Original

REVISED

COMPUTER AIDED DESIGN OF ELECTRICAL MACHINES

A simple generalised design procedure for design of an electrical machine is outlined in the flow chart of fig. 1

1. GIVEN SPECIFICATION:

Consists of performance requirement as defined by the customer's need and IS specifications.

2. CHOICE OF MATERIALS ETC.

Based on given specifications, the designer choses materials : magnetic, conducting and insulating for electrical design and other materials for frame, bearings etc. This depends upon the availability of materials & manufacturers specifications.

3. ASSUMPTIONS OF BASIC DESIGN PARAMETERS:

Such as specific magnetic & electric loading, space factor, stacking factor, etc.

4. DESIGN PROCESS:

Consists of calculations to estimate the various dimensions of magnetic and electric circuits and making thermal and mechanical designs.

5. PERFORMANCE CALCULATION:

Predetermination of performance under no load & load conditions, estimation of temp. rise efficiency, regulation & cost etc.

6. COMPARISON:

Compare the estimated performance with the customer's requirement. If not satisfactory (which is generally the case), modify the basic assumptions so as to bring the final design closer to the objective.

SOFTWARE

1. Motor Expert: (S/W developed by JASON TECH, INC Korea, CAD/CAE program for designing and Analyzing Permanent Magnet DC & Small AC motors.
2. CAD-CAM: (14th Release) Window based.
3. MATLAB: Circuit Analysis, Control, Power System.
4. CAD of Electrical Machines & Power Equipment.
5. Graphic Tools in Computers :[For all types of Drawings of elec. machines]
   Corel Draw (s/w for drawing), Photoshop (Adv. Version of Corel draw)

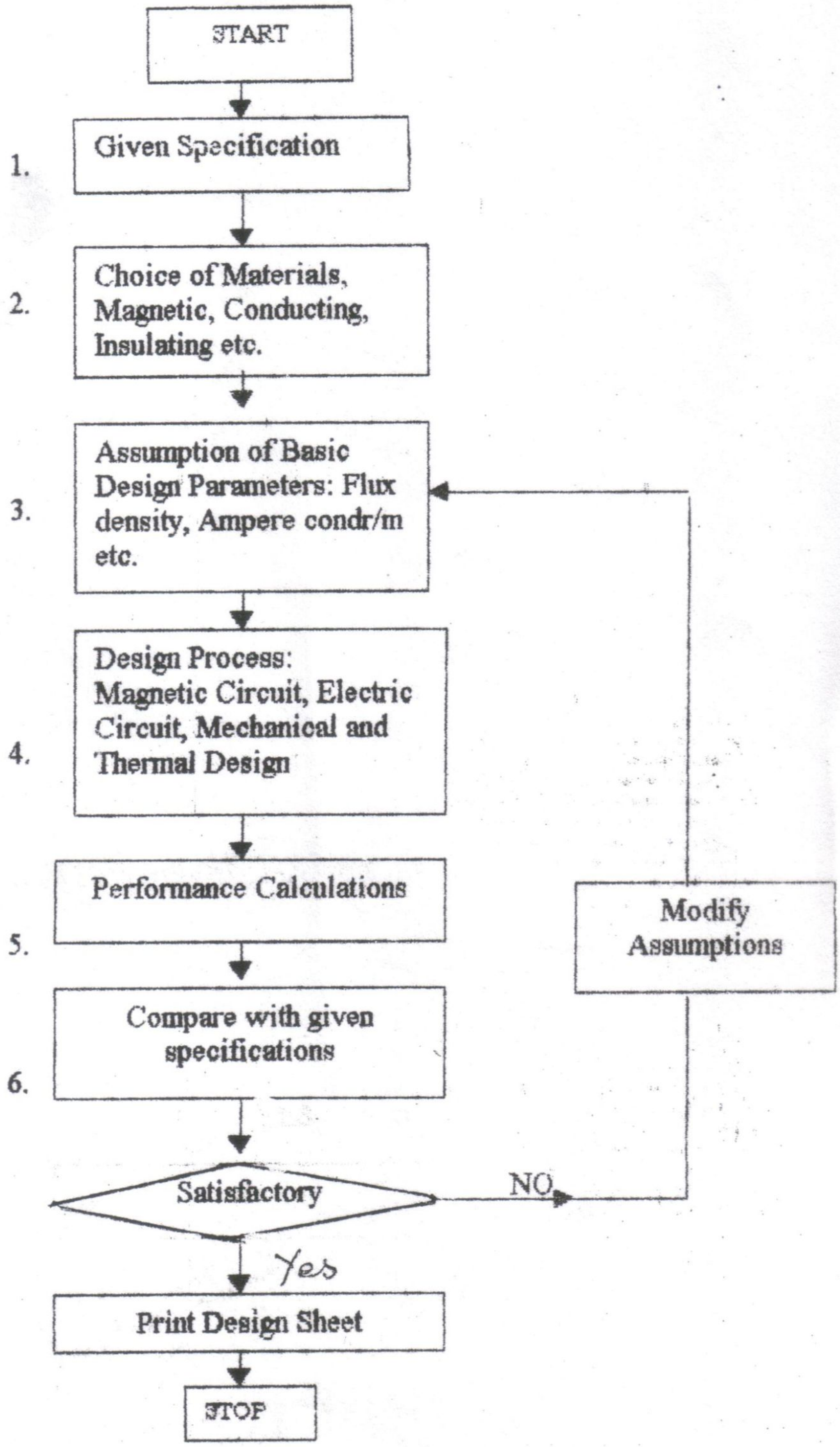


Fig. 1. Design Flow Chart

(Generalized computer aided design procedure)

Various Methods of Computer Aided Design

With the aid of digital computer if is possible to obtain a large no. of alternative designs for the same machine, so that an optimization of some sort can be achieved. The process of design may be anyone of the following:

1. Analysis
2. Synthesis
3. Hybrid Process

ANALYSIS:

In this process the dimensions of the machine are estimated by experience selecting suitable volume making use of output equation and thus estimating all the dimensions of the m/c and the performance by known methods. The performance so estimated is compared with the desired result as specified and any divergence is eliminated by successive iterations by making small changes in dimensions. Here computer is used as a calculating aid. The whole process of design may be described by a closed loop flow diagram given in fig.2.

SYNTHESIS:

The process of synthesis is the exact opposite of the Analysis. Here the starting point is the desired performance and the computer is required to work backward and determine the optimum machine dimensions. The process involves the formulation of suitable inverted performance equations which are differential equations connecting the performance to the various design parameters like length, diameter, air-gap, current density etc. The designer is also required to feed in the boundary conditions or constraints of the equations.

This method makes full use of the logic abilities of the computer and theoretically the most desirable method for design using computer. On a general basis it is a very difficult process & may often lead to unfeasible solution. The flow diagram is given in fig. 3.

HYBRID PROCESS:

It is a combination of the Analysis & Synthesis and involves partial synthesis using the standard frames, slots & conductors decided on the basis of availability in the market.

It is a practical method because it makes possible the use of standardization which is important for economic and practical design.

Since the synthesis methods involve greater cost, the major part of the program is based upon analysis with a limited portion of the program being based upon synthesis. This approach makes the design more practical and economical.

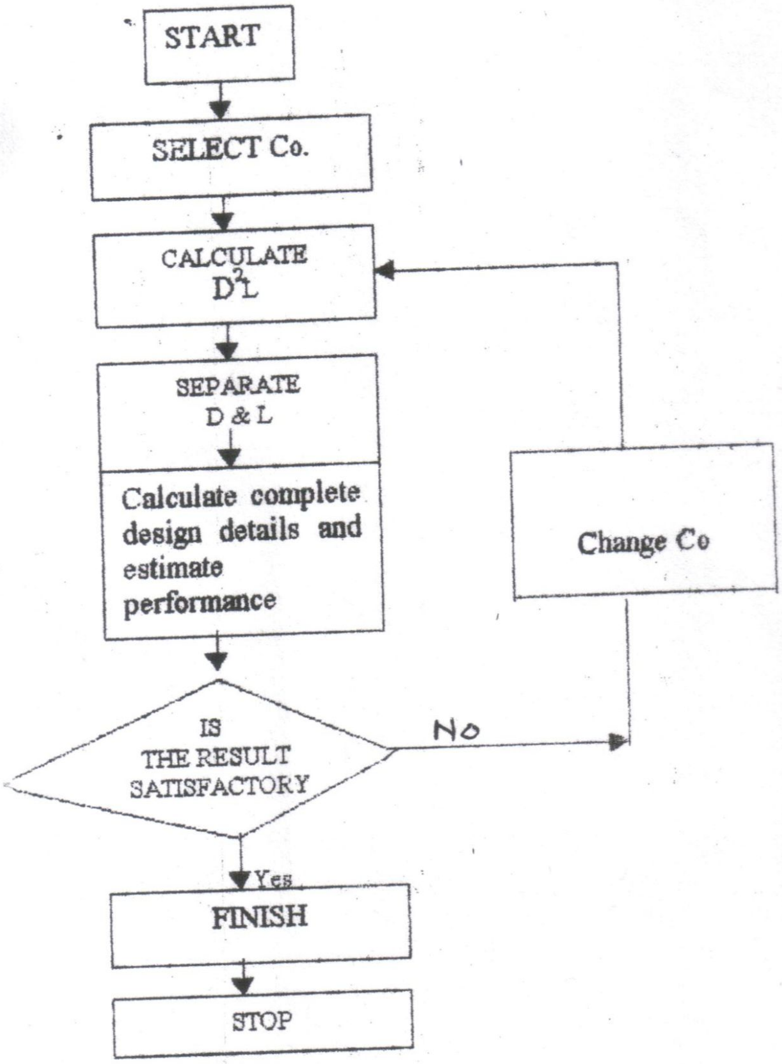


Fig. 2: Analysis Method of Design of Rotating M/c
Co = Output Coefficient
D = Core dia, L = Length

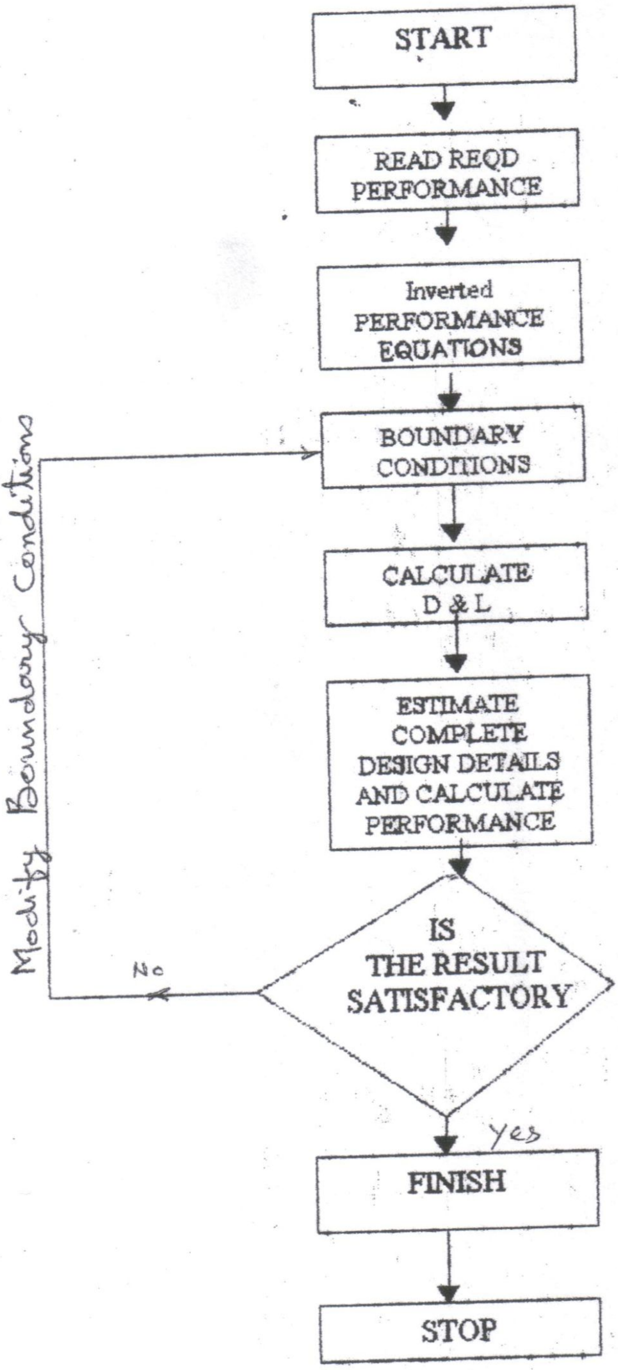


Fig. 3. Synthesis Method of Design

Optimization:

It can be defined as the process of finding the conditions that give a maximum or minimum value of a function. Many of the problems related to the analysis, design, construction or maintenance of an equipment or a system can be reduced to that of determining the largest or smallest value of a function of several variables. The theory of these methods in usually referred to as mathematical programming method.

The optimization in electrical machine design is very complicated as the number of variables and the number of constraints involved are very large and the situation is still more complex as it is very difficult to find out precise functional relationships between them.

The aim is to work out the design at its best with regard to a particular feature satisfying all the constraints and meeting the desired performance. The most important part in the optimization is defining the specific objective. The problem is to process through the weighted combination of several conflicting requirements.

Take the case of optimization of three phase induction motor design, the criteria may depend upon the requirements. From the customers view point, the initial cost plus the running cost of the motor should be minimized. Whereas, from the manufactures point of view, the material and production cost should be minimized. Thus it is possible to have either minimum weight or minimum volume or minimum cost design.

Next look constraints and limitations on the motor for example: pull out torque, starting torque, starting current, full load p.f., full load slip, full load temp rise, full load η etc. The select independent variables for the motor, there are a large number of such variables. Select the most important of them. Suppose the motor is to be designed for minimum cost, the following factors affecting cost function may be taken up.

> Stator bore dia, core length, depth of stator slot, width of slot,
> depth of stator yoke, depth of rotor slot, width of rotor slot,
> airgap flux density, end ring width & depth, airgap length

The constraint functions are expressed in terms of the equivalent circuit parameters which are expressed in terms of independent variables.

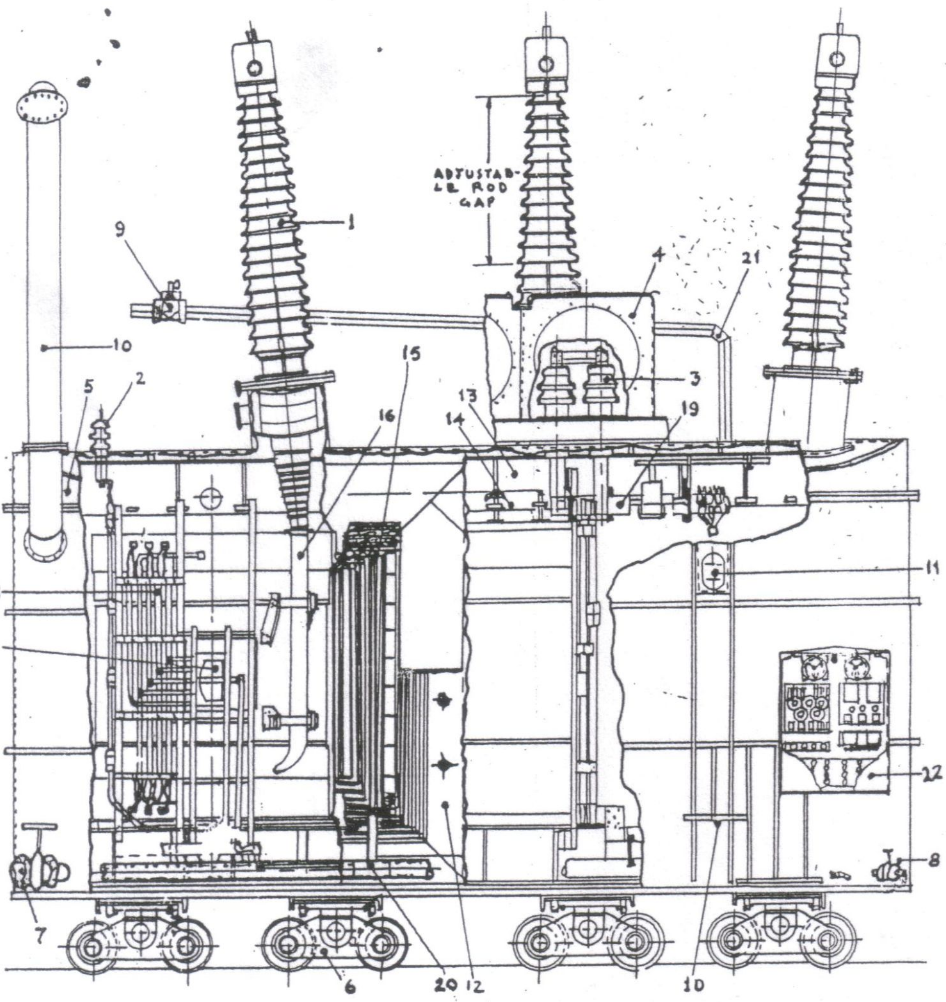
The problem of optimization of induction motor design is now first formulated as a mathematical programming problem. Initially a feasible design is worked out by programming. Then, this initial feasible design is used to actual the optimization program.

Optimization Techniques Employed in the Design of Electrical Machine:

The following methods are applied :

1. Random Search Method
2. Hooks & Jeeves Method
3. Simplex Method
4. Some other methods, like Powell Method, Davidon-Fletcher-Powell method, etc.

SECTIONAL VIEW OF 250 MVA, 21/230 KV GENERATOR TRANSFORMER



1. 220KV HIGH VOLTAGE BUSHING
2. 33 KV NEUTRAL BUSHING
3. 22 KV LOW VOLTAGE BUSHING
4. BUS DUCT TO GENERATOR
5. TRANSFORMER TANK AND COVER
6. BIDIRECTIONAL ROLLERS
7. OIL VALVES
8. FILTER AND DRAIN VALVES
9. BUCHHOLZ
10. RELIEF VENT
11. LIFTING AND JACKING LUGS
12. CORE
13. END FRAME
14. COIL CLAMPING BOLTS
15. WINDING AND INSULATION ARRANGEMENT
16. HIGH VOLTAGE LEAD ARRANGEMENT
17. TAPPING SWITCH
18. TAPPING LEAD ARRANGEMENT
19. LOW VOLTAGE LEADS ARRANGEMENT
20. FORCED COOLING PIPE WORK
21. CONSERVATOR PIPE WORK
22. MARSHALLING BOX (control equipment)

Fig. 4

Transformer Design:

EMF Per Turn

$E_t = K_t\sqrt{Q}$

Type		K_t
3-Ph. Shell		1.3
3-Ph. Core	: Power	0.6-0.7
	: Distribution	0.45
1-phase	: Shell	1.0-1.2
	: core	0.75-0.85

Output Equation.

1-Phase Core type/Shell type

$$Q = 2.22\, f A_i A_w B_m \delta K_w \cdot 10^{-3} \text{ KVA}$$

3-Phase core type

$$Q = 3.33\, f A_i A_w B_m \delta K_w \cdot 10^{-3} \text{ KVA}$$

3-Phase Shell type

$$Q = 6.66\, f A_i A_w B_m \delta K_w \cdot 10^{-3} \text{ KVA}$$

$$K_w = \frac{10}{30 + KV}$$

KV is hv wdg voltage

for higher rating transf. $K_w = 0.15 - 0.20$ (1MVA & above)

Cooling

Plain tank transf. upto 30 KVA

Tanks with tubes " 3 MVA

Tanks with External Radiators " 10 MVA

Oil immersed & self cooled 12.5 W/m²/°C

If cooled by Air blast (AB or OB) : 18-20 W/m²/°C (50-60% more dissipation)

When forced oil circulation, rate of oil 12 Li/min/KW of losses

Quantity of cooling water can be calculated [1.5 Li/min/KW Loss]

Heat dissipated by cooling tubes = 8.5-9 W/m²/°C.

Vol. of air reqd. $= \frac{0.78Q}{\theta} \times \frac{760}{H} \times \frac{273 + \theta_i}{273}$ m³/sec

where Q = Loss in KW
θ = Rise in temp. °C
θ_i = Initial temp. °C
H = Pressure in mm of Hg.

Vol of H_2 reqd $= \frac{}{\theta} \cdot \frac{}{H} \cdot \frac{}{273}$ /sec.

Table 6.1 Strip width for optimum fill

Plate width/diameter d^*

No of steps	% fill	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}
4	88.5	.935	.80	.60	.355							
5	90.8	.950	.85	.71	.53	.31						
6	92.3	.96	.89	.78	.63	.47	.28					
7	93.4	.97	.90	.82	.71	.58	.43	.25				
9	94.8	.98	.93	.87	.80	.71	.60	.50	.37	.22		
11	95.8	.98	.94	.89	.83	.76	.71	.65	.56	.45	.33	.19

*Refer to Fig 5

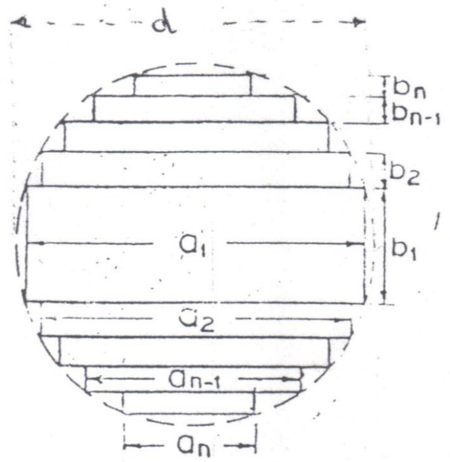


Fig. 5 : Pertaining strip width

$$\% \text{ Fill} = \frac{\text{Gross area under step core}}{\text{Area of circum circle}}$$

$$b_n = \frac{a_1 - a_2}{2}$$

$$b_1 = a_n$$

d = circumscribing dia

For square core

$$\% \text{ Fill} = \frac{0.5}{\frac{\pi}{4} \cdot 1^2} = \frac{2}{\pi}$$
$$= 0.64$$

For 4 step core

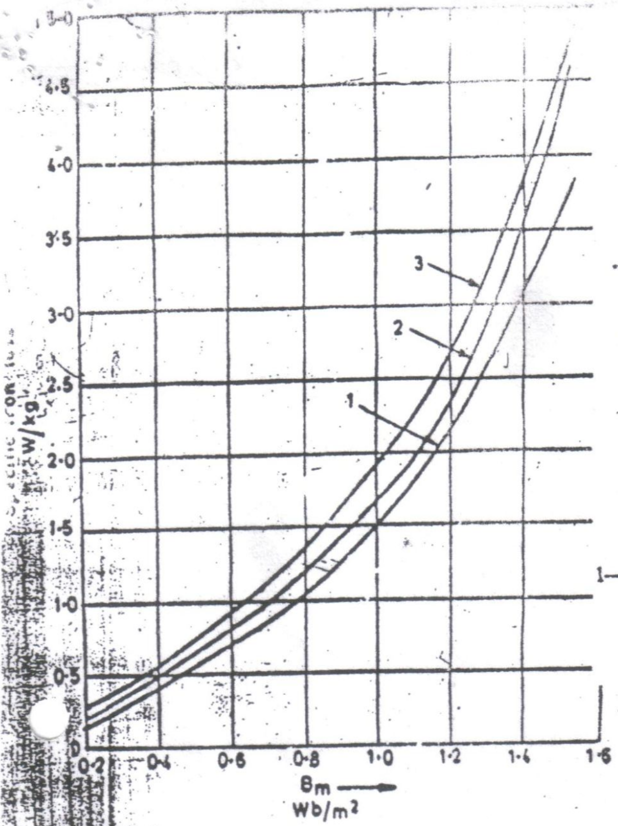
$$\% \text{ fill} = \frac{0.625/.9}{\frac{\pi}{4} \cdot 1^2}$$
$$= 0.885$$

$$\text{Area of circum circle} = \frac{\text{Gross area under step core } (= Ai/0.9)}{\% \text{ fill}} = \frac{\pi}{4} d^2$$

Table 6.2 Choice of number of steps

Gross core-section cm² X 10	No. of steps	No. of ducts
< 3	1	–
3 — 5	2	-
5 — 7	3	–
7 — 15	4	-
15 — 45	5	
45 – 80	6	1
80 – 200	7	1
200 – 400	9	2
400 – 750	11	2

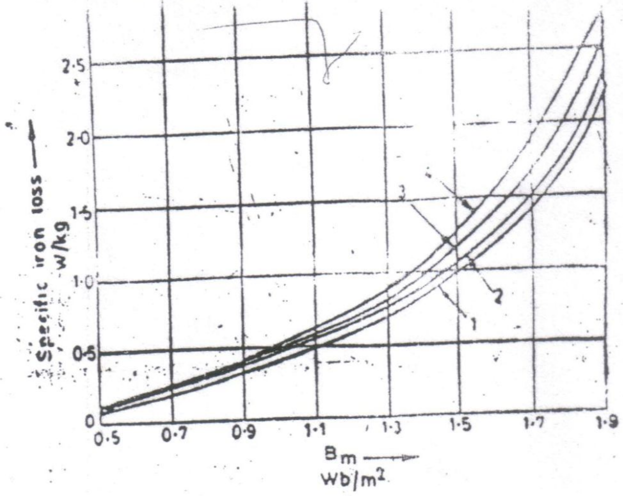
$$< 3 \rightarrow < 3 \times 10 = 30 \text{ cm}^2$$



1—48 Quality 2—41 Quality 3—42 Quality

4·27. Loss curves of Electrical sheet steel (Non oriented) 0·35 mm thick.

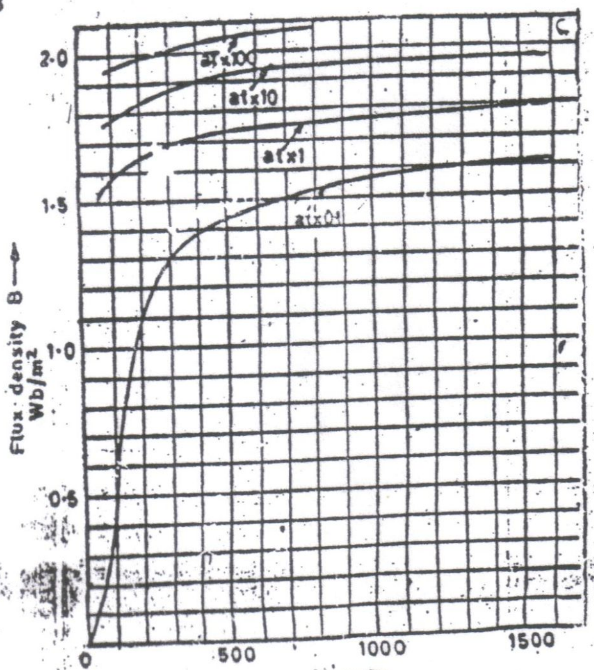
Fig 6



1—Grade 48 2—Grade 51 3—Grade 56 4—Grade 62

Fig. 4·30. Loss curves of Electrical sheet steel (oriented) 0·33 mm thick
0·35mm

Fig 7



4·4. B—H curve for Electrical steel (cold rolled grain oriented) Grade 123 (Grade 56 of M/s G.K.W.)

Fig 8

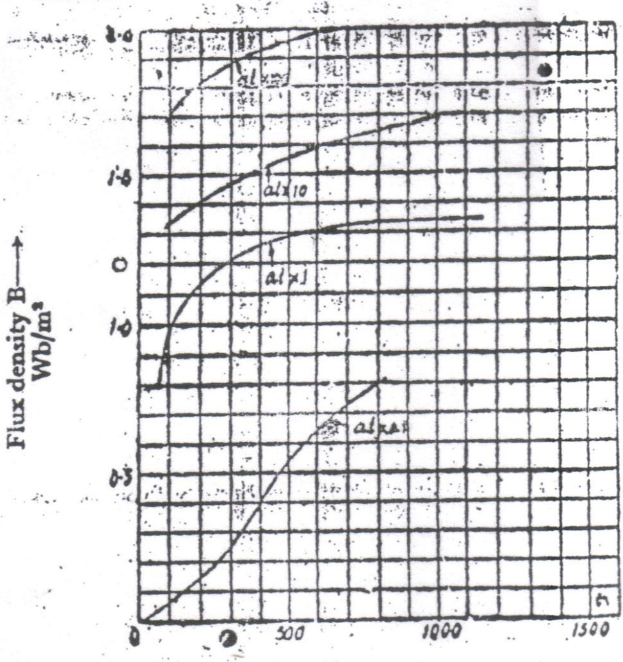


Fig. 4·3. B—H curve for electrical steel (non oriented) Grades 203 and 190, Grades 92 and 86 (cold rolled non oriented transformer steel) of M/s G.K.W

fig 9

Ref: A.K.S. p. 123, 122
p 147, 149

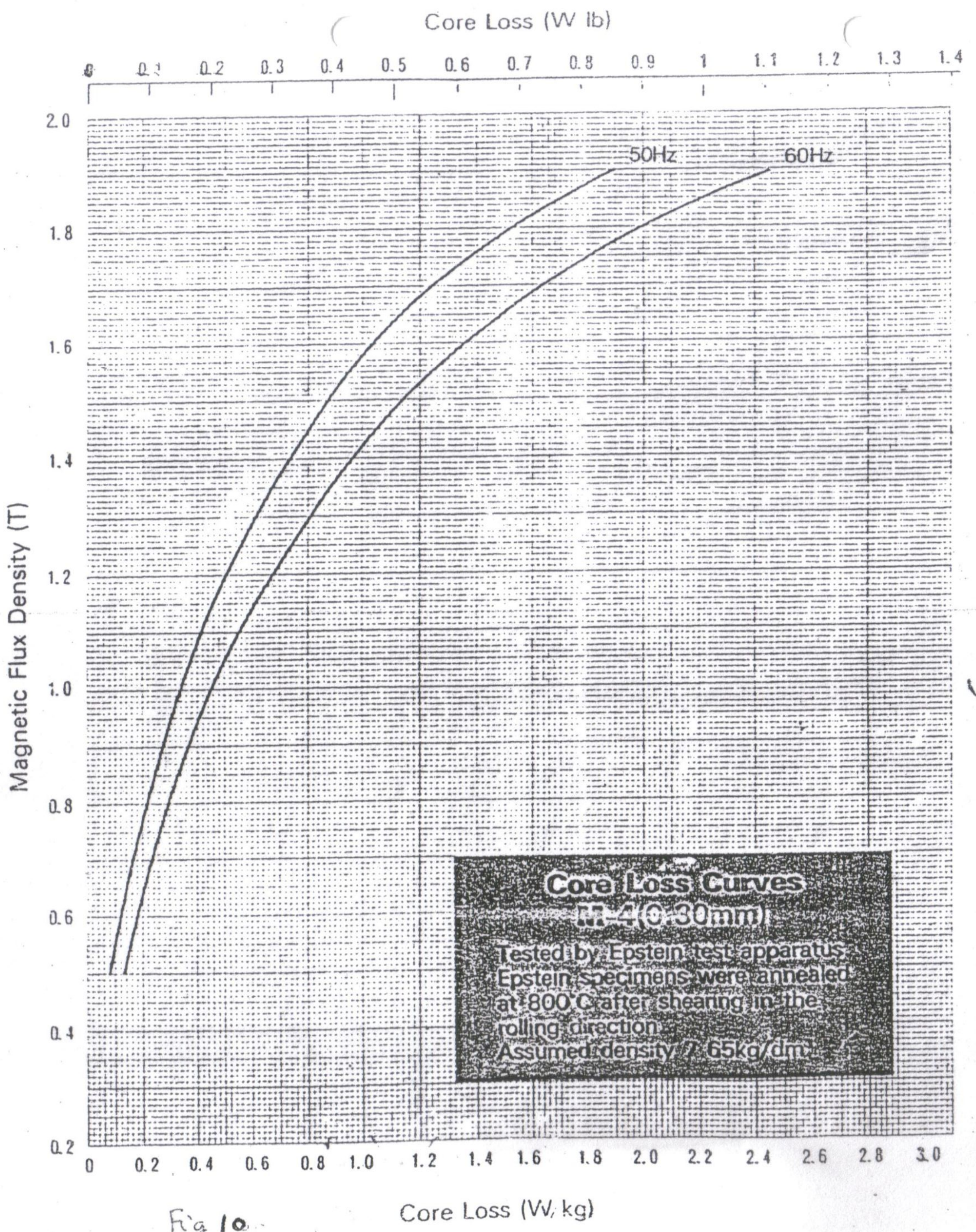


Fig 10

Nippon
Transformer
Loss Curves

Usual steel = 7600 kg/m^3
M-4 steel (0.3 mm)
= 6500 kg/m^3

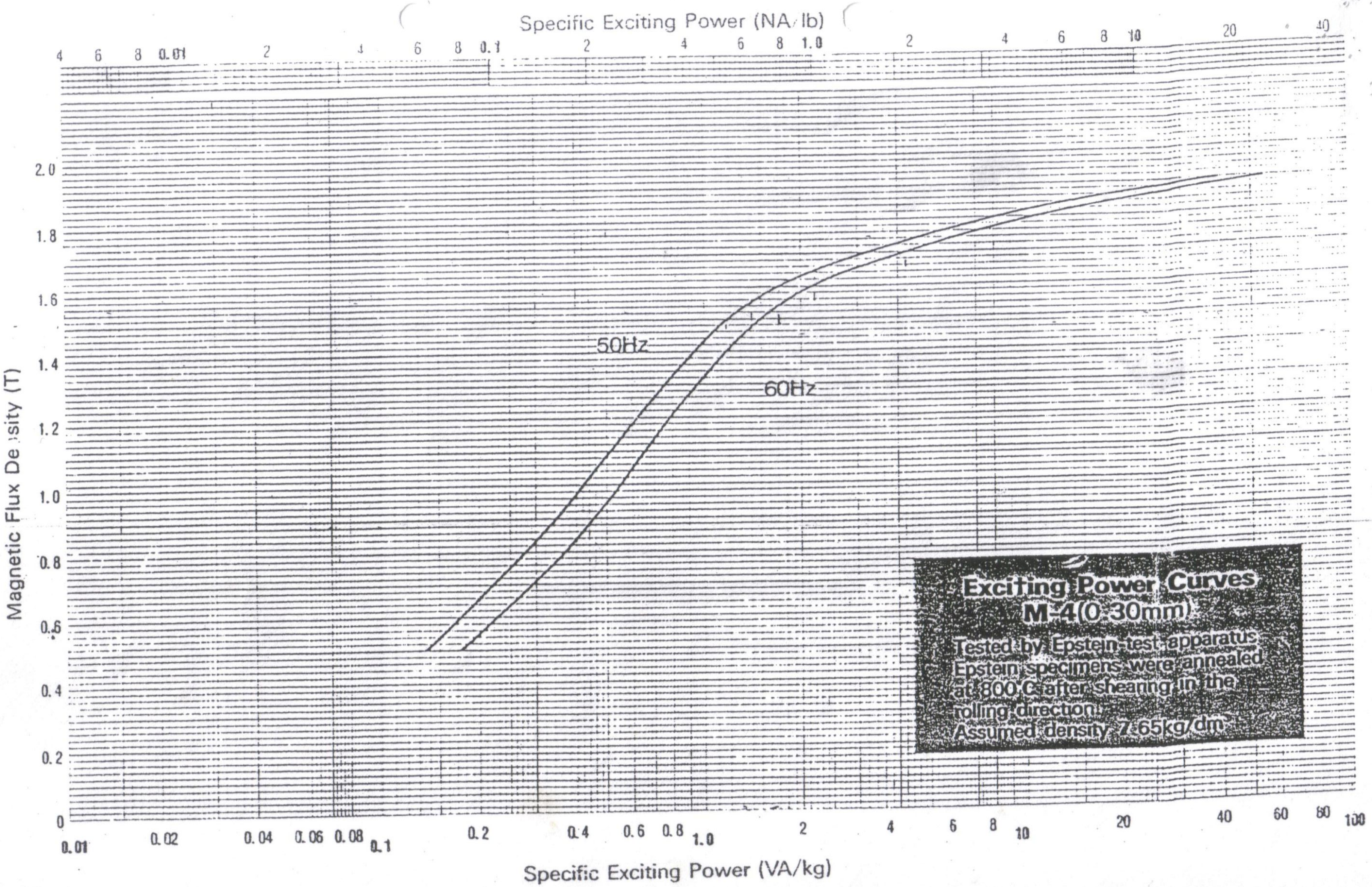

Specific Exciting Power (VA/lb)
4
6
8
0.01
2
4
6
8
0.1
2
4
6
8
1.0
2
4
6
8
10
20
40
Magnetic Flux Density (T)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
50Hz
60Hz
Exciting Power Curves
M-4(0.30mm)
Tested by Epstein test apparatus
Epstein specimens were annealed
at 800 C after shearing in the
rolling direction
Assumed density 7.65kg/dm
0.01
0.02
0.04
0.06
0.08
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
40
60
80
100
Specific Exciting Power (VA/kg)

Fig 11

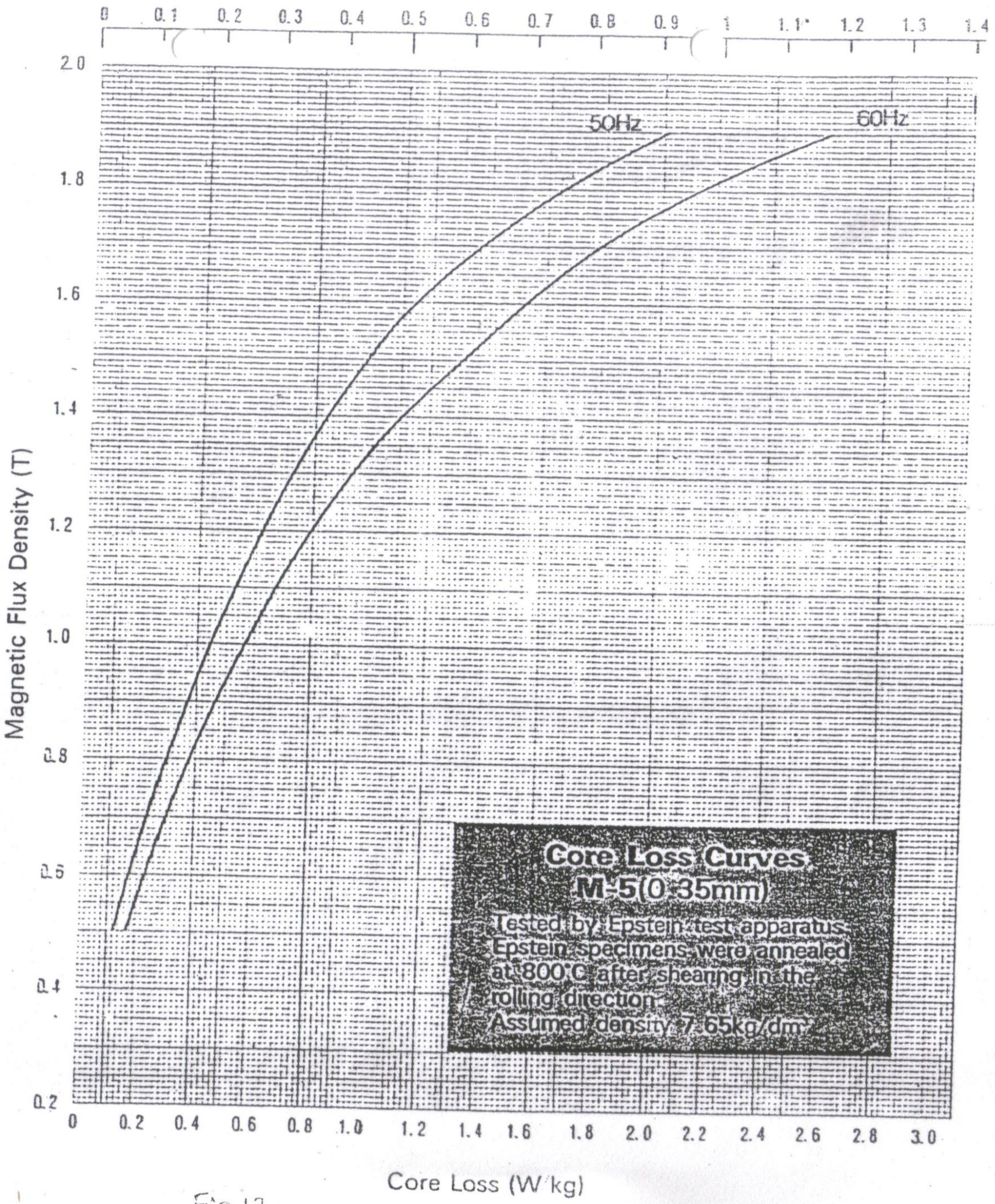

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Magnetic Flux Density (T)
50Hz
60Hz
Core Loss Curves
M-5(0.35mm)
Tested by Epstein test apparatus.
Epstein specimens were annealed at 800°C after shearing in the rolling direction.
Assumed density 7.65kg/dm³
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Core Loss (W/kg)

Fig 12

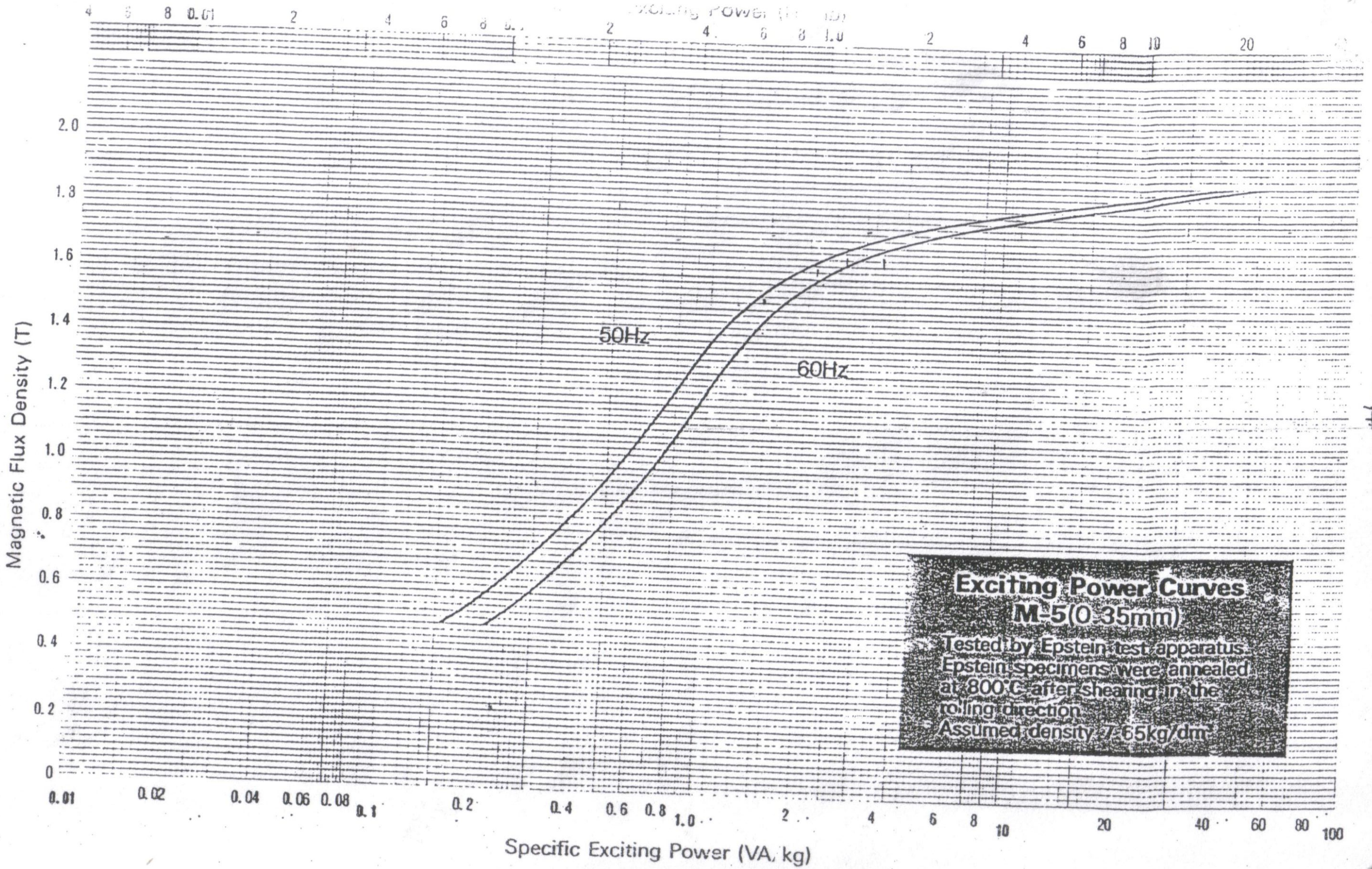

Exciting Power
4
6
8
0.01
2
4
6
8
2
4
6
8
1.0
2
4
6
8
10
20
Magnetic Flux Density (T)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
0.01
0.02
0.04
0.06
0.08
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
40
60
80
100
Specific Exciting Power (VA/kg)
50Hz
60Hz
Exciting Power Curves
M-5(0.35mm)
Tested by Epstein test apparatus.
Epstein specimens were annealed
at 800°C after shearing in the
rolling direction.
Assumed density 7.65kg/dm³

Fig 13

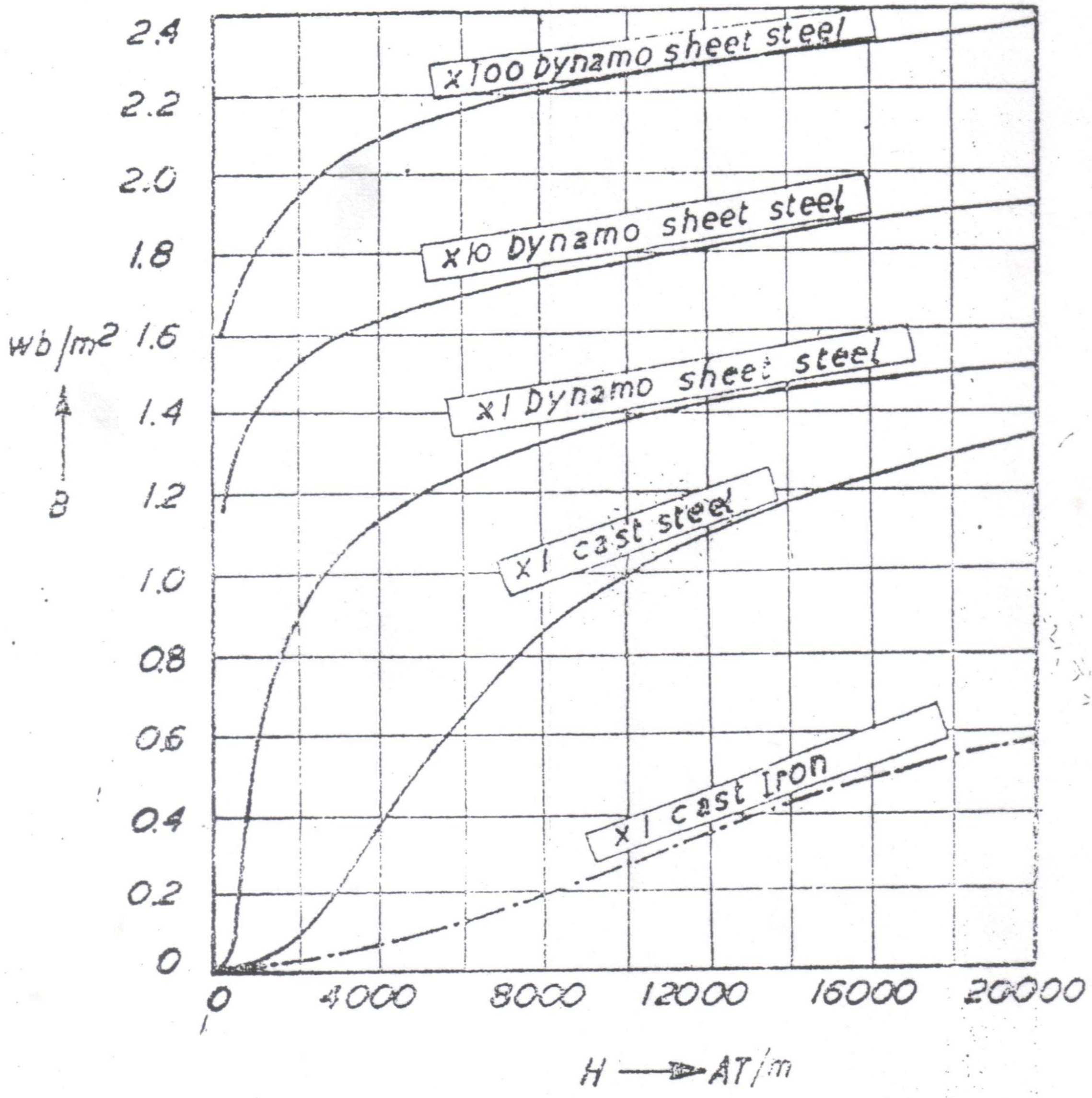


Fig.1A B−H Curves .

$$K_t = \frac{\text{Area of slot } A_s}{\text{Area of tooth } A_t}$$

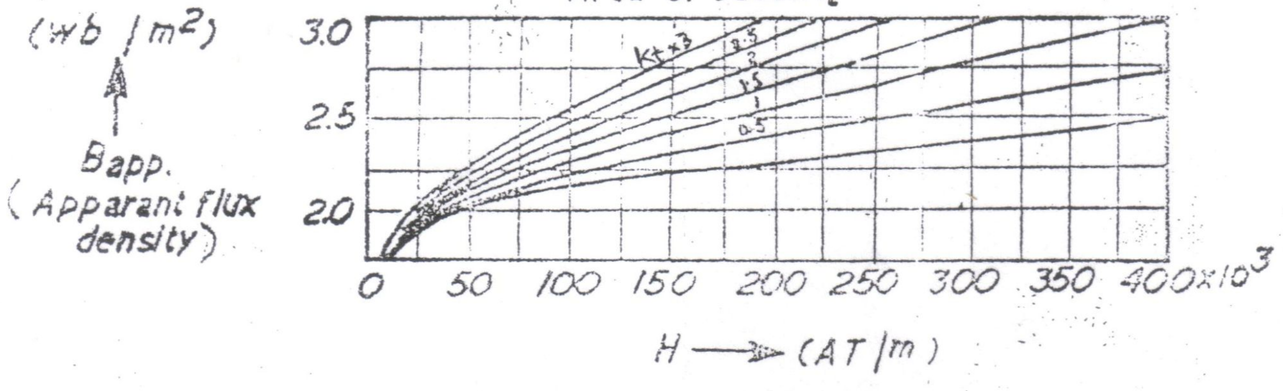


Fig 15. B − H Curves for armature teeth for various values of Kt taking into account the magnetic unloading of teeth .