD CURRENT COMES FROM ARMATURE VOLTAGE.



$$E_g = V_a + R_a(I_f + I_L)$$

PLUS SATURATION CURVE CAN SOLVE PROBLEMS.

IT IS HELPFUL TO NORMALIZE THE EQUATION TO SATURATION CURVE REF. VALUES.

$$\underbrace{\frac{E_g}{E_n}}_{\text{VERT AXIS}} = \underbrace{\frac{V_a + R_a I_L}{E_n}}_{\text{VERT NORMAL}} + R_a \underbrace{\frac{I_n}{E_n}}_{\text{RATIO OF NORMALS}} \times \underbrace{\frac{I_f}{I_n}}_{\text{HORIZ AXIS}}$$

EX: D.C GEN, 10KW, 240V, 2800 RPM, 15 HP.

$R_a = 1\Omega$

$V_{a,\text{NO LOAD}} = 260\text{V}$ (NO LOAD VOLTAGE) @ $I_f = 2.75$ A

USE FIG 7.2, NORM TO NO-LOAD VALUES.

FIND R_f TO S.E. @ RATED SPECS.

KNOW THAT $I_L = \frac{10{,}000}{240} = 41.6\text{A}$, $E_n = 260$, $I_n = 2.75\text{A}$.

$$\frac{E_g}{E_n} = \frac{240\text{V} + 1\Omega \cdot 41.6\text{A}}{260\text{V}} + 1\Omega \frac{2.75\text{A}}{260\text{V}} \times \frac{I_f}{I_n}$$

$$\frac{E_g}{E_n} = 1.083 + 0.0106 \frac{I_f}{I_n},$$ INTERSECTS CURVE AT

$\frac{E_g}{E_n} = 1.1$, $\frac{I_f}{I_n} = 1.138$, SO $R_f = \frac{V_a}{I_f} = \frac{240}{1.138 \cdot 2.75} = 76.7\,\Omega$.

- REGULATION:

UNDER NO-LOAD, $E_g = I_f(R_f + R_a)$

NORMALIZED,

$$\frac{E_g}{E_n} = (R_f + R_a)\frac{I_f}{I_n}\left(\frac{I_n}{E_n}\right) = \underbrace{(R_f + R_a)\left(\frac{I_n}{E_n}\right)}_{\text{SLOPE}} \frac{I_f}{I_n}.$$

INTERSECT WITH SAT CURVE FOR NO-LOAD VOLTAGE, $\frac{E_g}{E_n}$.

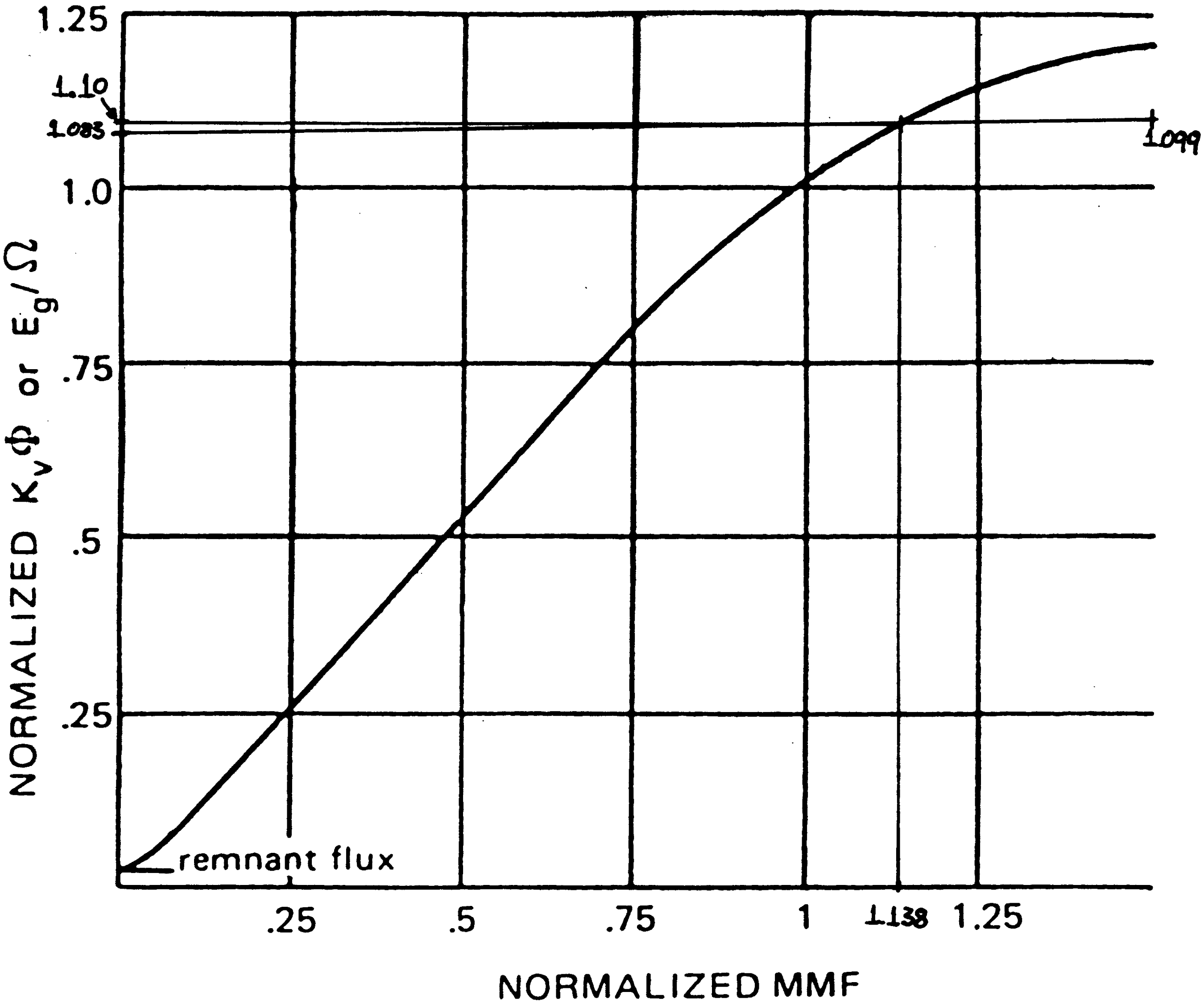
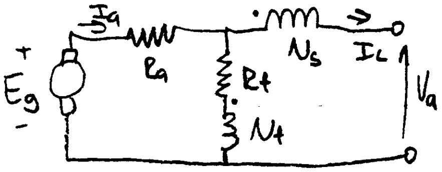


Figure 7.2 Saturation curve

NO PAGE 4!

COMPOUND GENERATORS

- USE I_L TO BOOST Φ



NOW $MMF = N_f I_f + N_s I_L$

AGAIN, NORMALIZE BY $N_f I_n$,

$$MMF_n = \frac{I_f + \frac{N_s}{N_f} I_L}{I_n}$$

FOR FLAT COMPOUNDING: (FLAT COMPOUNDING WORKS FOR LIMITED RANGE OF OP. POINTS)

OPS = OPERATING POINT SLOPE, THEN

Ⓐ $$\frac{N_s}{N_f} = \frac{R_a I_n}{OPS \cdot E_n}$$

$$\frac{E_g}{E_n} = \frac{V_a + R_a I_L \left(1 - \frac{N_s}{N_f}\right)}{E_n} + R_a \left(\frac{I_n}{E_n}\right) MMF_n$$

IF SAT CURVE WAS LINEAR FUNCTION, WE COULD SOLVE SIMULT. IT'S NOT, SO MUST ITERATIVELY GO FROM SLOPE

IF THIS OP. POINT IS CLOSE TO CHOSEN OPS, USE IT IN $R_f = \frac{V_a}{I_f}$.

IF NOT, CALL IT NEW OP. POINT AND START FROM Ⓐ

EX:

DC GEN RATINGS: 10KW 2800 RPM
240V 15 HP

HAS PARAMETERS: $R_a = 0.48\,\Omega$

NO LOAD $V_a = 260V$ @ 2800 RPM, $I_f = 2.75A$, EXCITED SEPARATELY.

USE FIG 7.2, NORMALIZED TO NO-LOAD VALUES.

FIND $\frac{N_s}{N_f}$ & R_f FOR FLAT COMPOUNDING AT RATED SPECS.

NORMALIZATION VALUES $E_n = 260V$, $I_n = 2.75A$.

AT NORMALIZATION POINT, OPS = 0.71,

SO $\frac{N_s}{N_f} = \frac{R_a I_n}{OPS \cdot E_n} = \frac{0.48 \cdot 2.75}{0.71 \cdot 260} = 0.00715$,

$$\frac{E_g}{E_n} = \frac{V_a + R_a I_L \left(1 - \frac{N_s}{N_f}\right)}{E_n} + R_a \left(\frac{I_n}{E_n}\right) MMF_n$$

$$= \frac{240 + (.48)\left(\frac{10{,}000}{240}\right)(1 - 0.00715)}{260} + (0.48)\left(\frac{2.75}{260}\right)(1)$$

$$= 1.0045$$

DON'T BORE WITH DERIVATION

GO TO EXAMPLE,

P2

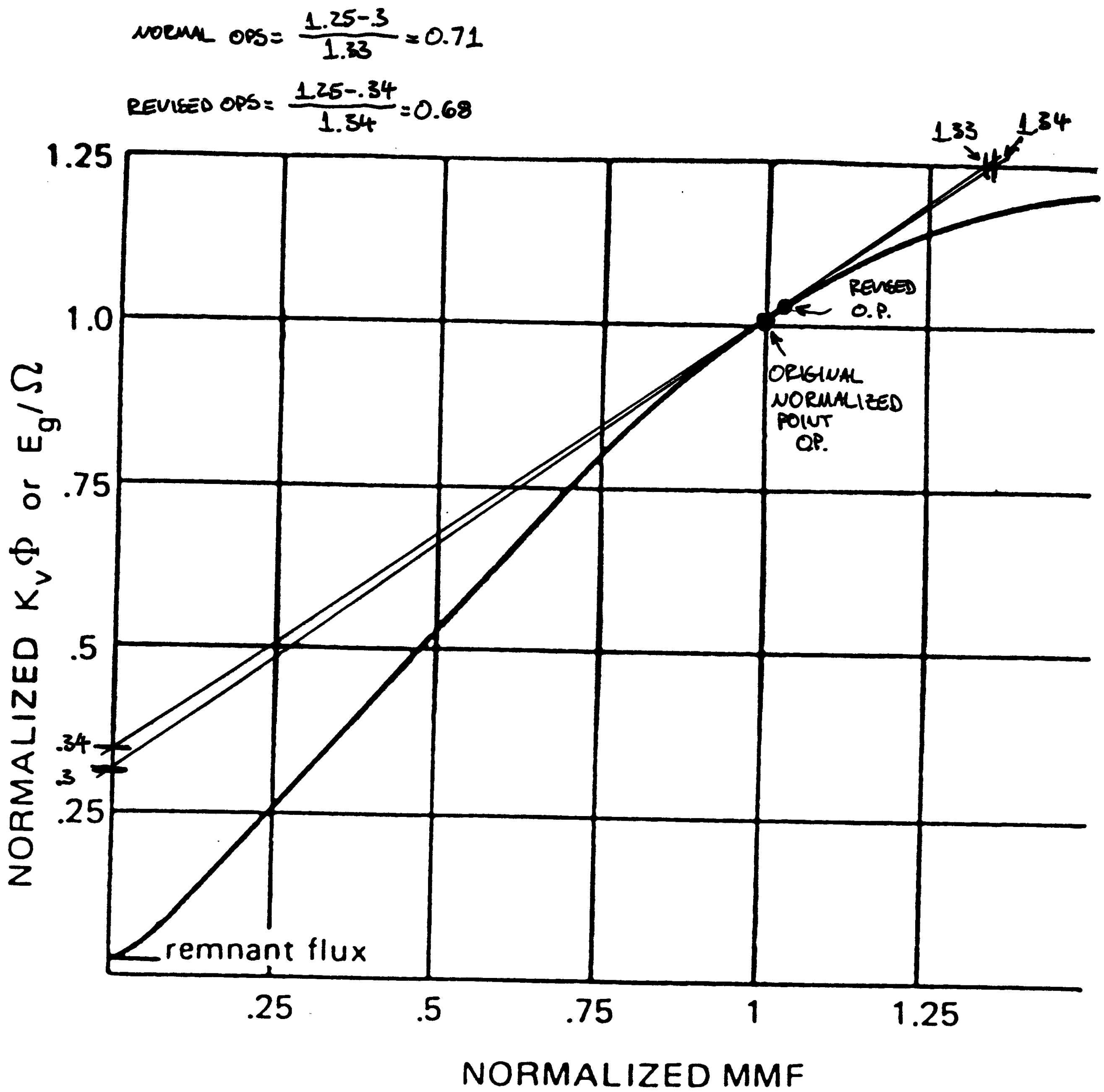
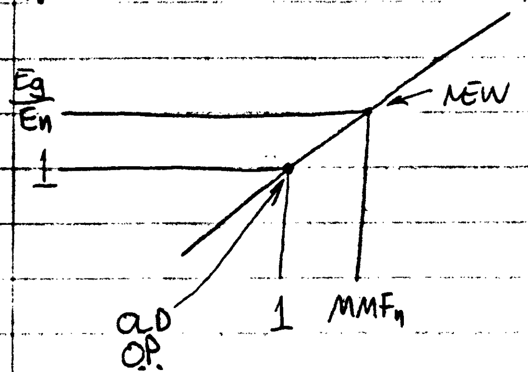


Figure 7.2 Saturation curve

MUST NOW FIND MMF_n, (YOU CAN GET FROM GRAPH, BUT USE LINEAR PROJECTION).



ASSUME A SLOPE OPS,

$$OPS = \frac{\frac{E_g}{E_n} - 1}{MMF_n - 1}$$

$$MMF_n = 1 + \frac{E_g/E_n - 1}{OPS}$$

ERROR IN SOLUTION BOOK

$$MMF_n = 1.0063$$

(WE ARE CLOSE, BUT WILL DO ITERATION TO ILLUSTRATE)

NEW $OPS = 0.68$

NOW $\frac{N_s}{N_f} = 0.00747$, $E_g = 261.2$ AS IN PREVIOUS EQUATIONS.

FROM BEFORE, $MMF_n = \dfrac{I_f + \frac{N_s}{N_f} I_L}{I_n}$

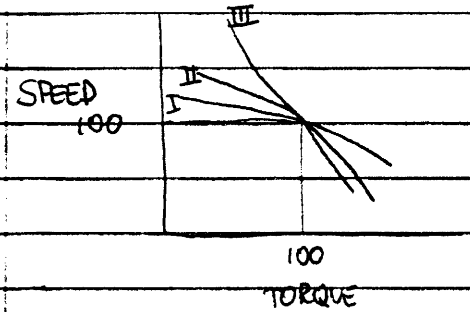
$$I_f = I_n MMF_n - \frac{N_s}{N_f} I_L$$

$$= 2.75 \cdot 1.0063 - 0.00747 \left(\frac{10{,}000}{240}\right)$$

$$I_f = 2.46A$$

SO $R_f = \dfrac{V_a}{I_f} = \dfrac{240}{2.46} = 97.6\,\Omega$

DC MOTORS



I = SEPARATE & SHUNT

II = COMPOUND

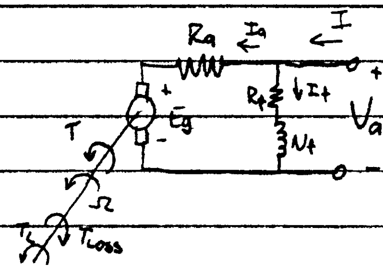
III = SERIES.

SEPARATLY EXCITED DC

- ANALYSIS SIMILAR TO S.E. DC GENERATOR
- SYSTEM EQUATIONS IN BOOK

SHUNT MOTOR

- POWER RELATIONSHIPS



$P_{IN} = P_a + P_f = V_a I_a + V_a I_f$

$P_a = P_s + I_a^2 R_a = E_g I_a + I_a^2 R_a$

$P_s = P_{LOSS} + P_{LOAD}$

$P_s = P_{LOSS} + T_L \Omega$

$E_g I_a = T \Omega = P_{LOSS} + T_L \Omega$

EX: DC SHUNT MOTOR, 200V, 25A, 1000 RPM, 5 HP.

$R_a = .5\Omega, \quad R_f = 100$

ROTATIONAL LOSSES:

$P_{IN} = V_a I = 5000W$

$5000W = P_a + \frac{V_a^2}{R_f}$

$P_a = 4600W$

$P_s = P_a - I_a^2 R_a$

$= P_a - \left(I - \frac{V_a}{R_f}\right)^2 R_a$

$P_s = 4336w$

$P_{LOSS} = P_s - 746(5)$

$P_{LOSS} = 606W.$

NO-LOAD SPEED:

NEXT PAGE

FIND

NO LOAD SPEED:

FROM BEFORE, $P_S = 4336W = T\Omega$

$$T = \frac{4336}{1000\frac{\pi}{30}} = 41.4\,Nm = K\Phi I_a$$

$$K\Phi = \frac{41.4}{23} = 1.8\,Wb \qquad \left(I_a = I - \frac{V_a}{R_f} = 25 - \frac{200}{100} = 23\right)$$

UNDER NO LOAD CONDX,

$$P_S = 606\,W = T\Omega$$
$$= K\Phi I_a \Omega$$

SO $I_a = \frac{337}{\Omega}$

NOW $V_a = I_a R_a + K\Phi\Omega$ (FROM LONG AGO)

$$200 = (.5)\left(\frac{337}{\Omega}\right) + 1.8\Omega$$

— SOLVE QUADRATIC —

$\Omega = 110, .9$

OR 1051, 8.6 RPM

COMPOUND DC MOTORS

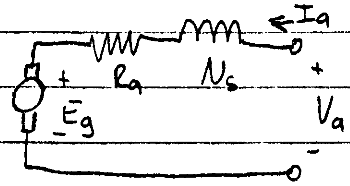
- CUMULATIVE COMPOUNDING
  FIELDS ADD IN Φ
- PRODUCES HIGH STARTING TORQUE

- DIFFERENTIAL COMPOUNDING
  FIELDS SUBTRACT IN Φ
- PRODUCES BETTER SPEED REGULATION

ALL ANALYSIS WE DID ON COMPOUND GENERATORS STILL VALID, EXCEPT FOR DIFFERENTIAL COMPOUNDING,

$$MMF = I_f N_f - I_a N_s$$

SERIES DC MOTORS – HIGH STARTING TORQUE.



SAME BASIC EQUATIONS AS BEFORE

EX: DC SERIES MOTOR, RUNS @ RATED SPEED, V_a, I_a, $R_a = .001$
LOAD TORQUE INCREASES BY 25%. WHAT % DOES Ω CHANGE?

$T = K\Phi I_a$ AND $\Phi \propto I_a$

LET $\Phi = \rho I_a$, SO

$T = K\rho I_a^2$

IF $1.25T = K\rho(\sqrt{1.25}\, I_a)^2$

SO I_a INCREASES BY $\sqrt{1.25} = 1.12$.

$V_a \approx E_g$ (SINCE R_a IS SO SMALL),

$E_g = K\Phi\Omega$

$= K\rho I_a \Omega$

$\Omega K\rho(1.12 I_a) = (.894\Omega)K\rho I_a$

SO Ω CHANGES BY FACTOR OF .894.

INDUCTION MOTORS

- JUST LIKE SPINNING TRANSFORMERS.

Ω_s : ANGULAR VELOCITY OF MMF WAVE IN STATOR

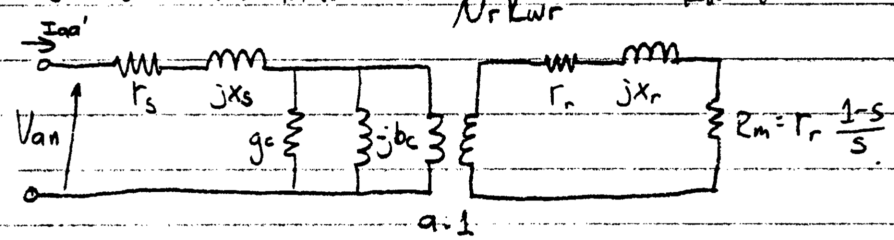
$\Omega_s = \frac{2\omega}{p}$ P = # POLES.
ω = INPUT ANGULAR VELOCITY OF POWER

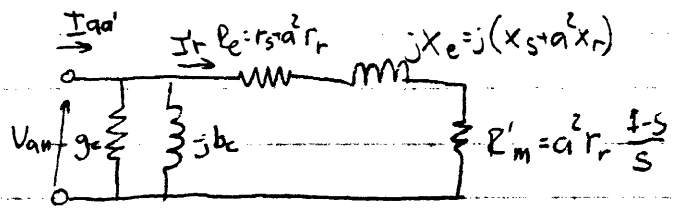
Ω_r : A.V. OF ROTOR.

SLIP $s = \frac{\Omega_s - \Omega_r}{\Omega_s}$ [MANY OTHER GOOD FORMULAS IN BOOK].

FREQUENCY SEEN BY ROTOR $\omega_r = s\omega$.

~~PER PHASE~~
TRANSFORMER TURNS RATIO $a = \frac{N_s K_{ws}}{N_r K_{wr}}$ K_w = WINDING FACTOR.





EX 440V MOTOR HAS PER PHASE PARAMS $X_e = .712\,\Omega$, $R_e = .283\,\Omega$,
1200RPM (6 POLE) $r_s = .126$ IN DELTA.

FIND STARTING TORQUE, I.

STATOR IN Δ: (q = # PHASES)

$R_e = r_s + a^2 r_r \rightarrow a^2 r_r = 0.157$

$$T_{START} = \frac{q|V_{an}|^2}{\Omega_s}\left[\frac{a^2 r_r}{R_e^2 + X_e^2}\right] = \frac{3\left|\frac{440}{\sqrt{3}}\right|^2}{1200 \times \frac{2\pi}{60}}\left[\frac{.157}{.283^2 + .712^2}\right] = 412\ Nm \quad (\text{EQ } 7.78)$$

SHUNT ELEMENTS CAN BE NEGLECTED, S=1,

$$I_{START} = \frac{440/\sqrt{3}}{\sqrt{R_e^2 + X_e^2}} = 332\ A.$$

STATOR IN Y:

SINCE $Z_{ln} = \frac{Z_{ll}}{3}$, ALL IMPEDANCES MULTIPLIED BY 3.

$T_{START} = 412 \times \frac{3}{3^2} = 137 \text{ Nm}$

$I_{START} = \frac{332}{3} = 111 \text{ A.}$

INDUCTION MOTOR TESTS

NO-LOAD TEST – JUST LIKE OPEN CKT XMFR TEST. $(S \approx 0)$

LOCKED ROTOR TEST – JUST LIKE SHORT CKT XMFR TEST $(S = 1)$.

NO LOAD

$g_c = \frac{P_{NL}}{|V_{an}|^2 q}$

$b_c = \frac{Q_{NL}}{|V_{an}|^2 q}$

LOCKED ROTOR

$R_e = \frac{P_{LR}}{I_{an}^2 q}$

$X_e = \frac{Q_{LR}}{I_{an}^2 q}$

EX NO LOAD TEST

3ϕ 440V, 1200W, 2500VA $\left(V_{an} = \frac{440}{\sqrt{3}} = 254 \text{V.}\right)$

$g_c = \frac{1200}{3 \cdot 254^2} = 6.2 \text{ mS.}$

$b_c = \frac{\sqrt{2500^2 - 1200^2}}{3 \cdot 254^2} = 11.3 \text{ mS.}$

LOCKED ROTOR TEST

$I = 21\text{A}$, $P_{in} = 375\text{W}$ P.F. = .37

$R_e = \frac{375}{3 \cdot 21^2} = .283 \,\Omega$

$X_e = \frac{P \cdot \tan \cos^{-1} .37}{3 \cdot 21^2} = .712 \,\Omega.$

USUALLY LUMP ROTATIONAL LOSSES IN WITH g_c.

YOU CAN DETERMINE r_s AND $a^2 r_r$ FROM POWER IN, POWER OUT & SLIP. VERY STRAIGHT FWD.

SEE EQ 7.83, P 7-14.

STARTING INDUCTION MOTORS (3ϕ)

COVERED IN BOOK

1) START IN Y, SWITCH TO Δ, IMPEDANCES x3.
2) USE AUTOTRANSFORMER TO ADJUST LINE-NUTRAL VOLTAGE
3) ADD RESISTANCE TO ROTOR.

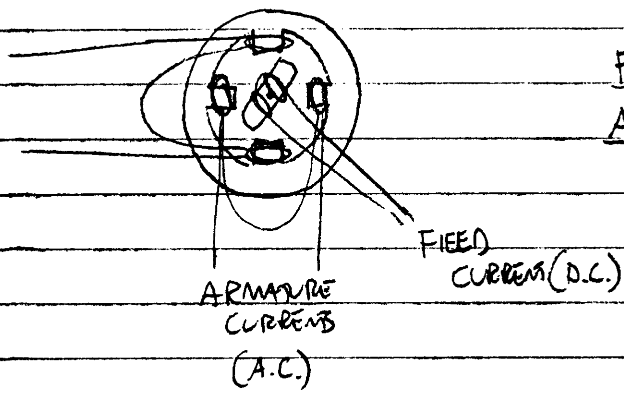
DO NOT CONFUSE WITH SINGLE ϕ INDUCTION MOTOR STARTING. THAT IS ANOTHER LECTURE.

SYNCHRONOUS MACHINES

- MOST COMPLEX ROTATING MACHINES.
- AS IN INDUCTION MACHINE,

$$\Omega_s = \frac{2\omega}{p}$$

BUT $\Omega_r = \Omega_s$, SO $S = 0$.

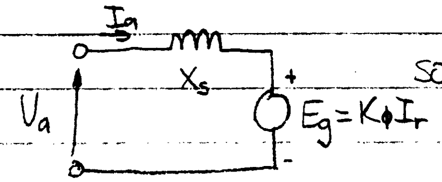


FIELD WINDINGS ON ROTOR

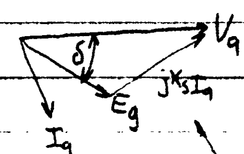
ARMATURE WINDINGS ON STATOR

(UNDERLINE PHASORS)

MOTOR PER PHASE CKT:



SO $\underline{V_a} = jX_s\underline{I_a} + \underline{E_g}$



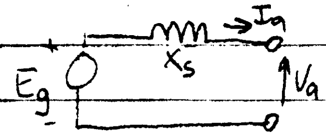
DECOMPOSE $\underline{E_g} = |E_g|\cos\delta - j|E_g|\sin\delta$.

SOLVING, $\underline{I_a} = \dfrac{|E_g|\sin\delta}{X_s} - j\dfrac{V_a - |E_g|\cos\delta}{X_s}$

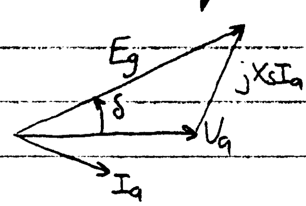
SIGN OF δ DISTINGUISHES

$$S = q\left[V_a \underline{I_a}^*\right] = q\left[\frac{V_a|E_g|\sin\delta}{X_s} + j\frac{V_a^2 - V_a|E_g|\cos\delta}{X_s}\right]$$

FOR GENERATOR:



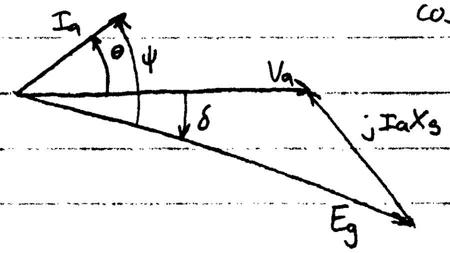
SO $\underline{E_g} = \underline{V_a} + j\underline{I_a}X_s$



BY SAME ANALYSIS,

$$S = q\left[\frac{|E_g|V_a\sin\delta}{X_s} + j\frac{|E_g|^2 - |E_g|V_a\cos\delta}{X_s}\right].$$

SYNCHRONOUS MOTORS

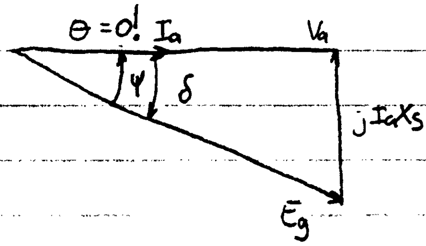


$\cos\theta$ = POWER FACTOR

INTO FORMULAS 7.111–7.114, P 7-20

FORMULAS GIVE EQUIPMENT FOR S.M. PROBLEMS.

NOTE THAT SINCE $|E_g| = K_\phi I_r$, WE CAN CORRECT POWER FACTOR ANGLE θ JUST BY VARYING I_r,



JUST BY REDUCING I_r, WE MADE $\theta = 0!$

EX: 3ϕ, 440V, 60Hz, 3600 RPM SYNC MOTOR HAS PER PHASE $X_s = 20\Omega$, $R_a = .5\Omega$, I_a = MINIMUM @ $I_f = 5A$, $P_{in} = 900W$. $I_{a,RATED} = 12A$

WANT TO FIND LOAD PWR EFFICIENCY

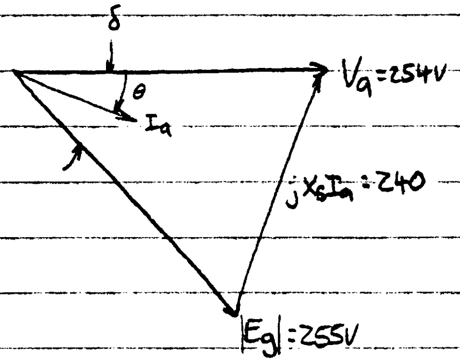
UNDER NO LOAD, $\delta \to 0$, $E_g \approx V_a$ SO I_a IN PHASE WITH $V_a = 254V$.

$P_{NL} = V_a I_a = 900W$, SO $I_a = \frac{900/3}{440/\sqrt{3}} = 1.18A$

$|E_g| = \left(V_a^2 + (I_aX_s)^2\right)^{1/2} = 255V.$

UNDER RATED LOAD, $I_a = 12A$, $X_sI_a = 240$

DRAW DIAGRAM $(a^2 = b^2 + c^2 - 2bc\cos\alpha)$



IMMEDIATELY, FROM LAW OF COSINES,
$\delta = -56.3^\circ$

FROM LAW OF SINES,
$\theta = -27.9$

LOAD POWER:

$$P_{LOAD} = 3(P_{IN} - P_{RESIST}) - P_{ROTATION}$$
$$= 3(V_a I_a \cos\theta - I_a^2 R_a) - 900$$
$$= 6970 \text{ W}$$

EFFICIENCY: $\eta = \frac{P_L}{P_{IN}} \times 100 = 86.3\%$

I_R FOR 5KVAR OF P.F. CORRECTION UNDER LOAD:

SINCE $|E_g| = K_\phi I_r$, AT $I_r = 5A$, $|E_g| = 255$, SO $K_\phi = 51$.

NEED APPARANT POWER $S = P_{IN} - j5000$

$$S = 8081 - j5000 = 3\underline{V}_a \underline{I}_a^*$$

$$\underline{I}_a^* = \frac{8081 - j5000}{3 \cdot 254} = 10.6 - j6.56 \text{ A}.$$

$$jX_s\underline{I}_a = j20\underline{I}_a = -131 + j212 \text{ V},$$

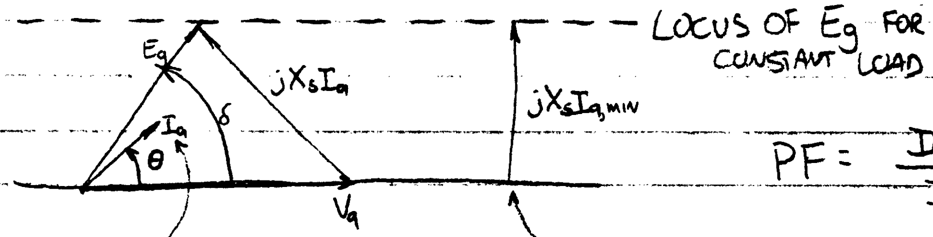
SINCE $E_g = -jX_s\underline{I}_a + \underline{V}_a = 385 - j212 \text{ V}$, $|E_g| = 440\text{v}$,

$$I_r = \frac{|E_g|}{K_\phi} = \frac{440}{51} = 8.6 \text{ A}.$$

SYNCHRONOUS GENERATORS

- MUST HAVE $\delta > 0$ FOR GENERATOR.
- SEE EQUATIONS 7.121–7.125, P 7-22 FOR PROBLEM SOLVING EQUIPMENT.
- UNDER CONSTANT LOAD:

$$T_{SHAFT} = 3 V_a |E_g| \sin\delta \, X_s \, \Omega_s$$

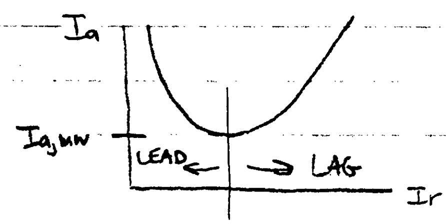


$$PF = \frac{I_{a,min}}{I_a}$$

IN BOOK — ARROW WRONG DIRECTION

— I_a MISLABELED

PLOT I_a VS. $I_r \propto E_g$,



EX:									
I_r (A)	2	3	5.5	8	12	15	20	23	27
I_a (A)	60	45	30	21	15	18	32	45	60

SYNC GEN, 60 HZ, 480V, 50 KVA, $I_r = 20A$, 30 HP, CONST LOAD.

→ ROTOR I FOR .8 LAG PF: $.8 = \frac{I_{a,min}}{I_a}$, $I_a = \frac{15}{.8} = 18.75\,A$

- INTERPOLATE: $\frac{I_r - 15}{18.75 - 18} = \frac{20-15}{32-18} \rightarrow I_r = 15.3A.$

→ I_r FOR $I_a = 40A$, LEADING, $\frac{40-45}{I_r - 3} = \frac{30-45}{5.5-3}$, $I_r = 3.83A.$

→ RESULTING $PF = \frac{15}{40} = 0.375$, LEADING.

SELF EXCITED DC GENERATOR EXAMPLE

S.E. GENERATOR, RATED 10KW, 240V, 2800 RPM.

$R_a = 1\,\Omega$, $V_{a,\,NO\ LOAD} = 260V$ @ $I_f = 2.75A$.

USE FIG 7.2, NORMALIZED TO NO-LOAD VALUES.

FIND R_f TO SELF EXCITE @ RATED SPECS.

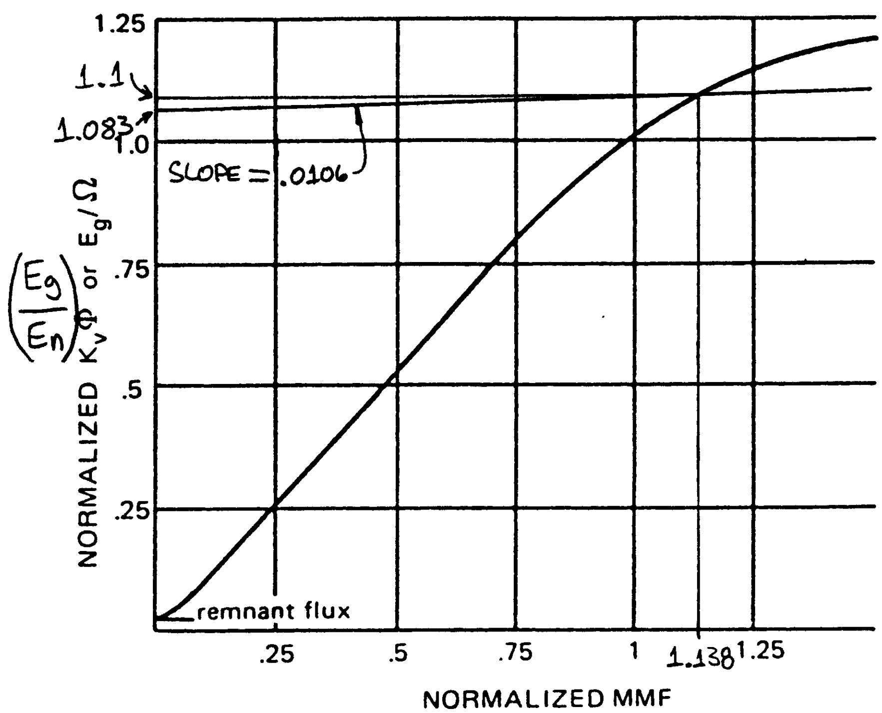


Figure 7.2 Saturation curve

$\left(\frac{I_f}{I_n}\right)$

① CURVE IS NORMALIZED TO NO-LOAD VALUES, SO $E_n = 260V$, $I_n = 2.75A$.

② $I_L = \frac{P}{V} = \frac{10{,}000}{240} = 41.6A$.

③ PLUG NUMBERS INTO NORMALIZED LOOP EQUATION:

$$\frac{E_g}{E_n} = \frac{V_a + R_a I_L}{E_n} + R_a \frac{I_n}{E_n}\frac{I_f}{I_n},$$

$$\frac{E_g}{E_n} = \frac{240 + 1 \cdot 41.6}{260} + 1 \cdot \frac{2.75}{260}\frac{I_f}{I_n},$$

$$\frac{E_g}{E_n} = 1.083 + 0.0106\,\frac{I_f}{I_n}.$$

PLOT THIS LINE ON CURVE.

④ LINE INTERSECTS CURVE AT

$$\frac{E_g}{E_n} = 1.1, \quad \frac{I_f}{I_n} = 1.138.$$

$$R_f = \frac{V_a}{I_f} = \frac{240}{1.138 \cdot 2.75} = 76.7\,\Omega.$$

COMPOUND GENERATOR EXAMPLE

DC GENERATOR HAS RATINGS: 10 KW 240 V 2800 RPM. $I_L = \frac{10\,000}{240} = 41.7A.$

AND PARAMETERS: $R_a = .48\Omega$

$V_{a,\ NO\ LOAD} = 260V$ @ $I_f = 2.75A$

USE FIG 7.2, NORMALIZED TO NO-LOAD VALUES.

FIND $\frac{N_s}{N_f}$ AND R_f FOR FLAT COMPOUNDING AT RATED SPECS.

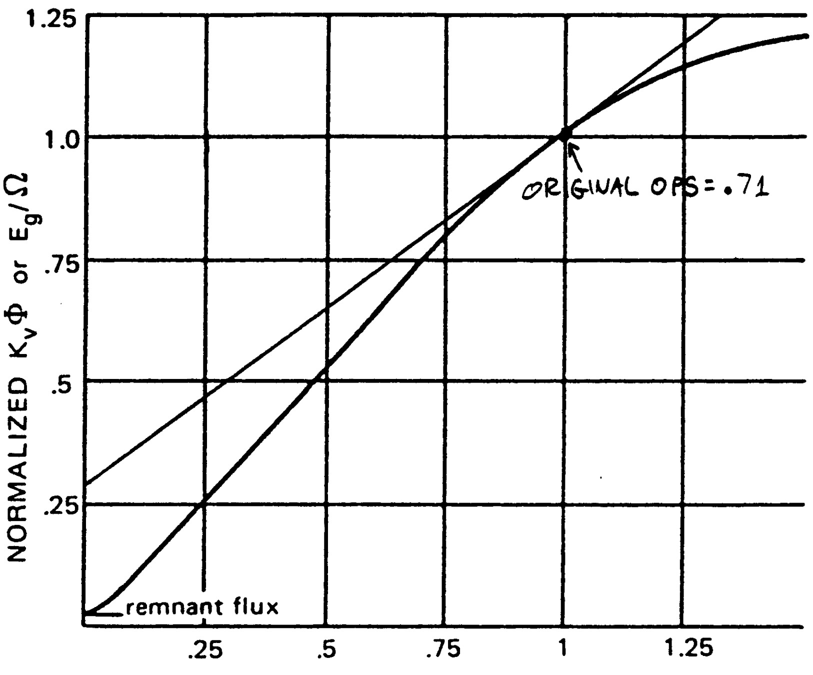


Figure 7.2 Saturation curve

① OBSERVE NORMALIZATION VALUES

$E_n = 260V \quad I_n = 2.75A.$

USE NORMALIZATION POINT AS FIRST GUESS AT PROPER OPERATING POINT, AND MEASURE SLOPE THERE.

OPS = .71.

② CALCULATE TURNS RATIO

$$\frac{N_s}{N_f} = \frac{R_a I_n}{OPS \cdot E_n} = \frac{.48 \cdot 2.75}{.71 \cdot 260}$$

$$\frac{N_s}{N_f} = 0.00715.$$

③ CALCULATE FIELD CURRENT

$$I_f = I_n \cdot MMF_n - \left(\frac{N_s}{N_f}\right) I_L$$

$$I_f = 2.75 \cdot 1 - .00715 \cdot 41.7$$

$$I_f = 2.45A.$$

④ CALCULATE NEW OPERATING PT.

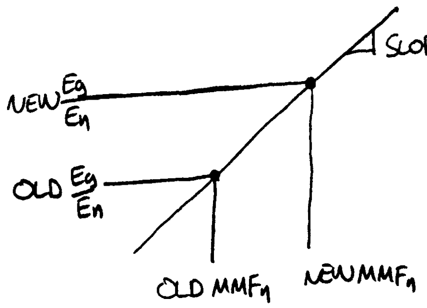
$$E_g = V_a + R_a(I_f + I_L)$$

$$E_g = 240 + .48(2.45 + 41.7)$$

$$E_g = 261V.$$

$$\frac{E_g}{E_n} = 1.0046.$$

(5) FIND NEW MMF_n VIA LINEAR APPROXIMATION.



$$OPS = \frac{\text{NEW } \frac{E_g}{E_n} - \text{OLD } \frac{E_g}{E_n}}{\text{NEW } MMF_n - \text{OLD } MMF_n}$$

$$\text{NEW } MMF_n = \frac{\text{NEW } \frac{E_g}{E_n} - \text{OLD } \frac{E_g}{E_n}}{OPS} + \text{OLD } MMF_n$$

IN THIS CASE,

$$\text{NEW } MMF_n = \frac{1.0046 - 1}{.71} + 1$$

$$\text{NEW } MMF_n = 1.00646.$$

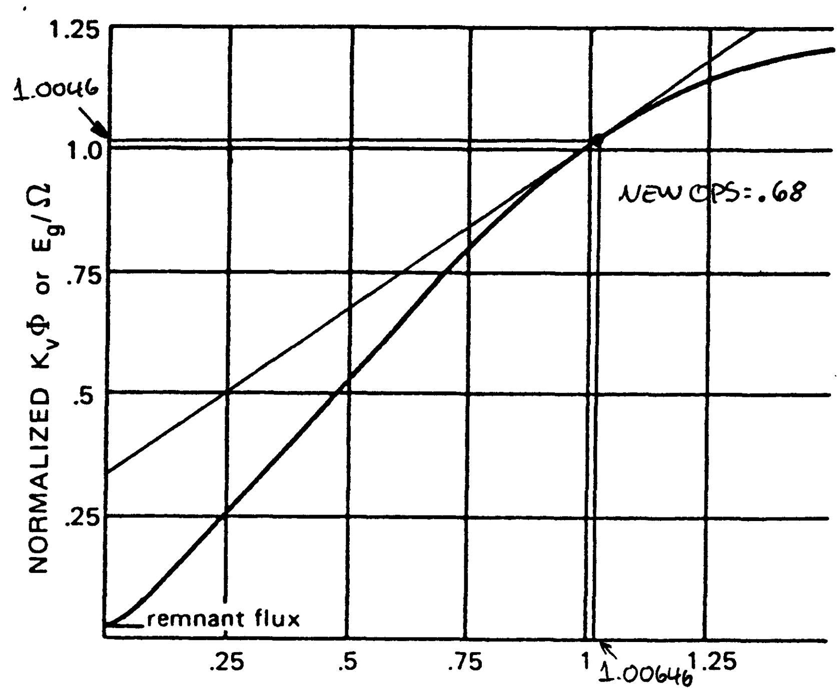


Figure 7.2 Saturation curve

(6) MEASURE SLOPE AT NEW OP. POINT.

$OPS = .68.$

(7) TURNS RATIO

$$\frac{N_s}{N_f} = \frac{R_a I_n}{OPS \cdot E_n} = \frac{.48 \cdot 2.75}{.68 \cdot 260}$$

$$\frac{N_s}{N_f} = 0.00747$$

(8) FIELD CURRENT

$$I_f = I_n \cdot MMF_n - \left(\frac{N_s}{N_f}\right) I_L$$

$$I_f = 2.75 \cdot 1.00646 - 0.00747 \cdot 41.7$$

$$I_f = 2.46\,A.$$

(9) OP. POINT

$$E_g = V_a + R_a(I_f + I_L)$$

$$E_g = 240 + .48(2.46 + 41.7)$$

$$E_g = 261\,V.$$

(10) NOTE THAT THE NEW E_g IS VERY CLOSE TO THE PREVIOUSLY CALCULATED E_g, SO WE MAY PROCEED TO STEP #11. IF THE NEW E_g IS NOT CLOSE, GO BACK TO STEP #5, AND ITERATE UNTIL IT CONVERGES.

(11) $\frac{N_s}{N_f} = 0.00747$, FROM ABOVE.

$$R_f = \frac{V_a}{I_f} = \frac{240}{2.46} = 97.6\,\Omega$$