COMPARATIVE DESIGN OF INDUCTION MOTORS

By

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CERTIFICATE

CERTIFIED that the Dissertation entitled "COMPARATIVE DESIGN OF INDUCTION MOTORS" which is being submitted by Sri Dinesh Kumar Gupta in partial fulfilment for the award of the Degree of Master of Engineering in Electrical Machine Design of University of Roorkee is a record of student's own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of three months from June 1, to August 31, 1962 for preparing dissertation for Master of Engineering Degree at the University.

Dated September 10, 1962

Place- ROORKEE.

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CONTENTS

(Note- Detailed contents are given at the beginning of every Section)

ABSTRACT

The present dissertation describes a new method of Induction motors design. "Comparative Design" is a process for quickly and simply arriving at an approximate winding by altering a known winding of known characteristics to meet the desired specifications. Some approximate relationships to assist this process have been obtained which connect the various operating quantities and the dimensions. The process has been extended to get balanced design of Polyphase, Two-phase and single-phase motors to give the same operating characteristics. A comparison has been made for the performances of the designed machines to operate on a given torque-slip curve of a high speed compressor drive.

INTRODUCTION

The best design is the best compromise among the several contending elements which must or should enter into it. In electrical machinery these are:

(1) The magnetic circuit, (or circuits),

(2) The magnetic circuit,

(3) The dielectric circuit (insulation),

(4) The thermal circuit,

(5) The mechanical circuit (means for supporting the various mechanical stresses),

(6) Cost balance,

(7) Manufacturing facility,

(8) Ease of maintenance and repair,

(9) Acoustical characteristics (reasonably quiet operation)

Cost is usually the main factor which governs the design. Cost is dependent on quality of material, quantity of material and the labour for manufacturing. Some times cost is not the main factor and then either efficiency, weight, quietness etc. are the predominent factors.

In the present design of 100 HP, 440 volt, 10,600 rpm, 180 c/s Submarine Compressor Drive Motor the weight has been given the criteria for most economical design. In this problem natural cooling is also not there and this is Freon cooled machine. So while designing, losses for the temperature rise also does not affect the design.

SECTION - 1

AN APPROACH TO PROBLEM

1. AN APPROACH TO PROBLEM

In the present dissertation on "The Comparative Design of Induction Motors" most economical designs have to be given for (i) three-phase (ii) two-phase and (iii) single phase motor to drive a high speed compressor. The specifications of the motor are- 100 H.P., 440 volt, 10,600 r.p.m., 180 c/s, freon cooled machine. The acceleration torque curve for the compressor has been given as shown in fig. 1.1.

1.1. DESIGN PROCEDURE

From the fundamentals of design and procedure outlined in section 2 and 4 for polyphase and single phase induction motors on elementary design is prepared. Its performance is then calculated in accordance with the procedure outlined in Section 3 and 5 for polyphase and single phase induction motors respectively. In order to get the most economical design maximum values of flux densities and current densities are used in various parts of magnetic and electric circuits without affecting much the efficiency of the machines. So in order to do this various dimensions are changed in accordance with certain known relations. After arriving at sufficiently economical design, torque/speed curve of induction motor designed is drawn. This torque-slip curve is to be matched with the given acceleration-torque curve of the compressor. In order to do proper matching either of (i) full load (ii) break-down and or (iii) starting torques are to be varied. This means a new design. So in order to arrive quickly to the known design, the following approximate relations are to be used which connect various operating quantities with dimensions.

1.2. IMPORTANT RELATIONS

The important relations have been derived from fundamentals to connect operating quantities (BDT, LRT, V, S, LRA, VA, & densities etc.) with dimensions of machine (L, D etc.). The relations are listed below:

No.1: $$(BDT)_2 = \left(\frac{V2}{V_1}\right)^2 \times \left(\frac{CKw_1}{CKw_2}\right)^2 \times \frac{1 - SfL_1}{1 - SfL_2} \times \frac{(HP)_1}{(HP_2)}$$

$$\times \frac{f_1}{f_2} \times \sqrt{\frac{P_2}{P_1}} \times \sqrt{\frac{L_1}{L_2}} \times \sqrt{\frac{D_1}{D_2}} \times (BDT)_1$$

No.2: $$(LRT)_2 = \left(\frac{V_2}{V_1}\right)^2 \times \left(\frac{CKw_1}{CKw_2}\right)^2 \times \frac{(HP)_1}{(HP)_2} \times \frac{f_1}{f_2} \times \sqrt{\frac{L_1}{L_2}} \times (LRT)_1$$

NO.3: $$S_{fl2} = \left(\frac{V_1'}{V_2}\right)^2 \left(\frac{CKw_2}{CKw_1}\right)^2 \times \frac{(HP)_2}{(HP)_1} \times \sqrt{\frac{L_2}{L_2}} \times (S_{fl1})$$

No.4: $$(LRA)_2 = \frac{(BDT)_2}{(BDT)_1} \times \frac{(HP)2}{(HP)_1} (LRA)_1$$

$(BDT)_2$ and $(BDT)_1$ are expressed either in ft. lbs. or % of the full load torque.

No.5: $$(LRA) = 2.4 \times (BDT) \times I_{fl}$$

No. 6: $$\text{Mag } (VA)_2 = \left(\frac{V_2}{V_1}\right)^2 \times \left(\frac{CKw_1}{CKw_2}\right)^2 \times \left(\frac{P_2}{P_1}\right)^2 \times \frac{f_1}{f_2} \times \frac{S_{F2}}{S_{F1}}$$

$$\times \frac{L2}{L_1} \times (VA)_1$$

No.7: $$(\text{Tooth Density})_2 = \frac{V_2}{V_1} \times \frac{CKW_1}{CKw_2} \times \frac{f_1}{f_2} \times \frac{P_2}{P_1} \cdot \frac{L1}{L_2} \ (\text{tooth density})_1$$

No.(8): $(\text{Core Density})_2 = \frac{V_2}{V_1} \times \frac{CKw_1}{CKw_2} \times \frac{f_1}{f_2} \times \frac{L_1}{L_2} (\text{Core density})_1$

No.9: $(BDT)_{lbs.ft.} = \frac{(VK_p)^2}{r_1 + \sqrt{r_1^2 + (x_1 + x_2)^2}}$

Subscript '1' refers to the winding of known characteristics,
Subscript '2' refers to the winding of whose characteristics, are to be determined.

When number of poles is increased, tooth density may become critical.

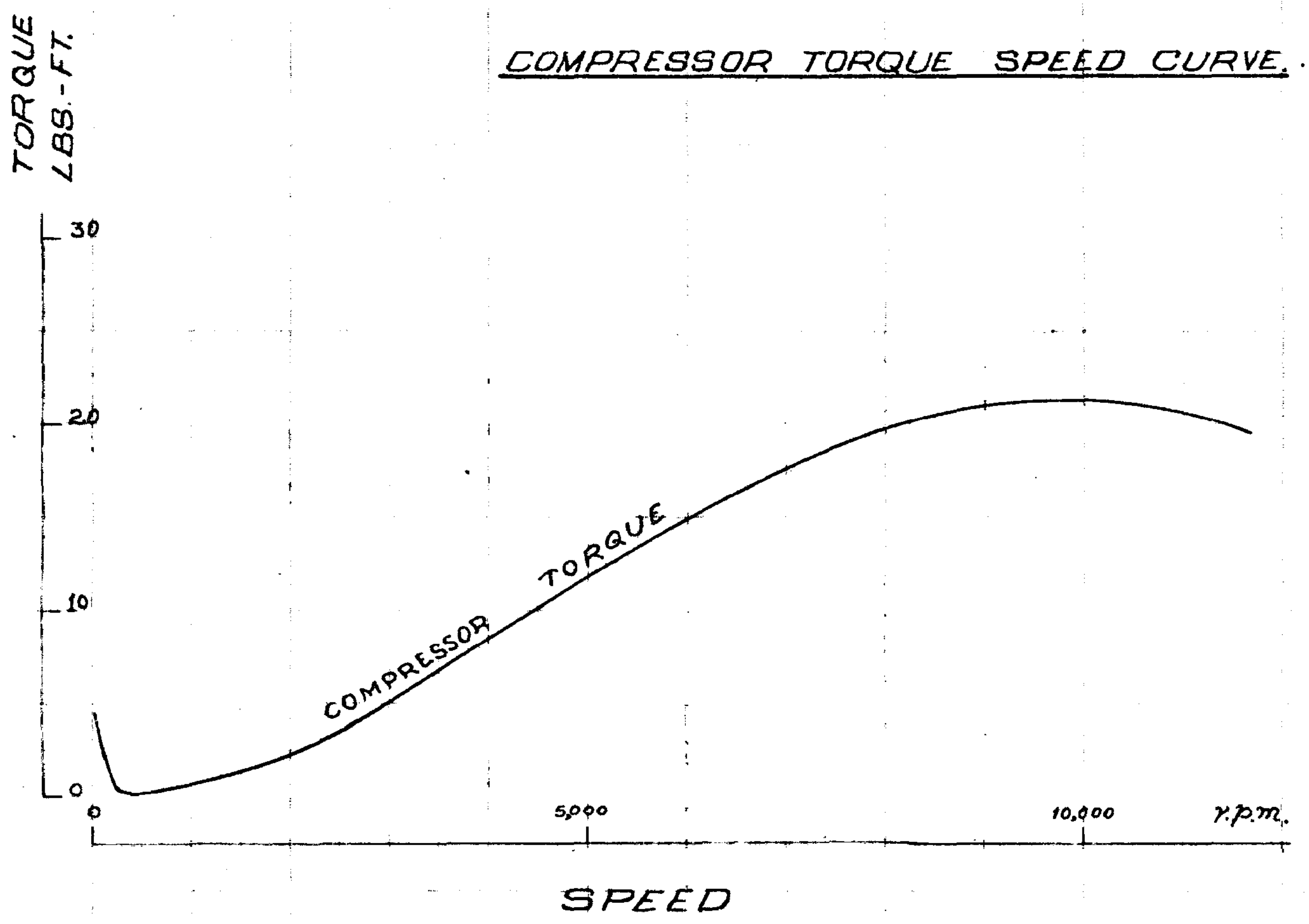
When number of poles is decreased, core density may become critical.

1.3 SYMBOLS

In above relations symbols used are:

BDT - Breakdown torque, % of Full load torque,
LRT - Locked rotor torque, % of full load torque.
LRA - Locked rotor ampers
V - Rated volts.
CKw - Effective series conductors per phase.
Sfl - Full load slip.
HP - Horse power rating.
f - Frequency.
P - Number of poles.
L - Length of the core stack.
SF - Saturation factor.
D - Gap diameter.
VA - Volt ampere capacity

Thus using the above relations a satisfactory design can be obtained.



COMPRESSOR TORQUE SPEED CURVE.

FIG. 1.1.

D. K. GUPTA.

SECTION - 2

BASIC DESIGN PROCEDURE FOR POLY PHASE INDUCTION MOTORS

2. BASIC DESIGN PROCEDURE FOR POLYPHASE INDUCTION MOTORS

Design procedures differ considerably depending upon too many factors to enumerate here. In general, a basic design procedure consists of the following steps:

a) Selection of a trial design,
b) A basic calculation of the trial design,
c) Evaluation of results of calculations,
d) Repetition of first three steps until a satisfactory design is found.

This procedure outlines the formulas required to evaluate the equivalent circuit constants necessary in the calculation of induction motor performance. The solution of the equivalent circuit for determining machine performance is covered in Section 3. Performance for any point on the speed torque curve from no load to locked rotor can be calculated using this section in conjuction with Section 3. Saturation of the leakage flux paths, and deep bar effect is taken into account in the formulas for all regions of the speed torque curve except the full load region where they can be neglected. Therefore, the formulas in this section have been grouped into sections according to the region of the speed torque curve being considered.

1. General - Items (1) thru (230)- Calculate for all cases. In 'General' the design procedure consists of following sub-sections.

2.1.1. Rating. This includes per-unit values of power, current, voltage and impedance. Items [illegible] thru (15)

2.1.2. Core Dimensions. This includes stator and rotor core dimensions. Items (16) thru (65).

2.1.3. Electrical. This includes winding specifications, slot fullness, weight and resistance of stator winding. Items (66) thru (94).

2.1.4. Saturation. This includes flux per pole, carter coefficients, densities and saturation factor. Items (95) thru (135).

2.1.5. Core Losses. These losses are calculated for stator core, teeth and surfaces at 60 cycles. The total of these is corrected for frequency. Items (136) thru (145).

2.1.6. Full Load Reactances. These are calculated on the basis of all leakage paths being unsaturated, except for the bridge of a closed slot rotor. Rotor bridge constant is calculated at an estimated value of full load current. Items (146) thru (184).

2.17. Full Load Secondary resistance (r_2). Items (185) thru (205).
2.1.8. No load losses are read out. Items (206) thru (217).
2.1.9. Cost calculations. This is calculated to find the cost of iron, copper and aluminum consumed. Items (218) thru (230).

2. Full Load Performance - Items (300) thru (319)- Calculate for full load condition and also for all points in load performance at other load points.

3. Locked Rotor- Items (400) thru (443)- Calculate for locked rotor condition.

4. Breakdown Torque- Items (500) thru (509)- Calculate for maximum torque region.

5. Speed Torque- Items (600) thru (602)- Calculate whenever a complete speed torque curve is desired.

6. Half Voltage Locked Rotor - Items (700) thru (701)- Calculate to obtain locked rotor data at half voltage.

In addition to machine dimension and winding data, certain data from the rotor and stator punchings are required before the claulcations of this section can be performed. Section 6.1. provides procedure for the required stator and rotor punching calculations.

This "Basic Design Calculations for Polyphase Motors" procedure is only applicable to Induction Motors having:

(i) A given frame size with partially closed stator slots,
(ii) Single Cage rotor having closed slots,
(iii) Round stranded wires in stator winding.
(iv) No rotor or stator ducts as there is no natural cooling problems.

BASIC DESIGN CALCULATIONS FOR POLYPHASE MOTORS

ITEM NO.	SYMBOL	
		2.1.1. RATING
		All dimensions in inches.
1		Frame (Code number to be given)
2		Horsepower.
3		Volts, Line.
4	m	Phases, number of
5	f	Frequency
6	P	Poles, number of
7	N_s	Synchronous RPM, $N_s = 120f/P = 120(5)/(6)$
8		Full-load RPM
9		Duty
10		Steel Punching Code. For Code number refer Item (142)
11		^oC Rise, rated.
		P.U. BASE.
12	V	For 3 phase motors, either $Y = \frac{\text{line volts}}{\sqrt{3}} = \frac{(3)}{\sqrt{3}}$ or Δ = line volts = (3) For 2 phase motors = line volts = (3)
13	P_{pu}	Base power = HP = .746 = (2) x .746
14	I_{pu}	Base amps $= \frac{P_{pu}}{m\ V} = \frac{(13) \times 10^3}{(12)\ (4)}$
15	Ω_{pu}	Base ohms $= \frac{V}{I_{pu}} = \frac{(12)}{(14)}$
		2.1.2. CORE DIMENSIONS
		Stator Core Dimensions.
16	D	Stator Punching O.D.
17	D_1	Gap diameter.

18	L_{g1}	Gross core length
19	N_{d1}	Radial ducts, number of
20	w_{d1}	Radial duct width
21	L_1	Net core length $L_1 = L_{g1} - N_{d1} w_{d1}$ = (18)-(19)(20)
22	k_{s1}	Stator stacking factor (.93 for Insulene Varnish)
23		Net iron, stator = $k_{s1} L_1$ = (22) (21)
24	S_1	Number of stator slots. From stator punching calculation sheet Item (3)
25		Type of Slots
26	d_1	Overall slot depth, stator. From stator calc. sheet, Item (4).
27	w_{10}	Slot opening, stator. From stator calc. sheet, Item (8)
28	λ_1	Slot pitch, stator. From stator calc. sheet, Item (15)
29	t_{10}	Tooth face, stator. From stator calc. sheet, Item (16)
30	t_1	Effective tooth width, stator (width 1/3 from minimum). From stator calc. sheet, Item (19)
31		Effective tooth length, stator. From stator calc. sheet (Item 20)
32	d_{y1}	Effective yoke depth, stator. From stator calc. sheet, Item (21).
33		Net slot winding area, stator. From stator calc. sheet, Item (31)
34		Permissible ND^2, stator, From stator calc. sheet, Item (32).
35	K_{s1a}	Stator slot constant, air portion. From stator calc. sheet, Item (36).
36	K_{s1w}	Stator slot constant, winding portion. From stator calc. sheet, Item (33)

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ROTOR CORE DIMENSIONS.

37	D_2	Rotor O.D. From rotor punching calc. sheet, Item(1)

38	D_b	Effective I.D., rotor. From rotor pchg. Calc.sheet, Item (2)
39	L_{g2}	Gross core length, rotor.
40	N_{d2}	Radial ducts, number of
41	W_{d2}	Radial ducts, width.
42	L_2	Net core length, rotor $= L_2 = L_{g2} - N_{d2} W_{d2}$ $= (39) - (40)\ (41)$
43	k_{s2}	Rotor stacking factor
44		Net iron, rotor $= k_{s2} L_2 = (43)\ (42)$
45	S_2	No. of rotor slots. From rotor pchg. Calc.sheet, Item (3)
46		Type of rotor slots
47		Skew in percent of rotor slot pitch (115% for all practical designs)
48	d_2	Overall slot depth, rotor (bar depth) From rotor pchg. Calc. sheet, Item (4)
49	w_{21}	Slot width at top, rotor. From rotor pchg. Calc.sheet, Item (9).
50	λ_2	Slot pitch, rotor. From rotor pchg. Calc.sheet, Item(11)
51	t_2	Effective tooth width, rotor (width 1/3 from min. section). From rotor pchg. Calc. sheet, Item (20).
52		Effective tooth length. From rotor pchg. Calc.sheet, Item (21)
53		Yoke depth of punching, rotor. From rotor pchg. Calc. sheet, Item (22).
54		Shaft material whether magnetic or non-magnetic.
55		Effective yoke depth of shaft. $= \frac{0.667\ D_b}{p^2} = 0.667\ (54)\ (38)/(6)^2$ for $= 0$ for shaft of non-magnetic material.
56	d_{y2}	Effective yoke depth, rotor = yoke depth of punching + yoke depth of shaft $= (53) + (55)$

57	K_{s2w}	Rotor slot constant, winding portion. From rotor pchg. Calc. sheet, Item (23)
58	d_b	Depth of bridge, minimum, closed slots only. From rotor pchg. Calc. sheet, Item (6)
59	d_{21}	Depth of slot mouth. From rotor pchg. Calc. sheet, Item (7).
60		Rotor slot area. From rotor pchg. Calc. sheet, Item(25)
61	K_{s2a}	Rotor slot constant, air portion. From rotor pchg. Calc. sheet, Item (28)
62	w_{23}	Slot width at bottom of slot. From rotor pchg. Calc. sheet, Item (10)
63	g	Air gap, actual, inches, $g = \frac{1}{2}(D_1 - D_2) = \frac{1}{2}\left[(14) - (34)\right]$
64	λ_p	Pole pitch, $\lambda_p = \pi(D_1 - g)/P = \pi\left[(14) - (57)\right]/(6)$
65	L	Axial length of air gap.

2.1.3. ELECTRICAL

66	Turns per coils, actual
67	Bare diameter, No. 1, inches.
68	Strand per conductor, No. 1
69	Bare diameter, No. 2, inches
70	Strand per conductor, No. 2.
71	Diameter over insulation, No. 1.
72	Diameter over insulation, No. 2.
73	Total $ND^2 = 2\,(66)\left[(68)(71)^2 + (70)(72)^2\right]$
74	Percent fullness = (total ND^2) x 100/net winding area $= 100\,(73)/(33)$
75	$\dfrac{\text{Actual } ND^2}{\text{Permissible } ND^2} = \dfrac{(73)}{(34)}$
76	$\dfrac{\text{Actual circular mils per conductor}}{1000} = \left[(67)^2\,(68) + (69)^2\,(70)\right] \times 10^3$

77 Type of connections (Delta, Star-3 phase or 2-phase.

78 q No. of parallel circuits.

79 Coil sides lie in slots 1 and .

80 Coil pitch in per unit = $\frac{\text{coil throw} \times P}{S_1}$

$= \frac{[(79) - 1] \times (6)}{(21)}$

WEIGHT AND RESISTANCE OF SECONDARY WINDING:

81 Equiv. C.M./1000 per conductor, equivalent Y, single circuit basis.

If winding is actually Y connected

= Actual C.M. per conductor x no. of parallel circuits.

= (76) x (78)

If winding is actually Δ connected

= Actual C.M. per conductor x no. of parallel circuits x $\sqrt{3}$

= (76) x (78) x $\sqrt{3}$

For 2-phase motors, this item is equiv. C.M./1000 per conductor, single circuit basis = Actual C.M. per conductor x no. of parallel circuits
= (76) x (78)

82 Equivalent turns per coil, equivalent Y, single circuit basis.

If winding is actually Y connected
= Actual turns per coil/no. of parallel circuits.
= (66) / (78)

If winding is actually Δ connected
= Actual turns per coil / $\sqrt{3}$ no. of parallel circuits.
= (66)/ $\sqrt{3}$ (78)

For 2-phase motors, this item is equiv. turns per coil, single circuit basis = actual turns per coil/ no. of parallel circuits.

83 Pull dimensions = $\frac{(D_1 + d_1)\,\pi \times \text{per unit coil pitch}}{P}$.

$= \frac{[(17) + (26)]\,\pi \times (80)}{(6)}$

84 K_1 This is the ratio $= \dfrac{\text{Length of the slanting portion of coil head}}{\text{Pull dimension}}$

K_1 for minimum coil head clearance,

$$K_1 = \frac{1}{\cos\theta}$$

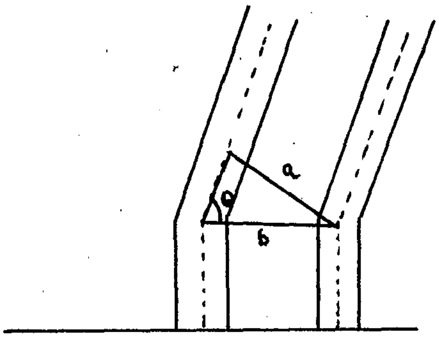
a = Coil clearance + avg slot width - slot insulation

b = Space available for coil

$$= \pi \frac{(D_1 + d_1)}{S_1}$$

$$\sin\theta = \frac{a}{b}$$

$$\theta = \sin^{-1}\left(\frac{a}{b}\right)$$



Hence $K_1 = \dfrac{1}{\cos\theta}$

85 K_2 Straight portion of coil head in inches.

For large motors $K_2 = 1.5 - 2.0$

For small motors $K_2 = 1.13 - 1.5$

86 Pin diameter (usually equal to 3/8" for formed coils only)

87 K_3 Knuckle length (formed coils only)

$$K_3 = 1.57\ (\text{pin dia.} + \tfrac{1}{2}\ d_1)$$

$$= 1.57\ \left[(86) + \tfrac{1}{2}(26)\right]$$

88 MLC Mean length of a conductor

= Pull dimension x K_1 + straight length + knuckle length + L_{g1}

$$= (83)\ (84) + (85) + (87) + (18)$$

89 C Series conductors per phase

$$C = \frac{2S_1 \times \text{equiv. turns per coil}}{m}$$

$$= \frac{2\ (24) \times (82)}{(4)}$$

90 Copper weight, pounds

$= 0.275 \times 10^{-3} \times C \times MLC \times m \times$ equivalent CM/1000 per conductor.

$= 0.275 \times 10^{-3} \times (89)\ (88)\ (4)\ (81)$

91 r_1 cold Primary resistance per phase, ohms at 25°C

$= 0.881 \times 10^{-3} \times C \times MLC/$equivalent CM/1000 per conductor.

$= 0.881 \times 10^{-3}\ (89)\ (88)/(81)$

92 Average temp. of primary winding, when hot, deg.cent.

93 $r_1$hot pu Primary resistance per phase, per unit ohms, hot

$$r_1 \text{ hot pu} = \frac{r_1 \text{ cold}}{\Omega\text{ pu}} \times \frac{235 + \text{hot temp}}{260}$$

$$= \frac{(91)}{(15)} \times \frac{235 + (92)}{260}$$

94 $r_1$pu Effective primary resistance per phase, per unit ohms, hot

$r_1$pu = constant x $r_1$hot pu = constant (93)

This constant includes allowance for stray load loss in primary due to various frequencies.

2.1.4. SATURATION

Flux per Pole:

95 ψ Phase belt angle, in electrical degrees

$\frac{180}{(m)} = \frac{180}{(4)}$ except in 2-phase machines where $\psi = 90^\circ$

96 R Coil per group, actual $= \frac{S_1/P}{180/} = \frac{(24)/(6)}{180/(95)}$

97 Numerator of item (95)

98 k_d Distribution factor

$$k_d = \frac{\sin(\psi/2)}{R \sin \frac{\psi}{2R}} = \frac{\sin \frac{(95)}{2}}{(96) \sin \frac{(95)}{2\ (96)}}$$

99 k_p Pitch factor

$k_p = \sin(\text{coil pitch} \times 90^\circ) = \sin\left[(30) \times 90\right]$

100 k_w Winding factor $k_w = k_d\,k_p$ = (98) (99)

101 Ck_w Effective conductors in series per phase $= Ck_w$ = (89) (100)

102 ϕ Flux per pole, kilolines

$$\phi = \frac{45000\ V}{f\ C\ k_w} = \frac{45000\ (13)}{(5)\ (101)}$$

CARTER COEFFICIENTS

103 $(5g + w_{10})$ = (28) [5 (63) + (27)]

104 Value of w_{10} $(g + w_{10})$ = (27) [(63) + (27)]

105 C_1 Carter, stator slots $= \frac{(103)}{(103) - (104)}$

106 C_2 Carter, rotor slots. For closed slots=1.02

107 Cd_1 Carter, stator ducts. For no stator duct $C_{d1} = 1$

108 C_{d2} Carter, rotor ducts. For no rotor duct $C_{d2} = 1$

DENSITIES AND SATURATION:

109 A_{y1} Stator core area = $2k_{s1}\,L_1\,d_{y1}$ sq.inches = 2(23)(32)

110 A_{t1} Stator teeth area = $k_{s1}\,L_1\,S_1\,t_1/P$ sq.inches = (23) (24) (30)/(6)

111 A_{y2} Rotor core area = $2k_{s2}\,L_2\,d_{y2}$ sq.inches =2(43)(65)(56)

112 A_{t2} Rotor teetch area = $k_{s2}\,L_2\,S_2\,t_2/P$ sq.inches = (43)(65)(45)(51)/(6)

113 A_g Air gap area $= \lambda\,pL$ = (64)(65)

114 K_p Primary flux constant - Assume value or $\left(1 - \frac{p}{100}\right) = \left(1 - \frac{(6)}{100}\right)$

115 B_{y1} Stator core density, kilolines per sq.inch

$$B_{y1} = \frac{\phi}{\text{stator core area}} = \frac{(102)}{(109)}$$

---

116 B_{t1} Stator teeth density, kilolines per sq.inch

$$B_{t1} = \frac{1.57\,\phi}{\text{stator teeth area}}$$

$$= \frac{1.57\,(102)}{(110)}$$

117 B_{y2} Rotor core density, kilolines per sq.inch

$$B_{y2} = \frac{K_p\,\phi}{\text{rotor core area}} = \frac{1.57(114)(102)}{(111)}$$

118 B_{t2} Rotor teeth density, kilolines per sq.inch

$$B_{t2} = \frac{1.57\,K_p\,\phi}{\text{rotor teeth area}} = \frac{1.57(114)(102)}{(112)}$$

119 B_g Air gap density, kilolines per sq.inch.

$$B_g = \frac{1.57\,K_p\,\phi}{\text{air gap area}} = \frac{1.57\,(114)(102)}{(113)}$$

120 ↑ AT/in, stator core density from item (115)

121 See Fig.2.1 AT/in, stator teeth. Density from item (116)

122 ↓ AT/in, rotor core. Density from item (117)

123 ↓ AT/in, rotor teeth. Density from item (118)

124 Stator core length $= \dfrac{1.571\,(D - d_{y1})}{P}$

$$= \frac{1.571\,[(16) - (32)]}{(6)}$$

125 Stator teeth = Effective teeth length,
stator = (31)

126 Rotor core length $= \dfrac{1.571\,(D_b + \text{Yoke depth of punching})}{P}$

$$= \frac{1.571\,[(38) + (56)]}{(6)}$$

127 Rotor teeth length = Effective teeth length,
rotor = (52)

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128 g_e Effective air gap length $g_e = gC_1 C_2 C_{d1} C_{d2}$

= (63) (105) (106) (107) (108)

129 Stator core AT = AT/in, stator core x stator core length
= (120) (124)

130 Stator teeth AT = AT/in, stator teeth x stator teeth length
= (121) (125)

131 Rotor core AT = AT/in, rotor core x rotor core length
= (122) (126)

132 Rotor teeth AT = AT/in, rotor teeth x rotor teeth length
= (123) (127)

133 Air gap AT = 313 x B_g x effective air gap length
= 313 x (119) (128)

134 Total AT per pole = (129) + (130)+ (131)+(132)+(133)

135 K_{sf} Saturation factor = $\frac{\text{Total AT per pole}}{\text{Air gap AT}} = \frac{(134)}{(133)}$

2.1.5. CORE LOSSES

136 Stator core volume = stator core area x stator core length x P
= (109) (124) (6) cu.in.

137 Stator teeth volume = stator teeth area x stator teeth length x P
= (110) (125) (6) cu.in.

138 } See fig.2.2. Stator core, watts/in^3 at 60 cy. Density from item(115)

139 } See fig.2.2. Stator teeth, watts/in^3 at 60 cy. Density from item (116)

140 Stator core , 60-cy. Loss in kw = stator core volume x watts /in^3 = (136) (138) /1000

141 Stator teeth, 60 cy. loss in kw = stator teeth volume x watts/in^3 = (137) (139) /1000

142 Surface loss at 60 cy. in kw

$$K_{HF}\, B_g^2 \sqrt{B_g} \left(\frac{1}{P\sqrt{P}}\right) D_1^2 \sqrt{\delta_1} \left(\frac{V10}{g}\right)^{1.25} (21)\, 10^{-9}$$

$$K_{HF}\,(124)^2 \sqrt{(124)}\, \frac{1}{(6)\sqrt{(6)}}\, (17)^2 \sqrt{(24)} \left[\frac{(27)}{(62)}\right]^{1.25} (21) \times 10^{-9}$$

K_{HF}	Grade of steel	Code
3.83	26 ga. Electrical	4343
3.83	24 ga. Motor	4345
4.30	24 ga. Non-silicon	437a

143 Total 60-cy. losses in kw = (140) + (141)+(142)

144 Frequency correction factor $= 0.8\left(\frac{f}{60}\right) + 0.2\left(\frac{f}{60}\right)^2$

$$= 0.8\left(\frac{(5)}{60}\right) + 0.2\left(\frac{(5)}{60}\right)^2$$

145 Core loss, total = Total 60 cy. loss x frequency correction factor in kw = (143) (144)

2.16 FULL LOAD REACTANCES

146 Per unit reactance constant $= \frac{2\, f\, (C_{kW})^2 m \times 10^{-8}}{\Omega\text{-pu}}$

$$= \frac{2\ (5)\ (101)^2\ (4) \times 10^{-8}}{(15)}$$

147 Per unit skew = skew in % rotor slot pitch xP/100S2

= (47) (6) /100 (46)

148 $1-C_{sk}$ For per unit skew upto 0.50 (error within 3%)

$1 - C_{sk} = 0.411 \times$ per unit skew^2

$= 0.411 \times (147)^2$

For per unit skew greater than 0.5, use

$$1 - C_{sk} = 1 - \frac{\sin(90 \times \text{p.u. skew})}{\frac{\pi}{2} \times \text{p.u. skew}}$$

$$= 1 - \frac{2 \sin 90 \times (147)}{\pi \times (147)}$$

149 C_{sk} $C_{sk} = 1 - (1 - C_{sk}) = 1 - (148)$

150 P_m Magnetising permeance $P_m = \frac{0.3234 \times A_g \times C_{sk}}{\text{air gap length} \times K_{gf} x P}$

$$= \frac{0.3234\ (113)\ (149)}{(128)\ (135)\ (6)}.$$

---

151 C_p Pitch correction for slot mutual
See Fig. 2.3; Refer to item (80) for pitch
Refer at to item (95) for phase-belt angle.

152 Modified stator slot constant, air portion
$= K_{sla}\, C_p = (35)\,(151)$

153 Modified stator slot constant, winding portion
$= K_{slw}\,(0.25 + 0.75\, C_p)$
$= (36)\left[0.25 + 0.75\,(151)\right]$

154 Modified stator slot constant, total = (152)+(153)

155 Stator slot factor $= \dfrac{3.19 \times L_1 \times \text{Modified stator slot constant}}{S_1\, k_w^2}$

$= \dfrac{3.19(\ 121\ )\ (154)}{(24)\ (100)^2}$

156 $\lambda_{1}/S_1 = (28) / (24)$

157 $\lambda_{2}/S_2 = (50)/(45)$

158 $\lambda_{1}/S_1 + \lambda_2/S_2 = (156) + (157)$

159 $2\, C_1\, C_2 = 2\,(105)\,(106)$

160 $\dfrac{C_1 + C_2 - C_1\, C_2}{2\, C_1\, C_2} = \dfrac{(105)\ (106) - (105)\ (106)}{(159)}$

161 ZZ Const. $\left(\dfrac{\lambda_1}{S_1} + \dfrac{\lambda_2}{S_2} \right) \dfrac{1}{g} \left(\dfrac{C_1 + C_2 - C_1\, C_2}{2\, C_1\, C_2} \right)^2$

$= (158)\ (160)^2/(63)$

162 $0.533\ L/C_{d1}\ Cd_2 = 0.533\ (65)/(107)(108)$

163 Stator zig zag factor = (161) (162)

164 Stator skew factor $(\ 1 - C_{sk})\ \ m/C_{sk} = (148)(150)/(149)$

165 Stator end const. - See Fig. 2.4. Refer item (64) for pole pitch and item (80) for coil pitch.

166 L_{e1} $L_{e1} = 1.525 \times (64) \times (80) + 1.100$

167 L_{e2} $L_{e2} = \text{MLC} - L_1 = (88) - (21)$

168 Modified stator end constant $= (165)\ \dfrac{L_{e2}}{L_{e1}}$

$= (165)\ \dfrac{(167)}{(166)}$

---

169 Stator end factor = modified stator end constant/P = (168)/(6)

170 Total stator leakage factor = (155) + (163) + (164) + (169)

171 Est. F.L. See amp $= \frac{810 \times H_p}{M\ V\ K_p} \times \frac{N_s}{N_{f1}}$

$$= \frac{810\ (2)}{(4)\ (12)\ (114)\ (217)}$$

172 $\frac{CK_w m}{S_2\ W_{21}} = \frac{(100)\ (4)}{(45)\ (49)}$

173 $\left[\frac{C\ k_w\ m\ I_2 \text{ estimated}}{S_w\ W_{21}}\right]^{0.9} = (172)\ (171)^{0.9}$

174 Full load $d_{be} = d_b + \frac{d_{21}}{8970}\left(\frac{C\ k_w\ m\ I_2}{W_{21}\ S_2}\right)^{0.9}$

$$= (58) + \frac{(59)}{8970}\ (173)$$

175 Rotor slot constant, bridge portion, full load

$$= \left(\frac{d_{21} + d_b - d_{be}}{d_{be}}\right)^{0.1} \frac{d_{be}}{W_{21}}\left(\frac{W_{21}\ S_2}{CK_w\ MI_2}\right)^{0.9}$$

$$= \left[\frac{(58) + (59) - (174)}{(174)}\right]^{0.1} \frac{(174)}{(49)\ (173)} \times 13{,}800$$

x13,800

or (61) if slots are not closed.

176 Rotor slot constant, total, full load = (175)+(57)

177 Rotor slot factor, F.L. $= \frac{3.19 L_2 \times \text{Rotor slot const.}}{S2}$

$$= \frac{3.19 (42)\ (176)}{(45)}$$

178 Rotor zigzag factor = stator zigzag factor =(163)

179 Rotor skew factor = stator skew factor =(164)

180 Total rotor leakage factor, full load = (177) + (178)+(179) = rotor slot factor+ rotor zigzag factor + rotor skew factor.

181 x_Mp.u. Magnetizing reactance = reactance constant x P_m = (146) (150)

182 x_1 p.u. Primary leakage reactance = reactance constant x_1
$= (146)\ (170)$

183 x_2 p.u. Secondary leakage reactance = reactance constant x_2
$= (146)\ (180)$

184 K_p Primary flux factor $K_p = \frac{x_M}{x_M + x_1} = \frac{(181)}{(181)+(182)}$

Compare this with item (114). If this differs by more than 0.05, item (117) to here should be repeated, for accuracy, after substituting (184) for (114).

2.1.7. FULL LOAD SECONDARY RESISTANCE (r_2)

185 Percent conductivity of cage material

Material	% Conductivity	After Heat Treat
Aluminum	50.0	
Secondary aluminum	21.7	29.7
Dow M	20-10	26.0
Gliding Bronze	43.5	
Aluminum Bronze	10.4	
Rome Welding Bronze	26.3	

Calculations that follow are based on use of same material in both bars and end rings.

186 Per unit resistance constant $= \frac{69.3 \times 10^{-6}\, m(Ck_w)^2}{\text{p.u.} \times \%\ \text{conductivity}}$

$= \frac{69.3 \times 10^{-6}(4)(100)^2}{(15)\ (185)}$

187 Bar extensions, total for both ends, measured axially, (usually 0).

188 Axial distance between end rings = L_{g2} + bar extension = (39) + (187)

189 A_b Bar area in square inch = (60) for die-cast rotors.

190 A_r Ring area in sq.in. (area of each ring)

191 D_o Ring O.D.

192 D_i Ring I.D.

193 Average ring diameter $= \frac{1}{2}(D_o + D_i)$

$= \frac{1}{2}\ (191) + (192)$

194 Diameter at rotor slot centres = $D_2 - d_2$ = (37)-(48)

195 D_r Larger of (193) (or (194)

196 $\frac{D_1}{D_r} = \frac{(192)}{(195)}$

197 K_{ring} See fig.2.5. $\frac{D_1}{D_r}$ from item (196), poles from item (6)

198 Bar correction for skew For die-cast rotor $= 1 + \left(\frac{p \times \text{p.u. skew}}{\text{axial distance between rings}}\right)^2$

$$= = 1 + \left[\frac{(64)\ (147)}{(188)}\right]^2$$

199 Bar correction for dead corners.

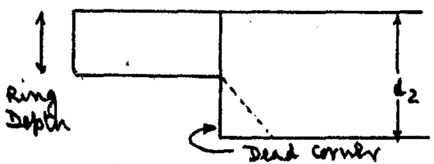
If item (194) > item (193), this item = 1.0

If item (193) > item (194), then

$$\text{Factor} = 1 + \frac{(D_1 - D_2 + 2d_2)^2}{2(D_2 - D_1) \times \text{axial distance between rings}}$$

$$= 1 + \frac{[(192) - (37) + 2\ (48)]^2}{2\,[(37) - (192)] \times (188)}$$

Note: This correction is based on the assumptions that the dead corner is a 45° triangle, and that the bar is a rectangular in cross section.



200 $$\text{Bar factor} = \frac{\text{axial distance between rings} \times \text{Correction for skew} \times \text{Correction for dead corner}}{S_2\ A_b}$$

$$= \frac{(188)\ (198)\ (199)}{(45)\ (189)}$$

201 $$\text{Ring factor} = \frac{0.637\ D_r\ K_{ring}}{P^2 \times A_r} = \frac{0.637\ (195)(197)}{(6)^2 \times (190)}$$

202 Bar factor + Ring factor = (200) + (201)

203 r_{2pu} cold Secondary resistance per phase in primary terms, ohms, at 25°C, full load = resistance constant x cage factor = (186) (202)

204 Average temperature of secondary winding, when hot, °C

---

205 r_{2}hot p.u. r_{2}, hot = r_{2}, cold $\frac{225 + \text{hot temp}}{250}$

$$= (203)\ \frac{225 + (204)}{250}$$

2.1.8. NO LOAD.

206 r_{fe} p.u. $= \frac{K_{p}^{2}\ P_{pu}}{\text{core loss}} = \frac{(184)^{2}\ (43)}{(145)}$

207 r_{M}pu "Series" core loss resistance, ohms per phase

$$r_{M} = \frac{x_{M}^{2} / r_{fe}}{1 + (x_{m}/r_{fe})^{2}}$$

$$= \frac{(181)^{2} / (206)}{1 + [(181) / (206)]^{2}}$$

208 x'_{M}pu "Series" magnetising reactance per phase, ohms

$$x'_{M} = \frac{x_{M}}{1 + (x_{M}/r_{fe})^{2}}$$

$$= \frac{(181)}{1 + [(181) / (206)]^{2}}$$

209 Z_{Mpu} Magnetising impedance, ohms per phase

$$Z_{M} = \sqrt{r_{M}^{2} + x'^{2}_{M}} = \sqrt{(207)^{2} + (211)^{2}}$$

210 r_{opu} Open circuit resistance, ohms per phase

$$r_{o} = r_{1} + r_{m} = (94) + (207)$$

211 X_{opu} Open circuit reactance, ohms per phase

$$X_{o} = x_{1} + x'_{M} = (182) + (208)$$

212 Z_{opu} Open circuit impedance, ohms per phase

$$Z_{o} = \sqrt{r_{o}^{2} + X_{o}^{2}} = \sqrt{(210)^{2} + (211)^{2}}$$

213 I_{o} No load current, amperes, $I_{o} = \frac{1.0}{Z_{o\ p.u}} \times I_{p.u.}$

$$= \frac{1.0\ (14)}{(212)}.$$

---

214 Friction and windage loss at synchronous speed.

215 Pri I^2_r, no load $= mI_o^2 r_1 /1000$ in KW.
$= (4)\ (213)^2(93)\ (15)/1000$

216 No load kilowatts $= (145) + (214) + (215)$

217 $\frac{N_{fl}}{N_s}$ $\frac{\text{Full load rpm}}{\text{syn. rpm}} = \frac{(8)}{(7)} = (1 - s_{fl})$

2.1.9 COST CALCULATIONS

218 P_i Cost per lb. of iron.

219 P_{cu} Cost per lb. of copper.

220 P_{AL} Cost per lb. of aluminum.

221 W_{i1} Weight of steel used for stator laminations, and for same number of rotor laminations
$= .28\ L_1\ (D + 0.25)^2 = .28\ (21)\ [(16) + 0.25]^2$

222 W_{i2} Weight of steel used for those rotor laminations in excess of number used in stator.
$= 0.28\ [L_2 - L_1]\ [D_1 + .25]\ [D_1 + .0625]$
$= 0.28\ [(42) - (21)]\ \ [(17) + .25]\ \ [(17) + .0625]$

223 W_i Gross weight of active iron used
$= W_{i1} + W_{i2} = (221) + (222)$

224 C_i Cost of iron $= P_i\ W_i = (218)\ (223)$

225 C_{cu} Cost of copper (stator) $= (90)\ (219)$

226 W_b Weight of rotor bars $= .098\ [(189)\ \ (39) + (187)\ ](45)$
This expression assumes aluminum bars. If a different material is used, substitute its density in lbs/in^3 for .098 in above formula.

227 W_r Weight of resistance rings excluding fan blades
$= 0.616\ (193)\ (190)$

228 W_{AL} Weight of aluminum $= W_b + W_r = (226) + (221)$

229 C_{AL} ~~Weight~~ Cost of aluminum $= W_{AL}\ \ C_{AL} = (228)\ (220)$

230 Total cost of active materials
$= (224) + (225) + (229)$

2.2. FULL LOAD PERFORMANCE

300	s	Slip at full load.
301	r_{2hot}	Equivalent secondary resistance.
302	x_{2pu}	Equivalent secondary leakage reactance Items (303) thru (319) are calculated in Section 3.
303	I_{2pu}	Secondary current
304	I_{1pu}	Primary current.
305		Secondary I^2r loss in KW
306		F&W lossin KW
307		Stray load loss in KW
308		HP
309		Primary I^2r loss in KW
310		Core loss in KW.
311		Total losses in KW
312		Input in KW
313		Efficiency.
314		Power factor
315	N_{fl}	R.P.M. at full load.
316		Torque full load.
317		Circular mils/ampere
318	I_1	Primary current.
319	I_2	Secondary current.

END OF FULL LOAD PERFORMANCE

2.3 LOCKED ROTOR PERFORMANCE

400 Estimated $x_L = x_1 + x_2$ @ full load = (162)+(183)

401 Estimated $I_{1Lpu} = \frac{V}{x_L} = \frac{1.0}{(400)}$

402 Estimated $I_{2Lpu} = .95\, I_{1L} = .95(401)$

403 Apparent zigzag flux $= 2.828m\, Ck_w x_x I_{pu}\, I_{1pu}$ x zigzag factor x 10^{-3}
$= 2.828(4)(100)(14)(401)(163) \times 10^{-3}$ flux in kiloline.

404 Effective rotor slot opening $= \frac{w21}{3} = \frac{(49)}{3}$

405 Sum of slot openings $= w_{10}$ + eff. slot opening
$= (27) + (404)$

406 $[\lambda 2 - (405)]^2/\lambda 2 = [(50) - (405)]^2/(50)$

407 $[\lambda 1 - (405)]^2/\lambda 1 = [(28) - (405)]^2/(28)$

408 Maximum zigzag area (406) + (407) $\frac{(23)}{2}$

409 Apparent zigzag flux density $= \frac{(403)}{(408)}$

410 Zigzag correction factor - See Fig. 2.6-density from (409)

411 Stator zigzag factor= (163) (410)

412 Maximum working density - largest of items (116) to (118)

413 Unbalanced air gap per unit MMF due to skewing

$$\frac{1.047 \times \text{p.u. skew} \times I_{1pu} \times I_{pu}}{I_o} + \frac{4}{3} = \frac{1.047\,(147)(401)(104)}{(213)}$$

414 Apparent maximum density due to skewing
= unbalanced MMF x K_{sf} x Max. density = (413) (135) (412)

415 Skew correction factor. See fig. 2.6 density from (414)

416 Stator skew factor = (164) (415)

417 P 1L Total stator leakage permeance, locked
= stator slot factor + stator end factor + stator zigzag factor + stator skew factor
= (155) + (159) + (411) + (416)

418 $$\left[\frac{Ck_w\, m\, I_{2L} I_{pu}}{S_2\, W_{21}}\right]^{0.9} = \left[(172)\ (402)\ (14)\right]^{0.9}$$

Note: If (418) > 8970, omit (419) and put (420) = 0

419 $$d_{beL} = d_b + \frac{d_{21}}{8970}\left[\frac{Ck_w\, m\, I_{2L}\, I_{pu}}{S_2\, W_{21}}\right]^{0.9}$$

$$= (58) + \frac{(59)\ (418)}{8970}$$

420 Rotor slot constant, bridge portion

$$\frac{13800\, d_{beL}}{W_{21}\ \frac{Ck_w\, m\, I_{2L}}{S_2\, W_{21}}}\left[\frac{d_b + d_{21} - d_{beL}}{d_{beL}}\right]^{0.1}$$

$$= \frac{13800\ (419)}{(49)(418)}\left[\frac{(58) + (59) - (419)}{(419)}\right]^{0.1}$$

421 Fictitious bar depth = overall slot depth

$$\sqrt{s \times \frac{\%\ \text{cond} \times f}{50 \times 60}} = (48)\ \sqrt{s \times \frac{(185)(6)}{50 \times 60}}$$ Here s = 1

422 K_J Deep bar correction for reactance - see fig. 2.7, bar depth from (421)

423 K_R Deep bar correction for resistance - See fig. 2.7 bar depth from (421)

424 K'_R Trapezoidal correction when (60) ≠ (189),

$$K'_R = \frac{\left(\frac{W_{21}}{W_{23}} + 1\right) K_R}{\frac{2W_{21}}{W_{23}} - \left(\frac{W_{21}}{W_{23}} - 1\right)\frac{1}{K_R}} = \frac{\left[\frac{(49)}{(62)} + 1\right](423)}{\frac{2(49)}{62} - \left[\frac{(49)}{(62)} - 1\right]\frac{1}{(423)}}$$

425 Rotor slot constant, wdg portion = $K_{s2w} K_J$ = (57) (422)

426 Rotor slot constant, total = Rotor slot const, bridge + rotor slot const, wdg. = (420) + (425)

427 Rotor slot factor $= \frac{3.19 L_2 \text{ x rotor slot const, total}}{S_2}$

$= \frac{3.19\ (42)\ (426)}{(45)}$

428 ρ_{2L} Total rotor leakage factor, locked rotor = Rotor slot factor + rotor zigzag factor + rotor skew factor = (411) + (416) + (427)

429 x_{1Lpu} Primary leakage reactance = React.Const x ρ_{1L} = (146) (417)

430 x_{2Lpu} Secondary leakage reactance = React.const x ρ_{2L} = (146) (428)

431 Bar factor corrected for deep bar = Bar factor x K'_R = (200) (424) when (60) = (189)

432 Cage factor = Ring factor + bar factor = (201) + (431)

433 r_{2Lpu} cold Resistance constant x Cage factor (186) (432)

434 Average cage temperature, locked, deg.cent.

435 r_{2Lpu} hot $r_{2Lpu\ hot} = r_{2Lpu\ cold}\ \frac{225 + \text{avg.cage temp. locked}}{250}$

$= (433)\ \frac{225 + (434)}{259}$

To calculate the locked rotor amps and torque refer to Section 3, Performance Calculations for squirrel cage Polyphase Induction Motors.

436 I_{2pu} Calculated in Sec. 3.

437 I_{1pu} Calculated in Sec. 3

438 I_{1pu} Calculated in Sec. 3.

439 T_L Locked rotor torque in % of full load

440 I_1 Calculated in Sec. 3.

441 Apparent locked rotor impedence.

$= \frac{1.0\ (\Omega\ pu)}{I} = \frac{1.0\ (1[illegible])}{(437)}$

442 R_a Apparent locked rotor resistance, ohms.

443 X_a Apparent locked rotor reactance, ohms.

END OF LOCKED ROTOR CALCULATION

2.4. BREAK DOWN TORQUE

500 x_{MT} Estimated reactance at maximum torque

$$x_{MT} = \frac{x_1 + x_2 + x_{1L} + x_{2L}}{2}$$

$$= \frac{(182) + (183) + (429) + (436)}{2}$$

501 s_M Estimated slip at breakdown torque

$$s_M = \frac{r_2}{\sqrt{r_1^2 + x_{MT}^2}} = \frac{(205)}{\sqrt{(94)^2 + (500)^2}}$$

502 Est I_{1Mpu}

$$\frac{I_{1FL} + I_{1L}}{2} = \frac{(304)\ (433)}{2}$$

503 Est. I_{2Mpu} $0.95\ I_{1Mpu} = 0.95\ (512)$

Repeat calculations (403) thru (443) except use I_{1Mpu}(502) in place of I_{1L}(401) and I_{2Mpu}(503) in place of I_{2L}(402). Also in item (421) use S_M(501) for the value of slip s. Then calculate the remaining items by the method outlined in Sec.3 using item (501) s_{M1} the estimated slip at breakdown torque as the slip in item (1) of Section 3.

504 x_{1Mpu} Primary leakage reactance, breakdown torque Item (429) recalculated for saturation condition at breakdown torque.

505 r_{2Mpu} Secondary resistance at breakdown torque, Item (435) recalculated at breakdown torque slip.

506 x_{2Mpu} Secondary leakage reactance at breakdown torque. Item (430) recalculated for saturation conditions at breakdown torque.

507 I_1 Primary amperes at breakdown torque calculated in Sec.3.

508 RPM Speed at breakdown torque. Calculated in Sec.3.

509 Torque in % of full load.Calculatedin Sec.3.

END OF BREAK DOWN TORQUE CALCULATION

2.5 SPEED TORQUE CURVE

600 Calculate a point on the speed torque curve for each of the following values of slips.9,.8,.7, .4, .2, .1, .05.

601 Est. I_{1spu} - Use the per unit value of primary current, I_{1pu} from previously calculated point on speed torque curve, i.e. for slip = 0.9 use value of I_{1pu} from slip = 1.0 (locked rotor); for slip = 0.8, use value of I_{2pu} from slip = 0.9 etc. Repeat calculations (403) thru (437) except use I_{1spu}(601) in place of I_{1L} (401) and I_{2spu} (602) in place of I_{2L} (402). Also in item (421) use (600) for the value of slip. Then calculate the performance for each point on the speed torque curve by the method outlined in Section 3 using the slip from item (600) as item (300) in Sec.3.

END OF SPEED TORQUE CURVE

2.6. HALF VOLTAGE LOCKED ROTOR

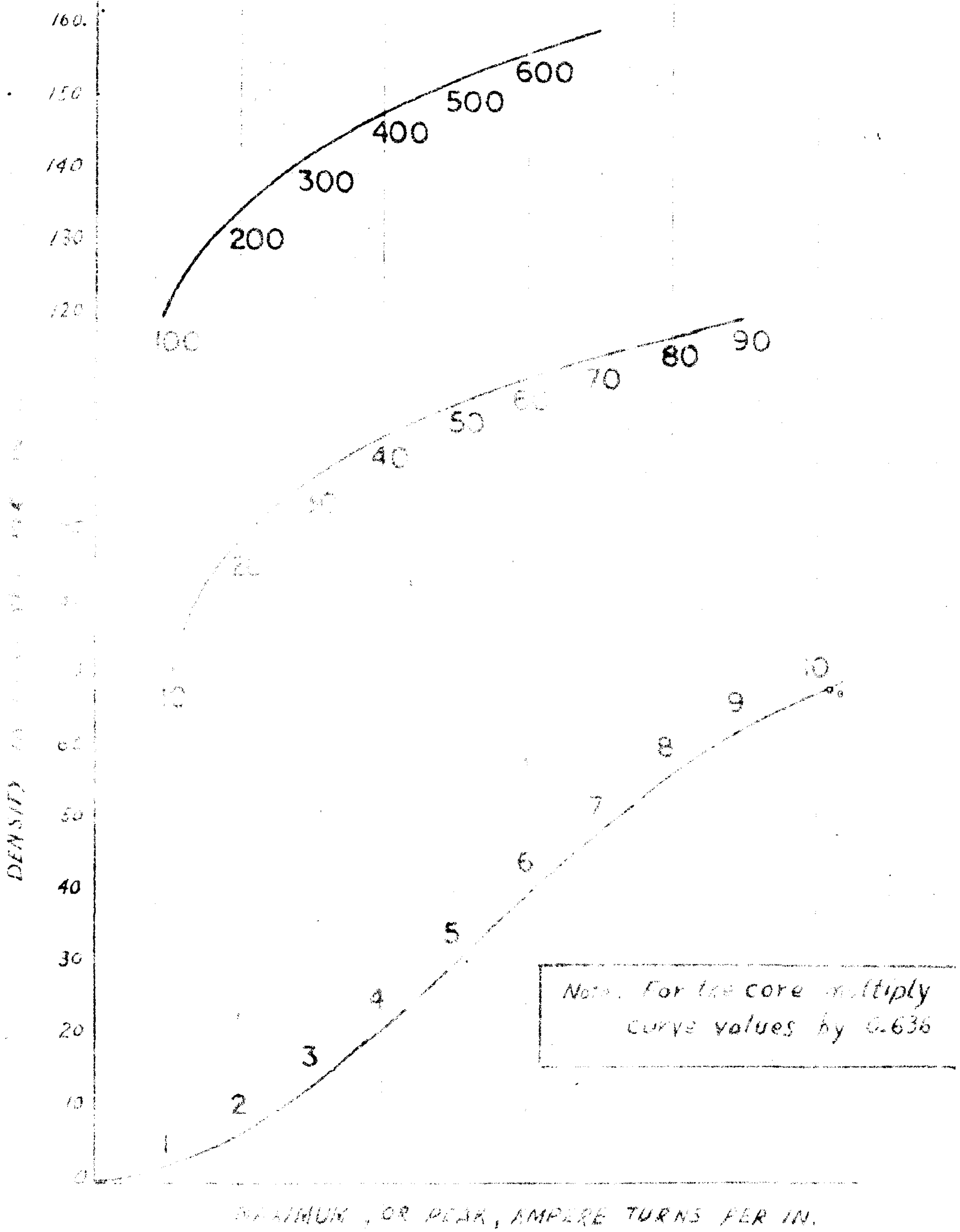
700 Estimated $I_{1Lpu} = \frac{(438)}{2}$

701 Estimated $I_{2Lpu} = \frac{(436)}{2}$

Calculate items (403) thru (435) except use I_{1Lpu}(700) in place of (401) and I_{2Lpu}(701) in place of (402). To calculate the locked rotor torque and amperes, refer to Sec. 3, except use per unit volts = 0.5 instead of 1.0 as shown in Section 3.

END OF HALF VOLTAGE LOCKED ROTOR

MAGNETIZATION CURVES FOR INDUCTION MOTOR TEETH



Note. For the core multiply curve values by 0.636

FIG. 2.1.

D.K GUPTA

IRON LOSS CURVE AT F = 60 C.P.S.

Grade of Steel	Code	Multiply W/in^3 by:
26 ga. Electrical	4343	1.0
24 ga. Motor	4345	0,82
24 ga. Non-Silicon	437a	1.45

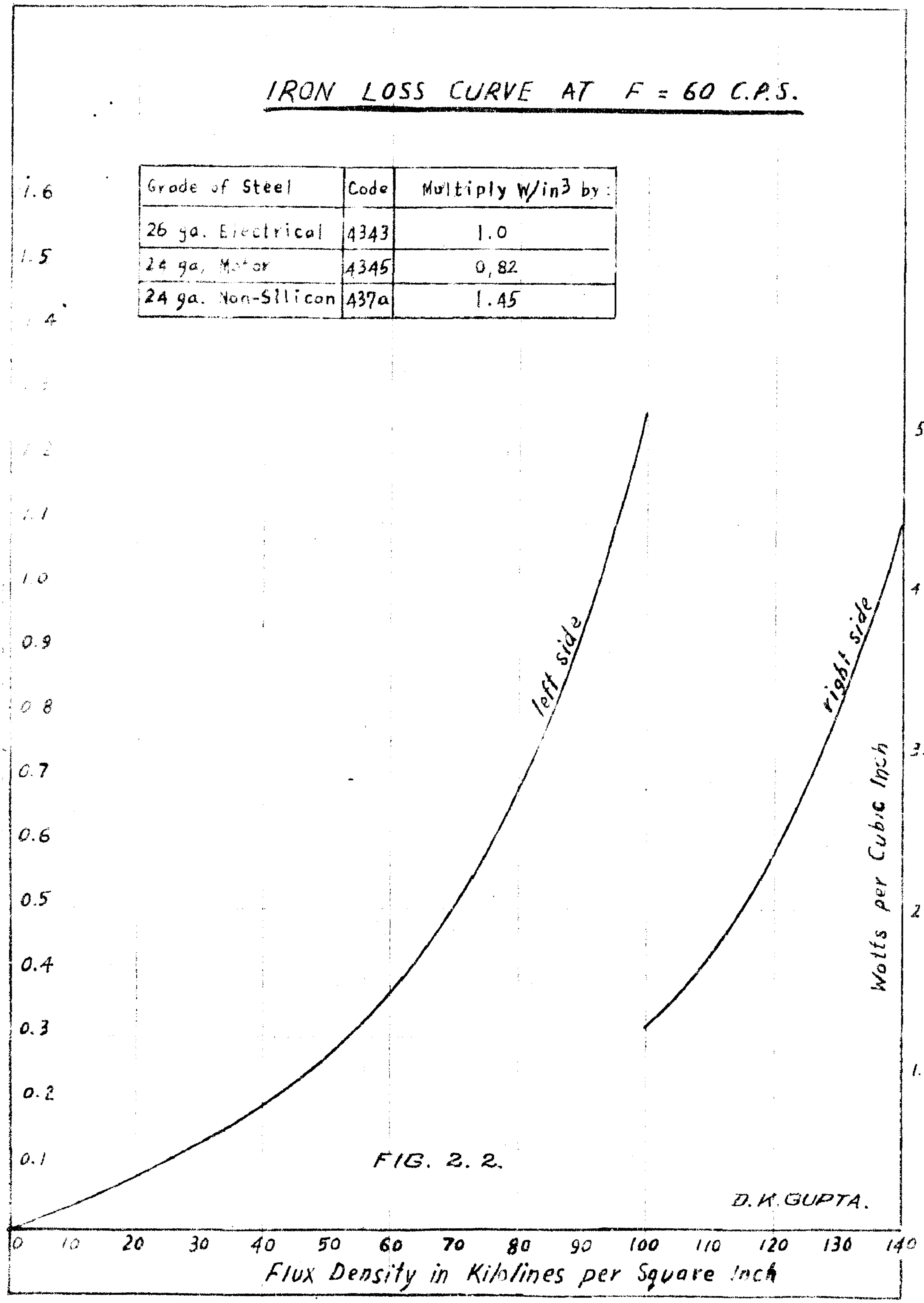
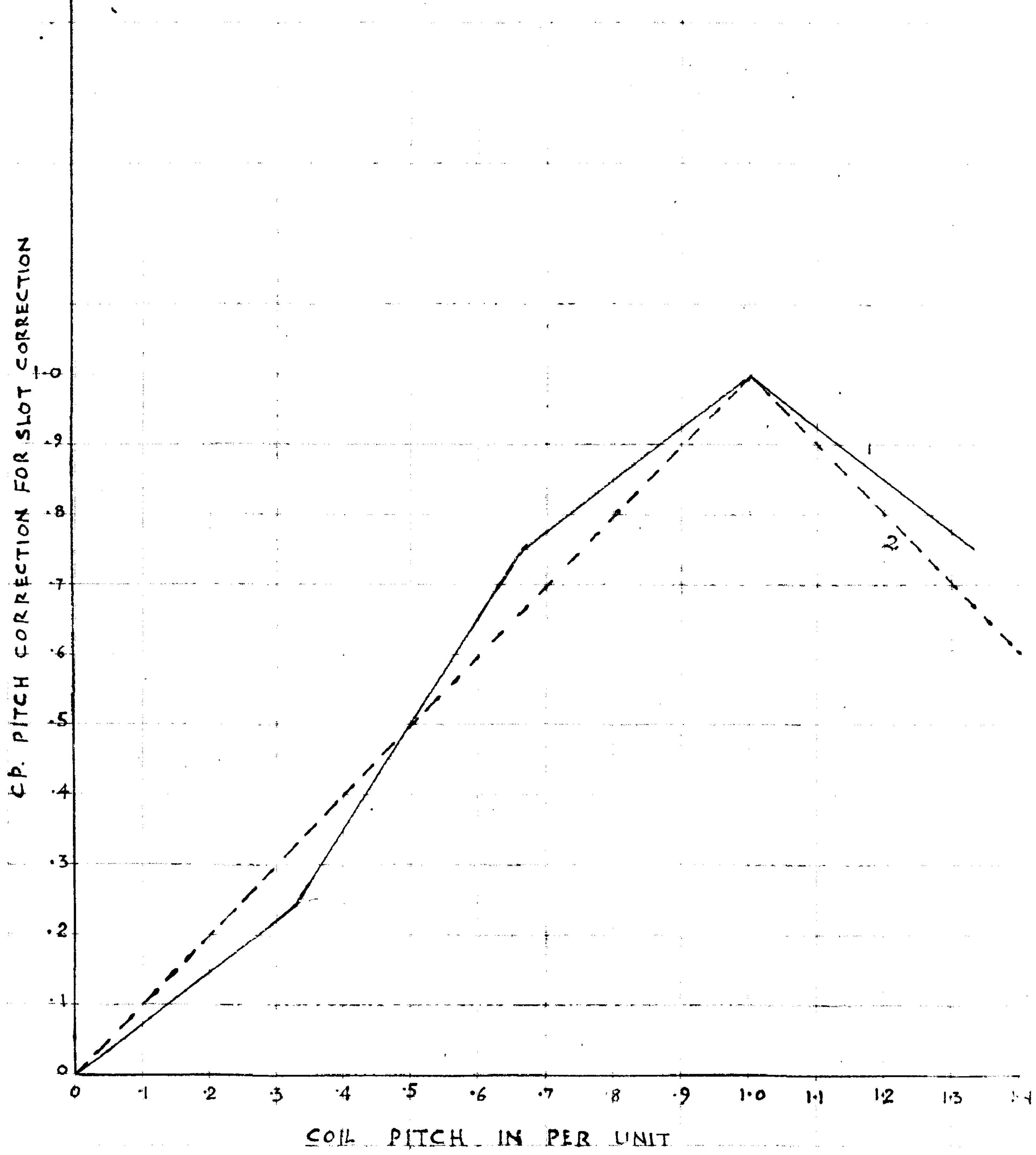


FIG. 2. 2.

PITCH CORRECTION FOR SLOT MUTUAL



CURVE 1 :- 3 PHASE, 60° PHASE BELT
" 2 :- 2 " , 90° " "

Fig. 2.3.
D.K.GUPTA

END-TURN LEAKAGE CONSTANT

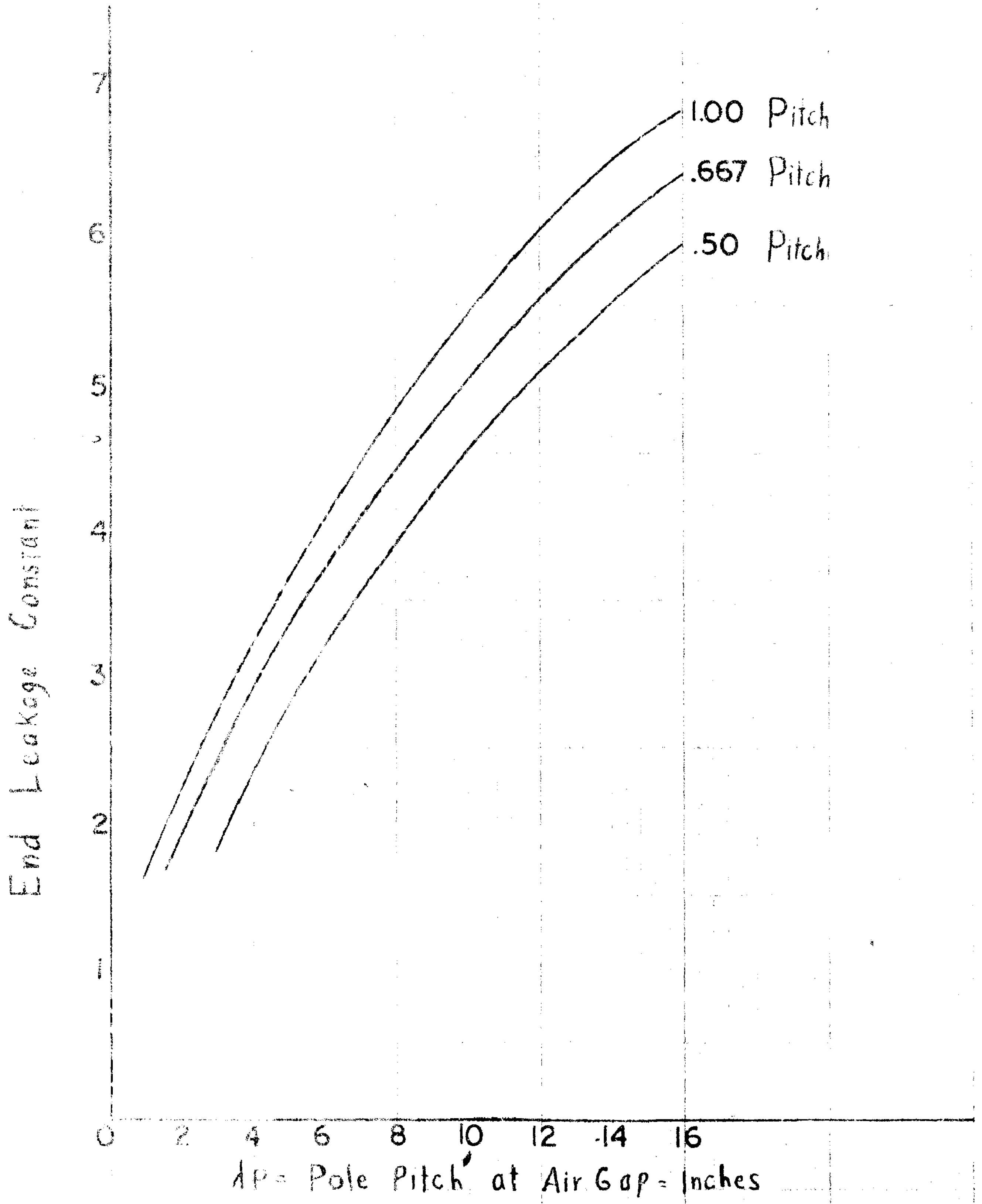


FIG. 2.4

D.K. GUPTA

EFFECT OF WIDE RESISTANCE RING ON SECONDARY RESISTANCE OF SQUIRREL-CAGE ROTORS

$$K_{ring} = \frac{P}{2}\left(1 - \frac{D_i}{D_r}\right)\frac{1+\left(\frac{D_i}{D_r}\right)^P}{1-\left(\frac{D_i}{D_r}\right)^P}$$

D_i = I.D. of end ring

D_r = effective diam. of current flow in ring.

P = no. of poles

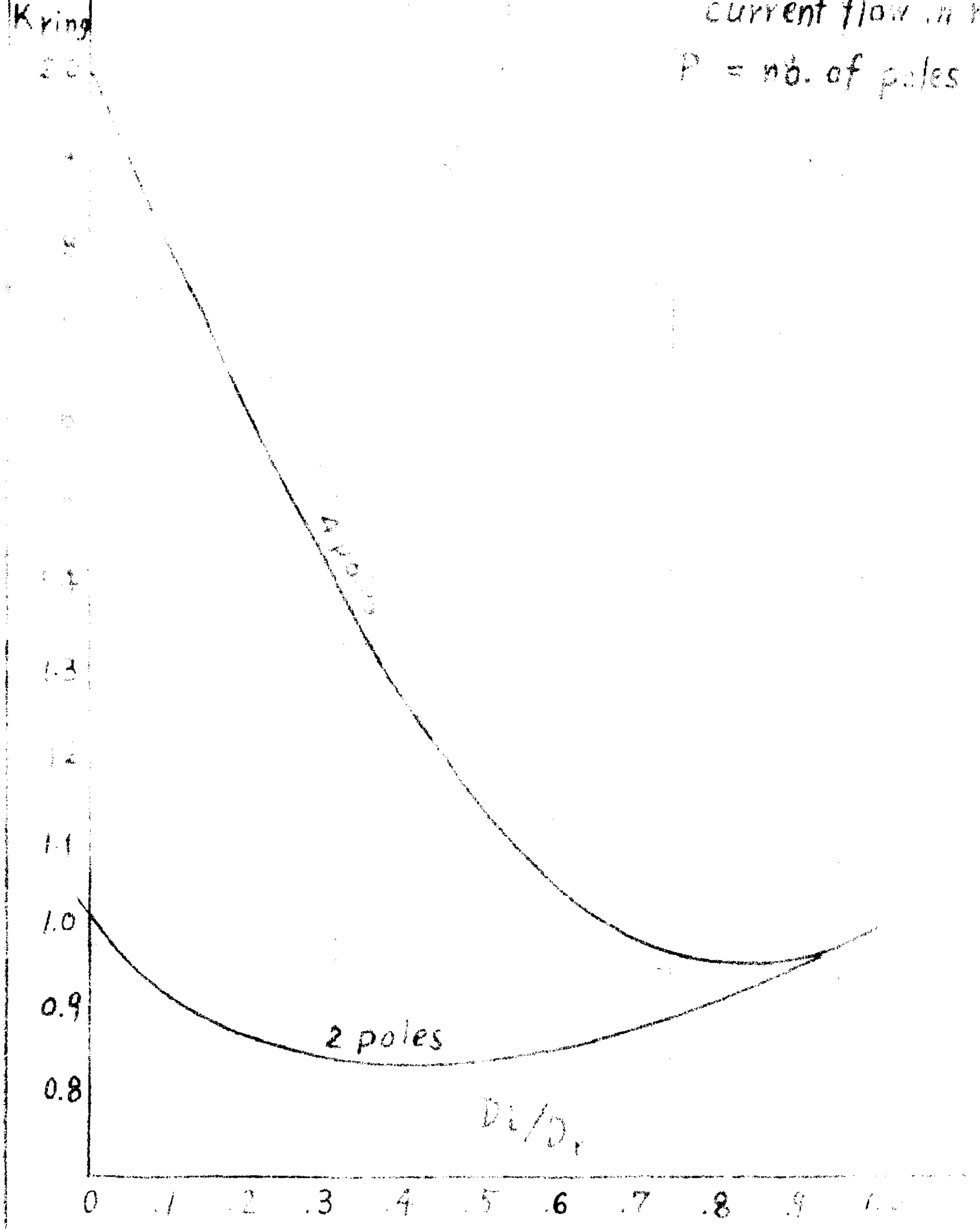


FIG. 2.5

D.K. GUPTA

EFFECT OF WIDE RESISTANCE RING ON SECONDARY RESISTANCE OF SQUIRREL-CAGE ROTORS

$$K_{ring} = \frac{P}{2}\left(1-\frac{D_i}{D_r}\right)\frac{1+\left(\frac{D_i}{D_r}\right)^P}{1-\left(\frac{D_i}{D_r}\right)^P}$$

D_i = I.D. of end ring
D_r = effective diam of current flow in ring.
P = no. of poles

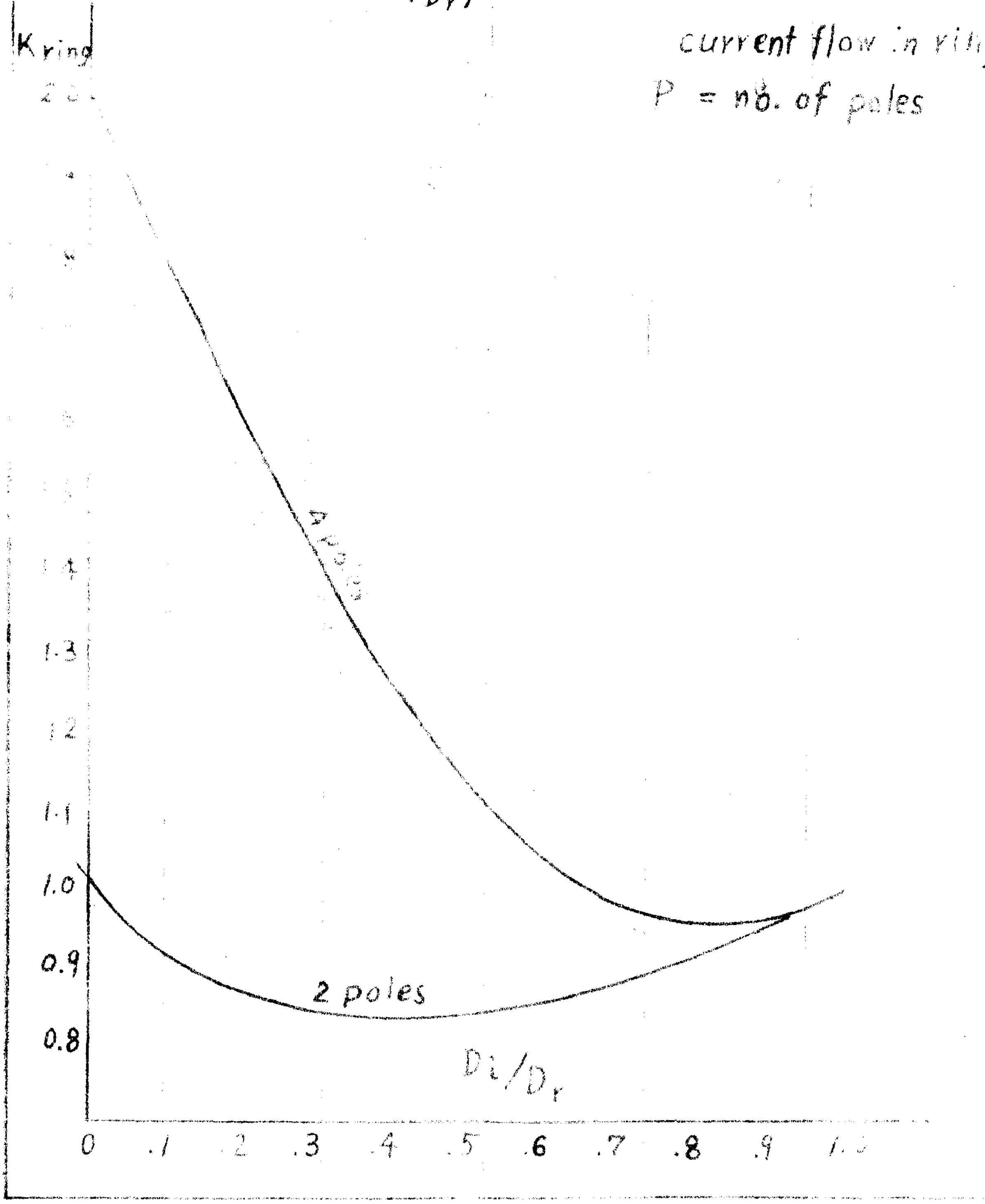


FIG. 2.5

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Effect of saturation of leakage paths on leakage reactance

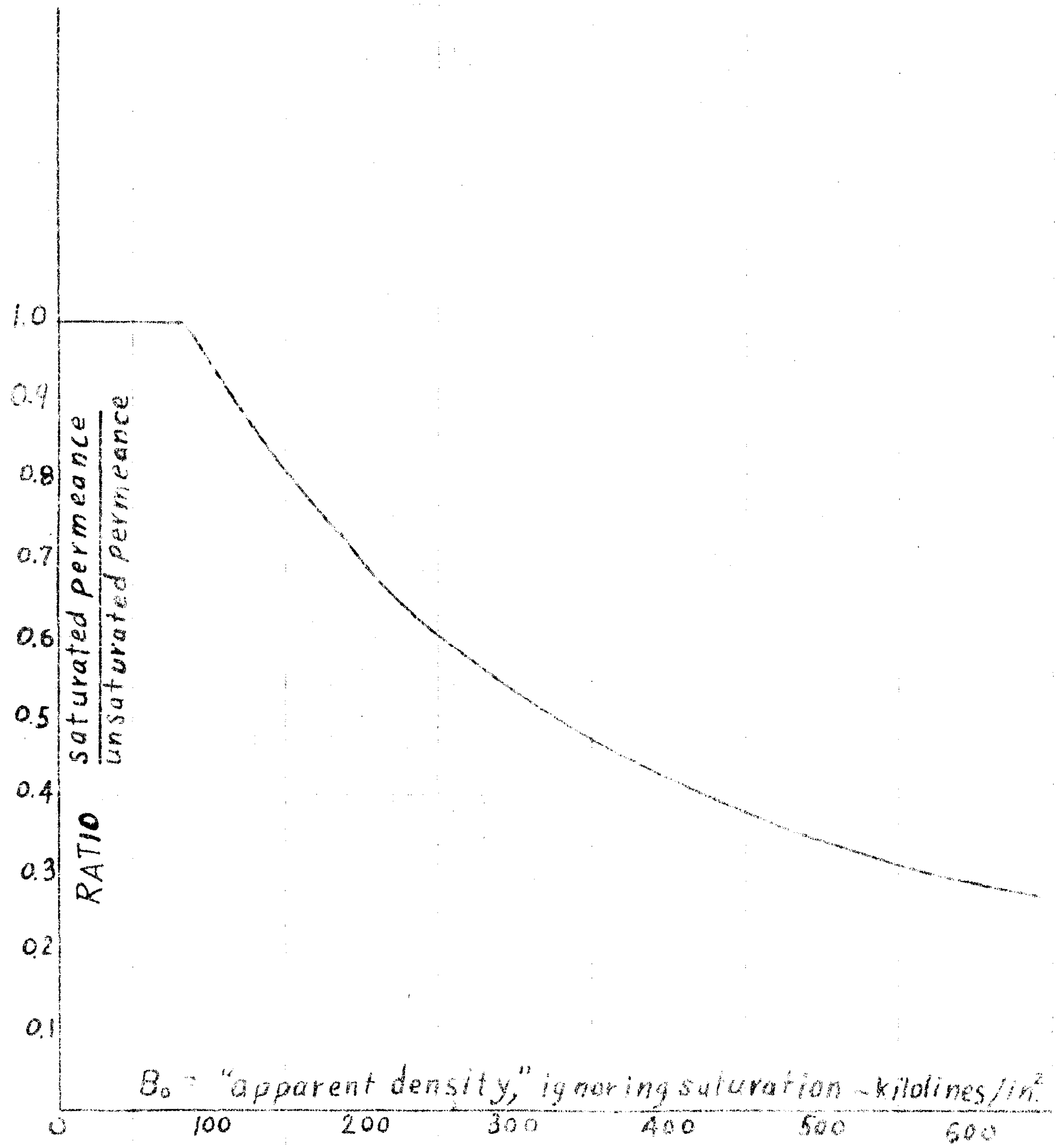

FIG. 2.6

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DEEP BAR CORRECTION FOR RESISTANCE
AND REACTANCE

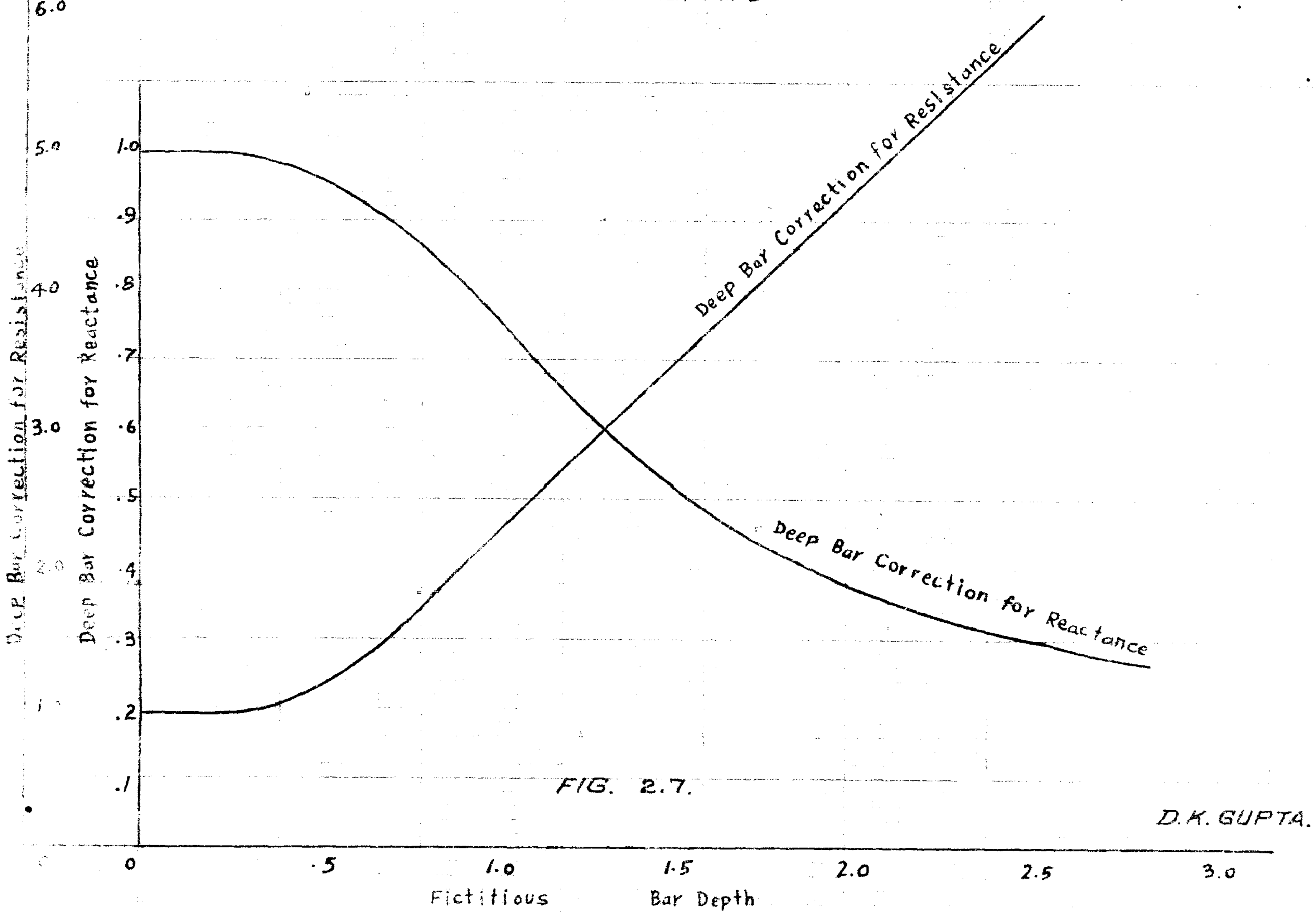


FIG. 2.7.

SECTION - 3

PERFORMANCE CALCULATIONS FOR POLYPHASE INDUCTION MOTORS

3. PERFORMANCE CALCULATIONS FOR POLYPHASE INDUCTION MOTORS.

This procedure is used to calculate the performance of a polyphase induction motor at any point along the speed torque curve from locked rotor to no load. The calculations are based on equivalent circuit basis. A diagram of the equivalent circuit is shown in Figure 3.1.

3.1. EQUIVALENT CIRCUIT.

In Fig. 3.1 is represented the equivalent circuit upon which the whole procedure is based. It is the exact equivalent circuit. The quantities which appear in the equivalent circuit are given below:

r_1 -- primary resistance per phase. This appears three times on design sheet.

- a) r_1 cold, in actual ohms.
- b) r_1 hot in per-unit (at temperature specified on input) This value is used for all stator I^2r loss calculations.
- c) r_1 effective. This is 1.15 x r_1 hot and is used in all circuit calculations of currents and torques.

x_1 -- primary leakage reactance, in per-unit. Three values of this appear on design sheet.

- a) at full-load conditions.
- b) at break down torque.
- c) at locked rotor.

r_M -- Fe loss resistance, p.u. This resistance simulates the total iron losses. It appears on design sheet under "no load."

x_M' -- Apparent magnetizing reactance, in per unit. This is the equivalent series value of the actual magnetizing reactance, and appears in the no-load section of the output form. The true magnetizing reactance x_M appears in the full-load reactance part of the output.

r_2 -- This is the secondary resistance referred to primary, in per unit. Hot and cold values for the full-load condition are given on the output form, just above the no-load section. It is also given, hot and cold, in the locked-rotor section, taking into account deep-bar effect.

x_2 -- Secondary leakage reactance, in per-unit. This item appears on the design sheet in three places.

a) at full-load condition,

b) at break-down torque,

c) at locked-rotor.

3.2. GENERAL EQUIVALENT CIRCUIT SOLUTION.

This section outlines the formulas requied in the solution of the equivalent circuit after the circuit constants are known. The appropriate value of slip is entered into item (1) depending upon whether a solution is desired for locked rotor, full load or another point on the speed torque curve. For full load or any load performance calculations, an assumed value of slip is used and the calculations carried out thru item (3.17), horse power output. If this value is not the desired load, a new assumption of slip should be made and the procedure repeated until the desired output is obtained. Then the remaining items (3.17) thru (3.28) can be calculated.

In the formulas which follow, symbols with bars over them, i.e. $\bar{I}$, designate vector quantities, and symbols without bars, i.e. I, designate scalar quantities. The voltage V is the per unit phase voltage, i.e., rated phase voltage, V = 1.0.

Item No.	Symbol	General Equivalent Circuit Solution
3.1	s	Slip
3.2	$\bar{Z}_{1pu}$	$r_{1eff} + jx_1$
3.3	$\bar{Z}_{Mpu}$	$r_M + jx_M$
3.4	$\bar{Z}_{2pu}$	$\frac{r_2}{s} + jx_2$
3.5	r_{2pu}	$\frac{r_2}{s} \times s$
3.6	x_{2pu}	x_2
3.7	$\bar{I}_{2pu}$	$\frac{V \bar{Z}_M}{\bar{Z}_1 \bar{Z}_M + \bar{Z}_1 \bar{Z}_2 + \bar{Z}_2 \bar{Z}_M}$
3.8	I_{2pu}	Scalar value of $\bar{I}_{2pu}$
3.9	$\bar{I}_{1pu}$	$\bar{I}_{2pu} \frac{\bar{Z}_M + \bar{Z}_2}{\bar{Z}_M}$
3.10	I_{1pu}	Scalar value of $\bar{I}_{1pu}$
		3.2.1. FULL LOAD AND LOAD PERFORMANCE
3.11		Secondary I^2r $\text{loss}_{pu} = I_2^2 \; r_2$
3.12	$F \& W_{pu}$	$\frac{(1-s)\ (\text{F\&W at syn. speed})}{P_{pu}}$
3.13		$\text{S.L. Loss}_{pu} = \frac{\%\ \text{S.L. loss}}{100}$

3.14 Secondary input$_{pu}$ $= I^2 \left(\frac{r_2}{s}\right)$

3.15 Output$_{pu}$ $= \frac{\text{Secondry input} - (F\&W + I_2^2 r_2)}{1 + \text{S.L. loss}_{pu}}$

3.16 Stray load loss = output x S.L. loss pu

3.17 H.P. = output$_{pu}$ x Rated HP

3.18 $\bar{I}_{Mpu}$ $\bar{I}_{2pu} = \frac{\bar{Z}_2}{\bar{Z}_M}$

3.19 I_{Mpu} Scalar value of $\bar{I}_{Mpu}$

3.20 Pri. I^2r loss$_{pu}$ $= I_1^{\,2} r_{1hot}$

3.21 Core loss$_{pu}$ $= I_M^2 r_M$

3.22 Total losses$_{pu}$ = F&W + Sec. I^2r + S.L.loss + Pri I^2r + core loss.

3.23 Input $= I_1^{\,2} r_1 + I_M^{\,2} r_M$ + Sec. input

3.24 Efficiency $= \frac{\text{Output}}{\text{Input}}$

3.25 Power factor $= \frac{\text{Input}}{VI_1}$

3.26 N_{fl} Full load RPM $= (1 - s)\, N_s$

3.27 Torque, full load $= \frac{7040 \times \text{output} \times P_{pu}}{N_{fl}}$ ft. lbs.

3.28 C Circular mils/ampere $= \frac{\text{Equiv. C.M.}}{I_{1\,pu} \times I_{pu}}$

3.2.2 LOCKED ROTOR

3.29 T_L Locked rotor torque in % of full load

$= 100\, I_2^{\,2}\,\text{pu}\; r_2 \times \frac{N_{fl}}{N_s}$

3.23. BREAK DOWN TORQUE & SPEED TORQUE CALCULATIONS

3.30 RPM $N_s (1 - s)$

3.31 Secondary $I^2 r \text{ loss}_{pu} = I_2^2 r_2$

3.32 $F\&W_{pu}$ $\frac{(1-s)\ (F\&W_{pu} \text{ at syn. speed})}{P_{pu}}$

3.33 $\text{S.L. loss}_{pu} = \frac{\%\ \text{S.L. loss}}{100}$

3.34 Secondary input $= I^2 (\frac{r_2}{s})$

3.35 Output $= \frac{\text{Secondary input} - (F\&W + I_2^2 r_2)}{I + \text{S.L. loss}_{pu}}$

3.36 T_M Torque in % of full load $100 \times \text{output}_{pu} \times \frac{N_{fl}}{RPM}$

END OF BREAK DOWN AND SPEED TORQUE CALCULATIONS

3.37 I_2 $I_{2pu} \times$ (Base amps)

3.38 I_1 $I_{1pu} \times$ (Base amps)

3.3 PERFORMANCE CALCULATIONS

The performance calculations for polyphase induction motors is made at

(i) Full-load,

(ii) Locked-rotor,

(iii) Breakdown Torque.

Full-load. The first trial value of slip is computed from the input rpm given. Then, the output is calculated at this slip. If the calculated output differs from rated by more than .05%, a new slip is calculated on the assumption that output is proportional to slip. Output is calculated with the new slip and compared with rated output; if the difference is more than 0.10%, a third value of slip is calculated and output calculated and checked to within 0.15%; the tolerance limit is thus raised slightly on each try until finally a calculated output is as close to rated output as possible. Then the items in the "full-load section" are computed and stored. Losses are calculated as follows:

F & W. This is (F & W at synchronous speed) x (1-s)

Stray load loss is calculated as a flat percentage of output.
Sec I^2R is $mI_2^2 r_2$ (r_2 is calculated at full-load temperature.)
Pri I^2R is $mI_1^2r_1$ (r_1 is calculated at full-load temperature)
Core loss is the loss calculated in r_M. This amounts to assuming that core loss is proportional to the square of the air-gap flux.

Locked-rotor. Rotor resistance is calculated, taking into account deep-bar effects in single-cage machines. The correction for reatance is taken from Fig. 2.7 Section 2. Basic deep-bar correction for resistance is made from an empirical curve that gives about 20% more correction for bars 1" or more deep than does the old curve on Fig. 2.7. In addition, for all die-cast rotors, a trapezoidal correction is applied to the deep bar effect; this correction reduces the deep bar effect if the rotor "slot width, top" is greater than the "slot width, bottom, " and increases it if the converse is true. There is no trapezoidal correction if slot sides are parallel.

After computing the rotor resistance, and the corrected slot constant, the locked-rotor current is first approximated from the full-load reactances. This approximate current is used to calculate the saturated reactances and the locked-rotor current is again computed. If the new current differs from the first approximation of current by more than 5%, the reactances are refigured using the current just calculated. This process is repeated until the current used for calculating reactance is within 5% of the final calculated locked-rotor current. The factors used in this final calculation are stored and appear on the output sheet.

The "apparent locked rotor resistance, reactance and impedance," are in absolute ohms and represent total motor impedance. Locked-rotor power factor can be calculated by dividing resistance by impedance.

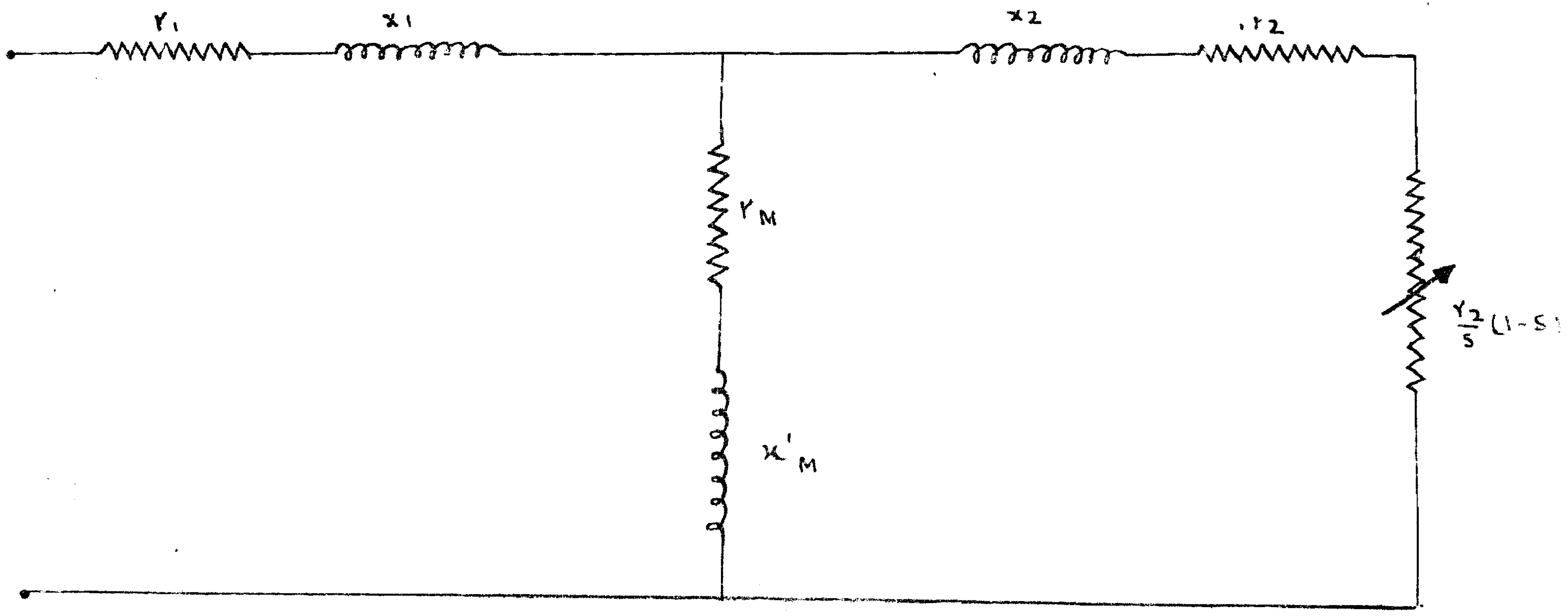
Locked-rotor torque is expressed in percent of full load torque, based upon calculated full-load rpm.

Breakdown Torque. The procedure calculates breakdown torque by evaluation of the equivalent circuit. First, the full-load and locked-rotor reactances are averaged and this average is used to calculate the slip and rpm at breakdown torque. Reactances are recalculated at some value of current within 5% of the actual current at breakdown, by an iterative procedure as desired for locked-rotor torque. Developed torque is calculated from the equivalent circuit using the value of reactances just calculated, as well as at new values of rotor resistance, with deep-bar effect adjusted to the actual slip at breakdown torque. Also, the torque required to overcome friction and windage, also stray-load losses, is subtracted to obtain net breakdown torque. Resultant breakdown torque is expressed as a percent of full-load torque, where full-load torque is based upon rated horsepower and calculated full-load rpm.

Item numbers from section 2 for the various circuit constants required in the "General Equivalent Circuit Solution" are given in the table below under "Input Data". The data resulting from the General Equivalent Circuit Solution which are required for use in Section 2 are listed by item under "output data". This section is used in conjuction with section 2 which calculates the equivalent circuit constants, the below table gives cross references item numbers of Section 2.

Section 2		Section 3		
Item No.	Symbol	Full load and load performance.	Locked Rotor	Breakdown Torque and speed torque calculations
		<u>INPUT DATA</u>		
3.1	s	(300) Assumed Value to give full load output.	s = 1.0	(501) or slip for speed torque calc.
3.2	$\bar{Z}_{1pu}$	(94) + j(182)	(94)+j(429)	(94) + j(504)
3.3	Z_{Mpu}	(207)+j(208)	(207)+j(208)	(207) + j(208)
3.4	Z_{2pu}	$\frac{(205)}{(300)}$ + j(183)	(435) +j(430)	$\frac{(505)}{(501)}$ +j(506)
		<u>OUTPUT DATA</u>		
3.5	r_{2pu}	(205)	(435)	(505)
3.6	x_{2pu}	(183)	(430)	(506)
3.8	I_{gpu}	(303)	(436)	
3.9	$\bar{I}_{1pu}$		(437)	
3.10	I_{2pu}	(304)	(438)	

3.11		(305)=Sec. I^2r in KW = (5.11)x(13)		
3.12		(306) = F&W in KW =(3.12)x(15)		
3.16		(307)=S.L.losses in KW =(3.16) x (13)		
3.17		(308)=HP output =(3.17)x(13)		
3.20		(309)=Pri. I^2r in KW = (3.20)x(13)		
3.21		(310)=Core loss in KW =(3.21)x(13)		
3.22		(311)=Total losses in KW = (3.22)x(13)		
3.23		(312)=Input in KW =(3.23)x(13)		
3.24		(313)=Efficiency		
3.25		(314)= Power factor		
3.26	N_{fl}	(315)=RPM at F.L.		
3.27		(316)=Torque,F.L.		
3.28		(317)=Circ.mils/amp		
3.29			(439)	
3.30				(508)=RPM.
3.36				(509)=Torque in % of F.L.
3.37	I_2	(319)		
3.38	I_1	(318)	(440)	(507)



EQUIVALENT CIRCUIT FOR POLYPHASE INDUCTION MOTOR

FIG. 3·1

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SECTION - 4

BASIC DESIGN PROCEDURE FOR SINGLE PHASE INDUCTION MOTORS

4. BASIC DESIGN PROCEDURE FOR SINGLE PHASE INDUCTION MOTORS

This procedure outlines the formulas and procedures to evaluate the equivalent circuit constants necessary to calculate the performance of a single phase induction motor with magnetic circuit dimensions and winding known. This section serves the same purpose for single phase motors that Section 2 does for polyphase motors. Four types of motors are covered.

(i) Capacitor Start,
(ii) Two Valve,
(iii) Permanent Split,
(iv) Split phase.

Procedures and formulas for calculating performance, using the equivalent circuit, are given in Section 5. Stator and rotor punchings are calculated as shown in Section 6. Performance for any point on the speed torque curve from no load to locked can be calculated using this Section in conjunction with Section 5. The formulas in this section have been also grouped into section according to the region of the speed torque curve as in Section 2.

BASIC DESIGN CALCULATIONS FOR SINGLE PHASE MOTORS

Item No.	Symbol		
		4.1.1. RATING.	
1		Type of motor	(1) Capacitor start (2) Two value (3) Permanent split. (4) Split phase.
2	HP	HP rating	
3	V_m	Main phase volts	
4	V_a	Aux. phase volts.	
5	f	Frequency.	
6	p	Poles.	
7	N_{fl}	Full load RPM, estimated.	
8	L	Gross iron.	
9.		Shaft material	
10.		Motor temperature, hot °C	
		4.1.2. ROTOR	
11		% Conductivity.	
12	A_b	Bar area	
13		Bar extension.	
14	A_r	Ring area.	
15	D_o	Ring O.D.	
16	D_i	Ring I.D.	
17		Skew, % rotor slots.	
18		% stray load loss, estimated.	
19		F & W at syn.RPM, watts.	

4.1.3. WINDING

Main Winding

20.	T_1	Outer most coil span (teeth)
21		TPC 1 outer most coil.
22		TPC 2
23		TPC 3
24		TPC 4
25		TPC 5
26		TPC 6
27		TPC 7
28		TPC 8
29		Strands/conductor.
30		Dia. bare.
31		Dia. over insultation.
32	q	No. of circuits.

Aux. Winding.

33	T_{1a}	Outer most coil span (teeth)
34		TPC 1 outer most coil
35		TPC 2
36		TPC 3
37		TPC 4
38		TPC 5

39		TPC 6
40		Strands/conductor
41		Dia. Bare.
42		Dia. over insulation.
43	q_a	No. of circuits.
44		Starting MFD
45		Running MFD

4.1.4. CORE PUNCHINGS

Stator Core Punching.

46	D	Outside dia. stator calc.sheet item (1)
47	D_1	Gap dia. stator calc. sheet item (2)
48		Type of slots.
49	S_1	No.of slots stator sheet item (3)
50	d_1	Slot depth stator sheet item (4)
51	W_{10}	Slot opening stator sheet item (8)
52	λ_1	Slot pitch stator sheet item (5)
53	t_{10}	Tooth face stator sheet item (16)
54	t_1	Effective tooth width stator sheet item (19)
55	d_{1e}	Effective tooth length stator sheet item (20)
56	d_{y1}	Effective yoke depth stator sheet item (21)

39		TPC 6
40		Strands/conductor
41		Dia. Bare.
42		Dia. over insulation.
43	q_a	No. of circuits.
44		Starting MFD
45		Running MFD

4.1.4. CORE PUNCHINGS

Stator Core Punching.

46	D	Outside dia. stator calc. sheet item (1)
47	D_1	Gap dia. stator calc. sheet item (2)
48		Type of slots.
49	S_1	No. of slots stator sheet item (3)
50	d_1	Slot depth stator sheet item (4)
51	W_{10}	Slot opening stator sheet item (8)
52	λ_1	Slot pitch stator sheet item (5)
53	t_{10}	Tooth face stator sheet item (16)
54	t_1	Effective tooth width stator sheet item (19)
55	d_{1e}	Effective tooth length stator sheet item (20)
56	d_{y1}	Effective yoke depth stator sheet item (21)

A_1	Net slot winding area stator sheet item (31)
	Permissible RD^2.
k_{s1a}	Slot constant, air. stator sheet item (36)
k_{s1w}	Slot constant, winding. stator sheet item (33)

ROTOR CORE PUNCHING

D_2	Outside dia. Rotor calc. sheet item (1)
D_b	Effective inside dia. Rotor sheet item (2)
S_2	No. of slots. Rotor sheet item (3)
	Type of slots.
d_2	Bar, depth. Rotor sheet item (4)
w_{21}	Slot width, top. Rotor sheet item (9)
λ_2	Slot pitch. Rotor sheet item (11)
w_{20}	Slot opening. Rotor sheet item (16)
t_2	Effective tooth width. Rotor sheet item (20)
d_2	Effective tooth length. Rotor sheet item (21)
	Yoke depth, punching. Rotor sheet item (22)
k_{s2w}	Slot constant, winding. Rotor sheet item (23)
d_b	Bridge thickness. Rotor sheet item (6),
d_{21}	Depth, slot mouth. Rotor sheet item (7)
A_2	Slot area, top. Rotor sheet item (25)
k_{s2a}	Slot constant, air. Rotor sheet item (28)
w_{23}	Slot width, bottom. Rotor sheet item (10)

P.U. BASE

V	Base volts = (3)

79 V_{apu} Aux. phase volts, pu = V_a/V_m = (4)/(3)

80 P_{pu} Base power = HP x 746 = (2) 746

81 I_{pu} Base amps = P_{pu}/V = (80)/(78)

82 Ω_{pu} Base ohms = V/I_{pu} = (78)/(81)

4.1.5. LOCATION OF COILS IN SLOTS

83 N_s Synchronous RPM, $N_s = 120\ f/p$ = 120(5)/(6)

84 K_s Stacking factor (0.93 for Insulene Varnish)

85 L_N Net iron = K_sL = (84) (8)

86 g Air gap, actual, inches. $g = \frac{1}{2}(D_1 - D_2) = \frac{1}{2}\left[(47)-(61)\right]$

87 λp Pole pitch, $\lambda p = \pi(D_1 - g)/p = \pi\left[(47)-(86)\right]/(6)$

88 Location of coils

S_1/p = (49)/(6)

Case	S_1/p	T_1(20)	T_{1a} (33)	Split
I	Even	$= S_1/p-1$	$= S_1/p-1$	None
II	Even	$= S_1/p$	$= S_1/p$	Both
III	Odd	$= S_1/p-1$	$= S_1/p$	Aux.
IV	Odd	$= S_1/p$	$= S_1/p-1$	Main

Case I. No Split Coils

Slots to be considered = $S_1/2p$ = (88)/2

Slot No.1 contains TPC_1

No.2 contains TPC_2, etc.

No.$(S_1/2p)$ contains TPC_{1a} + main wdg. in same slot if any

No. $(S_1/2p-1)$ ~~$(S_1/2+1)$~~ contains TPC_{2a} + main wdg. in same slot if any, etc.

Case II. Both Coils Split.

Slots to be considered = $(S_1/2p + 1)$ =
= $[(88)/2+1)$

Slot No.1 contains $2TPC_1$

Slot No.2 contains TPC_2 etc

No. $(S_1/2p+1)$ contains $2TPC_{1a}$ + main wdg. in same slot, if any.

No. $[(S_1/2p + 1)-1]$ contains TPC_{2a} + main wdg. in same slot, if any, etc.

Case III Aux.Wdg.Split

Slots to be considered = $(S_1/2p + .5)$
= $[(88)/2+.5]$

Slot No.1 contains TPC_1

No.2 contains TPC_2, etc.

No. $(S_1/2p + .5)$ contains $2TPC_{1a}$ + main wdg. in same slot, if any.

No. $[(S_1/2p + .5)-1]$ contains TPC_{2a} + main wdg. in same slot, if any, etc.

Case IV Main Wdg. Split.

Slots to be considered = $(S_1/2p + .5)$
= $[(88)/2 + .5]$

Slot No.1 contains $2TPC_1$

No.2 contains TPC_2, etc.

No. $(S_1/2p + .5)$ contains TPC_{1a} + main wdg. in same slot; if any.

No. $[(S_1/2p + .5)-1]$ contains TPC_{2a} + main wdg. in same slot, if any, etc.

Example 36 slots, 6 poles
main wdg.-3 coils per pole, $T_1 = 6$

Aux. wdg.- 2 coils per pole, $T_{1a} = 6$

Calculations $S_1/p = 36/6 = 6$ and is even
$T_1 = T_{1a} = S_1/p = 6$

$\therefore$ Example in case II- Both coils split

Using rules for Case II

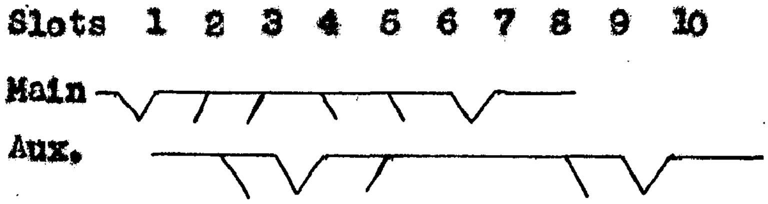
Slots to be considered = $(S_1/2p + 1) = 4$

Slot No.1 contains $2TPC_1$

Slot No.2 contains TPC_2

No.3 contains $TPC_3 + TPC_{2a}$

No.4 contains $2TPC_{1a}$



89 Case number, selected

90 Slots to be considered.

91 Slot No.1, contains

92 Slot No.2 contains.

93 Slot No.3 contains.

94 Slot No.4 contains.

95 Slot No.5 contains.

96 Slot No.6 contains.

97 Slot No.7 contains.

98 Slot No.8 contains.

99 Slot No.9 contains.

100 Slot No.10 contains.

4.16. WINDING RESISTANCE AND COPPER WEIGHT MAIN WINDING

Slots	TPC	Span T_N	Pitch Factor	Effective TPC	N_N	% Full
1	(21)	(20)	(108)	(115)	(123)	(132)
2	(22)	(102)	(109)	(116)	(124)	(133)
3	(23)	(103)	(110)	(117)	(125)	(134)
4	(24)	(104)	(111)	(118)	(126)	(135)
5	(25)	(105)	(112)	(119)	(127)	(136)
6	(26)	(106)	(113)	(120)	(128)	(137)
7	(27)	(107)	(114)	(121)	(129)	(138)
	(101)			(122)		

101	TPP	Turns per pole, TPP = Total of items (24) to (30)
102	T_2	TPC_2 coil span, $T_2 = T_1 - 2 = (20)-2$
103	T_3	TPC_3 coil span, $T_3 = (20) - 4$
104	T_4	TPC_4 coil span $T_4 = (20)-6$
105	T_5	TPC_5 coil span $T_5 = (20) - 8$
106	T_6	TPC_6 coil span $T_6 = (20)-10$
107	T_7	TPC_7 coil span $T_7 = (20)-12$
108 to 114		Pitch factor = $\sin\left(\frac{T_N}{S_{1/p}} 90^\circ\right) = \sin\left(\frac{T_N}{(88)} 90^\circ\right)$
115 to 121		Effective turns per coil = TPC_N x pitch factor N.
122	TPP_e	Effective turns per pole, TPP_e = Total of items (115) to (121)
123		2 (no. of main wdg. coils) -1
124		(123) - 2
125		(123)-4
126		(123) - 6
127		(123) - 8
128		(123) - 10
129		(123) - 12
130		Actual CM per conductor/1000 = $(29)(30)^2 \times 10^3$
131		Total $D^2 \times 10^2 = (29)(31)^2 \times 10^2$

132 to 138 $\% \text{ full} = TPC \times (D^2 \times 10^2) / \text{wdg. area} \; \frac{TPC_N \times (1}{(57) + A_s}$

If slot contains split coils , multiply by 2

$A_s = 0$ for two coil sides per slot

$A_s = .007$ for one coil side per slot.

With one coil side per slot, no separator is used and the wdg. area is equal to item (57) plus the area of a slot separator.

139

$$\frac{TPC_1 + N_1 + TPC_2 \times N_2 \text{ ---etc.}}{TPP}$$

$$= \frac{(21)\ (123) + (22)\ (124) \text{---etc.}}{(101)}$$

140 ACS Weighted average coil span, ACS

$$= \frac{TPC_1 \times T_1 + TPC_2 \times T_2 \text{ --- etc.}}{TPP}$$

$$= \frac{(21)\ (20) + (22)\ (102) \text{ ---etc.}}{(101)}$$

141 C Total series conductors, $C = \frac{2 \times P \times TPP}{q}$

$$= \frac{2(6)\ (101)}{(32)}$$

142 K_w Winding factor $= \frac{\text{Eff turns per pole}}{\text{Turns per pole}}$

$$= \frac{TPP_e}{TPP} = \frac{(122)}{(101)}$$

143 C_e Effective series conductors, $C_e = CK_w = (141)(142)$

144 MLC Mean length conductor, $MLC = L + L_{ec}$

$$= L + \left[.5 \ \left(\frac{\pi(D_1 + d_1)}{S_1} - t_1 \right) (139) + \frac{\pi(D_1 + d_1)ACS}{S_1} \right]$$

$$= (8) + \left[.5 + \left(\frac{\pi\left[(47) + (50)\right]}{(49)} - (54) \right) (139) + \frac{\pi\left[(47) + (50)\right](140)}{(49)} \right]$$

145 r_1 cold ohms resistance @ 25°C , r_1 cold

$$= \frac{0.881 \times 10^{-3} \times MLC \times C}{q \times CM/1000}$$

$$= \frac{0.881 \times 10^{-3} (144)\ (141)}{(32)\ (130)}$$

146 r_1 pu hot Resistance, per unit, hot, r_{1pu} hot

$$= \frac{r_1 \text{ cold}}{\Omega \text{ pu}} \times \frac{235 + \text{hot temp}}{260}$$

$$= \frac{(145)}{(82)} \times \frac{235 + (10)}{260}$$

147 Copper weight, lbs. $= 0.275 \times 10^{-3} \times MLC \times C \times q \times CM/1000$

$= 0.275 \times 10^{-3} (144)(141)(32)(131)$

AUXILARY WINDINGS

Slots	TPC	Span T_N	Pitch Factor	Effective TPC	N_N	% Full
5	(34)	(33)	(153)	(158)	(164)	(171)
4	(35)	(149)	(154)	(159)	(165)	(172)
3	(3[illegible])	(150)	(155)	(160)	(166)	(173)
2	(37)	(151)	(156)	(161)	(167)	(174)
1	(38)	(152)	(157)	(162)	(168)	(175)
	(148)			(163)		

148 TPP_a Turns per pole, TPP_a=Total of items (34)thru(38)

149 T_{2a} TPC_{2a} coil span, $T_{2a} = T_{1a} - 2 = (33) - 2$

150 T_{3a} TPC_{3a} coil span, $T_{3a} = (33) - 4$

151 T_{4a} TPC_{4a} coil span, $T_{4a} = (33) - 6$

152 T_{5a} TPC 5a coil span, $T_{5a} = (33)-8$

153 to 157 Pitch factor = $\text{Sin} \left(\frac{T_{Na}}{S_1/p} \, 90^\circ \right) = \text{Sin} \left(\frac{T_{Na}}{(88)} \, 90^\circ \right)$

158 to 162 Effective TPC = TPC_{Na} x pitch factor N

163 TPP_{ea} Effective turns per pole, TPP_{ea} = Total of items (158) - (162)

164 2 (no. of aux. wdg. coils) - 1

165 (164) - 2

166 (164) - 4

167 (164) - 6

168 (164) - 8

169 CM_a Actual CM per conductor /1000 = $(40)\ (41)^2 \times 10^3$

170 Total $D^2 \times 10^2$ $(40)\ (42)^2 \times 10^2$

171 to 175 % full = TPC ($D^2 \times 10^2$) /wdg. area $\frac{TPC_N\ (170)}{(57) + (A_s}$

176 $$\frac{TPC_{1a} \times N1 \times TPC_{2a} \times N_2 \ldots\text{etc.}}{TPPa}$$

$$= \frac{(34)\ (164) + (35)\ (165)\ \ldots\ldots\text{etc.}}{(148)}$$

177 ACS_a Weighted average coil span, ACS_a

$$\frac{TPC_{1a} \times T_{1a} + TPC_{2a} \times T_{2a} \ldots\text{. etc.}}{TPP_a}$$

$$= \frac{(34)\ (33) + (35)\ (149)\ \ldots\text{.etc.}}{(148)}$$

178 Ca Total series conductors, $C_a = \frac{2 \times p \times TPP_a}{q_a}$

$$= \frac{2\ (6)\ (148)}{(43)}$$

179 k_{wa} Winding factor $= \dfrac{\text{Eff turns per pole}}{\text{Turns per pole}}$

$$= \frac{TPP_{ea}}{TPP_a} = \frac{(166)}{(148)}$$

180 C_{ea} Effective series turns, $C_{ea} = C_a\, k_{wa} = (178)(179)$

181 a a Ratio, $a = \dfrac{C_{ea}}{C_e} = \dfrac{(180)}{(143)}$

182 MLC_a Mean length conductor, $MLC_a = L + L_{ec}$

$$= L + \left[.5 + \left(\frac{\pi(D_1 + d_1)}{S_1} - t_1 \right) (176) + \frac{\pi(D_1 + d_1)ACS_a}{S_1} \right]$$

$$= (8) + \left[.5 \left(\frac{\pi[(47) + (50)]}{(49)} - (54) \quad (176) \right) + \frac{\pi[(47) + (50)](177)}{(49)} \right]$$

183 r_{1a} cold Ohms resistance @ 25°C , r_{1a} cold

$$\frac{0.881 \times 10^{-3} \times MLCa \times Ca}{qa \times CMa/1000} = \frac{0.881 \times 10^{-3} \times (182)(178)}{(43)\ (169)}$$

184 r_{1a} hot pu Resistance ,per unit, hot, r_{1a}pu hot

$$= \frac{r_{1a}\ \text{cold}}{\Omega\ \text{pu}} \times \frac{235 + \text{hot temp}}{260}$$

$$= \frac{(183)}{(82)} \times \frac{235 + (10)}{260}$$

185 Copper weight, lbs $= 0.275 \times 10^{-3} \times MLCa \times Ca \times qa \times CMa/1000$

$$= 0.275 \times 10^{-3} (182)(178)(43)(169)$$

TOTAL SLOT FULLNESS

% full total = % full mean wdg. + % full aux.wdg.

186 % full slot No.1

187 No.2

188 No.3

189 No.4

190		No.5
191		No.6
192		No.7
193		No.8
194		No.9
195		No.10

4.1.7. SATURATION

196	ϕ	Flux per pole, kilolines, $\phi = \frac{45000V}{f\,C_e} = \frac{45000(78)}{(5)(143)}$
197		$\lambda_1\,(5g + w_{10}) = (52)\left[5\,(86) + (51)\right]$
198	C	$w_{10}\,(g + w_{10}) = (51)\left[(86) + (51)\right]$
199	C_1	Carter, stator slots, $C_1 = \frac{(197)}{(197) - (198)}$
200	C_2	Carter, rotor slots = 1.02 for closed slots.
201		Effective yoke depth of shaft = $0.667\,L_b D_b/p^2$
		$= \frac{0.667\,(9)\,(62)}{(6)^2}$
202	d_{y2}	Effective yoke depth, rotor, $d_{y2} = (71)\,(201)$
203	A_{y1}	Stator core area = $2L_N\,d_{y1} = 2\,(85)\,(56)$
204	A_{t1}	Stator teeth area = L or $S_1 t_1/p = (85)(49)(54)/(6)$
205	A_{y2}	Rotor core area = $2\,L_N\,d_{y2} = 2\,(85)\,(202)$
206	A_{t2}	Rotor teeth area = $L_N\,S_2\,t_2/p = (85)(63)(69)/(6)$
207	A_g	Air gap area = $pL = (87)\,(8)$
208	K_f	Primary flux constant, assume = $\left(\frac{1-p/100}{1+2p/100}\right)$
		$= \left(\frac{1-(6)/100}{1+2(6)/100}\right)$
209	K_c	$K_c = \left(\frac{1-p/100}{2-K^2{}_f}\right) = \left(\frac{1-(6)/100}{2-(208)^2}\right)$

Densities - Kilolines per square Inch.

210	B_{y1}	Stator core density = ϕ/A_{y1} = (196)/(203)
211	B_{t1}	Stator teeth density = 1.57 ϕ/A_{t1} = 1.57(196)/(204)
212	B_{y2}	Rotor core density = $K_c\phi/A_{y2}$ = (209)(196)/(205)
213	B_{t2}	Rotor teeth density = $1.57K_c\phi/A_{y2}$ = 1.57(209)(196)/(206)
214	B_g	Air gap density = $1.57K_f\ \phi/A_g$ = 1.57 (208)(196)/(207)

Ampere Turns per Inch of Path Length

215		AT/in, stator core from Fig.4.1, density from item (210)
216		AT/in, stator teeth from Fig.4.1, density from item (211)
217		AT/in, rotor core from Fig.4.1, density from item (212)
218		AT/in, rotor teeth from Fig.4.1, density from item (213)

Length of Path- Inches.

219		Stator core length = $1.571(D-d_{y1})/p$ = 1.571 [(46) -(56)] /(6)
220		Stator teeth length = d_{1e} = (65)
221		Rotor core length = $1.571\ (D_b + d_{y2})/\phi$ = 1.5.71 (61)+(71) /6)
222		Rotor teeth length = d_{e2} = (70)
223	g_e	Effective gap length = $gC_1\ C_2$ = (86)(199)(200)
224		Stator Core AT = (215) (219)
225		Stator teeth AT = (216) (220)
226		Rotor core AT = (217) (221)
227		Rotor teeth AT = (218) (222)

228 Air gap AT $= 313\ B_g\ g_e = 313\ (214)\ (223)$

229 Total AT per pole $= (224) + (225) + (226) + (227) + (228)$

230 K_{sf} Saturation factor $= \frac{(229)}{(228)}$

4.1.8. CORE LOSSES

231 Stator core volume $= A_{y1}$ x stator core length x p $= (203)\ (219)\ (6)$

232 Stator teeth volume $= A_{t1}$ x stator teeth length x p $= (204)\ (220)(6)$

233 Stator core, watts/in^3 at 60 cy. From Fig.2.2. and using item (210)

234 Stator teeth, watts/in^3 at 60 cy. From Fig.2.2 and using item (211)

235 Stator core loss in watts at 60 cy $= (231)\ (233)$

236 Stator teeth loss in watts at 60 cy $= (232)(234)$

237 Surface loss in watts at 60 cy.

$$= 3.83 \times 10^{-6}\ Bg^2 \sqrt{Bg} \left(\frac{1}{p\sqrt{p}} \right) D_1{}^2 \sqrt{S_1} \left(\frac{W10}{g}\right)^{1.25} \times L$$

$$= 3.83 \times 10^{-6}\ (214)^2 \sqrt{(214)} \left(\frac{1}{(6)\sqrt{(6)}} \right) (47)^2 \sqrt{(49)} \left(\frac{(51)}{(86)}\right)^{1.25} \times (8)$$

238 Total 60 cy. core losses in watts $= (235) + (236)+(237)$

239 Frequency correction factor $= 0.8\left(\frac{f}{60}\right) + 0.2\left(\frac{f}{60}\right)^2 = 0.8\ \frac{(5)}{60} + 0.2\ \left(\frac{(5)}{60}\right)^2$

240 Core loss total $= (238)\ (239)$

4.1.9 FULL LOAD REACTANCE

241 Per unit reactance constant $= \dfrac{4 \quad f\, C_e^2 \times 10^{-8}}{pu}$

$$= \frac{4 \quad (5) \quad (143)^2 \times 10^{-8}}{(82)}$$

242 React. Const. x 100, pu = (241) x 100

243 Per unit skew $= \dfrac{\text{skew in\% rotor slot pitch} \times p}{100 \; S_2}$

$$= \frac{(17) \quad (6)}{100 \quad (63)}$$

244 $(1-C_{sk})$ $1 - C_{sk} = .41123(243)^2 - .05073 \; (243)^2$

245 C_{sk} $C_{sk} = 1 - (1-C_{sk}) = 1 - (244)$

246 P_M Magnetizing permeance, $P_M = \dfrac{.3234 Ag \; C_{sk}}{ge \; K_{sf} \; P}$

$$= \frac{.3234 \; (207) \; (245)}{(223) \; (230)(6)}$$

247 K_{s1} Stator slot constant total, $K_{s1} = K_{s1a} + K_{s1w}$

$$= (59) + (60)$$

248 C_x Stator slot correction factor

$$C_x = \frac{(TPC_1^2 + TPC_2^2 \; .. \; \text{etc})S_1}{TPP2 \quad K_W2 \; 4p}$$

$$= \frac{\lfloor (21)^2 + (22)^2 \text{ --- etc } \rfloor (49)}{(101)^2 \; (142)^2 \; 4 \; (6)}$$

249 P_{s1} Stator slot permeance, $P_{s1} = \dfrac{3.19 \; L \; K_{s1} \; C_x}{S_1}$

$$= \frac{3.19 \; (8) \; (247) \; (248)}{(49)}$$

250 P_{zz} zigzag permeance, $= 0.533 \; L \left(\dfrac{\lambda_1}{S_1} + \dfrac{\lambda_2}{S_2}\right) \dfrac{1}{g}$

$$\left\{\frac{C_1 + C_2 - C_1 \, C_2^2}{2C_1 \; C_2}\right\}$$

$$= 0.533 \; (8) \left[\frac{(52)}{(49)} + \frac{(67)}{(63)}\right] \frac{1}{(86)} \left[\frac{(199)+(200)-(199)(200)}{2(199) \; (200)}\right]$$

---

251 P_{sk} Skew permeance, $P_{sk} = \frac{(1-C_{sk})P_M}{C_{sk}} = \frac{(244)(246)}{(245)}$

252 Weighted average pu coil pitch $= \frac{ACS \times p}{S_1}$

$$= \frac{(140)(6)}{(49)}$$

253 Stator end constant from Fig. 2.4 wih item (87) for pole pitch and item (252) for coil pitch

254 P_{e1} Stator end permeance, $P_{e1} = \frac{(253)\ (M_{LC} - L)}{\left[1.525\ (87)(252)+1.1\right] p}$

$$= \frac{(253)\ \left[(144) - (8)\right]}{\left[1.525\ (87)(252)+1.1\right]\ (6)}$$

255 P_1 Total stator permeance = (249) + (250)+(251)+(254)

256 Est.FL sec. amp $= \frac{600\,(HP)N_s}{VK_f\ N_{f1}} = \frac{600\,(2)\ (83)}{(78)\ (208)\,(7)}$

This is an estimate of the backward Field Rotor Current.

257 $\frac{(2\ C_e\ I_2\ \text{est})^{0.9}}{S_2\ d_b} = \left(\frac{2(143)\ (256)}{(63)(73)}\right)^{0.9}$

258 Rotor slot constant, bridge portion, full load

$$= 13{,}800\ \left(\frac{d_{21}}{W21}\right)^{.1} \left(\frac{S_2\ d_b}{2C_e\ I_2}\right)^{0.9}$$

$$= 13{,}800 \left[\frac{(74)}{(66)}\right]^{0.1} \frac{1}{(257)}$$

259 K_{s2} Rotor slot constant, total full load =(72)+(258)

260 P_{s2} Rotor slot permeance, FL $= \frac{3.19L\ K_{s2}}{S_2}$

$$= \frac{3.19(8)\ (259)}{(63)}$$

261 P_2 Total rotor permeance = (250) + (251) + (260)

262 x_M pu Magnetising reactance = React. Const. x P_M

$$= (241)\ (246)$$

263 x_1 pu Stator leakage reactance = React. Const x P_1

$$= (241)\ (255)$$

264 x_2 pu Rotor leakage reactance = React. const x P_2

$$= (241)\ (261)$$

265 K_f Primary flux const, $K_f = \dfrac{x_M}{2x_1 + x_M + x_2}$

$$= \frac{(262)}{2\ (263) + (262) + (264)}$$

4.1.10 FULL LOAD ROTOR RESISTANCE

Calculations that follow are based on the use of same material in both bars and end rings.

266 Per unit resistance constant $= \dfrac{138.6 \times 10^{-6}\ C_e^{2}}{\text{pu} \times \%\ \text{cond.}}$

$$= \frac{138.6 \times 10^{-6} \times (143)^2}{(82)\ (11)}$$

267 Resistance constant x 100, pu = (266) x 100

268 Bar length = (stack + extension) correction for skew.

$$= \left[L + (13)\right]\left[1 + \left(\frac{p \times \text{pu skew}}{L + (13)}\right)^2\right]$$

$$= \left[(8) + (13)\right]\left[1 + \left(\frac{(87)\ (243)}{(8) + (13)}\right)^2\right]$$

269 Bar factor $= \dfrac{\text{Bar length}}{S_2\ A_b} = \dfrac{(268)}{(63)\ (12)}$

270 D_r Diameter at rotor slot centres = $(D_2 - d_2)$ = (61) - (65)

271 K_{ring} See Fig. 2.5, $\dfrac{D_1}{D_r}$ from $\dfrac{(16)}{(270)}$, poles from (6)

272 Ring factor $= \dfrac{0.637\ D_r\ K_{ring}}{p^2\ A_r} = \dfrac{0.637\ (270)(271)}{(6)^2\ (14)}$

273 r_2 coldpu Rotor resistance, cold, pu, r_2 cold pu

$$= \text{Resistance const (bar factor + ring factor)}$$
$$= (266)\ \left[(269) + (272)\right]$$

274 $r_2$hot pu $r_2$hot pu = r_2 cold pu $\dfrac{225 + \text{hot temp}}{250}$

$$= (273)\ \frac{225 + (10)}{250}$$

4.1.11. BACKWARD FIELD ROTOR CONSTANTS

275 Fictitious bar depth , S = 2

$$= \text{overall slot depth} \sqrt{S \times \frac{\%\ \text{cond f.}}{50 \times 60}}$$

$$= (65) \sqrt{2 \times \frac{(11)(5)}{50 \times 60}}$$

276 K_J Deep bar correction for reactance; s = 2.sec. Fig. 2.7, bar depth from (275)

277 K_R Deep bar correction for resistance, s = 2 .sec. Fig. 2.7, bar depth from (275)

278 K_R^1

$$K_R^1 = \frac{\left[\left(\frac{W21}{W23}\right) + 1\right] K_R}{2\left(\frac{W21}{W23}\right) - \left[\left(\frac{W21}{W23}\right) - 1\right]\frac{1}{K_R}}$$

$$= \frac{\left(\frac{(56)}{(77)} + 1\right)(277)}{\frac{2(66)}{(77)} - \left[\frac{(66)}{(77)} - 1\right]\frac{1}{277}}$$

279 K_{2S} Rotor slot constant, S = 2

= Slot constant, bridge + KJ (slot const, wdg)

= (269) + K_J (72)

280 P_{2S} Rotor slot permeance, S = 2 = $\frac{3.19L\ K_{2s}}{S_2}$

$$= \frac{3.19(8)\ (279)}{(63)}$$

281 P_2 Total rotor permeance, s = 2 = (250)+(251)+(280)

282 x_2 pu S=2 Rotor leakage reactance , s = 2 , pu = React. const x P_2

= (241) (281)

283 r_2 cold pu s = 2 Rotor resistance, s = 2, cold, pu

= Resistance const (bar factor) K_R^1 + Ring factor

= (266) [(269) (278) + (272)]

284 r_2 hot pu s = 2 Rotor resistance, S = 2 , hot, pu

$$= r_2 \text{ cold pu } \frac{225 + \text{hot temp}}{250} = (283)\frac{225 + (10)}{.250}$$

4.2. NO LOAD PERFORMANCE

285	S	Slip at no load, S = 0
286	r_{2bfl}	Backward field rotor resistance, pu = r_2 hot pu (s = 2) /2 = (284)/2
287	X_{2bfl}	Backward field rotor reactance, pu = x_{2pu} (S = 2)/2 = (282)/2
288	X_{1afl}	Aux. wdg. stator leakage reactance, pu = 1.0 a^2 x_{1pu} = $(181)^2$ (263)

Items (289) thru (294) calculating in Section 5.

289	Main winding amps.
290	Aux. winding amps.
291	No. load amps.
292	No load watts.
293	Aux. winding volts
294	Capacitor volts.

4.2. NO LOAD PERFORMANCE

285	s	Slip at no load, $s = 0$
286	r_{2bfl}	Backward field rotor resistance, pu = r_2 hot pu ($s = 2$) /2 = (284)/2
287	X_{2bfl}	Backward field rotor reactance, pu = x_{2pu} ($S = 2$)/2 = (282)/2
288	X_{1afl}	Aux. wdg. stator leakage reactance, pu = 1.0 a^2 x_{1pu} = $(181)^2$ (263)

Items (289) thru (294) calculating in Section 5.

289	Main winding amps.
290	Aux. winding amps.
291	No. load amps.
292	No load watts.
293	Aux. winding volts
294	Capacitor volts.

4.3 FULL LOAD PERFORMANCE

300	s	Slip at no load, $s = 0$
301	r_{2ffl}	Forward field rotor resistance, pu = r_{2hot} pu = (274)/2
302	r_{2bfl}	Backward field rotor resistance, pu= (286)
303	X_{2ffl}	Forward field rotor reactance, pu = $X_{2pu}/2$=(264)/2
304	X_{2bfl}	Backward field rotor reactance, pu = (287)
305	X_{1afl}	Aux. wdg. stator leakage reactance,pu = (288)
306		Primary I^2r, watts
307		Secondary I^2r, forward, watts.
308		Secondary I^2r, backward, watts.
309		Core losses, watts.
310		F&W loss, watts.
311		Stray load loss, watts.
312		Total losses, watts.
313	N_{fl}	RPM
314		% full load
315	T_{fl}	Torque, oz-ft.
316	I_{fl}	Full load amperes, line
317	I_{mfl}	Main wdg. amperes.
318	I_{afl}	Aux. wdg. amperes.
319		Main wdg. watts.
320		Aux.wdg. watts.
321		Efficiency
322		Power factor.
323	V_{cfl}	Capacitor volts.
324		Circular mils/ampere $= \frac{1000\ (130)(32)}{(317)}$

4.4 CALCULATION OF ROTOR RESISTANCES AT ANY SLIP s

350 s Slip of forward field.

351 Fictictious bar depth, forward field =

$$\text{overall slot depth}\sqrt{\frac{\%\ \text{Cond}\ f_s}{50\text{x}60}}$$

$$= (65)\sqrt{\frac{(11)\ (5)\ (350)}{50\ \text{x}\ 60}}$$

352 K_J Deep bar correction for reactance, use Fig.2.7, Bar depth from (351)

353 KR Deep bar correction for resistance, use Fig.2.7, Bar depth from (351)

354 K_R'

$$K_{R'} = \frac{\left(\frac{W21}{W_{23}} + 1\right) KR}{\frac{2W_{21}}{W23} - \left(\frac{W21}{W23} - 1\right)\frac{1}{K_R}}$$

$$= \frac{\left[\frac{(66)}{(77)} + 1\right](353)}{\frac{2(66)}{(77)} - \left[\frac{(66)}{(77)} - 1\right]\frac{1}{(353)}}$$

355 r_{2fpu} cold Rotor resistance, forward field, cold

= 0.6 x res. const.(ring factor + bar factor)

= 0.6 x (266) [(272) + (269) (354)]

356 r_{2fpu} hot Rotor resistance, forward field, hot

$$= r_{2f}\ \text{cold}\ \frac{225 + \text{hot temp}}{250} = (355)\ \frac{225 + (10)}{250}$$

357 2-s Slip backward field

<u>Note</u> If s = 1, skip (358) and put (359)=(352); (363) = (356)

358 Fictitious bar depth, backward field

$$= (65)\sqrt{\frac{(11)(5)(357)}{50\text{x}60}}$$

359 K_{Jb} Deep bar correction for reactance, use Fig.2.7, Bar depth from (358)

---

360 K_{Rb} Deep bar correction for resistance, use Fig.2.7, Bar depth from (358)

361 K_{Rb}'

$$K_{Rb}' = \frac{\left[\frac{(66)}{(77)} + 1\right] (360)}{\frac{2(66)}{(77)} - \left[\frac{(66)}{(77)} - 1\right]\frac{1}{(360)}}$$

362 r_{2bpu} cold Rotor resistance, backward field, cold

$$0.5(266) \left[(272) + (269)\,(361) \right]$$

363 r_{2bpu} hot Rotor resistance, backward field, hot

$$=(362)\,\frac{225 + (10)}{250}$$

---

364 Effective rotor slot opening $= \frac{W21}{3} = \frac{(66)}{3}$

365 Sum of slot openings $= w_{10} + (364) = (51)+(364)$

366 Minimum zigzag area

$$= \left[\frac{\left[(52) - (365)\right]^2}{(52)} + \frac{\left[(67)-(365)\right]^2}{(67)}\right]\frac{(85)}{8}$$

367 Maximum working density of useful flux = largest of items (210) to (213) inclusive.

4.5 LOCKED ROTOR

400 Estimated $X_L = x_1 + x_2 = (263) + (264)$

401 Estimated locked-rotor amps in main wdg

$$= I_{mL} = \frac{V}{X_L} = \frac{1.0}{(400)}$$

402 Estimated $I_{2Lpu} = 0.95\ I_{mL} = 0.95\ (401)$

403 Apparent zig-zag flux = $2.828\ C_s I_{mL} \times \text{ZZ perm} \times 10^{-3}$

$$= 2.828\ (143)\ (81)\ (401)(250) \times 10^{-3}$$

404 Apparent zig-zag flux density = $\frac{(483)}{(366)}$

405 Zig-zag correction factor. Use Fig.2.6, density from (404)

406 P_{zzL} Zig-zag permeance = (250)(405)

407 Unbalanced air gap per unit mmf, due to skewing

$$= \frac{1.047 \times \text{pu skew} \times I_{Lpu} \times I_{pu}}{I_o} + \frac{4}{3}$$

$$= \frac{1.047\ (243)\ (401)\ (81)}{(291)} + \frac{4}{3}$$

408 Apparent max.density due to skewing

$$= (407)\ (230)\ (367)$$

409 Skew correction factor. Use Fig. 2.6, density from (408)

410 P_{SKL} Skew permeance = (261) (409)

411 X_{1L} Total stator leakage reactance , pu

$$(249) + (254) + (406) + (409)$$

4.5.1. ROTOR LEAKAGE REACTANCE, at any current and slip.

412 $$\frac{2C_s\ I_{2L}\ I_{pu}}{S_2\ W_{21}} = \frac{2(143)(402)(81)}{(63)\ (66)}$$

If (412) 8970, omit (413) and put (414) = 0

413 $d_{beL} = d_b + \frac{d_{21}}{8970}\,(412) = (73) + \frac{(74)}{8970}\,(412)$

414 Rotor slot constant , bridge portion

$$= \frac{13800\ d_{beL}}{w_{21}(412)}\ \frac{d_b + d_{21} - d_{beL}}{d_{beL}}$$

$$= \frac{13800\ (413)}{(66)(412)}\ \frac{(73) + (74) - (413)}{(413)}$$

415 Rotor slot constant, forward field

$$= (414) + (352)\ (72)$$

416 Rotor slot permeance, forward field

$$= \frac{3.19\ L\ K_{s2L}}{S_2} = \frac{3.19\ (8)\ (415)}{(63)}$$

417 P_{2fL} Total rotor leakage permeance, forward field
$= (406) + (410) + (416)$

418 x_{2fL} Rotor leakage reactance, forward field

$$0.5\ (241)\ (417)$$

If $s = 1$, omit (419) thru (421) and put (422) = (418)

419 Rotor slot constant, backward field

$$= (414) + (359)\ (72)$$

420 Rotor slot permeance, backward field

$$= \frac{3.19\ (8)\ (419)}{(63)}$$

421 Total rotor leakage permeance, backward field
$= (406) + (410) + (420)$

422 x_{2bL} Rotor leakage reactance, backward field

$$0.5\ (241)\ (421)$$

423 r_{2L} r_2 hot, locked rotor $= 2 \times r_2 + L = 2\ (356)$

424 x_{2L} x_2 locked rotor $= 2 \times\ x_{2fL} = 2(418)$

425 x_{1aL} Aux. wdg. stator leakage reactance

$$x_{1aL} = \frac{P_{La}}{P_{Lm}} \times a^2\ x_{1L}\ ;\ \text{Assume}\ \frac{P_{La}}{P_{Lm}} = 1$$

$$\frac{P_{La}}{P_{Lm}} \times (181)\ (411)$$

4.5.2. LOCKED ROTOR CALCULATIONS

Put s = 1.0 and start at (350), calculating the needed constants the equivalent circuit. The following items are computed during evaluation of the equivalent circuit and calculations made as in Section5.

426	R_m	Main winding, resistance, total, hot, pu from (5.49)
427	X_m	Main winding reactance, total, pu, from (5.49)
428	R_a	Aux. winding resistance ,hot, pu, from (5.52)
429	X_a	Aux.winding reactance, hot, pu, from (5.52)
430	r_{cL}	Capacitor resistance, pu, from (5.4 a)
431	x_{cL}	Capacitor reactance , pu, (5.37)
432		Locked watts.
433		Locked torque, oz-ft.
434	I_L	Locked amps, linel
435	I_{mL}	Locked amps in main wdg.
436	I_{aL}	Locked amps in aux.wdg.
437	E_{cL}	Capacitor volts.
438	E_{aL}	Aux.wdg. volts.

4.6. BREAK DOWN TORQUE

500 X_{MT} Estimated reactance at breakdown torque

$$X_{MT} = \frac{x_1 + x_2 + x_{1L} + x_{2L}}{2}$$

$$= (263) + (264) + (411) + (424)$$

501 $$\frac{r_2}{X_{MT}} = \frac{(274)}{(500)}$$

4.8 EVALUATION OF CAPACITANCE OF CONDENSERS.

Starting Micro farads $= \frac{10^6}{2\pi} \left(\frac{1}{f} \right) \left(\frac{I_L}{E_{cL}} \right)$

$$= \frac{10^6 (434)}{2\pi(5)(437)}$$

Running Micro farads $= \frac{10^6}{2\pi} \left(\frac{1}{f} \right) \left(\frac{I_{af1}}{V_{cf1}} \right)$

$$= \frac{10^6 (318)}{2\pi(5)(323)}$$

---

502 S_{MT} Estimated slip at breakdown torque, From Section 5, and (501)

503 Estimated main winding amperes at breakdown torque

$$\text{Est } I_{MT} = \frac{I_{mf1} + I_{m1}}{2}$$

$$= \frac{(317) + (435)}{2}$$

504 Estimated I_{2MT} = 0.95 I_{MT} = 0.95 (503)

Substitute item (502) for it (350) and calculate items (351) to (363) inclusive. Substitute item (503) for it (401) and calculate items (402) to (422) (425) inclusive.

These calculations give the circuit constants needed to compute torque as calculated in Section 5.

505 I_{MT} Main wdg. amperes at breakdown torque

506 N_{MT} Speed at breakdown torque.

507 T_{MT} Breakdown torque, oz-ft.

4.7 SWITCH OPERATING SPEED.

600 Slip at switch operating speed s = .24
Use constants as calculated for breakdown torque.
Refer to Section 5 for results.

601 Speed at switch operation.

Start Conditions

602 Torque at switch operating speed, oz-ft.

603 Main winding amperes at switch operating speed.

604 Capacitor volts at switch operating speed.

605 Aux. winding volts at switch operating speed.

Run Conditions.

606 Main winding amperes at switch operating speed.

607 Torque at switch operating speed.

4.8 EVALUATION OF CAPACITANCE OF CONDENSERS.

Starting Micro farads $= \frac{10^6}{2\pi} \left(\frac{1}{f}\right) \left(\frac{I_L}{E_{cL}}\right)$

$= \frac{10^6 (434)}{2\pi(5)(437)}$

Running Micro farads $= \frac{10^6}{2\pi} \left(\frac{1}{f}\right) \left(\frac{I_{cf1}}{V_{cf1}}\right)$

$= \frac{10^6 (318)}{2\pi(5)(323)}$

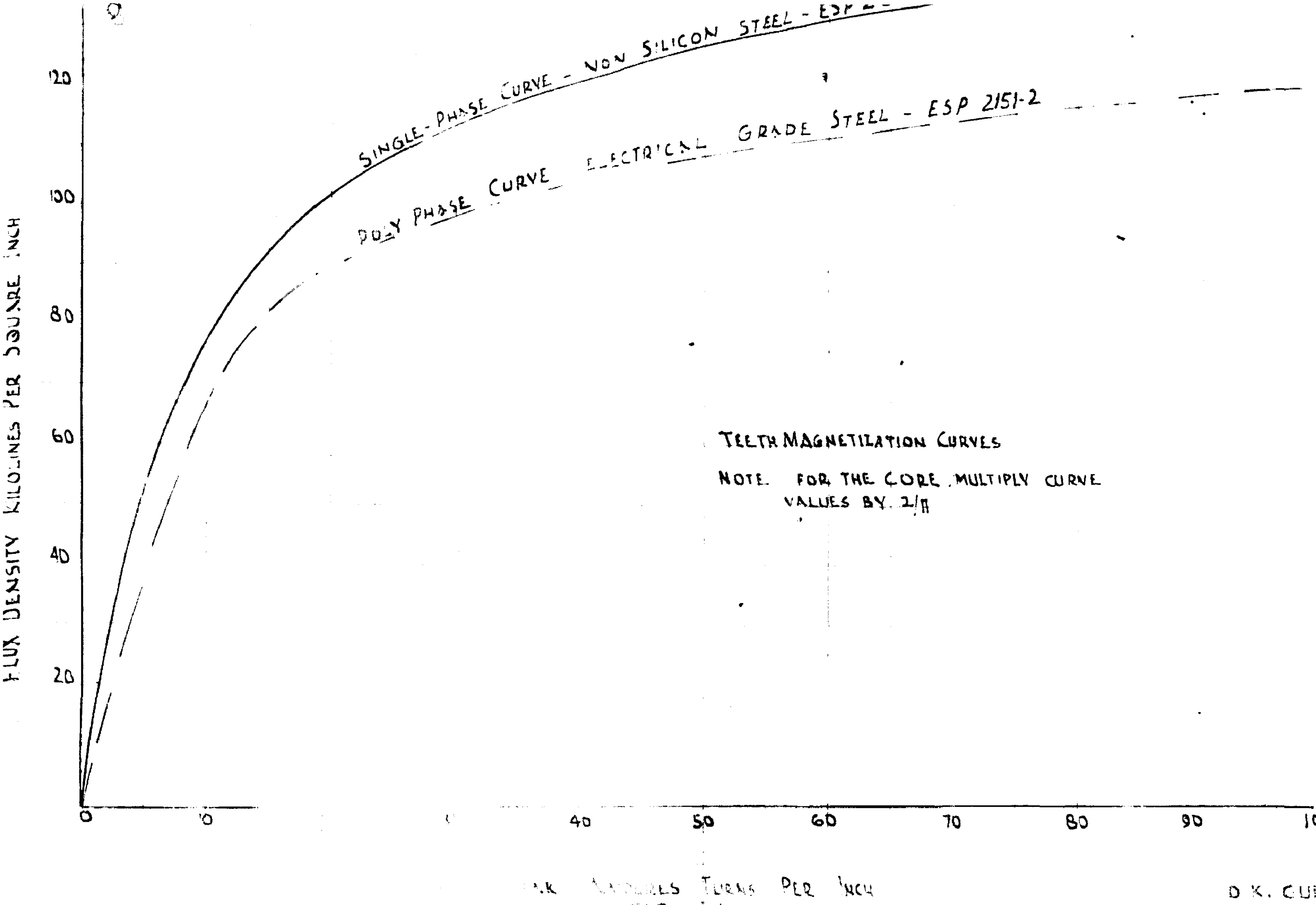

SINGLE-PHASE CURVE - NON SILICON STEEL - ESP
POLY PHASE CURVE ELECTRICAL GRADE STEEL - ESP 2151-2
TEETH MAGNETIZATION CURVES
NOTE. FOR THE CORE MULTIPLY CURVE VALUES BY 2/π
FLUX DENSITY KILOLINES PER SQUARE INCH
120
100
80
60
40
20
0
10
40
50
60
70
80
90
100
PEAK AMPERES TURNS PER INCH
D K. GUPTA

FIG. [illegible]

SECTION - 5

PERFORMANCE CALCULATIONS FOR SINGLE PHASE INDUCTION MOTORS

5.1. Equivalent Circuit.

5.2. Equivalent Circuit Calculations.

- 5.2.1. Full Load Values.
- 5.2.2. Locked Rotor Values.
- 5.2.3. Unvarying Circuit Constants.

5.3 General Equivalent Circuit Solution.

5.4. Calculation of Absolute Values.

5.5. Calculation Chart.

5.6. Effects of Microfarads on Starting Torque.

- 5.6.1. Mfds for Maximum Starting Torque.
- 5.6.2. Mfds for Maximum Starting Torque. per Ampere.

5. PERFORMANCE CALCULATIONS FOR SINGLE PHASE INDUCTION MOTORS.

This procedure is used to calculate the performance of a single phase induction motor at any point along the speed torque curve from locked rotor to no load. The calculations are based on the equivalent circuit as per shown in fig. 5.1.

5.1. EQUIVALENT CIRCUIT

In Fig. 5.1. is represented the equivalent circuit upon which the whole procedure is based. It is the exact equivalent circuit. The quantities which appear in the equivalent circuit are given in Section 3.1. This equivalent circuit has been derived by the Double Revolving Field Theory of Single phase induction motors.

5.2. EQUIVALENT CIRCUIT CALCULATIONS

5.1		Type of motor 1) Capacitor Start 3) Perm.Split 2) Two-value 4) Split Phase
5.2		H.P. Rating.
5.3	V_m	Main-phase volts, actual
5.4	V_a	Aux.-phase volts, actual
5.5	f	Frequency
5.6	P	No.of poles.
5.7	N_{fl}	Full-load RPM, estimated
5.8	a	Winding ratio = $\frac{CK_{wa}}{SK_{wm}}$
5.9		% Stray load loss
5.10		Friction and windage, at syn.RPM, watts.

5.11		Fe loss, watts.
5.12	C_L	Starting mfd.
5.13	C_{fL}	Running mfd.

5.2.1. FULL LOAD VALUE

5.15	r_1	Res.of Main winding, hot, p.u.
5.16	r_{1a}	Res. of aux.winding, hot, p.u.
5.17	r_{2ffl}	Rotor res.to forward field, f.l., p.u.
5.18	r_{2bfl}	Rotor res. to backward field, f.l., p.u.
5.19	x_{1fl}	Pri. leakage reactance of main wdg., f.l.,p.u.
5.20	x_{2ffl}	Rot. leakage reactance to forward field, f.l.,p.u.
5.21	x_{2bfl}	Rot. leakage reactance to backward field,f.l.,p.u.
5.22	x_{1afl}	Pri. leakage reactance of aux.wdg., f.l., p.u.
5.23	x_M	Magnetizing Reactance, referred to main wdg.,p.u.

5.2.2. LOCKED ROTOR VALUES.

5.24	r_{2fL} $= r_{2bL}$	Rotor res.toforward and backward fields, locked,p.u.
5.25	X_{1L}	Pri.leakage reactance of main wdg., locked,p.u.
5.26	X_{2fL} X_{2bL}	Rot.leakage react. to forward and backward fields, locked p.u.
5.27	X_{1aL}	Pri.leakage reactance of aux.winding,locked,p.u.

PER- UNIT BASES

5.28	V_m	Base volts = V_m = 1.0
5.29	V_{apu}	Aux.ph.volts, p.u. = V_a/V_m = (5.4)/(5.28)

5.30 P_{pu} Base power = HP x 746 = [illegible]

5.31 I_{pu} Base amps. = P_{pu}/V_m = (5.30)/(5.28)

5.32 Ω_{pu} Base ohms = V_m/I_{pu} = (5.28) (5.31)

5.33 N_s Base speed = syn.RPM = 120 f/p = 120 (5.5)/(5.6)

5.34 <u>5.2.3. UNVARYING CIRCUIT CONSTANTS</u>

Stray-load loss at full load, p.u. = (5.9)/100

5.35 Friction and windage, at syn.speed, p.u. = (5.10)/(5.30)

5.36 Fe loss, p.u. = (5.11)/(5.30)

5.37 X_{cL} Capac.reactance, starting, p.u.

if $C_L = 0$, $X_{cL} = 0$ if (5.12) = 0, (5.37) = 0

$$\text{if } C_L = 0,\ X_{cL} = -\frac{159.156}{fC_{L\ pu}}$$

$$= -\frac{159.155}{(5.5)\ (5.12)(5.32)}$$

5.38 X_{cfl} Capac. reactance, running, p.u.

if $C_{fl} = 0$, $X_{cfl} = 0$ if (5.13) = 0, (5.38) = 0

$$\text{if } C_{fL} \neq 0,\ X_{cfl} = \frac{-159.155}{fC_{L\text{-}pu}} = \frac{-159.156}{(5.5)(5.13)(5.32)}$$

5.39 g_M Conductance of magnetizing branch, mhos, p.u.

$$= \frac{1}{r_{fe}} = \text{p.u. fe loss} \left(\frac{x_1 + 0.5\,x_M + x_{2bfl}}{0.5x_M}\right)^2$$

$$(5.36)\left[\frac{(5.19) + 0.5\ (5.23) + (5.21)}{0.5\ (3.23)}\right]^2$$

5.40 b_M Susceptance of magnetizing branch, mhos, p.u.

$$= \frac{2}{x_M} = \frac{2}{(5.23)}$$

5.40a r_{cl} Equivalent series resistance of stg. capac., p.u. $= -.07X_{cL} = .07$ (5.37)

5.40b r_{cfl} Equivalent series resistance of rng. capac., p.u. $=0$

5.3. GENERAL EQUIVALENT CIRCUIT SOLUTION

5.41 s Slip, in p.u.

5.42 $\bar{y}_{2f}$ Admittance of forward-field rotor circuit, p.u.

if $s = 0$, $\bar{y}_{2f} = 0$

if $s \neq 0$

$$\bar{y}_{2f} = \frac{1}{\frac{r_{2f}}{s} + j\,x_{2f}} = g_{2f} - jb_{2f}$$

5.43 $\bar{y}_{2b}$ Admittance of backward-field rotor circuit, p.u.

if $s = 2$, $\bar{y}_{2b} = 0$

if $s \neq 2$,

$$\bar{y}_{2b} = \frac{1}{\frac{r_{2b}}{2-s} + j\,x_{2b}} = g_{2b} - jb_{2b}$$

5.44 Y_f Apparent admittance of forward field, including magnetizing reactance, p.u.

$$= \bar{y}_{2f} + g_M - jb_M = G_f - j\,B_f$$

5.45 $\bar{Z}_f$ Apparent impedance to forward field, including magnetizing reactance, p.u.

$$= \frac{1}{Y_f} = R_f + j\,X_f$$

5.46 $\bar{Y}_b$ Apparent admittance of backward field, including magnetizing reactance, p.u.

$$= \bar{y}_{2b} + g_M - jb_M = G_b - j\,B_b$$

5.47 $\bar{Z}_b$ Apparent impedance to backward field, including magnetizing reactance, p.u.

$$= \frac{1}{Y_b} = R_b + j\,X_b$$

5.48 $\bar{Z}_1$ Prileakage impedance, p.u.

$$= r_1 + j\,x_1$$

5.49 $\bar{Z}_T$ Total impedance of main winding

$$= \bar{Z}_1 + \bar{Z}_f + \bar{Z}_b = R_m + j\,X_m$$

COMBINED WINDING ONLY

5.50 $\bar{z}_{1a}$ Pri leakage impedance of aux.wdg.

$$= r_{1a} + jx_{1a}$$

5.51 $\bar{Z}_c$ Impedance of capacitor

$$= r_c + j X_c$$

5.52 $\bar{Z}_{Ta}$ Total impedance of auxiliary winding circuit

$$= \bar{z}_{1a} + Z_c + a^2 (Z_f + Z_b) = R_{Ta} + jX_{Ta}$$

5.53 $\bar{I}_m$ Current flowing in main winding

$$\bar{I}_m = \frac{Z_{Ta} + jV_{apu} a (\bar{Z}_f - \bar{Z}_b)}{\bar{Z}_T \bar{Z}_{Ta} - a (\bar{Z}_f - \bar{Z}_b)} = A + jB \qquad \text{If } s = 1.0 \quad \bar{I}_m = \frac{1}{\bar{Z}_T}$$

5.54 $\bar{I}_a$ Current flowing in auxiliary winding

$$\bar{I}_a = \frac{V_{apu} \bar{Z}_T - ja (\bar{Z} - \bar{Z}_b)}{\bar{Z}_T \bar{Z}_{Ta} - a (\bar{Z}_f - \bar{Z}_b)} = g + jh \qquad \bar{I}_a = \frac{V_{apu}}{\bar{Z}_{Ta}}$$

MAIN WINDING ONLY

5.55 $\bar{I}_m$ Current flowing in main winding

$$\bar{I}_m = \bar{I} = \frac{1}{\bar{Z}_T} = A + jB$$

5.56 $\bar{I}_f$ Equivalent forward-field current = $\bar{I}_m$

5.57 $\bar{I}_b$ Equivalent back-ward field current = $\bar{I}_m$

COMBINED WINDING ONLY

5.58 $\bar{I}_f$ Equivalent forward-field current = $\bar{I}_m - ja\bar{I}_a$

5.59 $\bar{I}_b$ Equivalent back-ward field current = $\bar{I}_m + ja\bar{I}_a$

5.60 T_f Forward torque, p.u. $T_f = (I_f^2 R_f) \frac{S_{2f}}{G_f}$

5.61 T_b Backward torque, p.u. $T_b = (I_b^2 R_b) \frac{S_{2b}}{G_b}$

5.62 T Net electrical torque, p.u. $T = T_f - T_b$

5.62 Stray load loss correction factor

$$= \frac{s(1-s)^2}{s_{fl}(1-s_{fl})^2} \quad \text{(Note = At full load, this item = 1)}$$

5.63 Output power, p.u. If $s = 1$, skip this item
If $s \neq 1$ output power p.u.

$$= \frac{(T - F\&W)\ (1-s)}{1 + (p.u.s.l)\ (\text{Stray corr.factor})}$$

$$= \frac{[(5.62) - (5.25)]\ [1-5.41]}{1 + [(3.34)\ (5.62a)]}$$

5.64 N RPM $= N_s (1 - s) = (5.33) [1 - (5.41)]$

5.65 Torque, in oz.-ft.
If $s \neq 1 = \dfrac{112.7 \times (5.63) \times (5.30)}{(5.64)}$

If $s = 1$, use
$T = \dfrac{112.7 \times (5.62)\ (5.30)}{(5.33)}$

5.66 % of rate output = 100 x (5.63)
if $s = 1.0$, skip this item.

5.4 CALCULATION OF ABSOLUTE VALUES

5.67 Comb. wdg. only Pri. I^2r losses $= [I_m^2\ r_1 + I_a^2\ r_{1a}]\ P_{pu}$

5.67a Main wdg only. Pri. I^2r losses $= I_m^2\ r_1\ P_{pu}$

5.68 Sec. I^2r (f) $= s\ T_f P$ pu

5.69 Sec. I^2r (b) $= (2-s)\ T_b\ P_{pu}$

5.70 Core loss
If $s = 0$, use it. (5.11)
If $s \neq 0$

$$\text{Core loss} = \left(\frac{T_f}{G_f} + \frac{T_b}{G_b} \right) g_M\ P_{pu}$$

5.71 Friction and windage = (5.10) x (1-s)

5.72 Stray-load loss = (5.62a) (5.63) (5.34) (5.30)

5.73 Total losses = (5.67) or (5.67a) + (5.68) + (5.69) + (5.70) + (3.71) + (3.72)

	Main winding only	Combined windings
5.74	Line Amperes = $I_{pu}\sqrt{A^2+B^2}$	Line Amperes=I_{pu} $(A+g)^2 + (B+h$
5.75	Main Wdg. Amps = $I_{pu}\sqrt{A^2+B^2}$	Main Wdg.Amps=I_{pu} $A^2 + B^2$
5.76	Aux.Wdg. Amps. = 0	Aux.Wdg.Amps=I_{pu} g^2+h^2

	Main Winding Only	Combined Windings
5.77	Main Winding Watts=AP_{pu}	Main Winding Watts= AP_{pu}
5.78	Aux.Winding Watts = 0	Aux.Wdg.Watts= $gV_{apu}P_{pu}$
5.79 E_c	Capacitor Voltage = 0	Cap.Volt.= $\bar{I}_a \bar{Z}_c\ {}^*V_m$
5.80	Aux.Wdg.Voltage $a\bar{I}_m (\bar{Z}_f - \bar{Z}_b)^* V_m$	Aux.Wdg.Voltage $V_{apu} + j0 - \bar{E}_c\ {}^*V_m$

* take scalar value of the vector.

5.81 Efficiency = $\dfrac{(5.77) + (5.78) - (5.73)}{(5.77) + (5.78)}$

5.82 Main wdg. only Power factor $= \dfrac{A}{\sqrt{A^2 + B^2}}$

5.82 Comb. wdg. $= \dfrac{A + g}{\sqrt{(A+g)^2 + (B+h)^2}}$

5.5 CALCULATION CHART

Type of Motor	Cap.Start	Two-Value	Perm.-Split	Split-phase.
No-load				
Slip = s	0	0	0	0
Main only or Combined Mfd.	Main —	Combined Rng	Combined Rng	Main —
Full Load				
Slip = s_{fl}, iterate until rated output is reached within 0.2%	—	—	—	—
Main or Combined Mfd.	Main —	Combined Rng	Combined Rng	Main —
Breakdown torque				
Slip = s @ 1st trial = s_1 2nd trial = s_2 3rd trial = s_3	If s_2 gives more torque than s_1, try s_3. If s_2 gives less torque than s_1, use s_1 Record the value of s_1, s_2, or s_3, whichever gives greatest torque.			
Main or Combined Mfd.	Main —	Combined Rng	Combined Rng	Main —
Switching Torque				
Slip = s	0.24	0.24	Omit. Put	0.24
Main or combined Mfd.	Both Stg.	Combined Stg. & Rng	all values =0	Both —
Locked rotor				
Slip = s	1.00	1.00	1.00	1.00
Main or combined Mfd.	Combined Stg	Combined Stg.	Combined Stg.	Combined —

5.6 EFFECTS OF MICROFARADS ON STARTING TORQUE

This procedure analyses the effect of microfarads on capacitor start and two value capacitor motors. These calculations are made after completion of basic calculations for single phase motors per section 4. Items numbered less than (700) refer to Section 4. This procedure calculates microfarads, angle, starting torque, line amperes, and capacitor volts for

a) Maximum starting torque.
b) Maximum starting torque per ampere.

It calculates the maximum microfarads for adequate switching torque.

The last mentioned quantity is conservative, and can be ignored if switching torque calculates satisfactorily. In general, it is desirable to use a value of microfarads near that for maximum starting torque per ampere, but always less than that for maximum starting torque.

5.61. MFDS FOR MAX. STARTING TORQUE

701 R_m = Base ohm x main res.hot = (82) x (428)
702 r_1 = (82) x (146)
703 r_2' = $R_m - r_1$ = (701) - (702)
704 X_m' = (82) x (427)
705 Z_m = $\sqrt{Rm^2 + X_m^2}$ = $\sqrt{(701)^2 + (704)^2}$
706 r_{1a} = (82) x (184)
707 r_{2a}' = $a^2 r_2'$ = $(181)^2$ x (703)
708 R_e = (82) x (430)

709 $R_{ac} = (706) + (707) + (708)$

710 $X_{a'} = 1.0 \times a^2 X_m = 1.0\,(181)^2\,(704)$

711 $X_{a'c} = \dfrac{-R_{ac} R_m}{Z_m + X_m'} = \dfrac{-(709)\,(701)}{(705)+(704)}$

712 $X_c = X_{ac} - X_a = (711) - (710)$

713 $R_c = 0.07\,X_c = 0.07 \times (712)$

714 Test to see if (713) differs from (708) by 10% or more. If it does, substitute (713) for (708), and go back to (709) If it does not, proceed on to (714)

714 $\text{mfd} = \dfrac{10^6}{2\pi f X_c} = \dfrac{159155}{f X_c} = \dfrac{159155}{(5)\,(712)}$

715 $Z_{ac} = \sqrt{R_{ac}^2 + X_{ac}^2} = \sqrt{(709)^2 + (711)^2}$

716 $\sin(\theta m - \theta a) = \dfrac{X_m R_{ac} - R_m X_{ac}}{Z_m\;Z_{ac}} = \dfrac{(704)(709)-(701)(711)}{(705)\;(715)}$

717 $\theta m - \theta a = \sin^{-1}(716)$

718 $\dfrac{.53239}{P} = \dfrac{.53239}{(6)}$

719 $I_m = (3)/(705)$

720 $I_{ac} = (4)/(715)$

721 Starting torque $= \dfrac{(716)\;(181)\;(703)\;(719)\;(720)}{(718)}$ oz.ft.

722 I_L line amps $= I_m Z_{mac} / Z_{ac}$

$$= \frac{(719)\sqrt{[(701) + (709)]^2 + [(704) + (711)]^2}}{(715)}$$

723 Cap. volts $= -(720) \times (712)$

724 Actual mfds

5.6.2. MFDS FOR MAX. STARTING TORQUE PER AMPERE

730 $X_m' R_{ac} - R_m X_{ac} = Z_m \sqrt{R_{ac} R_{mac}}$

$$= (705)\sqrt{(709)\,[(709) + (701)]}$$

731 $X_{ac} = \dfrac{(704)\ (709) - (730)}{(701)}$

732 $X_c = X_{ac} - X_a = (731) - (710)$

733 $R_c = .07\ X_c = .07 \times (732)$

Test to see if (733) differs from (708) by 10% or more. If it does, substitute (733) for (708) recompute (709) and go back to (730). If it does not, proceed to (734)

734 $\text{Mfd} = \dfrac{159155}{(5)\ (732)}$

735 $Z_{ac} = \sqrt{(709)^2 + (731)^2}$

736 $\sin(\theta m - \theta ac) = \dfrac{(730)}{(705)\ (735)}$

737 $I_{ac} = (4)/(735)$

738 $\text{Starting torque} = \dfrac{(736)\ (181)\ (703)\ (719)\ (737)}{(718)}$

739 $\theta m - \theta ac = \sin^{-1}(736)$

740 $\text{Line amps} = I_m\ Z_{ac}/Z_{am}$

$$= \frac{719 \sqrt{[(701) + (709)]^2 + [(704) + (731)]^2}}{(735)}$$

741 Cap. volts = (737) (732)

742 $\text{Mfd for switching torque} = \dfrac{159155}{2(5)\ (703)\ (181)\ [1 + (181)]^2}$

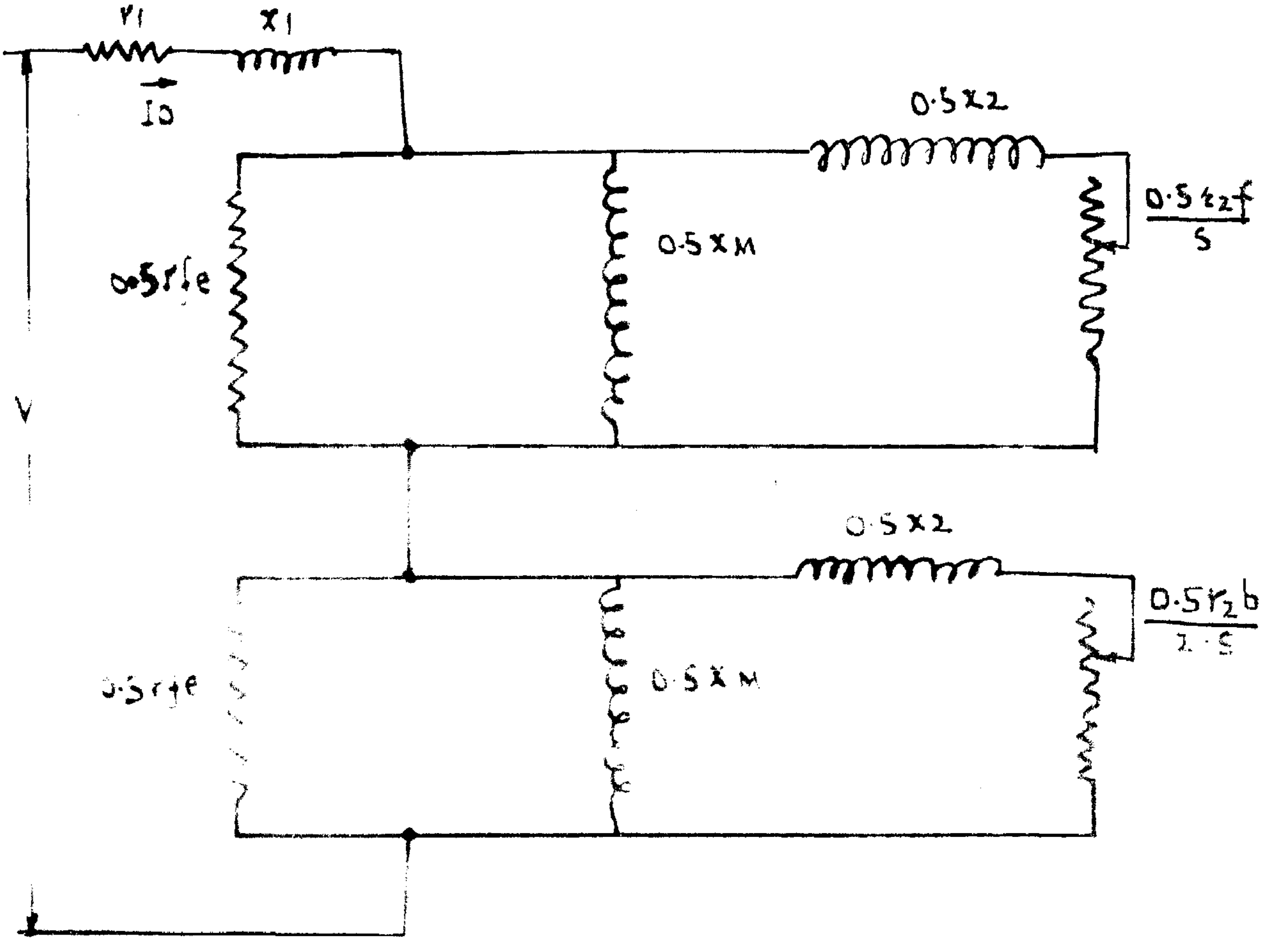


FIG. 5·1· EQUIVALENT CIRCUIT OF SINGLE PHASE INDUCTION MOTOR

D.K. GUPTA

SECTION- 6

DESIGN WORK AND PERFORMANCE

6. DESIGN WORK AND PERFORMANCE

Based on the Basic Design Procedures for Polyphase and Single Phase Induction motors, designs are made for 100 H.P., 180 cycles, 2 pole, 440 volts compressor drive motor.

Starting from the fundamentals of designs air gap diameter and outside diameter for stator core are obtained. Then the stator and rotor core punchings are designed as in Section 6.1.

6.1 STATOR AND ROTOR PUNCHING CALCULATIONS

In the present design, Trapezoidal Round Bottom semi-closed slots have been used in stator punching and trapezoidal closed slots for the rotor punching. The dimensioned slots have been shown in fig. 6.1 and 6.2 respectively.

6.1.1 Design of Stator and Rotor Slots

When the air gap diameter is known then for a given number of slots in stator, slot pitch is calculated $= \pi D_1 / S_1$. Knowing the current density and current carried by each conductor, the slot area can be approximately calculated. The whole stator punching is then designed as in 'Theory and Design of Small Induction Motors' by C.G. Veinott on page 385. After rough calculations are made an enlarged drawing is prepared and the Stator Punching Calculation sheet is filled in with the help of Fig. 7.3 to Fig.7.5 slot constants for air and windings are calculated. Two such designs have been made here on sheets Nos. 6.1.2. Sta I and 6.1.2. Sta II.

For designing rotor punching and in fixing the number of rotor slots following rules are to be applied: To minimize noise and vibration, $S_1 - S_2$ must not equal ± 1, ± 2, $\pm (P \pm 1)$ or $\pm (P \pm 2)$. To avoid cusps, $S_1 - S_2$ must not equal $\pm P$ or for three-phase motors, $-2P$ or $-5P$. To avoid cogging, $S_1 - S_2$ must not equal $\pm mP$ or any multiple of $\pm mP$ for polyphase motors. For quietness, S_2 should differ from S_1 by 20 percent or more. For low stray-load losses, make S_2 smaller than S_1 by a small amount of the order of 15 percent. The rotor punching is designed as in 'Theory and Design of Small Induction Motors' by C.G. Veinott on page 392. As in stator punching design, the Rotor Punching Calculation sheet is filled in and slot constants evaluated. Three such designs have been made here on sheets Nos. 6.1.3 Rot I; 6.1.3 Rot II; and 6.1.3 Rot III.

During the whole Induction Motors Design for three phase and two phase connections the followings have been used:

Stator : No.6.1.2 Sta II

Rotor : No.6.1.3 Rot II

Stator and rotor designs of No.6.1.2. Sta I and No.6.1.3 Rot I have been outright rejected. Rotor No.6.1.3 Rot III has been used in single phase connections to get better performance.

STATOR PUNCHING CALCULATION SHEET
NO. 6.1.2. Sta I

1	D	Outside diameter	13.375	21	d_{y1}	Eff. yoke depth $= \left[\frac{D - D_1 - 2d_1}{0.2r_{13}} + 0.2r_{13} \right]$	1.666
2	D_1	Gap diameter (bore)	7.500	22		Slot cell thickness	0.165
3	S_1	No. of slots	36	23		Topstick dimensions	1/16
4	d_1	Overall slot depth	1.330	24		Middle stick dimensions	1/32
5	d_{10}	Depth of tooth tip. For open slots.	.05	25		Slot cell area	.0322
6	d_{11}	Depth of slot mouth	.06	26		Slot area useless due to topstick	.0341
7	d_{14}	Depth of trapezoidal section		27		Middlestick area	.0106
8	w_{10}	Slot opening.	.174	28		Area of additional insulation, if any	—
9	w_{11}	Slot width at top	.347	29		Total area of insulation, ~~if any~~ = (25) + (26) + (27) + (28)	.0769
10	r_{13}	Radius of slot bottom	.290	30		Gross slot area	.6386
11	w_{13}	Slot width at bottom	.580	31		Net slot-winding area = (30) - (29)	.5617
12	d_{12}		.072	32		Permissible ND^2	.455
13	d_{13}	For part. closed $d_{14} - d_{12}$		33	K_{s1w}	Slot constant, wdg. port (Fig. 7.3 or Fig 7.4)	.870
14	w_{12}	Slot with at top of wdg. $= w_{11} + (w_{13} - w_{11}) \frac{d_{12}}{d_{14}}$		34		Slot constant, air port. exclusive of fringing.	.455
15	λ_1	Slot pitch $= \pi D_1 / S_1$	.654	35		Slot-mouth fringing (Fig. 7.5)	.120
16	t_{10}	Tooth face $= \lambda_1 - w_{10}$	.480	36	K_{s1a}	Slot constant, air portion = (34) + (35)	.575
17	t_{11}	Tooth width, top	.245				
18	t_{13}	Tooth width bottom $= \pi \left[\frac{D_1 + 2(d_1 - r_{13})}{S_1} \right] - w_{13}$	.245				
19	t_{1a}	Effect. tooth width (wdth. 1/3 from min. sect)	.245				
20		Effect. toothlgth $= d_1 - 0.5r_{13}$	1.182				

STATOR PUNCHING CALCULATION SHEET NO.6.1.2.STA II

1.	D	Outside diameter	11.400
2	D_1	Gap diameter (bore)	6.375
3	S_1	No. of slots	36
4	d_1	Overall slot depth	1.200
5	d_{10}	Depth of tooth tip for open slots	.04
6	d_{11}	Depth of slot mouth	.05
7	d_{14}	Depth of trapezoidal section.	
8	w_{10}	Slot opening	.134
9	w_{11}	Slot width at top	.267
10	r_{13}	Radius of slot bott. -om	.260
11	w_{13}	Slot width at bottom	.520
12	d_{12}		
13	d_{13}	For part. closed: $d_{14} - d_{12}$	
14	w_{12}	Slot width at top of wdg. $= w_{11} + (w_{13} - w_{11}) \frac{d_{12}}{d_{14}}$	
15	λ_1	Slot pitch $= \pi D_1 / S_1$	.556
16	t_{10}	Tooth face $= \lambda_1 - w_{10}$	.422
17	t_{11}	Tooth width, top	.208
18	t_{13}	Tooth width bottom $= \left[\frac{D_1 + 2(d_1 - r_{13})}{S_1}\right] \pi - w_{13}$	.207
19	t_1	Effect. tooth width (wdth, 1/3 from min sect.)	.207
20		Effect tooth lgth $= d_1 - 0.5 r_{13}$	1.071

21	d_{y1}	Eff. yoke depth $= \left[\frac{D - D_1 - 2d_1}{2} + 0.2 r_{13}\right]$	1.414
22		Slot cell thickness	.0165
23		Top stick dimensions	.116
24		Middle stick dimensions	.132
25		Slot cell area	.2888
26		Slot area useless due to top stick	.0309
27		Middle stick area	.0094
28		Area of additional insulation, if any	—
29		Total area of insulation = (25) + (26) + (27) + (28)	.0691
30		Gross slot area	.4916
31		Net slot winding area = (30) - (29)	.4225
32		Permissible ND2	.362
33	K_{s1w}	Slot constant, wdg port. (Fig. 7.3 or Fig. 7.4)	.900
34		Slot-constant, air port. exclusive of fringing.	.576
35		Slot-mouth fringing (fig. 7.5)	.120
36	k_{s1a}	Slot constant, air portion = (34) + (35)	.696

ROTOR PUNCHING CALCULATION SHEET
NO.6.1.3. ROT I

1	D_2	Outside diameter	7.400
2	D_b	Effective I.D.	2.937
3	S_2	No.of slots	31
4	d_2	Overall slot depth	1.183
5		Diameter at slot centres $= D_2 - d_2$	6.217
6	d_b	Minimum depth of bridge.	.005
7	d_{21}	Depth of slot mouth	.035
8	d_{24}	Depth of trap sect.	1.143
9	w_{21}	Slot width at top	.180
10	w_{23}	Slot width at bottom	.180
11	λ_2	Slot pitch $= \pi D_2/S_2$	.750
12	d_{20}	Depth of teeth tip	
13	d_{22}		
14	d_{23}		
15	w_{20}	Slot opening	.000
16	w_{22}	Slot width at top of winding	
17	t_{20}	Tooth face $= \lambda_2 = w_{20}$	
18	t_{21}	Tooth width, top	.531
19	t_{23}	Tooth width, bottom	.345
20	t_2	Effective tooth width 1/3 from min section)	.407

21		Effective tooth length	1.183
22		Yoke depth of pchg. $= \frac{(D_2 - 2d_2 - D_b)}{2}$	1.048
23	K_{s2w}	Slot constant, wdg. portion (Fig.7.4)	2.50[illegible]3
25		Slot area	.209
28	K_{s2a}	Slot constant, air portion.	.900

ROTOR PUNCHING CALCULATION SHEET
No.6.1.3 Rot II

	D_2	Outside diameter	6.295
	D_b	Effective I.D.	2.437
	S_2	No. of slots	31
	d_2	Overall slot depth	.975
		Diameter at slot centres $= D_2 - d_2$	6.320
	d_b	Minimum depth of bridge	.005
	d_{21}	Depth of slot mouth	.035
	d_{24}	Depth of trap. sect.	.935
	w_{21}	Slot width at top	.142
0	w_{23}	Slot width at bottom	.142
1	$\lambda 2$	Slot pitch $= \pi D_2/S_2$	.638
2	d_{20}	Depth of tooth tip	
4	d_{23}		
5	w_{20}	Slot opening	.000
6	w_{22}	Slot width at top of winding.	
7	t_{20}	Tooth face $= \lambda 2 - w_{20}$	
	t_{21}	Tooth width, top	.489
	t_{23}	Tooth width, bottom	.298
	t_2	Effective tooth width (width. 1/3 from min. section)	.362

21		Effective teeth length	.975
22		Yoke depth of pchg. $= \frac{(D_2 - 2d_2 - D_b)}{2}$	.954
23	K_{s2w}	Slot constant, wdg. portion (Fig. 7.4)	2.687
25		Slot area	.135
28	K_{s2a}	Slot constant, air portion	.000

ROTOR PUNCHING CALCULATION SHEET
NO. 6.1.3 ROT III

	D_2	Outside diameter	6.298
	D_b	Effective I.D.	2.437
	S_2	No. of slots	31
	d_2	Overall slot depth	.400
		Diameter at slot centers $= D_2 - d_2$	5.898
	d_b	Minimum depth of bridge.	.008
	d_{21}	Depth of slot mouth	.035
	d_{24}	Depth of trap. sect.	.360
	w_{21}	Slot width at top	.357
10	w_{23}	Slot width at bottom	.357
11	$\lambda 2$	Slot ~~width at~~ pitch $= \pi D_2 / S_2$	.638
12	d_{20}	Depth of tooth tip	
13	d_{22}		
14	d_{23}		
15	w_{20}	Slot opening	.000
16	w_{22}	Slot width at top of winding	
17	t_{20}	Tooth face $= \lambda 2 - w_{20}$	
18	t_{21}	Tooth width, top	.272
19	t_{23}	Tooth width, bottom	.200
20	t_2	Effective tooth width (width, 1/3 from min section)	.224

21		Effective tooth length	.400
22		Yoke depth of pchg. $= \dfrac{(D_2 - 2d_2 - D_b)}{2}$	1.528
23	K_{s2w}	Slot constant, wdg. portion (Fig. 7.4)	.530
25		Slot area	.136
26	k_{s2a}	Slot constant, air portion.	.000

6.2 THREE PHASE DESIGNS

The design is started from a stator connected three phase induction motor (Design No.6.2.1) and by the use of relations stated in Section 1 the final design of delta connected three phase induction motor is obtained (Design No.6.2.2.).When the windings are connected in series instead of parallel design No.6.2.3. is obtained. The complete performances of the above designs have been made and given along with the design sheets.

6.3 TWO PHASE DESIGNS

An initial design No.6.3.1. is prepared with a stack length of 4.5". With the use of same relations of Section 1 the final design No.6.3.2. is obtained. When the windings are series connected it is design No.6.3.3. The complete performances of the above designs have been made and given along with the design sheets. To get a high starting torque Rome Welding Bronze material is used, instead of aluminum as the cage material, in designs 6.3.2. and 6.33. The percentage conductivity of new material is 26.3. The new performance with this material has been calculated and given on 'Summary of Basic Design Calculations- Polyphase Induction Motors' on sheets Nos. 6.3.4 and 6.3.5.

6.4. SINGLE PHASE DESIGNS

Design has been made for permanent split phase motor in design No.6.4.1 and its performance fully calculated. The design is not satisfactory. So 6.4.2 a Two-value capacitor motor has been made and its performance has been calculated. The design and performance at series connections have also been made in design 6.4.3.

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTORS

6

RATING

Design Number	6.2.1.
HP Rating	100
Line Volts	440
Phases	3
Frequency	180
Poles	2
FL RPM	10600

CORE DIMS

Gross Iron,Sta	5.500
No.Sta Ducts	.000
Width Sta Ducts	.000
Gross Iron, Rotor	5.500
No.Rotor Ducts	.000
Width Rotor Ducts	.000
Skew % Rotor Ducts	115
Shaft Material	Magnetic

Cost/lb. Iron	1.00
Cost/lb. Copper	1.00
Cost/lb. Alum.	1.00

ELECTRICAL SPEC.

Star	Connections
2	No.of circuits
5	Actual TPC
9	Stds/Cond
.0641	Dia Bare
.0673	Dia Over Ins
13	Coilthrow 1 &
1.19	K_1
1.13	K_2
60.0	Phase Belt Angle
.956	Dist Fact k_d

ROTOR

50.00	% Conductivity
.000	Bar Extensions
.209	Bar Area
1.970	Ring Area
7.25	Ring O.D.
4.25	Ring I.D.
2.00	% S.L.Loss
4.00	F&W in KW

STATOR PUNCHING

Sta Pchg Calc No.	6.1.2 StaI	.480	Tooth Face
Outside Dia.	13.375	.245	Eff.Tooth Width
Gap Dia.	7.500	1.182	Eff Tooth Length
Type of Slots	Part.closed	1.666	Yoke Depth, Pchg
No.Slots	36	.5617	Net Slot Wdg.Area
Slot Depth	1.330	.455	Permissible ND2
Slot Opening	.174	.575	Slot Const.Air
Slot Pitch	.654	.870	Slot Const.Wdg.

ROTOR PUNCHING

Rot Pchg Calc.No.	6.1.3 Rot I	.407	Eff Tooth Width
Outside Dia.	7.400	1.183	Eff. Tooth Length
Eff I.D.	2.937	1.048	Yoke Depth,Pchg
No.of slots	31	2.503	Slot Const,Wdg.Top
Type of Slots	Closed	.005	Bridge Thns.
Bar Depth	1.183	.035	Depth,Slot Mouth
Slot Width,Top	.180	.209	Slot Area, Top
Slot Pitch	.750	.000	Slot Const,Air
Slot Opening	.000	.180	Slot Width,Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS-POLYPHASE INDUCTION MOTORS

Design Number	6.2.1
Base ohms	2.6
Air gap	.050
Pole pitch	11.70

ELECTRICAL SPEC.

Total ND^2	.407
% full	72.3
Coil pitch,p.u.	.666
Equiv.CM/1000	73.96
Equiv.TPC	2.50
Pull dimension	9.25
MLC	17.63
Copper wt.	64.55
r_1 cold	.0126
r_1 hot, p.u.	.00578
r_1 effect.	.00664
Pitch factor	.866
Eff ser conds/ph.	49.7

SATURATION

Flux/pole, K-lines	1278
Eff air gap	.05933
Sta core density	75.0
Sta teeth density	89.0
Rot core density	79.6
Rot teeth density	69.6
Air gap density	30.6
AT, Sta core	65.8
AT, Sta teeth	23.6
At, Rot core	26.3
AT, Rot teeth	10.8
AT, air gap	567.8
Total AT	694.3
Sat factor	1.222

CORE LOSSES

Sta core loss, KW	.179
Sta teeth loss, KW	.047
Surface loss, KW	.061
Total core loss,KW	1.211

FULL LOAD REACTANCE

React constx100,p.u.	3.226
Per-unit skew	0.10
Sta slot factor	0.809
Sta zz factor	
Sta skew factor	
Sta end factor	
Pri leakage perm	
Rot bridge constan.	.648
Rot slot factor	1.78
Mag react, p.u.	4.60
Pri leak react, p.u.	.142
Sec leak react,p.u.	.091

.887	Bar Factor
.437	Ring Factor
.00524	r_2 cold, p.u.
.00628	r_2 hot, p.u.

NO LOAD

.364	Fe loss res p.u.
4.58	App mag react p.u
20.	No-load amps
.019	Pri I^2r
5.230	No-load KW

LOCKED ROTOR

.251	Sta zz factor
.220	Sta skew factor
.338	Rot Bridge constant
.723	Rot slot factor
.124	Pri leak react, p.u.
.0385	Sec leak react, p.u.
.0188	Cold sec res, p.u.
.0244	Hot sec res, p.u.
.0796	App lock rot res
.421	App lock rot react.
.429	App lock rot imped.
591	Lock rot, amps
87.1	Torque % of F.L.

BREAKDOWN TORQUES

.13	Pri leak react p.u.
.074	Sec leak react p.u.
318	Pri amps
10458	RPM at bd torq.
214	Bd torq.% of F.L.

FULL LOAD

.0080	Slip
82.830	K-watts input
120.	Pri amps
115	Sec amps
3.967	F&W
1.890	Stray load loss
.647	Sec I^2r
.652	Pri I^2r
1.110	Core loss
8.266	Tot losses, KW
.9001	
[illegible]	Torque ,lb-ft.
613.7	CM/amp
270.20	Cost of iron
64.65	Cost of copper
10.40	Cost of aluminum
345.16	Total,act mat'l, lbs.

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTORS

RATING

Design Number	6.2.2
HP Rating	100
Line Volts	440
Phases	3
Frequency	180
Poles	2
FL RPM	10 600

CORE DIMS

Cross Iron, Sta	4.000
No. Sta Ducts	.000
Width Sta Ducts	.000
Cross Iron, Rotor	4.000
No. Rotor Ducts	.000
Width Rotor Ducts	.000
Skew % Rotor Ducts	115
Shaft Material	Magnetic

Cost/lb. Iron	1.000
Cost/lb. Copper	1.000
Cost/lb. Alum.	1.00

ELECTRICAL SPEC.

Delva	Connections
2	No. of circuits
11	Actual TPC
5	Stds/Cond
.0508	Dia Bare
.0538	Dia Over Ins
11	Coil throw 1 & [illegible]
1.19	K_1
1.13	K_2
60.0	Phase Belt Angle
.956	Dist Fact k_d

ROTOR

50.0	% Conductivity
.000	Bar Extensions
.135	Bar Area
.[illegible] 1'32	Ring Area
6.187	Ring O.D.
3.687	Ring I.D.
2.00	% S.L. Loss
1.000	F&W in KW

STATOR PUNCHING

Sta Pchg Calc No.	6.1.2 StaII
Outside Dia.	11.500
Gap Dia	6.375
Type of Slots	Part closed
No. Slots	36
Slot Depth	1.200
Slot Opening	.134
Slot Pitch	.556

STATOR PUNCHING

.422	Tooth Face
.207	Eff. Tooth Width
1.071	Eff. Tooth Length
1.414	Yoke Depth, Pchg
.4225	Net Slot Wdg. Area
.362	Permissible ND^2
.696	Slot Const. Air
.900	Slot Const. Wdg.

ROTOR PUNCHING

Rot Pchg Calc No.	6.1.3 Rot II
Outside Dia.	6.295
Eff. I.D.	2.437
No. of slots	31
Type of slots	Closed
Bar Depth	.975
Slot Width, Top	.142
Slot Pitch.	.638
Slot Opening.	.000

ROTOR PUNCHING

.362	Eff. Tooth Width
.975	Eff. Tooth Length
.954	Yoke Depth, Pchg.
2.687	Slot Const, Wdg. Top
.005	Bridge Tkns.
.035	Depth, Slot Mouth
.135	Slot Area, Top
.000	Slot Const, Air
.142	Slot Width, Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS POLYPHASE INDUCTION MOTORS

Desing number	6.2.2
Base ohms	2.6
Air gap	.040
Pole pitch	9.95
ELECTRICAL SPEC.	
Total ND2	.318
% full	74.8
Coil pitch,p.u.	.555
Equiv.CM/1000	44.7
Equiv.TPC	3.17
Full dimension	6.61
MLC	13.00
Copper wt.	36.52
r1 cold	.0195
r1 hot,p.u.	.00897
r1 effect, p.u.	.01031
Pitch factor	.766
Eff ser conds/ph	65.8
SATURATION	
Flux/pole, K-lines	1137
Eff.air gap	.04665
Sta core density	108.1
Sta teeth density	129.0
Rot core density	110.2
Rot teeth density	84.0
Air gap density	44.0
AT,Sta core	247.3
AT, Sta teeth	156.8
AT, Rot core	92.0
AT, Rot teeth	15.4
AT, air gap	642
Total AT	1153.0
Sat factor	1.794
CORE LOSSES	
Sta core loss,KW	.234
Sta teeth loss, KW	.076
Surface loss, KW	.076
Total Core loss,KW	1.586
FULL LOAD REACTANCE	
React constx100,p.u.	4.072
Per-unit skew	.074
Sta slot factor	.677
Sta zz factor	.350
Sta skew factor	.173
Sta end factor	2.225
Pri leakage perm	3.42
Rot bridge constant	0.69
Rot slot factor	1.39
Mag react,p.u.	3.12
Pri leak react,p.u.	.1393
Sec leak react,p.u.	0.078

.988	Bar factor
.561	Ring factor
.00773	r2 cold, p.u.
.00930	r2 hot, p.u.
	NO LOAD
.225	Fe loss res p.u.
3.11	App mag react p.u.
30	No-load amps
.063	Pri I^2r
2.640	No-load KW
	LOCKED ROTOR
.162	Sta zz factor
.046	Sta skew factor
.351	Rot Bridge constant
.651	Rot slot factor
.126	Pri leak react, p.u
.035	Sec leak react, p.u
.0223	Cold sec res, p.u.
.0268	Hot sec res, p.u.
.0949	App lock rot res
.419	App lock rot react.
.429	App lock rot imped
591	Lock rot, amps
94.5	Torque % of F.L.
	BREAKDOWN TORQUE
.13	Pri leak react p.u.
.064	Sec leak react p.u.
342	Pri amps
10276	RPM at bd torq.
223	Bd torq.% of F.L.
	FULL LOAD
.0116	Slip
80.500	K-watts input
120	Pri amps
111	Sec amps
.987	F & W
1.492	Stray load loss
0.904	Sec I^2r
1.008	Pri I2r
1.460	Core loss
5.851	Tot losses,KW
100.06	HP
.9272	Eff.
.878	P.F.
10674	RPM
49.2	Torque, lb-ft.
371.7	CM/amp
155.32	Cost of iron
36.52	Cost of copper
5.65	Cost of aluminum
197.49	Total, act mat'l,lbs

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTORS

RATING			ELECTRICAL SPEC.
Design Number	6.2.3	Delta	Connections
HP Rating	25	1	No.of Circuits
Line Volts	440	11	Actual TPC
Phases	3	5	Stds/Cond
Frequency	120	.0508	Dia Bare
Poles	2	.0538	Dia Over Ins
FL RPM	10600	11	Coilthrow 1 & _.
		1.19	K_1
		1.13	K_2
		60.0	Phase Belt Angle
		.956	Dist Fact k_d

CORE DIMS			ROTOR
Gross Iron,Sta	4.000	60.0	% Conductivity
No.Sta Ducts	.000	.000	Bar Extensions
Width Sta Ducts.	.000	.135	Bar Area
Gross Iron,Rotor	4.000	1.32	Ring Area
No.Rotor Ducts	.000	6.187	Ring O.D.
Width Rotor Ducts	.000	3.687	Ring I.D.
Skew % Rotor Ducts	115	2.00	% S.L.Loss
Shaft Material	Magnetic	1.000	F&W in KW
Cost/lb.Iron	1.000		
Cost/lb.Copper	1.000		
Cost/lb.Alum.	1.00		

STATOR PUNCHING			STATOR PUNCHING
Sta Pchg Calc.No.	6.1.2 Sta II	.422	Tooth Face
Outside Dia.	11.500	.207	Eff Tooth Width
Gap Dia.	6.375	1.071	Eff. Tooth Length
Type of Slots	Part Closed	1.414	Yoke Depth Pchg.
No.Slots.	36	.4225	Net Slot Wdg.Area
Slot Depth	1.200	.362	Permissible ND^2
Slot Opening	.134	.696	Slot Const.Air
Slot Pitch.	.556	.900	Slot Const.Wdg.

ROTOR PUNCHING			ROTOR PUNCHING
Rot Pchg Calc.No.	6.1.3 Rot II	.362	Eff. Tooth Width
Outside Dia.	6.295	.975	Eff. Tooth Length
Eff I.D.	2.437	.864	Yoke Depth, Pchg
No.of Slots.	31	2.687	Slot Const, Wdg.Top
Type of Slots.	closed	.005	Bridge Tkns.
Bar Depth	.975	.035	Depth, Slot Mouth
Slot Width,Top	.142	.135	Slot Area, Top
Slot Pitch	.638	.000	Slot Const, Air
Slot Opening.	.000	.142	Slot Width,Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS POLYPHASE INDUCTION MOTORS

Design Number	6.2.3.
Base ohms	10.4
Air gap	.040
Pole pitch	9.95
ELECTRICAL SPEC.	
Total ND^2	.918
% full	74.8
Coil pitch,p.u.	.555
Equiv.CM/1000	22.3
Equiv.TPC	6.34
Full dimension	6.61
MLC	13.00
Copper wt.	36.52
$r_1$cold	.0780
r_1 hot ,p.u	.00897
r_1 effect, p.u.	.01031
Pitch factor	.766
Eff. ser cond s/ph	111.6
SATURATION	
Flux/pole, K-lines	568.5
Eff air gap	.04665
Sta core density	54.0
Sta teeth density	64.5
Rot core density	55.1
Rot teeth density	42.0
Air gap density	22.0
AT, Sta core	101.4
AT, sta teeth	28.2
AT, Rot core	48.8
AT, Rot teeth	7.5
AT, air gap	341.2
Total AT	506.9
Sat factor	1.481
CORE LOSSES	
Sta [illegible] core loss,KW	.081
Sta teeth loss,KW	.021
Surface loss,KW	.013
Total Core loss,KW	.441
FULL LOAD REACTANCE	
React constx100,p.u.	4.072
Per-unit skew	.074
Sta slot factor	.677
Sta zz factor	.350
Sta skew factor	.173
Sta end factor	2.225
Pri leakage perm	3.44
Rot bridge constant	.92
Rot slot factor	1.52
Mag react,p.u.	3.34
Pri leak react,p.u.	.140
Sec leak react,p.u.	.084

.988	Bar factor
.560	Ring factor
.00773	r_2 cold,p.u.
.0093	r_2 hot, p.u.
	NO LOAD
.261	Fe loss res p.u.
3.42	App mag react p.u.
8.2	No-load amps
.014	Pri I^2r
1.612	No-load KW
	LOCKED ROTOR
.291	Sta zz factor
.089	Sta skew factor
.481	Rot Bridge constant
.723	Rot slot factor
.132	Pri leak react, p.u.
.048	Sec leak react,p.u.
.0223	Cold sec res,p.u.
.0268	Hot sec res,p.u.
.38	App lock rot res.
1.68	App lock rot react.
1.73	App lock rot imped
126	Lock rot, amps
82.5	Torque % of F.L.
	BREAK DOWN TORQUE
.142	Pri leak react p.u.
.072	Sec leak react p.u.
84	Pri amps
10283	RPM at bd torq.
199	Bd torq. % of F.L.
	FULL LOAD
.0136	Slip
21.100	K-watts input
31.2	Pri amps
32.1	Sec amps
.987	F&W
.373	Stray load loss
.226	Sec I^2r
.252	Pri I^2r
.365	Core loss
2.203	Tot losses, KW
25.01	HP
.8872	Eff
.874	P.F.
10652	RPM
12.40	Torque, lb-ft.
710.2	CM/amp
155.32	Cost of iron
36.52	Cost of copper
5.65	Cost of aluminum
197.49	Total act mat'l, lbs.

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTORS

RATING

Design Number	6.3.1
HP Rating	100
Line Volts	440
Phases	2
Frequency	180
Poles	2
FL RPM	10600

CORE DIMS

Gross Iron, Sta	4.500
No. Sta Ducts	.000
Width Sta Ducts	.000
Gross Iron, Rotor	4.500
No. Rotor Ducts	.000
Width Rotor Ducts	.000
Skew % Rotor Ducts	115
Shaft Material	Magnetic

Cost/lb. Iron	1.00
Cost/lb. Copper	1.00
Cost/lb. Alum	1.00

ELECTRICAL SPEC.

Two-phase	Connections
2	No. of circuits
7	Actual TPC
5	Stds/Cond.
.0641	Dia Bare
~~12~~ .0673	Dia Over Ins
~~1.19~~ 12	Coilthrow 1 & _.
~~1.13~~ 1.19	K_1
~~90.0~~ 1.13	K_2
~~.900~~ 90.0	Phase Belt Angle
.900	Dist Fact k_d

ROTOR

50.0	% Conducitivity
.000	Bar Extension
.135	Bar Area
1.320	Ring Area
6.187	Ring O.D.
3.687	Ring I.D.
2.000	% S.L. Loss
1.000	F.&W in KW

Stator Punching

Sta Pchg Calc. No.	6.1.2. Sta II
Outside Dia.	11.500
Gap Dia.	6.375
Type of Slots	Part Closed
No. Slots	36
Slot Depth	1.200
Slot Opening	.134
Slot Pitch	.556

Stator Punching

.422	Tooth Face
.207	Eff. Tooth Width
1.071	Eff. Tooth Length
1.414	Yoke Depth, Pchg
.4255	Net Slot Wdg. Area
.362	Permissible ND^2
.696	Slot Const. Air
.900	Slot Const. Wdg.

ROTOR PUNCHING

Rot Pchg Calc. No.	6.1.3 Rot II
Outside Dia.	6.295
Eff. I.D.	2.437
No. of Slots	31
Type of Slots	closed
Bar Depth	.975
Slot Width, Top	.142
Slot Pitch.	.638
Slot Opening.	.000

ROTOR PUNCHING

.362	Eff. Tooth Width
.975	Eff. Tooth Length
.954	Yoke Depth, Pchg
2.687	Slot Const, Wdg. Top
.005	Bridge Tkns.
.035	Depth, Slot Mouth
.135	Slot Area, Top
.000	Slot Const, Air
.142	Slot Width, Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS POLYPHASE INDUCTION MOTORS

Design Number	6.3.1
Base ohms	5.2
Air gap	.040
Pole pitch	9.95
ELECTRICAL SPEC.	
Total ND2	.317
% full	74.5
coil pitch, p.u.	.611
Equiv. CM/1000	41.0
Equiv. TPC	3.50
Full dimension	7.27
MLC	14.28
Copper wt.	40.67
r_1 cold	.0385
r_1 hot, p.u.	.00886
r_1 effect, p.u.	.0101
Pitch factor	.819
Eff ser conds/ph	92.8
SATURATION	
Flux/pole, K-lines	1184
Eff air gap	.0466
Sta core density	100.0
Sta teeth density	119.3
Rot core density	101.9
Rot teeth density	77.6
Air gal density	40.7
AT, Sta core	167.10
AT, Sta teeth	93.2
AT, Rot core	61.3
AT, Rot teeth	11.8
AT, air gap	594.4
Total AT	927.7
Sat factor	1.561
CORE LOSSES	
Sta core loss, KW	.194
Sta teeth loss, KW	.064
Surface loss, KW	.071
Total core loss, KW	1.383
FULL LOAD REACTANCE	
React constx100, p.u.	3.760
Per-unit skew	.074
Sta slot factor	.836
Sta zz factor	.394
Sta skew factor	.224
Sta end factor	2.30
Pri leakage perm	3.75
Rot bridge constant	.701
Rot slot factor	1.67
Mag react, p.u.	3.73
Pri leak react, p.u.	.141
Sec leak react, p.u.	.082

1.104	Bar Factor
.561	Ring factor
.00767	r_2 cold, p.u.
.00920	r_2 hot, p.u.
	NO LOAD
.276	Fe loss res p.u.
.3.71	App mag react p.u.
22	No-load amps
.044	Pri I^2r
2.420	No-load KW
	LOCKED ROTOR
.191	Sta zz factor
.068	Sta skew factor
.369	Rot Bridge constant
.741	Rot slot factor
.127	Pri leak react, p.u.
.037	Sec leak react, p.u.
.0227	Cold sec res, pu
.0273	Hot sec res, p.u.
.1918	App lock rot res
.857	App lock rot react.
.8785	App lock rot imped
500	Lock rot, amps
92.3	Torque % of F.L.
	BREAKDOWN TORQUE
.13	Pri leak react p.u.
.067	Sec leak react p.u.
290	Pri amps
10290	RPM at bd torq
219	Bd torq, % of F.L.
	FULL LOAD
.0113	Slip
80.260	K-Watts input
102	Pri amps
96	Sec amps
.987	F&W
1.490	Stray load loss
.887	Sec I^2r
.960	Se Pri I^2r
1.270	Core loss
5.594	Tot losses, KW
100.08	HP
.9302	Eff
.892	P.F.
10677	RPM
49.2	Torque, lb-ft.
401.8	CM/amp
174.73	Cost of iron
40.67	Cost of copper
5.85	Cost of aluminum
221.27	Total act mat'l, lbs.

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTOR

RATING

Design Number	6.3.2.
HP Rating	100
Line Volts	440
Phases	2
Frequency	180
Poles	2
FL RPM	10600

CORE DIMS.

Gross Iron, Sta	6.500
No. Sta Ducts	.000
Width Sta Ducts	.000
Gross Iron, Rotor	6.500
No. Rotor Ducts	.000
Width Rotor Ducts	.000
Skew % Rotor Ducts	115
Shaft Material	Magnetic

Cost/lb. Iron	1.00
Cost/lb. Copper	1.00
Cost/lb. Alum.	1.00

ELECTRICAL SPEC.

Two-Phase	Connections
2	No. of circuits
6	Actual TPC
7	Stds/Cond
.0571	Dia. Bare
.0602	Dia Over Ins
12	Coil Throw 1 & ...
1.19	K_1
1.13	K_2
90.0	Phase Belt Angle
.900	Dist Fact k_d

ROTOR

~~26.3~~ 50.0	% Conductivity
.000	Bar Extension
.135	Bar Area
.440	Ring Area
6.187	Ring O.D.
3.687	Ring I.D.
2.00	% S.L. Loss
1.000	F&W in KW

STATOR PUNCHING

Sta Pchg Calc. No.	6.1.2 Sta II	.422	Tooth Face
Outside Dia.	11.500	.207	Eff. Tooth Width
Gap Dia.	6.375	1.071	Eff. Tooth Length
Type of Slots	Part. closed	1.414	Yoke Depth, Pchg
No. Slots	36	.4255	Net Slot Wdg. Area
Slot Depth	1.200	.362	Permissible ND2
Slot Opening	.134	.696	Slot Const. Air
Slot Pitch.	.556	.900	Slot Const. Wdg.

ROTOR PUNCHING

Rot Pchg Calc. No.	6.1.3. Rot II	.362	Eff. Tooth width
Outside Dia.	6.295	.975	Eff. Tooth Length
Eff. I.D.	2.437	.954	Yoke Depth, Pchg
No. of slots.	31	2.687	Slot Const, Wdg. Top
Type of Slots	closed	.005	Bridge Tkns.
Bar Depth	.975	.035	Depth, Slot Mouth
Slot width, Top	.142	.135	Slot Area, Top
Slot pitch	.638	.000	Slot Const, Air
Slot Opening.	.000	.142	Slot Width, Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS POLYPHASE INDUCTION MOTORS

Design Number	6.3.2.
Base ohms	5.2
Air gap	.040
Pole pitch	9.95
Electrical Spec.	
Total ND2	.304
% full	71.5
Coil pitch, p.u.	.611
Equiv. CM/1000	45.6
Equiv TPC	3.00
Full dimension	7.27
MLC	16.28
Copper wt.	44.14
r_1 cold	.0339
r_1 hot, p.u.	.0091
r_1 effect, p.u.	.0105
Pitch factor.	.819
Eff ser conds/ph	79.6
SATURATION	
Flux/pole, K-lines	1381
Eff air gap	.0466
Sta core density	80.8
Sta teeth density	96.4
Rot core density	82.3
Rot teeth density	62.7
Air gap density	32.9
AT, Sta core	70.0
AT, Sta teeth	30.0
AT, Rot core	25.1
AT, Rot teeth	9.1
AT, air gap	480.1
Total AT	614.3
Sat factor	1.279
CORE LOSSES	
Sta core loss, KW	.151
Sta teeth loss, KW	.044
Surface loss, KW	.060
Total core loss, KW	1.077
FULL LOAD REACTANCE	
React constx100, p.u.	2.76
Per-unit skew	.074
Sta slot factor	1.206
Sta zz factor	.570
Sta skew factor	.396
Sta end factor	2.30
Pri leakage perm.	4.47
Rot bridge constant.	.76
Rot slot factor	2.30
Mag react, p.u.	4.83
Pri leak react, p.u.	.123
Sec leak react, p.u.	.020

1.573	Bar Factor
.560	Ring factor
.0072	r_2 cold, p.u.
.0114	r_3 hot, p.u.
	NO LOAD
.352	Fe loss res p.u.
4.84	App mag react p.u.
17.1	No-load amps
.028	Pri I_2r
2.105	No-load KW
	LOCKED ROTOR
.292	Sta zz factor
.148	Sta skew factor
.387	Rot Bridge constant
1.082	Rot slot factor
.109	Pri leak react, p.u.
.042	Sec leak react, p.u
.023	Cold sec res, p.u.
.027	Hot sec res, p.u.
.195	App lock rot res
.783	App lock rot react.
.807	App lock rot imped
.544	Lock rot, amps
110.6	Torque % of F.L.
	BREAKDOWN TORQUE
.112	Pri leak react p.u.
.073	Sec leak react p.u.
842	Pri amps
10134	RPM at bd torq.
233	Bd torq. % of F.L.
	FULL LOAD
.0136	Slip
80.080	K-watts input
99	Pri amps
95	Sec amps
.985	F&W
1.490	Stray load loss
1.068	Sec I^2r
.919	Pri I^2r
1.000	Core loss
5.472	Tot losses, KW
99.99	HP
.9315	Eff
.915	P.F.
10652	RPM
49.3	Torque, lb-ft.
459.3	CM/amp.
252.39	Cost of iron
44.14	Cost of copper
6.67	Cost of aluminum
303.20	Total act mat'l, lbs

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR POLYPHASE INDUCTION MOTORS

RATING

Design Number	6.3.3
HP Rating	25
Line Volts	440
Phases	2
Frequency	180
Poles	2
FL RPM	10600

CORE DIMS

Gross Iron,Sta	6.500
No.Sta Ducts	.000
Width Sta. Ducts	.000
Gross Iron, Rotor	6.500
No.Rotor Ducts	.000
Width Rotor Ducts	.000
Skew % Rotor Ducts	115
Shaft Material	Magnetic

Cost/lb.Iron	1.00
Cost /lb.Copper	1.00
Cost/lb.Alum	1.00

Electrical Spec.

Two-Phase	Connections
1	No.of circuits
6	Actual TPC
7	Stds/Cond.
.0571	Dia Bare.
.0602	Dia. Over Ins
12	Coilthrow 1 & __.
1.19	K_1
1.13	K_2
90.0	Phase Belt Angle
.900	Dist.Fact k_d

ROTOR

~~26.3~~ 50.0	% Conductivity
.000	Bar Extension
.135	Bar Area
.440	Ring Area
6.187	Ring O.D.
3.687	Ring I.D.
2.000	% S.L.Loss
1.000	P&W in KW

STATOR PUNCHING

Sta Pchg Calc.No.	6.1.2.StaII
Outside Dia.	11.500
Gap Dia.	6.375
Type of Slots.	Part closed
No.Slots.	36
Slot Depth	1.200
Slot Opening	.134
Slot Pitch.	.556

STATOR PUNCHING

.422	Tooth Face
.207	Eff. Tooth Width
1.071	Eff Tooth Length
1.414	Yoke Depth, Pchg.
.4255	Net Slot Wdg.Area
.362	Permissible ND^2
.696	Slot Const.Air
.900	Slot Const.Wdg.

ROTOR PUNCHING

Rot Pchg Calc.No.	6.1.3 RotII
Outside Dia.	6.295
Eff. I.D.	2.437
No.of slots.	31
Type of slots.	closed
Bar Depth	.975
Slot width,Top	.142
Slot Pitch	.638
Slot Opening.	.000

ROTOR PUNCHING

.362	Effect. Tooth Width
.975	Eff. Tooth Length
.954	Yoke Depth,Pchg.
2.687	Slot Const, Wdg.Top
.005	Bridge Thns.
.035	Depth,Slot Mouth
.135	Slot Area ,Top
.000	Slot Const.Air
.142	Slot Width,Bottom.

SUMMARY OF BASIC DESIGN CALCULATIONS POLYPHASE INDUCTION MOTORS

Design Number	6.3.2
Base ohms	20.8
Air gap	.040
Pole pitch	9.95
ELECTRICAL SPEC.	
Total ND2	0.304
% full	71.5
Coil pitch,p.u.	.611
Equiv.CM/1000	22.8
Equiv.TPC	6.00
Full dimension	7.27
MLC	16.28
Copper wt.	44.14
r_1 cold	.1356
r_1 hot,p.u.	.0091
r_1 effect,p.u.	.0105
Pitch factor	.819
Eff ser conds/ph.	159.2
SATURATION	
Flux/pole, K-lines	690.5
Eff air gap	.0466
Sta core density	40.4
Sta teeth density	48.2
Rot core density	41.10
Rot teeth density	31.3
Air gap density	16.45
AT, sta core	30.5
AT, Sta teeth	7.7
AT, Rot core	10.4
AT, Rot teeth	4.5
AT, air gap	240.0
Total AT	293.1
Sat factor.	1.222
CORE LOSSES	
Sta core loss, KW	.045
Sta teeth loss,KW	.010
Surface loss, KW	.010
Total core loss,KW	.277
FULL LOAD REACTANCE	
React constx100,p.u.	2.76
Per-unit skew	.074
Sta slot facter	1.206
Sta zz factor	.570
Sta skew factor	.414
Sta end factor	2.30
Pri leakage perm.	4.49
Rot bridge constant	1.10
Rot slot factor	2.53
Mag react,p.u.	5.05
Pri leak react,p.u.	.124
Sec leak react,p.u.	.097

1.573	Bar Factor
.560	Ring factor
.0072	r_2 cold, p.u.
.0114	r_2 hot, p.u.
%	NO LOAD
0.396	Fe loss res p.u.
5.02	App mag react p.u.
4.1	No-load amps
.0064	Pri I^2 r
1.284	No-load KW
	LOCKED ROTOR
.468	Sta zz factor
.273	Sta skew factor
.529	Rot Bridge constant
1.177	Rot slot factor
.117	Pri leak react,p.u.
.053	Sec leak react,p.u.
.023	Cold sec res,p.u.
.027	Hot sec res,p.u.
.780	App lock rot res.
3.53	App lock rot react.
.361	App lock rot imped
121	Lock rot, amps
87.8	Torque % of F.L.
	BREAKDOWN TORQUE
0.120	Pri leak react p.u
.084	Sec leak react p.u
79.	Pri amps
10175	RPM at bd torq.
206	Bd torq.% of F.L.
	FULL LOAD
.0143	Slip
20.810	K-watts input
26	Pri amps
24.9	Sec amps
.985	F&W
.373	Stray load loss
.291	Sec I^2r
.255	Pri I^2r
.255	Core loss
2.054	Tot losses,KW
25.01	HP
.8962	Eff
.913	P.F.
10644	RPM
12.3	Torque,lbft
881.4	CM/amp
252.39	Cost of iron
44.14	Cost of copper
6.67	Cost of aluminum
303.20	Total act mat'l,lbs.

SUMMARY OF BASIC DESIGN CALCULATIONS-POLYPHASE INDUCTION MOTORS

Design Number	6,3,4
Base ohms	5.2
Air gap.	.040
Pole pitch	9.96
ELECTRICAL SPEC.	
Total ND^2	.304
% full	71.5
coil pitch,pu	.611
Equiv.CM/1000	456
Equiv.TPC	300
Pull dimension	7.27
MLC	16.20
Copper wt.	44.14
r_1 cold	.0239
r_1 hot	.0091
r_1 effect,p.u.	.0105
Pitch factor	.819
Eff ser conds/ph.	79.6
SATURATION	
Flux /pole,K-lines	1331
Eff air gap	.0466
Sta core density	80.8
Sta teeth density	96.4
Rot core density	82.3
Rot teeth density	62.7
Air gap density	32.9
AT, sta core.	70.0
AT, Sat teeth	30.0
AT, Rot core	25.1
AT, Rot teeth	9.1
AT, Airgap	480.1
Total AT	614.3
Sat factor	1.272
CORE LOSSES	
Sta core loss,KW	.151
Sta teeth loss, KW	.044
Surface loss,KW	.060
Total core loss,KW	1.077
FULL LOAD REACTANCE	
React constx100,p.u.	2.76
Per-unit skew	.074
Sta slot factor	1.206
Sta zz factor	.570
Sta skew factor	.396
Sta end factor	2.30
Pri leakage perm.	4.47
Rot bridge constant	.760
Rot slot factor	2.30
Mag react, p.u.	4.83
Pri leak react,p.u.	.123
Sec leak react,p.u.	.090

1.573	Bar Factor
1.682	Ring factor
.0209	r_2 cold, p.u.
.0331	r_2 hot, p.u.
	NO LOAD
.352	Fe loss res p.u.
4.84	App mag react p.u.
17.1	No-load amps
.028	Pri I^2 r
2.105	No-load KW
	LOCKED ROTOR
.311	Sta zz factor
.155	Sta skew factor
.404	Rot bridge constant
1.422	Rot slot factor
1.09	Pri leak react,p.u.
.052	Sec leak react,p.u.
.0393	Cold sec res,p.u.
.04716	Hot sec res,p.u.
.294	App lock rot res.
.840	App lock rot react.
.890	App lock rot imped.
494	Lock rot, amps
150.4	Torque % of F.L.
	BREAKDOWN TORQUE
.112	Pri leak react p.u.
.072	Sec leak react p.u.
3.36	Pri amps
8906	RPM at bd torq.
228	Bd torq.% of F.L.
	FULL LOAD
.0409	Slip
82.212	K-watts input
102	Pri amps
97.8	Sec amps
.968	F&W
1.490	Stray load loss
3.285	Sec I^2r
.992	Pri I^2r
.996	Core loss
7.721	Tota losses,KW
99.85	HP
.9060	Eff.
9148	P.F.
10357	RPM
50.6	Torque,lb-ft.
446.9	CM/amp
252.39	Cost of iron
44.14	Cost of copper
4.00	Cost of aluminum
300.39	Total act mat'l,lbs.

SUMMARY OF BASIC CALCULATION POLYPHASE INDUCTION MOTORS

Design Number	6.33.
Base ohms	20.8
Air gap	.040
Pole pitch	9.95
ELECTRICAL SPEC	
Total ND2	0.304
% full	71.5
Coil pitch,p.u.	.611
Equiv.CM/1000	22.8
Equiv.TPC	6.00
Full dimension	7,27
MLC	16.28
Copper wt.	44.14
r_1 cold	.1356
r_1 hot,p.u.	.0091
r_1 effect,p.u.	.0105
Pitch factor	.819
Eff.ser conds/ph.	159.2
SATURATION	
Flux /pole,K-lines	690.5
Eff air gap	.0466
Sta core density	40.4
Sta teeth density	48.2
Rot core density	41.10
Rot teeth density	31.3
Air gap density	16.45
AT, Sta core	30.5
AT, Sta teeth	7.7
AT, Rot core	10.4
AT,Rot teeth	4.5
AT,air gap	240.0
Total AT	293.1
Sat factor	1.222
CORE LOSSES	
Sta core loss,KW	.045
Sta teeth loss,KW	.010
Surface loss,KW	.010
Total core loss,KW	.277
FULL LOAD REACTANCE	
React constx100,p.u.	2.76
Per-unit skew	.074
Sta slot factor	1.206
Sta z_z factor	.570
Sta skew factor	.414
Sta end factor	2.30
Pri leakage perm.	4.49
Rot bridge constant	1.10
Rot slot factor	2.53
Mag react, p.u.	5.05
Pri leak react,p.u.	.124
Sec leak react,p.u.	.097

1.573	Bar Factor
1.682	Ring factor
.02095	r_2 cold,p.u.
.0114	r_2 hot,p.u.
	NO LOAD
.396	Fe loss res p.u.
5.02	App mag react p.u.
4.1	No-load amps
.0064	Pri I^2r
1.284	No-load KW
	LOCKED ROTOR
.483	Sta z_z factor
.280	Sta skew factor
.544	Rot Bridge constant
1.516	Rot slot factor
.118	Pri leak react,p.u.
.063	Sec leak react,p.u.
.0393	Cold sec res,p.u.
.0471	Hot sec res,p.u.
1.174	App lock rot res.
3.749	App lock rot react.
3.930	App lock rot imped
112	Lock rot, amps
122.8	Torque % of F.L.
	BREAK DOWN TORQUE
.121	Pri leak react p.u.
.084	Sec leak react p.u.
78	Pri amps
9029	RPM at bd torque.
202	Bd torq.% of F.L.
	FULL LOAD
.0430	Slip
21.381	K-watts input
27	Pri amps
26	Sec amps
.956	F&W
.372	Stray load loss
.897	Sec I^2r
.270	Pri I^2r
.264	Core loss
2.749	Tot losses,KW
24.9	HP
.8713	Eff
.912	P.F.
10335	RPM
12.7	Torque,lb-ft.
866.1	CM/amp
252.39	Cost of iron
44.14	Cost of copper
4.00	Cost of aluminum
300.39	Total act mat'l lbs.

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR SINGLE-PHASE INDUCTION MOTORS

RATING			ROTOR
Design Number	6.4.1	75	Motor Temp °C
Type of Motor	Perm.-Split	50	% conductivity
HP Rating	100	.125	Bar Area
Main Phase Volts	440	.000	Bar Extension
Aux. Phase Volts	440	1.320	Ring Area
Frequency	180	6.187	Ring O.D.
Poles	2	3.687	Ring I.D.
FL RPM	10,500	115	Skew % Rotor Slots
Gross Iron	4.5	2.00	% Stray Load Loss
Shaft Material	Magnetic	1000	F & W at syn RPM, Watts

MAING WINDING			AUX.WINDING
Outer Coil Span(Teeth)	17	17	Outer Coil Span(Teeth)
TPC Outer Coil.	14	16	TPC Outer Coil
TPC	7	8	TPC
TPC	7	8	TPC
TPC	7	8	TPC
TPC	7	8	TPC
TPC	7	6	TPC
TPC	7	5	Stds/Cond
TPC	7	.0641	Dia Bare
Stds/Cond.	5	.0673	Dia Over Ins
Dia Bare	.0641	2	No.of Circuits
Dia over Ins.	.0673	.00	Stg.MFD
No.of Circuits.	2	183	Rng.MFD

STATOR PUNCHING			STATOR PUNCHING
Sta Pchg Calc.No.	6.1.2.StaII	.422	Tooth Face.
Outside Dia.	11.500	.207	Eff. Tooth Width
Gap Dia.	6.375	1.071	Eff. Tooth Length
Type of Slots.	Part-Closed	1.414	Eff. Yoke Depth
No.of Slots.	36	.4225	Net Slot Wdg.Area
Slot Depth	1.200	.362	Permissible ND2
Slot Opening	.134	.696	Slot Const.Air
Slot Pitch.	.556	.900	Slot Const.Wdg.

ROTOR PUNCHING			ROTOR PUNCHING.
Rot Pchg Calc.No.	6.1.3 Rot II	.362	Eff. Tooth Width
Outside Dia.	6.295	.975	Eff. Tooth Length
Eff.I.D.	2.437	.954	Yoke Depth Pchg.
No.of Slots.	31	.2687	Slot Const.Wdg.Top
Type of Slots.	Closed	.005	Bridge Tkns.
Bar Depth	.975	.035	Depth, Slot Mouth
Slot Width, Top	.142	.135	Slot Area, Top.
Slot Pitch.	.638	.000	Slot Const, Air.
Slot Opening.	.000	.142	Slot Width, Bottom.

SUMMARY OF BASIC DESIGN CALCULATIONS
SINGLE PHASE INDUCTION MOTORS

Design Number	6.41.
Base Amps	169.5
Base Ohms	2.60
Base Number	1.00

MAIN WINDING

Winding Factor	.738
Eff.Series Cond.	93.04
MLC	16.11
r_1 Cold, Ohms	.0435
r_2 Hot, PU	.0200
Copper Weight.	22.94

AUX.WINDING

Winding Factor	.862
Eff.Series Cond.	92.14
a Ratio	1.001
MLC	16.69
r_{1a} Cold, Ohm	.0386
r_{1a} Hot, PU	.0177
Copper Weight.	20.36

% FULL

% Full, Slot	No.1	73.3
	No.2	36.6
	No.3	36.6
	No.4	69.2
	No.5	79.8
	No.6	79.8
	No.7	79.8
	No.8	79.8
	No.9	83.8
	No.10	.000

SATURATION

.04	Air Gap
.0466	Eff.Air Gap
99.9	Sta Core Density
119.1	Sta. Teeth Density
91.5	Rot Core Density
69.7	Rot Teeth Density
39.1	Air Gap Density
1.285	Saturation Factor

FL RESISTANCE

7.64	React Const x 100 PU
0.742	PU Skew
120.4	Mag Perm.
.714	Sta. Slot Perm
.394	Zig Zag Perm.
.272	Skew Perm.
2.76	Sta.End Perm.
1.39	Rotor Slot Perm
.320	Rot Bridge Constant.
9.08	Mag React.PU
.312	Sta Leak React, PU
.155	Rot Leak React. PU
.921	Pri Flux Const.K_f

ROT RESISTANCE

.924	Res Const x 100
1.104	Bar Factor
.561	Ring Factor
.018	r_2 Hot, PU
156.3	Fe Wgt
5.85	Al Wgt

NO LOAD

Main Wdg Amps	166.4
Aux Wdg Amps	210.2
NL Amps	250.7
NL Watts	19530
Aux Wdg Volts	791.8
Cap. Volts	1015

RUN START SWITCH

1058	BDT, Oz Ft
.000	RPM
.000	Torque, Oz Ft.
.000	Main Wdg.Amps
.000	Cap Volts
.000	Aux. Wdg Volts
.000	Main Wdg Amps
.000	Torque, Oz Ft.

SUMMARY OF BASIC DESIGN CALCULATIONS
SINGLE PHASE INDUCTION MOTORS (CONT'D)

FULL LOAD			LOCKED ROTOR
Pri I^2r	1645	.313	Zig Zag Perm
Sec I^2r, Forward	567	.173	Skew Perm.
Sec I^2r, Backward	4056	.570	Rot Slot Perm
Core Loss	2128	.000	Rot Bridge Const.
F&W Loss	992	.299	Sta Leak React, PU
Stray Load Loss	1493	.079	Rot Leak React, Pu
Total Losses, Watts.	10881	.0548	r_2 Hot, PU
Slip	.0071	.0740	Main Res Hot, PU
RPM	10723	.378	Main React, PU
% Full Load.	100.11	.0720	Aux Res Hot, PU
Torque,Oz Ft.	784.9	.379	Aux React, PU
FL Amps	250.7	.000	Cap Res, PU
Main Wdg Amps	88.2	.000	Cap React, PU
Aux Wdg Amps	164.3	73.1	Locked K-Watts.
Main Wdg Watts.	25842	3.28	Locked Torque,Oz ft.
Aux Wdg Watts	59790	879.2	Locked Amps
Eff	.8728	439	Main Wdg Amps
P.F.	.776	439	Aux Wdg Amps
Cap Volts	793	.000	Cap Volts
CM/Amp	465.8	440	Aux Wdg Volts
Main Wdg Amps BDT	226.4		
RRM at BDT	10559		

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR SINGLE PHASE INDUCTION MOTORS

RATING			ROTOR
Deign Number	6.42	75.0	Motor Temp °C
Type of motor	Two-value	26.3	% Conductivity
HP Rating	100	.135	Bar Area
Main Phase Volts	440	.000	Bar Extension
Aux. Phase Volts	440	.185	Ring Area
Frequency	180	6.187	Ring O.D.
Poles	2	3.687	Ring I.D.
FL RPM	10,600	115	Skew % Rotor Slots.
Gross Iron	6.5	2.00	% Stray Load Loss
Shaft Material	Magnetic	1000	F & W at syn.RPM,Watts.

MAIN WINDING			AUX. WINDING
Outer Coil Span(Teeth)	17	17	Outer Coil Span(Teeth)
TPC Outer Coil	10	12	TPC Outer Coil
TPC	5	6	TPC
TPC	5	6	TPC
TPC	5	6	TPC
TPC	5	4	TPC
TPC	5	4	TPC
TPC	5	7	Stds/Cond
TPC	5	.0641	Dia Bare
Stds./Cond.	7	.0673	Dia Over Ins
Dia. Bare	.0641	2	No.of circuits
Dia Over Ins	.0673	500	Stg.MFD
No.of Circuits.	2	125	Rng.MFD

STATOR PUNCHING			STATOR PUNCHING
Sta Pchg Calc No.	6.1.2 Sta.II	.422	Tooth Face
Outside Dia	11.500	.207	Eff. Tooth Width
Gap Dia	6.375	1.071	Eff. Tooth Length
Type of Slots	Part.closed	1.414	Eff. Yoke Depth
No.Slots	31	.4255	Net Slot Wdg.Area
Slot Depth	1.200	.362	Permissible ND2
Slot Opening	.134	.696	Slot Const.Air
Slot Pitch.	.556	.900	Slot Const.Wdg.

ROTOR PUNCHING			ROTOR PUNCHING.
Rot.Pchg Calc.No.	6.1.3 Rot III	.224	Eff.Tooth Width
Outside Dia.	6.295	.400	Eff.Tooth Length
Eff. I.D.	2.437	1.528	Yoke Depth , Pchg
No.of Slots	31	.530	Slot Const, Wdg.Top
Type of Slots	Closed	.005	Bridge Tkns.
Bar Depth	.400	.035	Depth, Slot Mouth
Slot Width, Top	.357	.135	Slot Area ,Top
Slot Pitch	.638	.000	Slot Const, Air
Slot Opening	.000	.357	Slot Width, Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS
SINGLE PHASE INDUCTION MOTORS

Design Number	6.4.2
Base Amps	169.5
Base Ohms	2.60
Base Number	1.00

MAIN WINDING

Winding Factor	.738
Eff. Series Cond.	66.46
MLC	18.11
r_1 Cold, Ohms	.0249
r_1 Hot, PU	0.114
Copper Weight	25.78

AUX.WINDING

Winding Factor	.874
Eff.Series Cond.	66.45
a Ratio	.999
MLC	19.00
r_{1a} Cold, Ohms	.0221
r_{1a} Hot,PU	.0101
Copper Weight	22.85

% FULL

% Full,Slot	No.1	73.3
	No.2	36.6
	No.3	36.6
	No.4	67.0
	No.5	67.0
	No.6	81.9
	No.7	81.9
	No.8	81.9
	No.9	87.9
	No.10	.000

SATURATION

.04	Air Gap
.0466	Eff.Air Gap
96.8	Sta Core Density
115.4	Sta.Teeth Density
62.3	Rot Core Density
109.2	Rot Teeth Density
37.8	Air Gap Density
1.254	Saturation Factor

FL RESISTANCE

3.83	React Const x 100 PU
.0742	PU Skew
178.2	Mag Perm
1.031	Sta Slot Perm
.570	Zig Zag Perm
.403	Skew Perm
2.762	Sta End Perm
.639	Rotor Slot Perm
.426	Rot Bridge Constant
6.86	Mag React PU
.183	Sta Leak Reactance, PU
.062	Rot Leak React, PU
.941	Pri Flux Const K_f

ROT RESISTANCE

.897	Res Const x 100
1.573	Bar Factor
4.34	Ring Factor
.0636	r_2 Hot, PU
225.8	F_e Wgt
3.23	At Wgt

NO LOAD

Main Wdg Amps	67.2
Aux Wdg Amps	102.8
NL Amps	93.9
NL Watts	5760
Aux Wdg Volts	520.3
Cap Volts	727.4

RUN START SWITCH

1482	BDT,Oz Ft
8208	RPM
2120	Torque, Oz Ft
552	Main Wdg Amps
470	Cap Volts
307	Aux.Wdg Volts
611	Main Wdg Amps
1224	Torque, Oz Ft

SUMMARY OF BASIC DESIGN CALCULATIONS
SINGLE PHASE INDUCTION MOTORS (CONT'D)

FULL LOAD			LOCKED ROTOR
Pri I^2r	665	.316	Zig Zag Perm
Sec I^2r,Forward	2829	.212	Skew Perm
Sec I^2r,Backward	647	.344	Rot slot perm
Core Loss	1883	.000	Rot Bridge Const.
F&W Loss	964	.166	Sta Leak React, PU
Stray Load Loss	1490	.033	Rot Leak React,Pu
Total Losses, Watts.	8468	.0677	r_2 Hot, PU
Slip	.0353	.0784	Main Res Hot, PU
RPM	10418	.200	Main React, PU
%Full Load	99.89	.1248	Aux Res Hot, PU
Torque,Oz Ft.	806.1	.480	Aux React, PU
FL Amps	192.3	.047	Cap Res, PU
Main Wdg Amps	124.8	.681	Cap React, PU
Aux Wdg Amps	85.4	163.7	Locked K-Watts
Main Wdg Watts	54363	570.7	Locked Torque ,Oz Ft.
Aux Wdg Watts	28675	547	Locked Amps
Eff.	.8980	786	Main Wdg Amps
P.F.	.981	341	Aux Wdg Amps
Cap Volts	604	605	Cap Volts
CM/Amp	460.7	190	Aux Wdg Volts
Main Wdg Amps at BDT	433.2		
RPM at BDT	9482		

	Maximum Starting Torque	Maximum Starting Torque Per Ampere.
Angle	79.3	63.1
T_s	5032	2906
Amp	2088	1053
E_c	1016	923
MFD	1560	1093
MFD	500 (Actual MFD)	1271 (MFD for Switching)

ELECTRICAL AND MAGNETIC SPECIFICATIONS FOR SINGLE PHASE INDUCTION MOTORS

RATING			ROTOR
Design Number	6.43.	75.0	Motor Temp oC
Type of Motor	Two value	26.3	% Conductivity
HP Rating	25	.135	Bar Area
Main Phase Volts	440	.000	Bar Extension
Aux.Phase Volts	440	.185	Ring Area
Frequency	180	6.187	Ring O.D.
Poles	2	3.687	Ring I.D.
FL RPM	10,600	115	Skew % Rotor Slots
Gross Iron	6.5	2.00	% Stray Load Loss
Shaft Material	Magnetic	1000	F&W at syn RPM, Watts.

MAIN WINDING			AUX. WINDING
Outer Coil Span (Teeth)	17	17	Outer Coil Span(Teeth)
TPC Outer Coil	10	12	TPC Outer Coil
TPC	5	6	TPC
TPC	5	6	TPC
TPC	5	6	TPC
TPC	5	4	TPC
TPC	5	4	TPC
TPC	5	7	Stds/Cond
TPC	5	.0641	Dia Bare
Stds/Cond.	7	.0673	Dia Over Ins.
Dia. Bare	.0641	2	No.of circuits
Dia over Ins.	.0673	500	Stg. MFD
No.of circuits	1	125	Rng MFD

STATOR PUNCHING			STATOR PUNCHING
Sta Pchg Calc.No.	6.1.2 StaII	.422	Tooth Face
Outside Dia.	11.500	.207	Eff Tooth Width
Gap Dia.	6.375	1.071	Eff Tooth Length
Type of Slots	Part. Closed	1.414	Eff Yoke Depth
No. slots	31	.4255	Net Slot Wdg. Area
Slot Depth	1.200	.362	Permissible ND^2
Slot Opening	.134	.696	Slot Const. Air
Slot Pitch.	.555	.900	Slot Const. Wdg.

ROTOR PUNCHING			ROTOR PUNCHING
Rot Pchg Calc No.	6.1.3 Rot III	.224	Eff Tooth Width
Outside Dia.	6.295	.400	Eff Tooth Length
Eff I.D.	2.437	1.528	Yoke Depth Pchg
No.of slots	31	.530	SlotConst, Wdg.Top
Type of slots	closed	.005	Bridge Thns.
Bar Depth	.400	.035	Depth, Slot Mouth
Slot Width, Top	.357	.135	Slot Area, Top
Slot Pitch.	.638	.000	Slot Const, Air
Slot Opening.	.000	.357	Slot Width, Bottom

SUMMARY OF BASIC DESIGN CALCULATIONS SINGLE PHASE INDUCTION MOTORS

Design Number	6.4.3
Base Amps	42.38
Base Ohms	10.4
Base Number	1.00

SATURATION

.04	Air Gap
.0466	Eff.Air Gap
48.4	Sta Core Density
57.7	Sta Teeth Density
31.16	Rot Core Density
54.6	Rot Teeth Density
18.9	Air Gap Density
1.154	Saturation Factor

MAIN WINDING

Winding Factor	.738
Eff. Series Cond.	132.9
MLC	18.11
r_1 Cold, Ohms.	.0996
r_1 Hot, PU	.0114
Copper Weight	25.78

AUX. WINDING

Winding Factor	.874
Eff Series Cond	66.45
a Ratio	.4995
MLC	19.00
r_{1a} Cold, Ohms	.0221
r_{1a} Hot, PU	.0101
Copper Weight	22.85

FL RESISTANCE

3.85	React Const x 100 PU
.074	PU skew
193.8	Mag Perm
1.031	Sta Slot Perm
.570	Zig Zag Perm
.439	Skew Perm
2.762	Sta End Perm
.889	Rotor Slot Perm
.799	Rot Bridge Constant
7.46	Mag React PU
.185	Sta Leak React, PU
.073	Rot Leak React, PU
.945	Pri Flux Const Kf

% FULL

% Full, Slot	No. 1	73.3
	No. 2	36.6
	No. 3	36.6
	No. 4	67.0
	No. 5	67.0
	No. 6	81.9
	No. 7	81.9
	No. 8	81.9
	No. 9	87.9
	No. 10	.000

ROT RESISTANCE

.897	Res Const x 100
1.573	Bar Factor
4.34	Ring Factor
.0636	r_2 Hot, PU
225.8	Fe Wgt
3.23	Al Wgt

NO LOAD

Main Wdg Amps	34.7
Aux Wdg Amps	83.6
NL Amps	81.4
NL Watts	3856
Aux Wdg Volts	284.3
Cap Volts	591.4

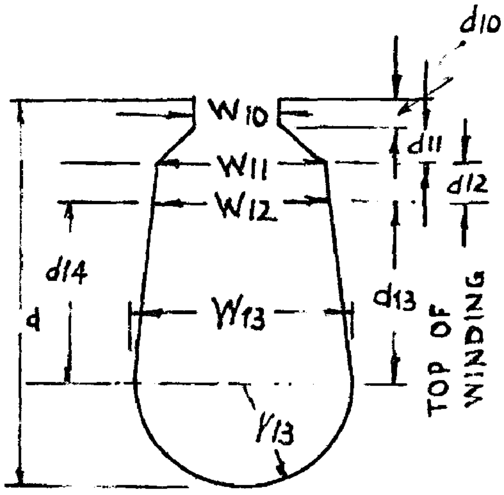
RUN START SWITCH

361	BDT, Oz Ft
8208	RPM
845	Torque, Oz Ft
95	Main Wdg Amps
582	Cap Volts
281	Aux Wdg Volts
132	Main Wdg Amps
272	Torque, Oz Ft.

SUMMARY OF BASIC DESIGN CALCULATIONS-SINGLE PHASE INDUCTION MOTORS (CONTINUED)

FULL LOAD			LOCKED ROTOR
Pri I^2r	167	.503	Zig Zag Perm
Sec I^2r, Forward	700	.413	Skew Perm
Sec I^2r, Backward	277	.344	Rot Slot Perm
Core Loss	425	.000	Rot Bridge Const
F&W Loss	966	.181	Sta Leak React, PU
Stray Load Loss	373	.048	Rot Leak React,Pu
Total Losses,Watts.	2908	.067	r_2 Hot, PU
Slip	.0335	.0782	Main Res Hot, PU
RPM	10437	.230	Main React, PU
% Full Load	100.15	.0311	Aux Res Hot, PU
Torque, z Ft.	201.7	.113	Aux React,PU
FL Amps	82.9	.0119	Cap Res, PU
Main Wdg Amps	13.8	.170	Cap React, PU
Aux Wdg Amps	74.0	67.1	Locked K-Watts
Main Wdg Watts	6018	256.6	Locked Torque, Oz Ft
Aux Wdg Watts	15578	238	Locked Amps
Eff	.8652	174	Main Wdg Amps
P.F.	.691	362	Aux Wdg Amps
Cap Volts	524	641	Cap Volts
CM/Amp	2084	227	Aux Wdg Volts
Main Wdg Amps BDT	88.0		
RPM at BDT	9561		

	Maximum Starting Torque	Maximum Starting Torque per Ampere
Angle	80.6	37.0
T_s	2203	347
Amp	1806	335
X_c	1128	690
MFD	1386	585
MFD	500 (Actual MFD)	1019 (MFD for Switching)



(A)

FIG. 6·1 - LETTER SYMBOLS FOR STATOR SLOTS

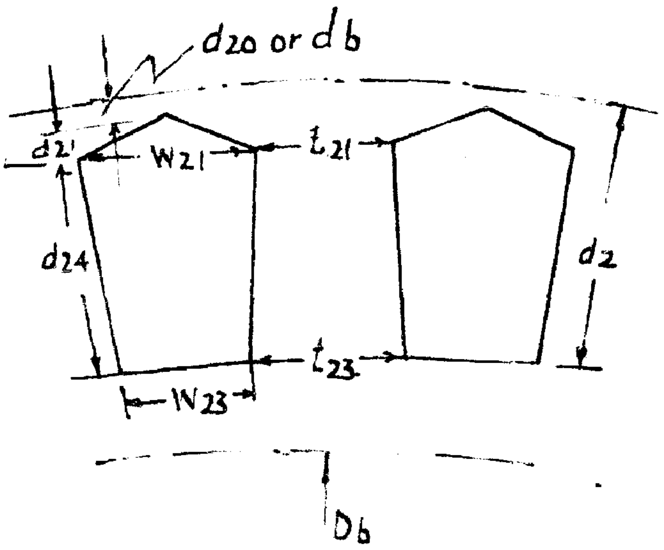


FIG. 6·2 - LETTER SYMBOLS FOR ROTOR SLOTS

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SLOT CONSTANT FOR WINDING PORTION OF ROUND BOTTOM SLOTS.

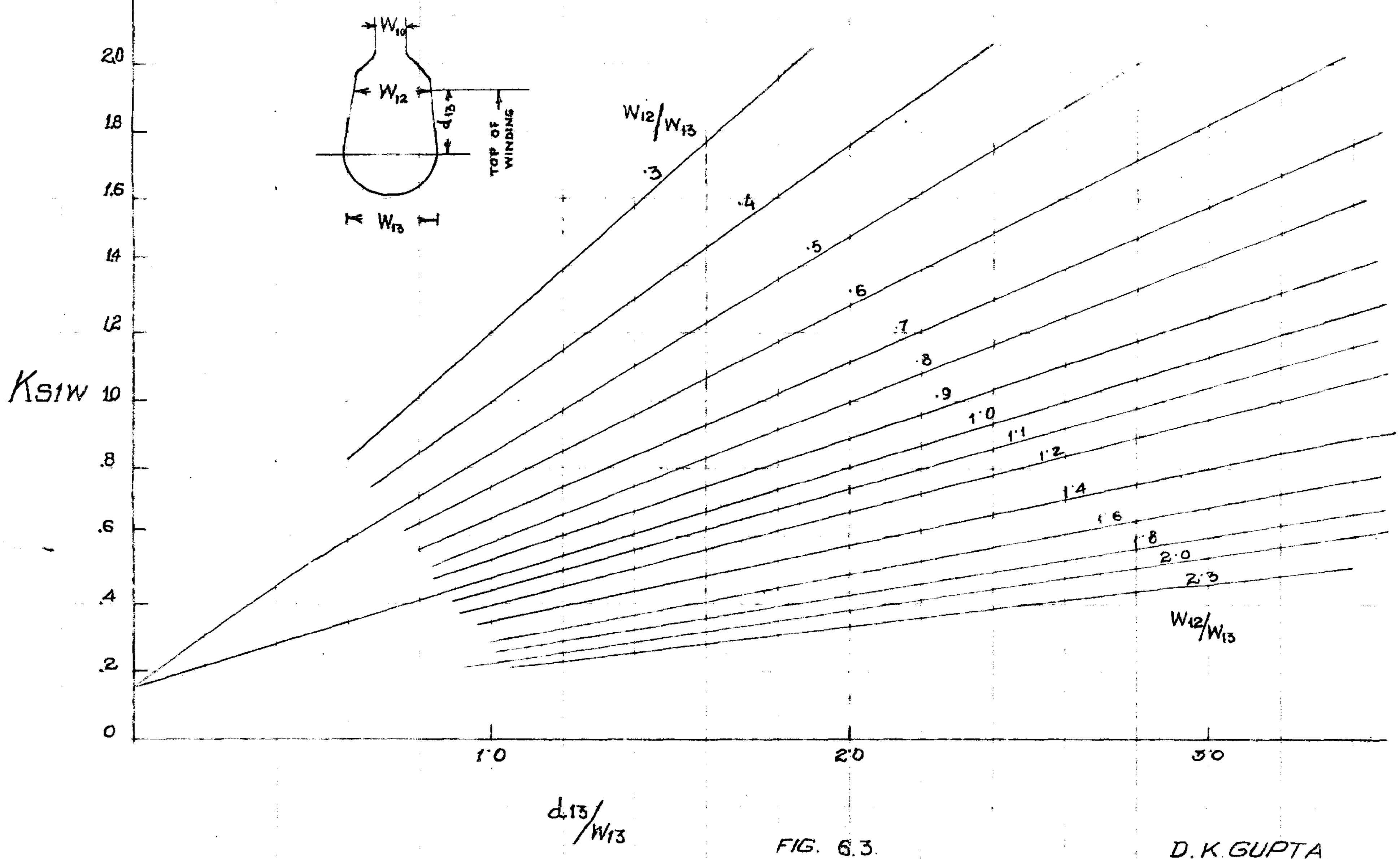


FIG. 6.3.

D. K. GUPTA.

SLOT CONSTANT FOR WINDING PORTION OF FLAT BOTTOM SLOTS.

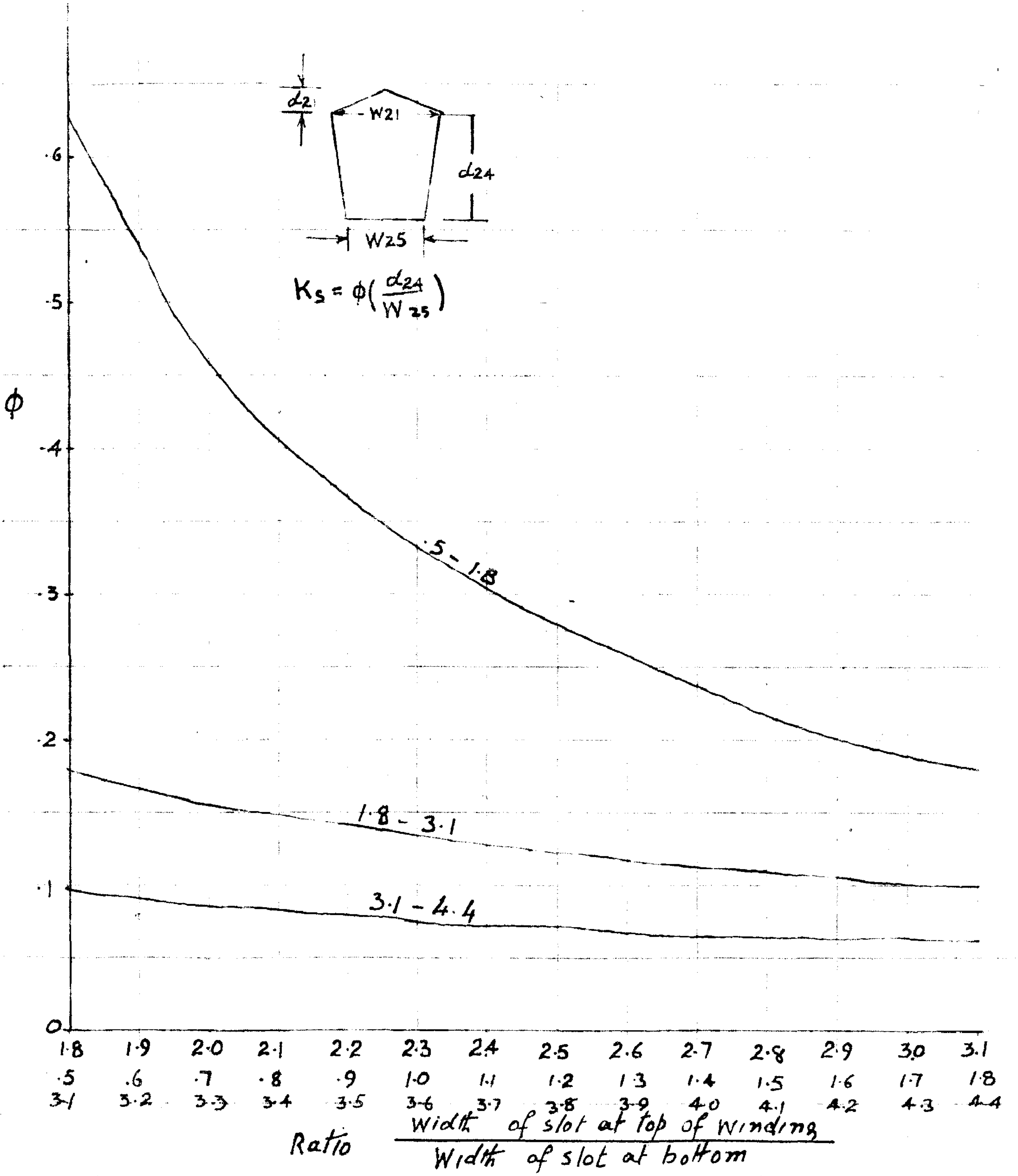


FIG. 6·4

D·K·GUPTA

SLOT MOUTH FRINGING

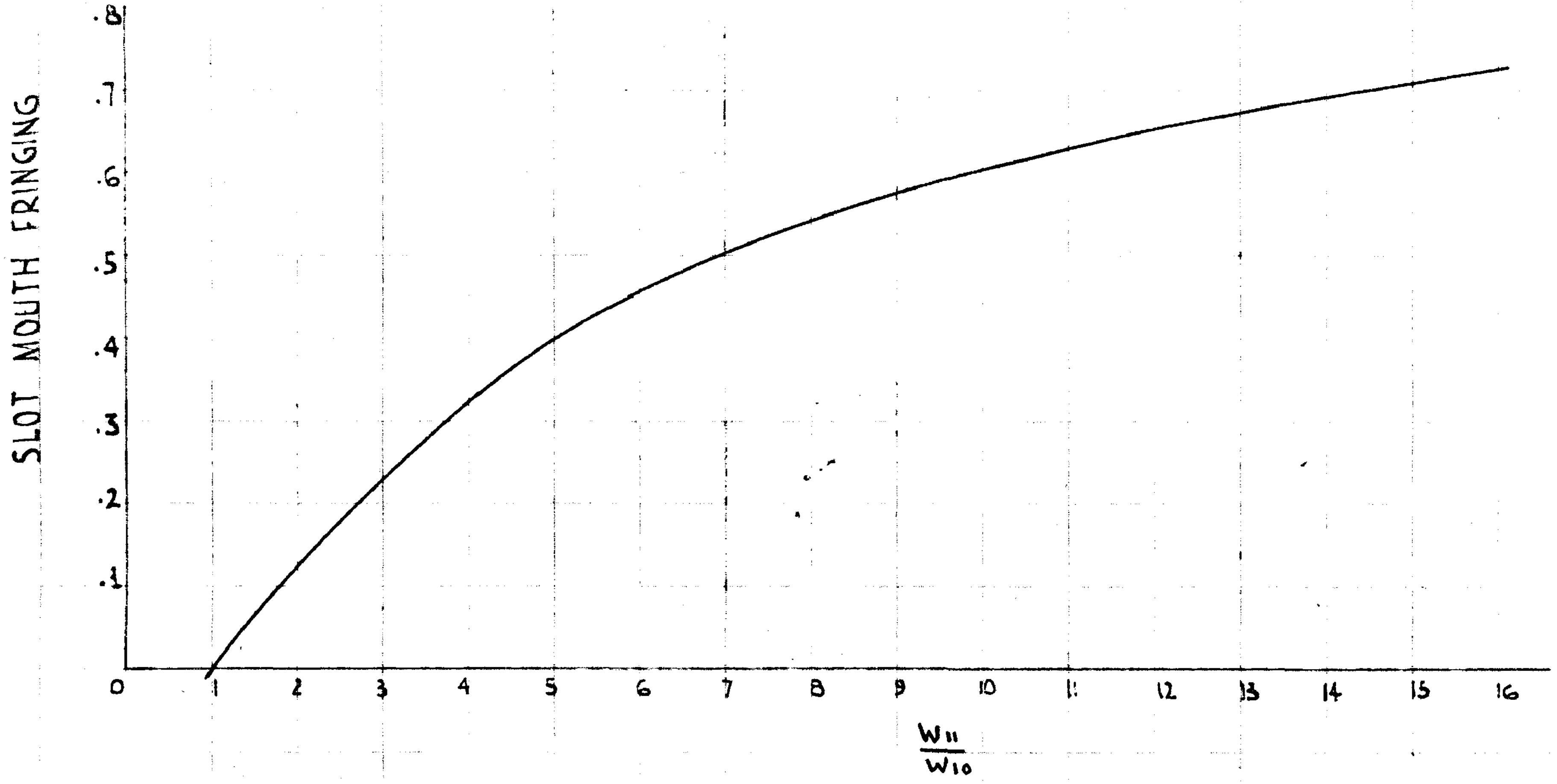


FIG. 6·5

D.K. GUPTA

SECTION - 7

COMPARISON OF DESIGNS

7. COMPARISON OF DESIGNS

The performance of three-phase, two-phase and single phase designed induction motors have been calculated in Section -6. For the performance following curves have been drawn.

(i) Torque vs. speed (Slip),
(ii) Load current vs. speed (slip),
(iii) Power Factor vs. Speed (slip),
(iv) KW Input Vs Speed (slip)

The figures which refer to designs are:

Fig. 7.1. corresponds to Design Calc. No. 6.2.2.
Fig. 7.2 " " " " " 6.2.3.
Fig. 7.3 " " " " " 6.3.2
Fig. 7.4 " " " " " 6.3.3
Fig. 7.5 " " " " " 6.3.4.
Fig. 7.6 " " " " " 6.3.5
Fig. 7.7 " " " " " 6.4.2.
Fig. 7.8 " " " " " 6.4.3

From the above performance curves and summary of basic design calculations the following comparison is made.

7.1	3 -Phase	2-Phase	Single Phase
7.1. PARALLEL CONNECTION			
Design No.	6.2.2	6.3.4	6.4.2.
NO LOAD			
Amps.	30	17.1	93.9
K.Watts	2.640	2.105	5.760
P.F.	0.16 lag	0.14 log	0.14 log.
Capacitor Volts	—	—	727.4

FULL LOAD

Amps	120	102	192.3
K.Watts	80.500	82.212	83.039
R.P.M.	10674	10357	10419
Efficiency	.9272	.9060	.8980
P.F.of motor	.876	.9148	.981
Corrected P.F.		0.7 lead	0.67 lead
F.L.Torque lbs.ft.	49.2	50.6	40.4
B.D.Torque % FL.	223	228	0184
L.R.Torque % FL.	94.5	150.4	71
HP	100.06	99.85	99.93

7.2 SERIES CONNECTION

Design No.	6.2.3.	6.3.5	6.4.3
L.R.Amps	126	112	238
L.R.Torque lbs.ft.	9.8	15.6	16.0
L.R.,P.F.	0.32 lag	0.3 lag	0.65 lead
L.R., P.F. Corrected	—	0.7 lead	0.65 lead
Accelerating Time.	20 sec.	26 sec	8 sec.

7.3. WEIGHT

Copper,lbs.	36.52	44.14	25.78
Iron,lbs.	155.32	252.39	225.80
Aluminum,lbs	5.65	6.67	3.23
Total,lbs.	197.49	303.20	254.81

7.4. P.F. CAPACITORS.

In single phase and two phase induction motors p.f. capacitors are used to improve the starting torque, to flatten the harmonic dips and in the running condition to improve the power factor.

For two-phase case then is 160 KVAR, 440 V, 3-phase, 60 cycle p.f. capacitor. In 180 cycle circuit 2-300 μfd, 440 V capacitors are needed. These transformation of frequency is done by the 100 KVA frequency tripler. The whole arrangement has been shown in fig.7.9.

For single-phase case there is 180 KVAR, 440V, 3-phase, 60 cycle p.f. capacitor. In 180 cycle circuit there are

1-350 μfd (440 V, continuous
(640 V, 1 min.

and 1-125 μfd (604 V, continuous
(640 V, 1 min.

p.f. capacitors. The whole arrangement has been shown in fig.7.10.

<u>Appendix: Calculation of Accelerating time:</u>

Refer to Design Calc. No.6.3. and Fig. 7.4.

WK^2 Compresser = 3 (Given)

W motor $= \frac{\pi}{4} \times (6.295)^2 \times 6.6 \times 2.83$

$= 57.4$ lbs.

K^2 Motor $= \left(\frac{3.15}{12}\right)^2 \times .5 = .0346$ ft.^{2}

WK^2 Motor $= 57.4 \times .0346 = 1.98$ lbs.ft.^{2}

Total WK^2 = 4.98 lbs.ft.^{2}

Motor Torque	14	14.75	15.25	16	17	18.25	19.75	21.5	24.0	25.0
Compressor Torque	1	1.5	3.75	6.5	10	13.5	16.25	18.75	20.25	21.0
Acclg.Torque	13	13.25	11.5	9.5	7.0	4.75	3.5	2.75	3.75	4.0
$\frac{1}{Tak} \times 10$	.77	.755	.87	1.05	1.43	2.11	2.86	3.63	2.67	2.5

$\overset{1}{+}$ = 1.8645

Acclg.time upto 10,000 rpm. $= \frac{4.98}{308} \times 1000 \times 1.8645 = 30.2$ sec.

Similarly accelerating time for other cases are determined.

Design Cal. No.	Acclg. Time.
6.3.5	26. sec.
6.4.3	8 sec.
6.2.3	20 sec.

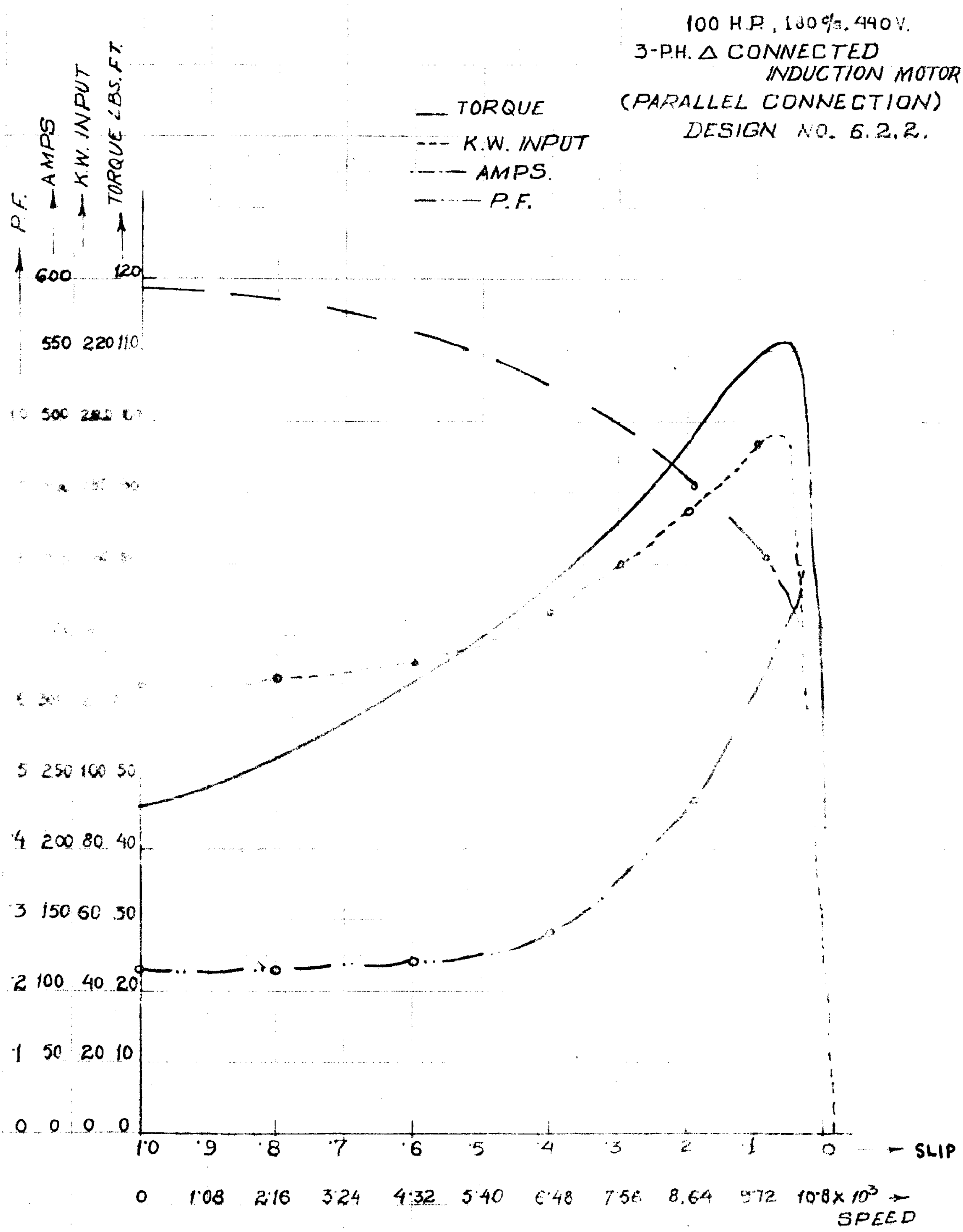


FIG. 7.3.

D.K.GUPTA

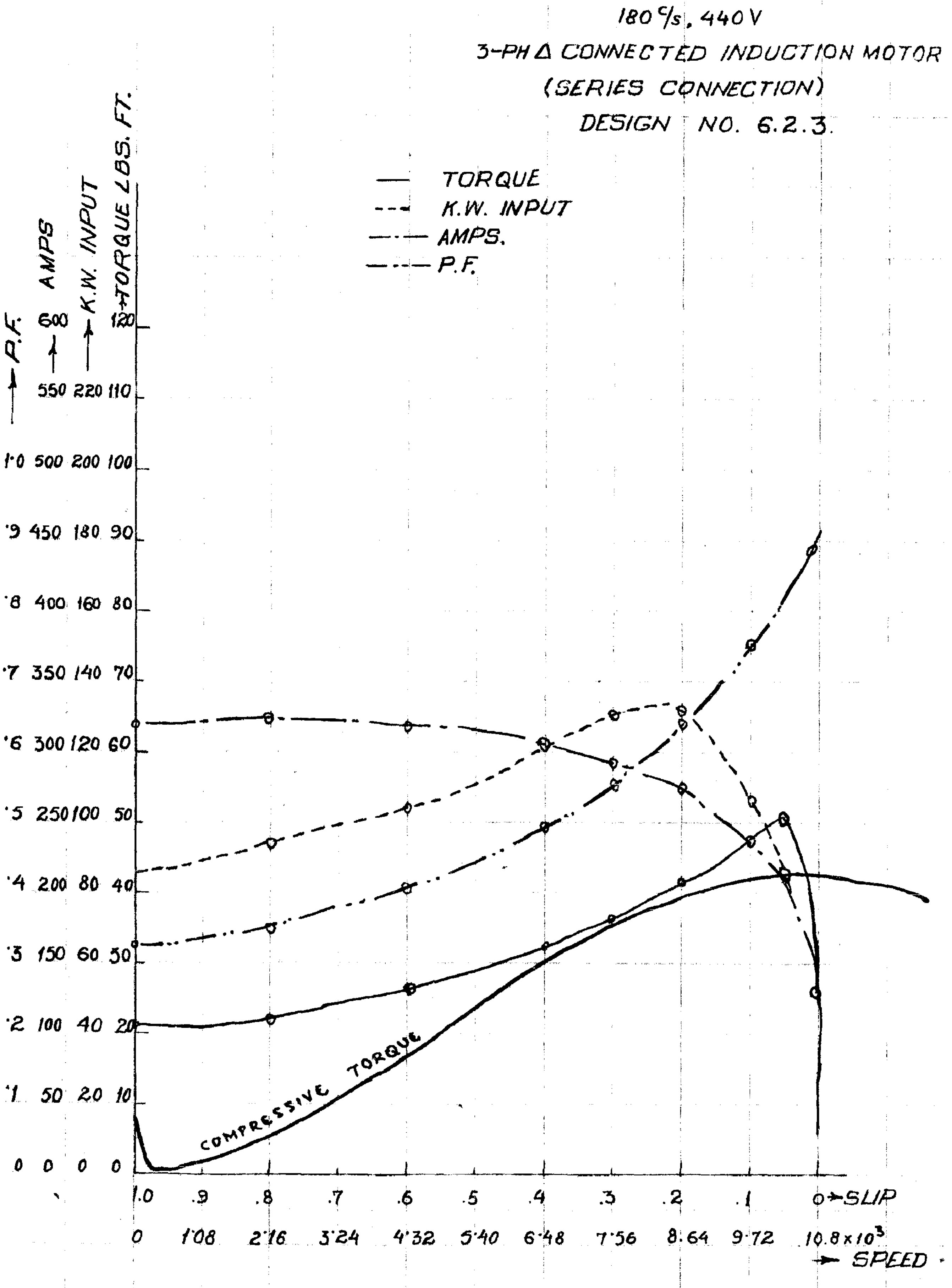

180 c/s, 440 V
3-PH Δ CONNECTED INDUCTION MOTOR
(SERIES CONNECTION)
DESIGN NO. 6.2.3.

FIG. 7.2

D. K. GUPTA.

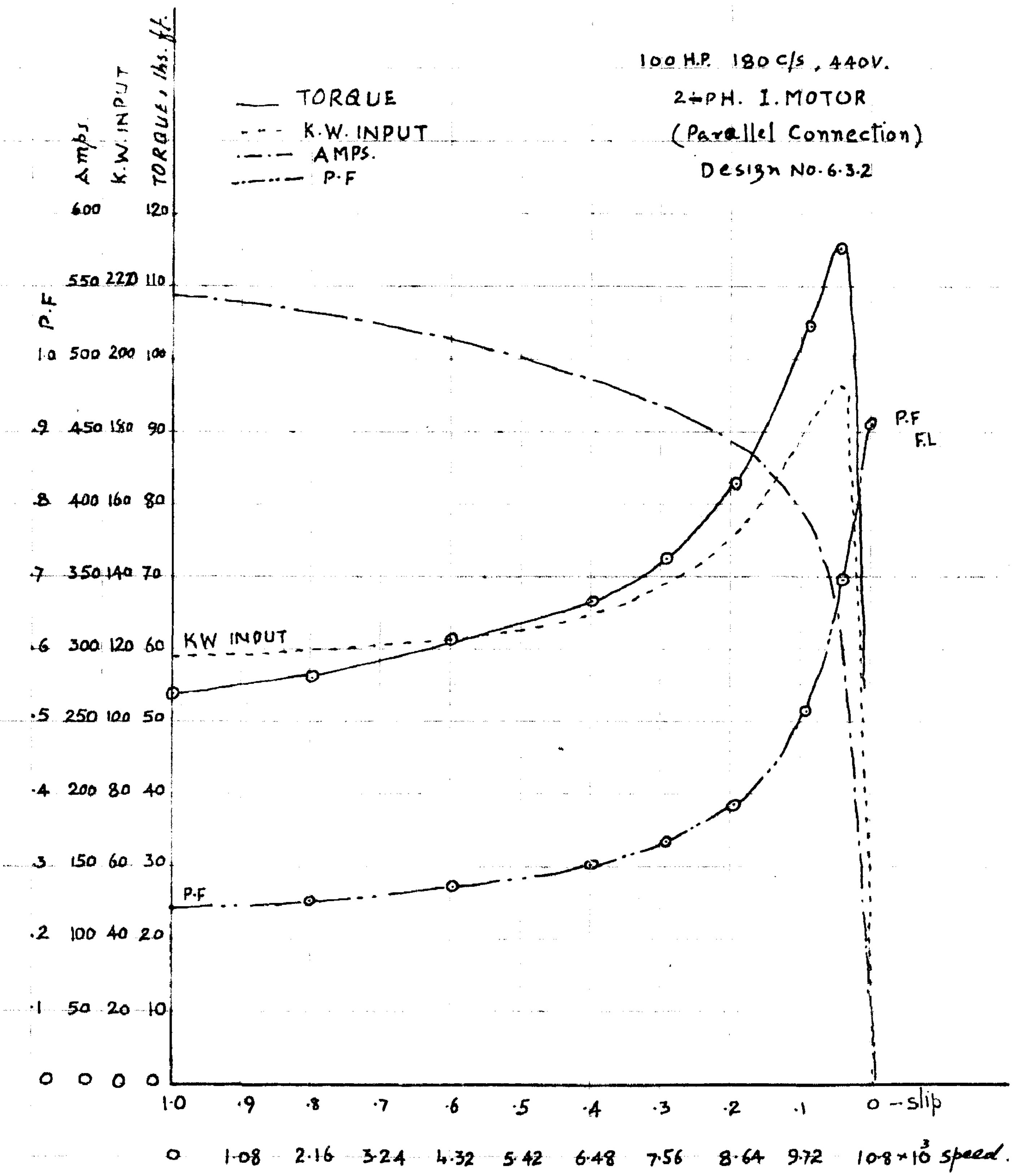


Fig. No. 7.3.

D.K. GUPTA

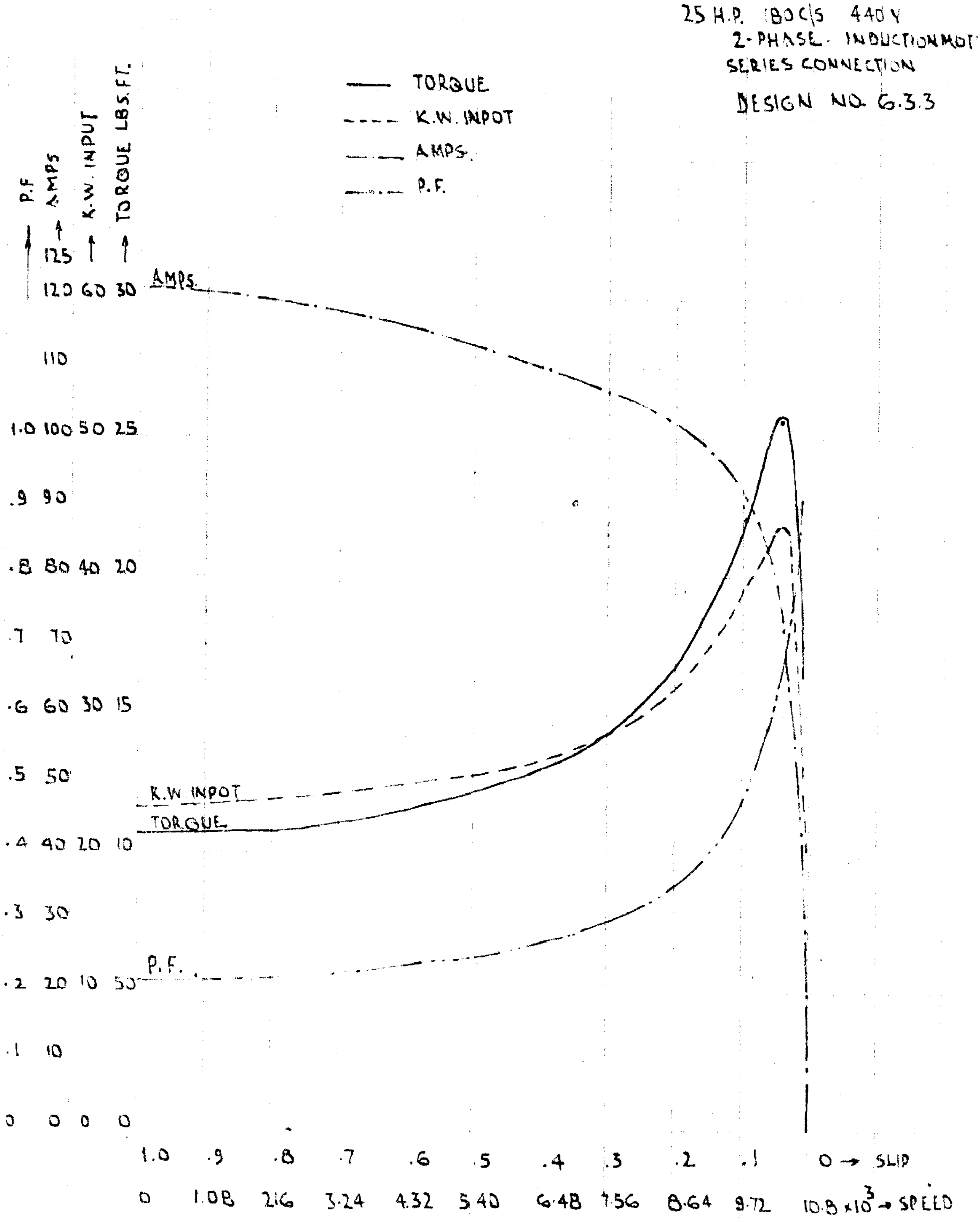


FIG. 7.4

D.K. GUPTA

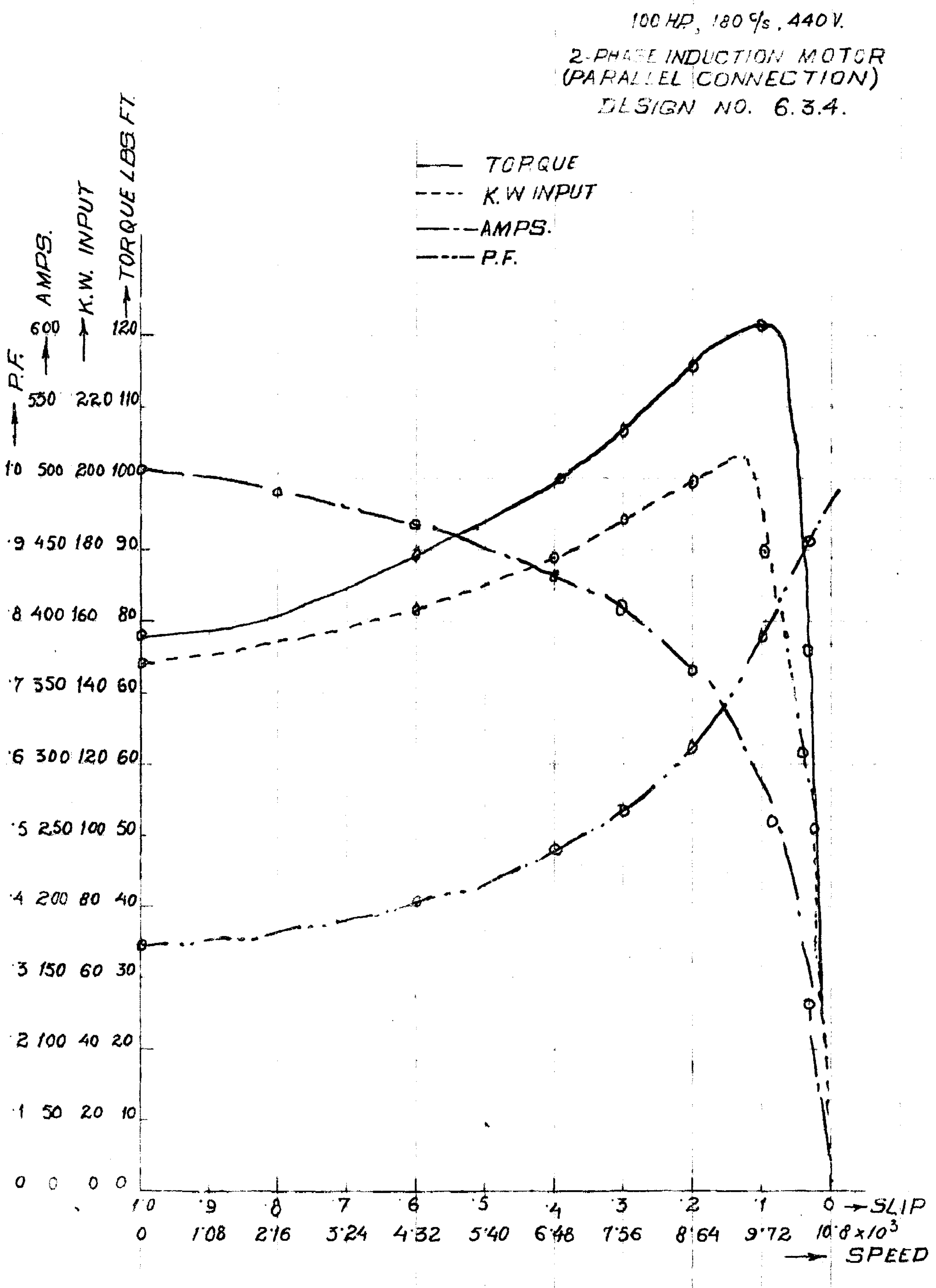
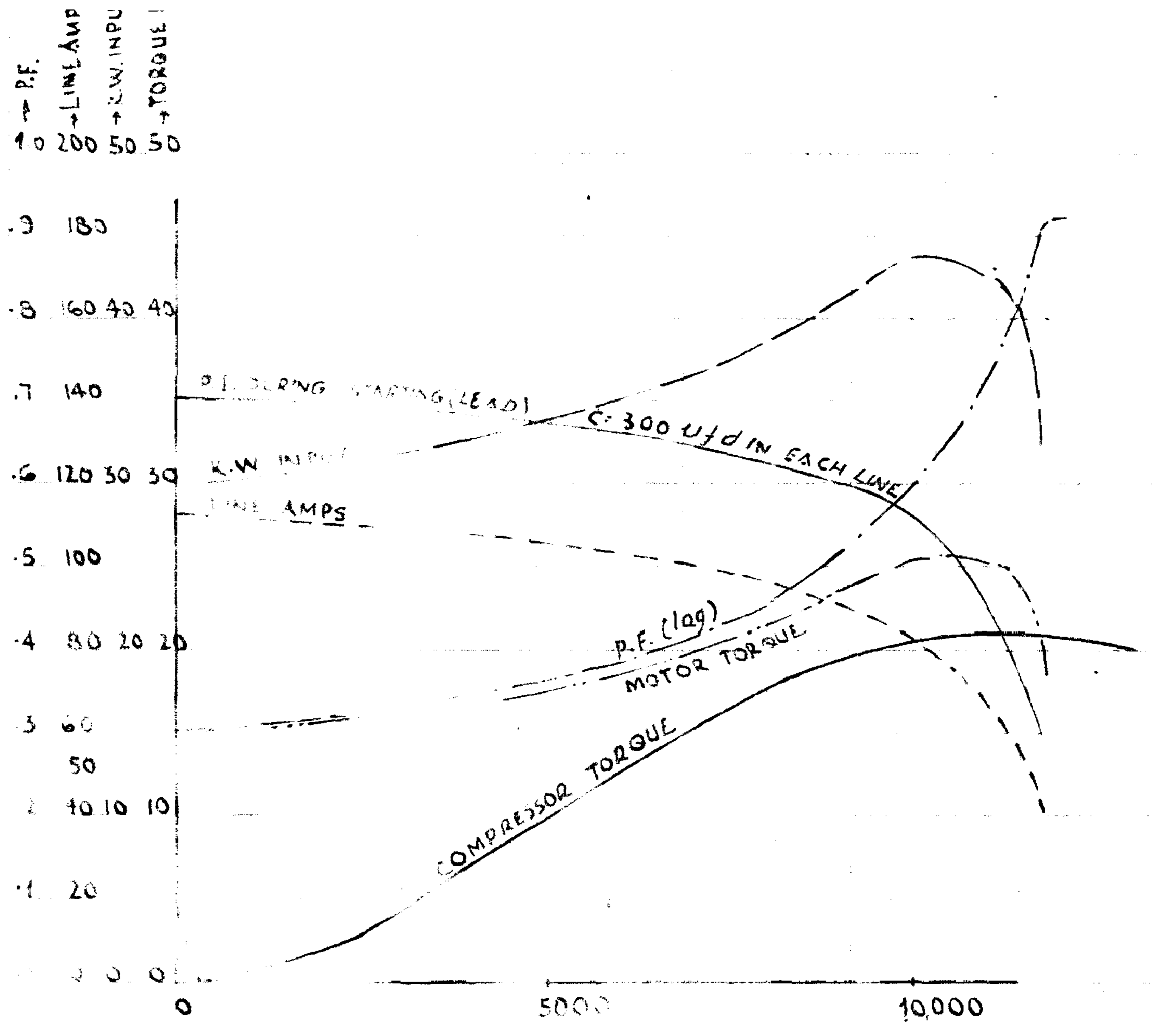


FIG. 7.5

D.K.GUPTA.

2 PHASE MOTOR SERIES CONNECTION
180 C/S. 440 V, 2 POLE

DESIGN NO. 6.3.5



SPEED

FIG. 7.6

D.K. GUPTA

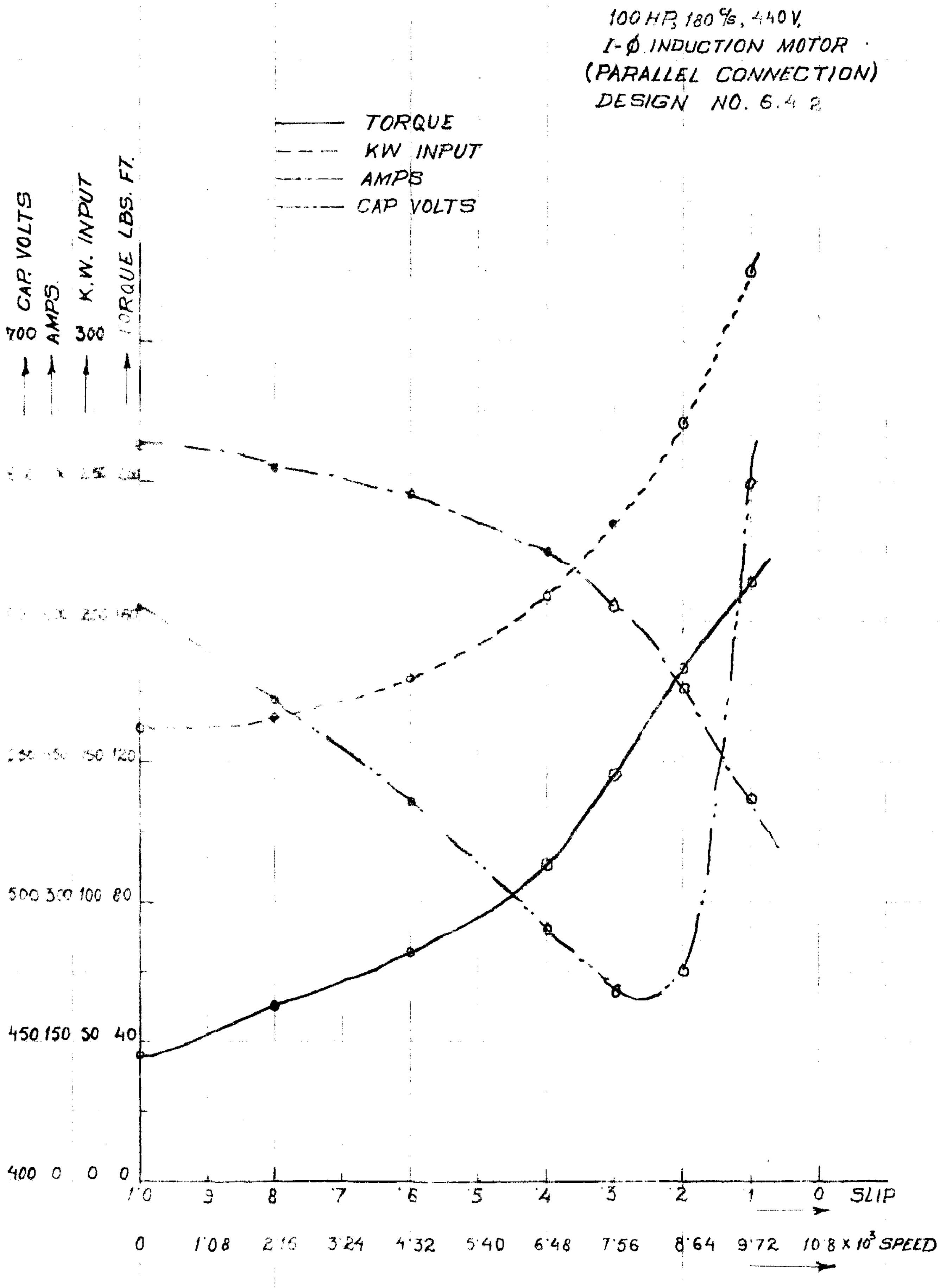


FIG. 7.7.

D. K. GUPTA.

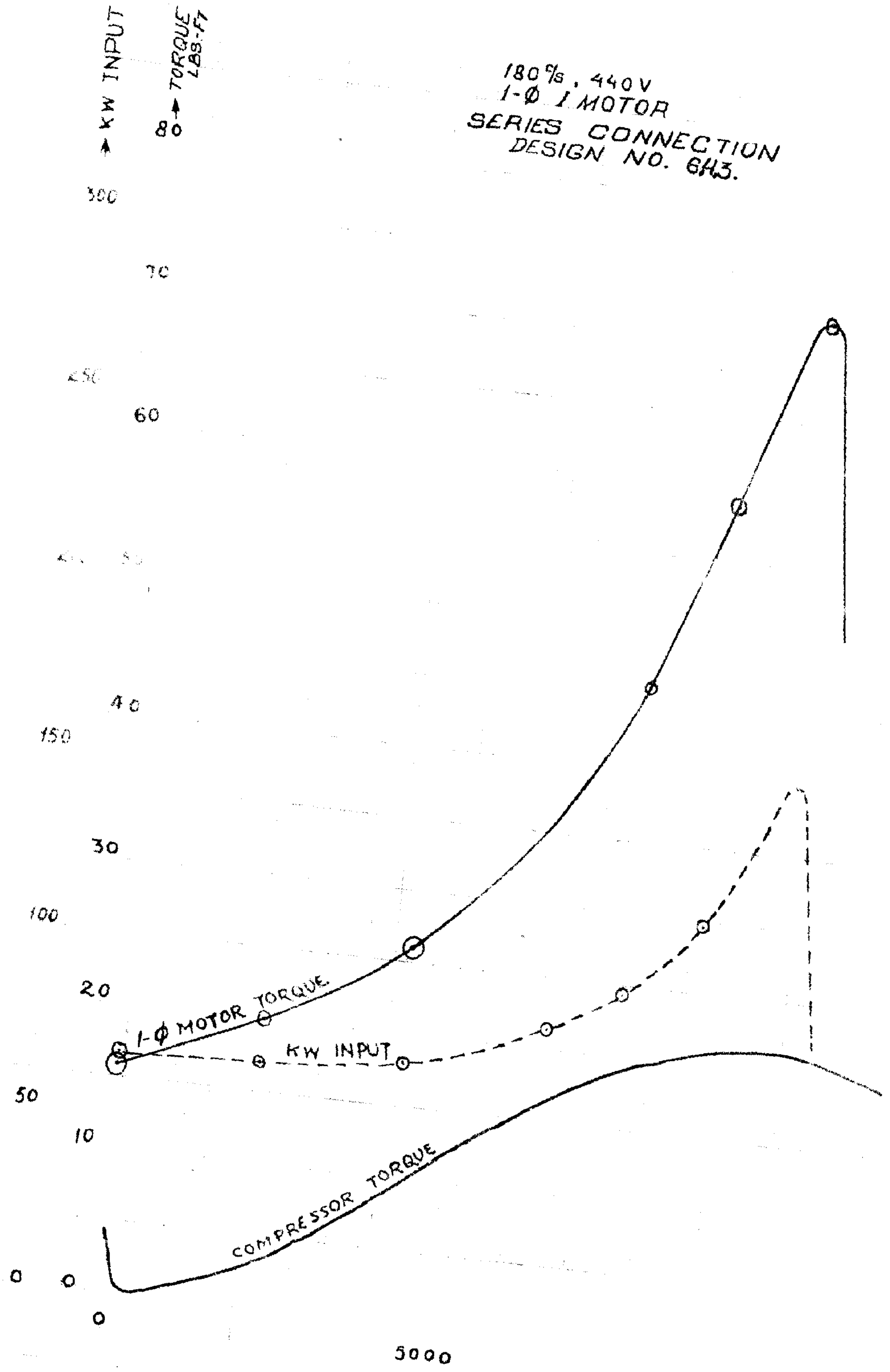


FIG. 7.8.

D.K.GUPTA

TWO PHASE SYSTEM
SCHEMATIC ARRANGEMENT OF CONNECTION

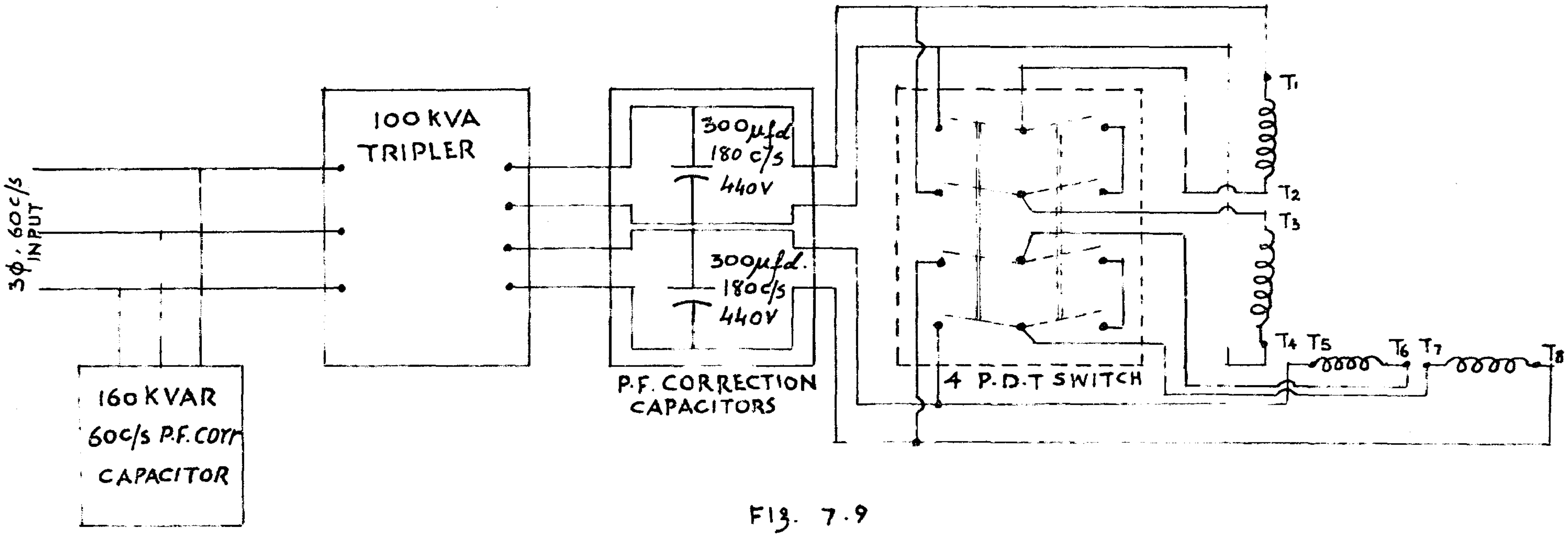


Fig. 7.9

D.K. GUPTA

SINGLE PHASE SYSTEM

SCHEMATIC ARRANGEMENT OF CONNECTIONS

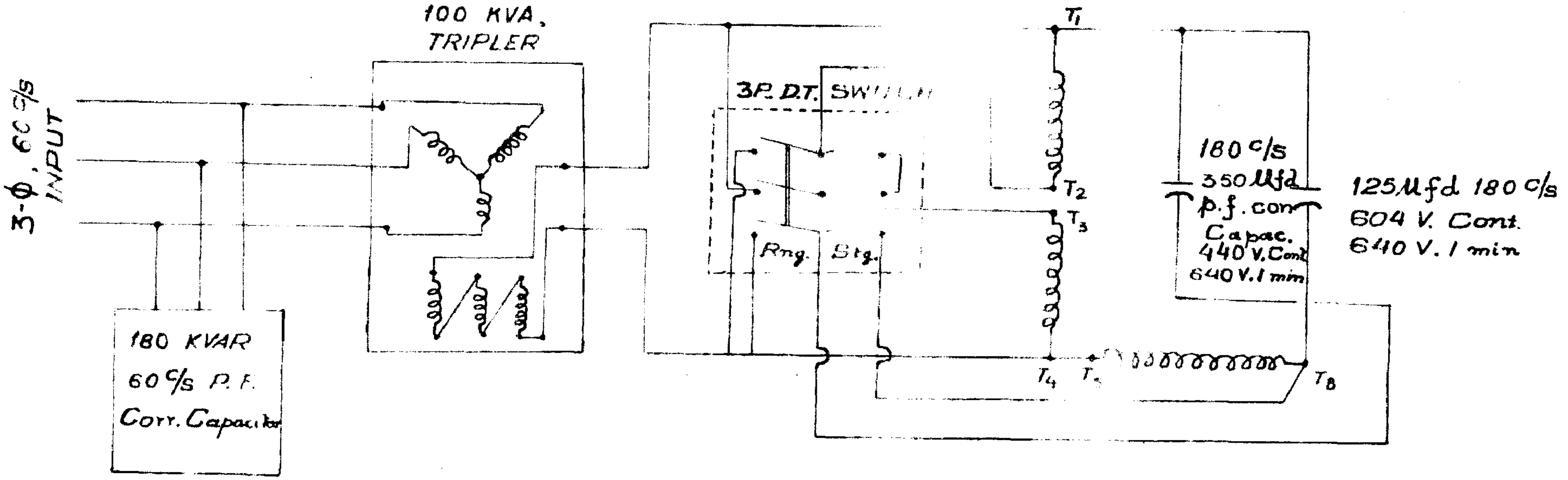


FIG. 7.10.

D.K. GUPTA.

8. CONCLUSION

From the designed machines it is seen that "Comparative Design" process helps a lot in saving time in designing most economical designs. The materials have been used to their maximum capacity giving rise to a minimum weight. When the designs are compared it is seen that they have got high efficiencies, excellent p.f. and gives best performances. The accelerating time is well with in perissible value. The whole beauty of the method lies in the 9 derived relations of Section 1 which makes the design simple for typical accelerating- torque curve of drive.

The designed induction motors are showing the best possible performance. The whole work is based on pure theory. The author wish that some day he will make actual machines and see the accuracy of the results. He is confident that there may be minor difference and that too may be due to manufacturing difficulty. The author thinks that full justice has been done with dissertation and reasonably correct results have been obtained.

9. BIBLIOGRAPHY

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