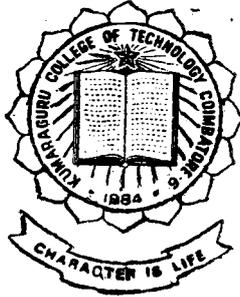


PC Based Design and Testing of Transformers

P - 200

Project Report 1993-94



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Submitted in partial fulfilment of the
requirements for the award of the Degree of

BACHELOR OF ENGINEERING

in Electrical and Electronics Engineering

of the Bharathiar University

Department of Electrical and Electronics Engineering

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CERTIFICATE

This is to certify that the project report entitled
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SYNOPSIS

Design and fabrication of transformers may be done with various aids. Design by hand calculation is considered to be the traditional one which consumes time and man power. Advancement in technology has led to the use of microprocessor as an aid for the design of transformer. The design can be made easy and more accurate by using a personal computer.

In this project an attempt is made to develop a software package in 'C' language for design of small and large capacity transformers. A 230V/24V-1A, 50Hz transformer is fabricated with design parameters obtained from the software. A 200 KVA, 6600/400V, 50Hz, 3 phase transformers are also designed using the software. As the performance characteristics of transformers are required to know its suitability for any application. An additional software is developed to plot the performance characteristics of transformer with test data stored as a lookup table in the computer.

Design particulars and test results are presented in this report. The developed software is very flexible and it can be used to design transformers of any rating.

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- 4.2.4 CHOICE OF FLUX DENSITY
- 4.2.5 WINDOW SPACE FACTOR
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- 4.2.7 DESIGN OF YOKE
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I. INTRODUCTION

Transformer is an a.c machine that (1) transfer electrical energy from one electric circuit to another (2) does so without a change of frequency (3) does so by the principle of electro-magnetic induction (4) has electric circuits that are linked by a common magnetic circuit. The energy transfer usually takes place with a change of voltage, although this is not always necessary. Since its basic construction requires no moving part it is often called the "static device." When secondary voltage of a transformer is higher than its input voltage, it is called a step-up transformer and when the secondary voltage is less than the voltage, it is called the step down transformer. The generated energy at power station should be transmitted at considerable distances for use in villages, towns and cities located at distant places. Transmission of Electrical energy at high voltage is economical. Therefore step-up transformers are used here. Likewise step-down transformers are used in distribution circuits.

1.1 ADVANTAGES OF COMPUTER FOR DESIGN OF TRANSFORMERS

THE COMPUTER has completely revolutionalized the field of design of electrical machines. The computer aided design eliminates the tedious and time consuming hand calculations thereby releasing the designer from Numerical drudgery to enable him to grapple with physical and logical ideas thereby accelerating the design process.

The use of computer makes possible more trial designs, and enable sophisticated calculation to be made without intolerable tedious and excessive time

The advantage of the use of computer for the design of Electrical Machines may be summed as follows

(1) It has capabilities to store amount of data, count integer, round off results to integers and refer tables, graphs and other data in advance.

(2) It makes it possible to select an optimized design with a reduction in cost and improvement in performance.

(3) It reduces the probability of error in design to produce highly accurate and reliable results.

(4) Larger manufacturing savings can be obtained by optimization of design. This optimization is economically feasible only through the use of digital computers.

The high rate of performing calculations at reasonable cost and the ability to carry out logical decisions are the most important qualities of present generation computers. Hence computers have been extensively used in design of Electrical Machinery.

1.2 SCOPE OF THE PROJECT

It is proposed to develop a computer software for the design of transformer. In view of the versatility of 'C' language, the software is to be developed in that language. The input to the software is the name - plate details of the transformer to be designed.

A test transformer is to be fabricated from the design data and its performance characteristics are to be checked with a

II CONSTRUCTIONAL DETAILS OF TRANSFORMER

The simple elements of a transformer consists of two coils having mutual inductance and a laminated steel core. The two coils are insulated from each other and the steel core. Other necessary parts are: a suitable container; suitable bushings (either of porcelain, oil filled of capacitor type) for insulating and bringing out the terminals of windings from the tank.

In all types of transformers, the core is constructed with sheet steel laminations to provide a continuous magnetic path with a minimum air gap included. The steel used is of high silicon content, sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities. The eddy current loss is minimised by laminating the core, the laminations being insulated from each other by a light coat of core plate varnish or by an oxide layer on the surface. The thickness of laminations varies from 0.35mm for a frequency of 50Hz to 0.5mm for a frequency of 25Hz. The joints in the alternate layers are staggered in order to avoid the presence of narrow gaps right through the cross-section of the core. Such staggered joints are said to be imbricated.

Constructionally, the transformers are of two general types distinguished from each other merely by the manner in which the primary and secondary coils are placed around the laminated steel core. The two types are known as i) core type and ii) shell type. Another recent development is spiral core or wound core type the trade name being spiral core transformer.

In the core type transformers, the winding surrounds a considerable part of the core and a considerable portion of the windings as shown in fig.1.

In the simplified diagram for the core type transformers fig 1(a) the primary and secondary windings are shown located on the opposite legs (or limbs) of the core, but in actual construction, these are always interleaved to reduce leakage flux.

In both core and shell type transformers the individual laminations are cut in the form of long strips L's, E's, I's as shown in the fig.2.

In order to avoid high reluctance at the joints where the laminations are bolted against each other, the alternate layers are stacked differently to eliminate these joints as shown in fig.1.

2.1 CORE TYPE TRANSFORMER

The coils used are form wound and are of the cylindrical type. The general form of these coils may be circular or oval or rectangular. In small size core type transformers a simple rectangular coils is used with cylindrical coils which are either circular or rectangular in form. But for large size core type transformers, round or circular cylindrical coils are used which are so wound as to fit over a cruciform core section as shown in fig.5. The circular cylindrical coils are used in most of the core type transformers because of their mechanical strength. Such cylindrical coils are wound in helical layers with the different layers insulated from each other by paper, cloth, mica board or cooling ducts. The general arrangement of these coils with respect to the core. Insulating cylinders of faller board are used to separate the cylindrical windings from the core and from each other. Since the low-voltage (LV) winding is easiest to insulate. It is placed nearest to the core in fig.3.

Because of laminations and insulations, the net or effective core area is reduced. It is found that, in general, the reduction in core sectional area due to the presence of paper, surface oxide etc. is of the order of 10% approximately.

As pointed out above, rectangular cores with rectangular cylindrical coils can be used for small size core type transformers as shown in fig.3. But the large sized transformers, it becomes wasteful to use rectangular cylindrical coils and so circular cylindrical coils are preferred. For such purposes, square cores may be used as shown in the fig.3. where circles represent the tabular former carrying the coils. Obviously, a considerable amount of useful space is still wasted. A common improvement on square core is to employ cruciform as shown in fig 5. which demands, atleast two sizes of core strips. For very large transformers, further core stepping as in fig 5. where atleast three sizes of core plates are necessary core stepping not only gives high space factor but also results in reduced length of the mean turn and the consequent I^2R loss. Three stepped core is the one most commonly used although more steps may be used for very large transformers as in fig.5. From the geometry of fig 5. it can be shown that maximum gross core section for fig 5. is $0.5d^2$ and for fig.5 it is $0.616d^2$ where d is the diameter of the cylindrical coil.

2.2 SHELL TYPE TRANSFORMERS

In their case also the coils are form wound, but are multi-layer disc type usually wound in the form of pan cakes. The different layers of such multi-layer discs are insulated

from each other by paper. The complete winding consists of stacked discs with insulation spaces between the coils. The space forming horizontal cooling and insulating ducts. A shell type transformers may have a simple rectangular form as shown in fig 4. or it may have a distributed form as shown in fig.4.

A very commonly used shell type transformer is the one known as berry transformer so called after the name of its designer and is cylindrical in form. The transformer are the centre as shown in section in fig.4.

It may be pointed out that cores and coils of transformers must be provided with rigid mechanical branching in order to prevent movement and possible insulation damage. Good branching reduces vibration and objectionable noise a humming sound during operation.

The spiral core transformer employs the newest development strip of ribbon of transformer steel wound in the form of a circular or elliptical cylinder. Such construction allows the coreflux to follow the grain of the iron. Cold-rolled steel of high silicon content enables the designer to use considerably higher operating flux densities with lower loss per kg. The use of higher flux densities reduces the weight per KVA. Hence the advantages of such construction are

- i) a relatively more rigid core.
- ii) lesser weight and size per KVA rating.
- iii) lower iron losses at higher operating flux densities and lower cost of manufacture.

Transformers are generally housed in tightly fitted sheet metal tanks filled with special insulating oil. This oil has been highly developed and its function is two fold. By circulation, it not only keeps the coils reasonably cool, but also provides the transformer with additional insulation not obtainable when the transformer is left in the air.

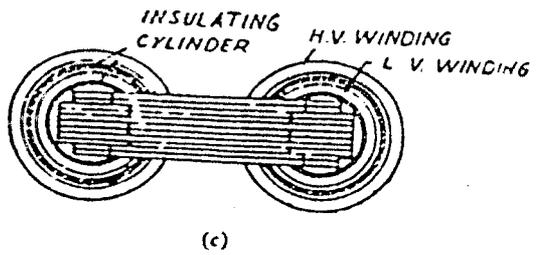
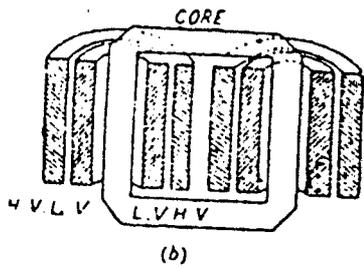
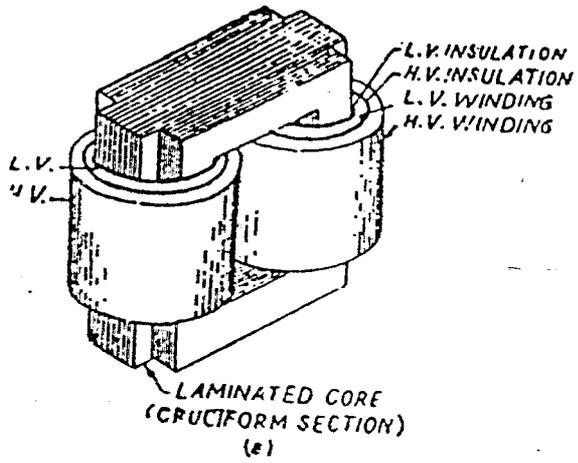
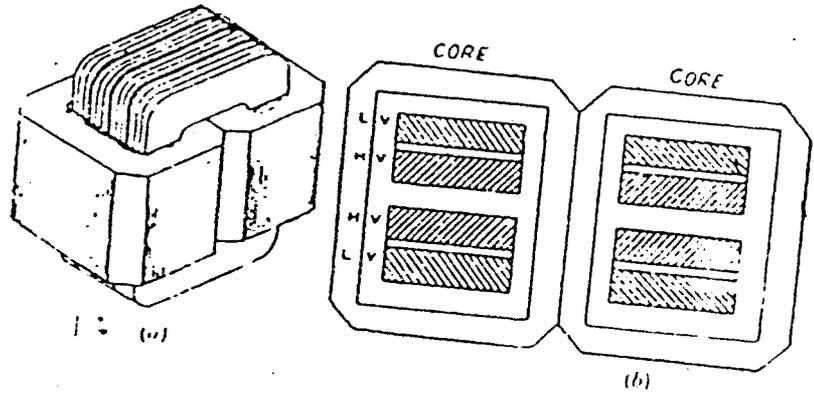
In cases where a smooth tank surface does not provide sufficient cooling area, the sides of the tank are corrugated or provided with radiators mounted on the sides. Good transformer oil should be absolutely free from alkalines, sulphur and particularly from moisture. The presence of even an extremely small percentage moisture in the oil is highly detrimental from the insulation view point because it lowers the dielectric strength of oil considerably. The importance of avoiding moisture in the transformer oil is clear from the fact that even an addition of 8 parts of water in 10,00,000 reduces the insulating quality of the oil to a value generally recognised as below standard. Hence, the tanks are sealed air-tight in smaller units. In the case large sized transformers where complete air-tight construction is impossible, chambers known as breathers are provided to permit the oil inside the tank to expand and contract as its

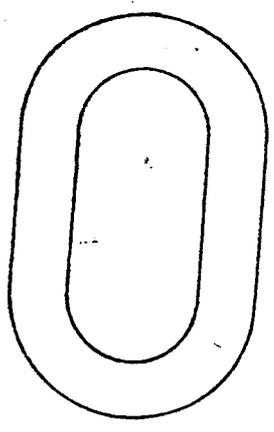
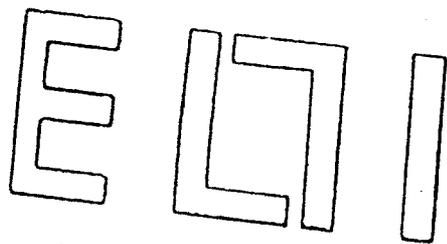
temperature increases or decreases. The atmospheric moisture is entrapped in these breathers and is not allowed to pass onto the oil. Another thing to avoid in the oil is sludging which is simply the decomposition of oil with long and continued use. Sludging is caused principally by exposure to oxygen during heating and results in the formation of large deposits of dark and heavy matter that eventually clogs the cooling ducts in the transformer.

No other feature in the construction of a transformer is given more attention and care than the insulating materials because the life of the unit almost solely depends on the quality, durability and handling of these insulating materials. All the insulating materials are selected on the basis of their high quality and their ability to preserve this high quality even after many years of normal use.

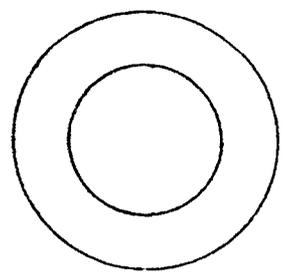
All the transformer leads are brought out of their cases through suitable bushings. There are many designs of these, their size and construction depending on the voltage of the leads. For moderate voltages porcelain bushings are used to illustrate the leads as they come out through the tank. In general, they look almost like the insulators used on the transmission lines. In high voltage installations, oil filled or capacitor type bushing are employed.

The choice of core or shell type constructions is usually determined by cost, because similar characteristics can be obtained with both types. For very high-voltage transformers or for multi winding design, shell type constructions is preferred by many manufactures. In this type, usually the mean length of coil turn is longer than in a comparable core type design. Both core and shell forms are used and selection is decided by many factors such as voltage rating, KVA rating, weight, insulation stress, heat distribution etc.

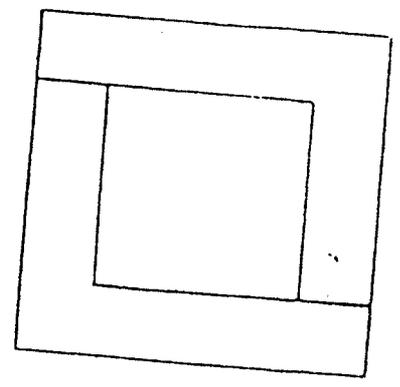




(a) Stadium

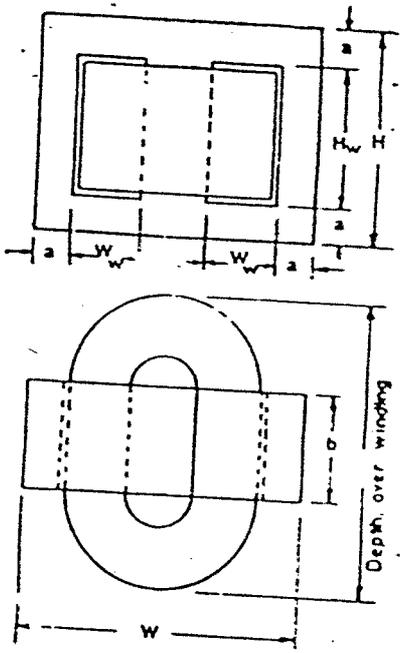
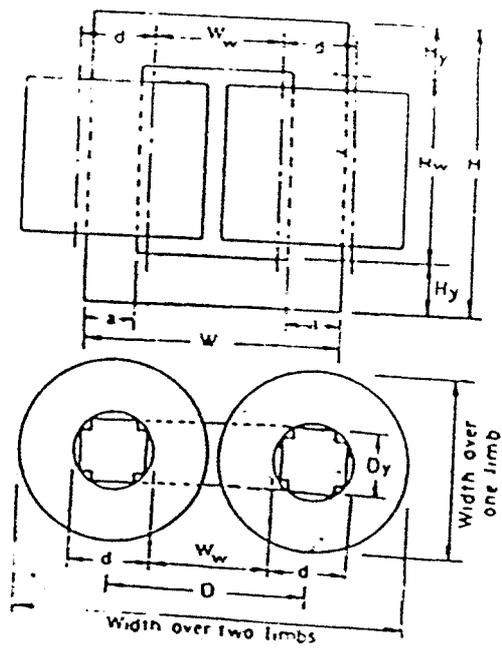


(b) Ring



(c) Rectangular

fig 2



As: 3

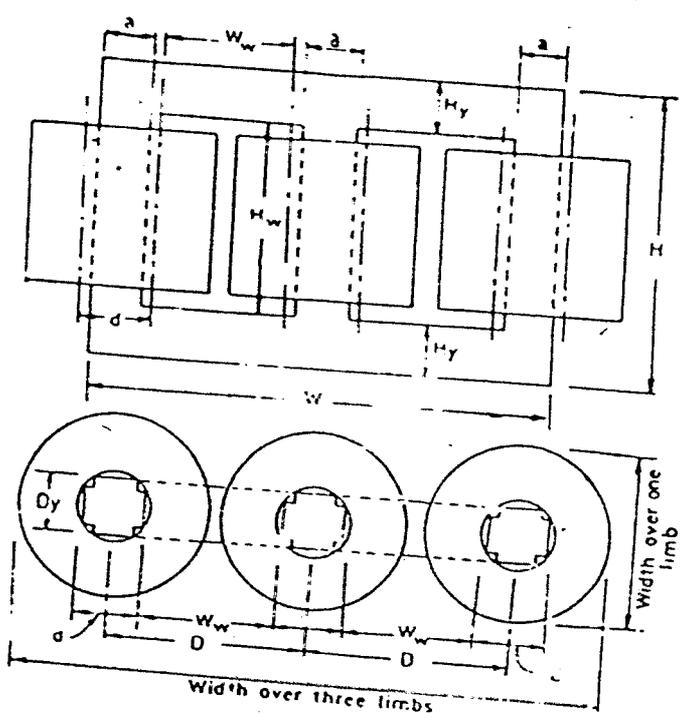
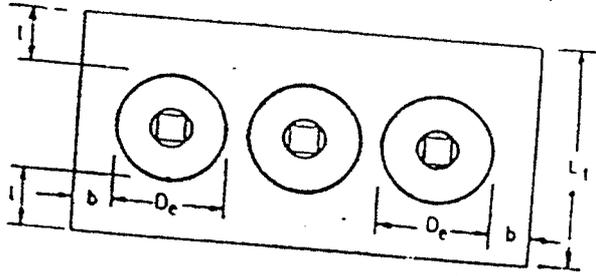
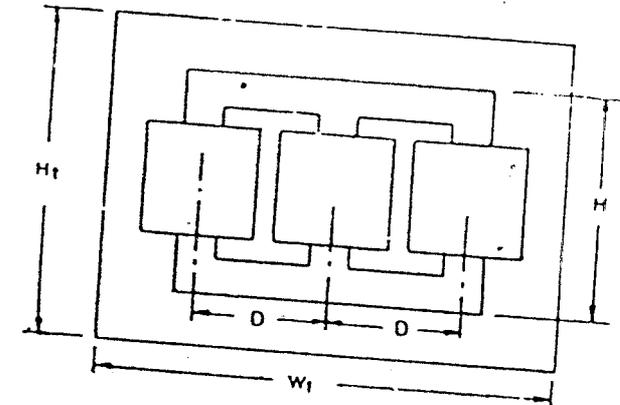
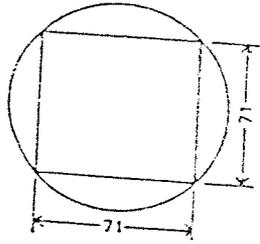
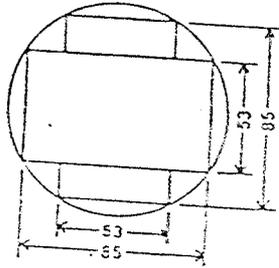


fig 4



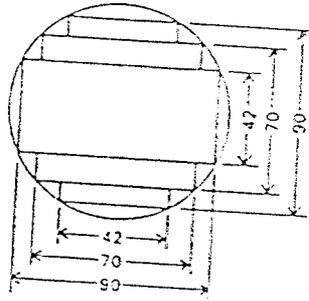
Square section

$$A_{cross} = 0.50d^2$$



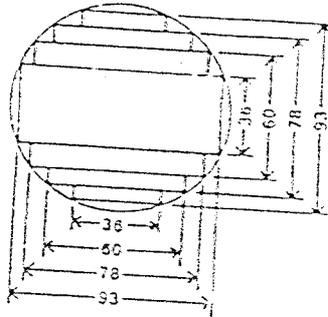
Cruciform section

$$A_{cross} = 0.62d^2$$



Three stepped sect

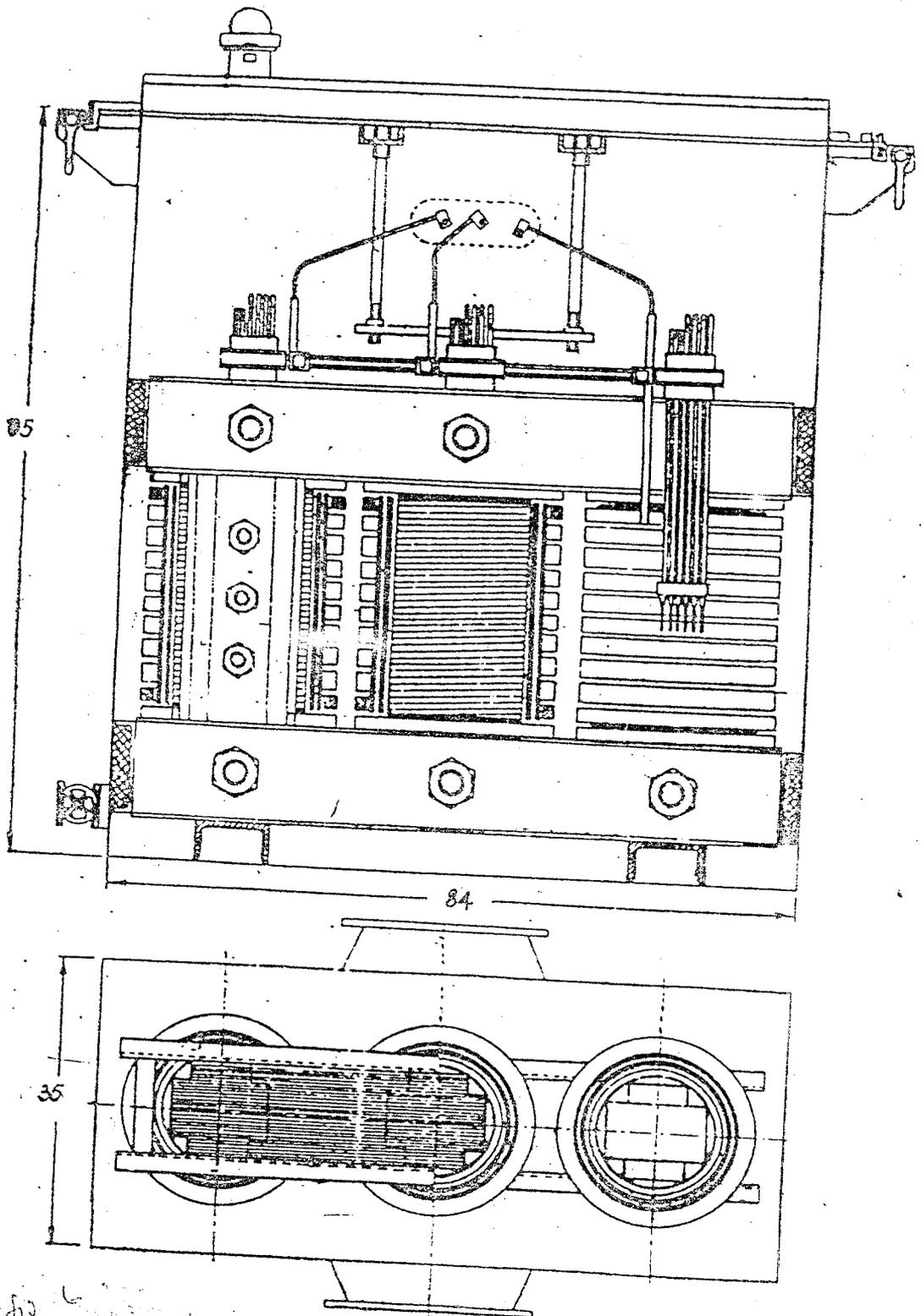
$$A_{cross} = 0.66d^2$$



Four stepped section

$$A_{cross} = 0.68d^2$$

(A)



25 KVA, 3 PHASE, 1160/433 VOLT, 50 HZ., CORE TYPE
DISTRIBUTION TRANSFORMER

FIG. 7.60

III DESIGN OF SMALL TRANSFORMER

3.1 PRIMARY DESIGN

As the first step to the design of a transformer, the primary and secondary voltage ratings and the secondary current rating must be clearly stated. Then decide on the core material to be used: ordinary steel stamping or cold rolled grain oriented (CRGO) stampings. CRGO has a higher allowable flux density and lower losses.

The optimum cross-sectional area of the core is approximately given by:

$$\text{core area} = 1.152 * \sqrt{\text{output voltage} * \text{output current}} \text{ sq.cm.}$$

For transformers with multiple secondaries, the sum of the output volt-amp. Product of each winding is to be used.

The Number of turns on the primary and secondary windings is decided by the turns per volt ratio.

$$\text{Turns per volt} = 1 / (4.44 * 10 \text{ frequency} * \text{core area} * \text{flux density})$$

Here the frequency is 50Hz for Indian domestic mains apply the flux density can be taken as about 1.0 weber/sq.m. For ordinary steel stampings and about 1.3 weber/sq.m for CRGO stampings.

3.2 PRIMARY WINDING DESIGN

The current in the primary winding is given by

$$\text{Primary current} = \frac{\text{sum of (output volts * output amps)}}{\text{primary volts * efficiency}}$$

The efficiency of small transformers varies between 0.75 to 0.96. A value of 0.87 can be used for ordinary transformers.

The proper wire size has to be selected for the winding. The wire diameter depends on the current to be supplied by the winding and the allowable current density of the wire. The current density may be as high as 233 amps/sq.cm in small transformer and as low as 155 amps/sq.cm in large ones. Usually, a value of 200 amps/sq.cm can be taken, on whose basis Table 1 is given

The Number of turns in the primary winding is given by

$$\text{Primary turns} = \text{Turns per volt} * \text{primary volts.}$$

The space taken up by the winding will depend upon the insulation thickness, method of winding and the wire diameter. Table 1 gives the approximate values of the turns per square cm from which we can estimate the window area occupied by the primary winding.

$$\text{Primary winding area} = \frac{\text{Primary turns}}{\text{Turns per sq.cm from Table 1}}$$

3.3 SECONDARY WINDING DESIGN

Since we have assumed that we know the secondary current rating, we can find out the wire size for the secondary winding by referring to table 1 directly.

The number of turns on the secondary is calculated in the same way as for the primary, but about 3% extra turns are to be added to compensate for the internal drop of secondary.

Voltage of the transformers, upon loading thus
secondary turns = 1.03 (turns per volt * secondary volts)

The window area required for secondary winding is found from table 1 as

$$\text{Secondary window area} = \frac{\text{Secondary turns}}{\text{Turns per sq.cm from table 1}}$$

3.4 CORE SIZE

The main criterion in selecting the total window area of winding space available.

$$\text{Total window area} = \text{primary window area} + \text{sum of secondary window areas} + \text{space for former and insulation}$$

Some extra area is required to accommodate the formers and insulation between windings. The actual amount of extra area varies, although 30% may be taken to start with but may have to be modified later. The suitable core sizes having a larger window area are selected from table 2.

Taking into accounts the gap between laminations while stacking them (the core stacking factor taken as 0.9). We have

$$\text{Gross core area} = \frac{\text{core area}}{0.9} \text{ sq.cm}$$

In general, a square central limb is preferred. For this the width of the tonge of lamination is

$$\text{Tongue width} = \sqrt{\text{Gross core area}} \text{ cm}$$

The stack should not be much less than the tongue width but may be more. However, it should not be more than one and half times the tongue width.

3.5 ASSEMBLY

The windings are wound on an insulating former which fits over the centre limb of the core. The primary is usually wound first, then the secondary, with insulation between windings. A final insulating layer is provided over the windings to protect them from mechanical damage.

When this wires are used their ends must be soldered thicker for bringing the terminals outside the former. The laminations are assembled over the former with alternate laminations reversed in assembly. The laminations must be held together tightly by a suitable clamping frame or by screws (if holds are provided in the laminations).

3.6 SHIELD

It is a good practice to use an electrostatic shield between the primary and secondary windings to prevent disturbances from passing through to the secondary from the primary. The shield is made out of a chopper foil which is wound between the two windings for slightly over a turn. Insulation must be provided along the length of the foil and care taken so that the two ends of the foil do not touch each other. A wire soldered to the foil is brought out and connected to the ground.

IV. DESIGN OF POWER AND DISTRIBUTION TRANSFORMERS

4.1 INTRODUCTION

DISTRIBUTION AND POWER TRANSFORMERS

The transformers used in power systems may be divided into two categories depending upon the type of service. These are :

1. Distribution Transformers.
2. Power Transformers.

DISTRIBUTION TRANSFORMERS

Transformers upto a rating of about 200KVA, used to step down the distribution voltage to a standard service voltage or from transmission voltage to distribution voltage are known as distribution transformers. They are kept in operation all the 24 hours a day whether they are carrying any load or not. Energy is lost as iron losses throughout the day while the copper losses account for loss in energy when the transformer is loaded. Therefore distribution transformers should have their iron small as compared with full load copper losses. In other words they should be designed to have maximum efficiency at a load much lower than full load (about 50 per cent). Owing to low iron loss, the distribution transformers have a good all day efficiency. Distribution transformers should have a good voltage regulation and therefore they should be designed for a small value of leakage reactance.

POWER TRANSFORMERS

They have a rating above 200 KVA and are used in generating stations and substations at each end of a power transmission line for stepping up or stepping down the voltage. They may be either single phase or three phase units. They are put in operation during load periods and are disconnected during light load periods. Therefore power transformers are designed to have considerably greater leakage reactance than is permissible in distribution transformers. As in the case of power transformers inherent voltage regulation is less important than the current limiting effect of the higher leakage reactance.

This design principle is used to design the distribution and transformers both three phase and single phase.

4.2 DESIGN DETAILS

4.2.1 DESIGN OF CORE

The transformer core is a closed magnetic circuit through the mutual flux (i.e) the flux linkage in both the windings. For the construction of the core we are using special alloy steel of high resistance and low hysteresis loss. All the laminations are insulated to maintain the sub-division and is also maintained that the laminations and insulations of core plates doesn't reduce the effective core area.

4.2.2 CORE CROSS SECTION

In small core type transformers rectangular section limbs with rectangular coils are used. But in large size to save the materials and hence the cost the cross section used is circular. Because it has minimum periphery for a particular area and so the windings have minimum lengths of mean turn. Still there are some spaces wasted. To use that space effectively 'cruciform' core is used. By this length of mean turn and consequent I^2R losses are reduced considerably. For large transformers more than three stepped limbs are used.

For shell type transformer simple rectangular cross section is used and coils being rectangular.

4.2.3 CALCULATION OF CORE AREA

The voltage per turn is calculated from equation $E_t = K\sqrt{Q}$, where K is a constant, Q is the rated KVA. The value of K can be chosen from the table and hence the value of E_t determined.

$$\text{Now, flux } \quad \text{O/m} = \frac{E_t}{4.44f}$$

Therefore the value of flux in the core can be calculated. The area of the core is found out by assuming a suitable value of maximum flux density B_m .

$$\text{Net core area required } AE = \frac{\text{O/m}}{B_m}$$

and

$$\text{Gross core area } A_{gi} = \frac{A_i}{K_i}, \quad K_i = 0.9$$

4.2.4 CHOICE OF FLUX DENSITY

The value of flux density in the core determines the core area. Higher values of flux density gives a smaller core area and therefore there is a saving in cost of iron. Also with the reduction in core area the length of mean turn windings is also reduced. Thus there is a saving in conductor costs also. But with higher flux density, the iron losses become high resulting in considerable temperature gradient across the core. High flux density necessitates a large magnetizing current which contains objection harmonics.

The value of flux density to be chosen also depends upon the service conditions of the transformer. As a distribution transformer has to be designed for a high all day efficiency, and therefore the values of flux density should be low in order to keep down the iron losses.

The usual values of maximum flux density B_m for transformers using hot rolled silicon steel are:

Distribution transformer - 1.1 to 1.35 wb/m²

Power transformer - 1.25 to 1.45 wb/m²

Lower values should be used for small rating transformers.

For transformers using cold rolled grain oriented steel the following values may be used.

For transformers upto 132 KV	- 1.55 wb/m ²
For 275 KV transformers	- 1.6 wb/m ²
For 400 KV and generator transformers	- 1.7 wb/m ²

4.2.5 WINDOW SPACE FACTOR

The window space factor is defined as the ratio of copper area in the window to the total window area. It depends upon the relative amounts of insulation and copper provided, which in turn depends upon the voltage rating and output of transformers. The following empirical formula may be used for estimating the value of window space factor.

$$K_w = 10 / (30 + KV)$$

Where KV is the voltage of L.V. winding in kilo - volt. The above formula is for transformer of ratings between 50 to 200 KVA.

Space factor is larger for large outputs and smaller for small outputs. For a transformer of about 1000 KVA rating $K_w = 12 / (30 + KV)$ and for transformers of about 20 KVA rating $K_w = 8 / (30 + KV)$. The values of space factor for intermediate ratings can be interpolated.

4.2.6 WINDOW DIMENSIONS

The leakage reactance is affected by the distance between adjacent limbs. If this distance is relatively small, the width of the winding is limited and this must counter balanced by increasing the height of the winding. Thus the windings are long and thin. This arrangement leads to low value of leakage reactance. If the height of the window is limited, the width of the window has to be increased in order to accommodate the coils. This results in short and wide coils giving a large value of leakage reactance.

The height and width of the window can be adjusted to give a suitable arrangement of windings and also to give a desired value of leakage reactance.

The area of the window depends upon total conductor area and the window space factor.

$$\text{Area of window } A_w = \frac{\text{total conductor Area}}{\text{window space factor}}$$

$$= \frac{2ap T_p}{K_w} \quad \text{for 1 phase transformers}$$

$$= \frac{4ap T_v}{K_w} \quad \text{for 3 phase transformers}$$

$$\begin{aligned} \text{Area of window } A_w &= \text{height of window} \times \text{width of window} \\ &= H_w \times W_w. \end{aligned}$$

The ratio of height to width of window H_w/W_w is between 2 to 4

By assuming a suitable value for ratio H_w/W_w , the height and width of window can be calculated.

4.2.7 DESIGN OF YOKE

The area of the yoke is taken as 15 to 25 percent larger than that of core for transformers using hot rolled silicon steel. This reduces the values of flux density obtaining in the yoke and therefore there is reduction in the iron losses and the magnetising current. For transformers using cold rolled grain oriented steel the area of yoke is taken equal to that of the core. The section of the yoke can either be taken as rectangular or it may be stepped. In the case of rectangular section yokes, the depth of the core. This depth of the core is equal to the width of the largest stamping when square or stepped cores are used.

For rectangular section yokes,

$$\begin{aligned} \text{Area of yoke } A_y &= \text{depth of yoke} \times \text{height of yoke} \\ &= D_y \times H_y. \end{aligned}$$

Where D_y = width of largest core stamping

$A_y = (1.15 \text{ to } 1.25) A_{gi}$ for transformers using hot rolled steel.

$A_y = A_{gi}$ for transformers using grain oriented steel.

4.2.8 OVERALL DIMENSIONS

For the overall dimensions in transformer problems, we use the following symbols.

- a - width of largest stamping
- d - diameter of circumscribing circle
- D - Distance between centres of adjacent limbs.
- Ww - width of window
- Hw - Height of window
- L - Length of limb
- Hy - Height of yoke
- H - overall height of transformer over yokes or overall height of frame
- W - length of yoke or overall length of frame

We have the following relations for single phase core type transformers.

$$D = d + Ww \quad Dy = a$$

$$H = Hw + 2 Hy \quad W = D + a$$

Width over to limbs = $D + \text{outer Diameter of h.v winding.}$

Width over one limb = outer Diameter of h.v winding.

we have, for a 3 phase core type transformers,

$$D = d + Ww$$

$$Dy = a$$

$$H = Hw + 2 Hy$$

$$W = 2D + a$$

Width over 3 limbs = $2D +$ outer diameter of H.V winding

Width over one limb = outer diameter of H.V winding

$$D_y = b; \quad H_y = a; \quad W = 2 W_w + 4a; \quad H = H_w + 2a$$

4.2.9 WINDING DESIGN

Number of turns in primary winding T_p is

$$T_p = \frac{\text{Voltage of primary winding}}{\text{Voltage per turns}} = \frac{V_p}{E_t}$$

Number of turns in secondary winding T_s is

$$T_s = \frac{V_s}{E_t}$$

Number of turns on low voltage winding per phase is

$$T_{l.v} = \frac{V_{l.v}}{E_t} = \text{an integer}$$

Number of high voltage winding turns per phase is

$$T_{h.v} = \frac{V_{h.v}}{V_{l.v}} \times T_{l.v}$$

If the tappings are located in the middle part of the h.v winding, then the number of windings turns must be even to ensure symmetry

Current in primary winding

$$I_p = \frac{\text{KVA per phase} \times 10^3}{V_p}$$

For distribution and small power transformers upto 50 KVA, the current density $S = 1.1$ to 2.3 A/mm^2

For large power transformers, current density varies from 2.2 to 3.2 A/mm^2

For minimum I^2R loss the value of current density in each of the windings should be equal.

PORTION OF THE WINDINGS

The low voltage winding is placed nearer to the core. This is because if we have high voltage winding nearer to the core then the insulation between the core and the high voltage windings and also with the low voltage should be high. This increases the cost as well as the length of mean turn. So usually high voltage winding is placed on the outside. Tappings are provided on the high voltage winding because it is convenient to tap the winding on the outside.

4.2.10 RESISTANCE OF WINDING

Let L_{mtp} , L_{mts} = length of primary and secondary windings respectively in meters

Y_p , Y_s = Resistance of primary and secondary windings respectively in meters

$$Y_p = \frac{P_{Tp} * L_{mtp}}{a_p} \quad \text{and}$$

$$Y_s = \frac{P_{Ts} * L_{mts}}{a_s}$$

$$\text{Total } I^2R \text{ loss in winding } P_c = I_p^2 r_p + I_s^2 r_s$$

Total resistance (per phase) of transformer referred to primary side

$$R_p = \frac{P_c}{I_p^2} = r_p + \frac{I_s^2}{I_p}$$

$$r_s = r_p + \frac{T_p^2}{T_s} r_s$$

per unit Resistance

$$E_r = I_p * R_p / V_p$$

4.2.11 CALCULATION OF LEAKAGE REACTANCE

The estimation of leakage reactance is primarily the estimation of the distribution of leakage flux and the resulting flux leakages of the primary and secondary windings. The distribution of the leakage flux depends upon the geometrical configuration of the coils and the neighbouring iron masses, and also on the permeability of the latter. The most common arrangements of the core and windings are core and shell type. In these two cases the field is sufficiently symmetrical and geometrical and therefore considerable simplification can be made and the value of total leakage reactance of transformer (per phase) referred to primary side.

$$X_p = 3.14f \times T_p^2 \times \frac{L_{mt}}{L_c} \times \left(a + \frac{b_p + b_s}{6} \right)$$

and per unit leakage reactance X_e is

$$X_e = \frac{\text{Primary current } X_p}{\text{Primary voltage}}$$

per unit impedance

$$E_z = \sqrt{(E_r)^2 + (X_e)^2}$$

4.2.12 CALCULATION OF REGULATION

On no load the secondary terminal voltage $V_s = V_p$. The drop in secondary terminal voltage from no load to the full load can be calculated by drawing the phasor diagram at lagging power factor $\cos \phi$

$$V_p = (V_p + I_p R_p \cos \phi + I_p X_p \sin \phi) + (I_p X_p \cos \phi - I_p R_p \sin \phi)$$

4.2.13 CALCULATION OF LOSSES

If P_i be the specific iron loss and P_c the specific $I^2 R$ loss at full load in W/Kg the total full load loss is

$$P_i + P_c = (P_i G_i + P_c G_i) \times 10^{-3} \text{ kw}$$

At any fraction of full load, the loss becomes $(P_i + X^2 P_c)$ since $I^2 R$ obviously depends upon the square of the load.

If S be the valid output, the efficiency at load x is

$$= \frac{xS}{(X_s + P_c + X^2 P_c)}$$

Which will be a maximum when $\frac{ds}{dx} = 0$

or when $(X_p + P_i + X^2 P_c) S = X_s (S + 2X P_c)$

that is when $P_i = X^2 P_c$

So that the efficiency is a maximum when the (Variable) $I^2 R$ loss is equal to the (constant) iron loss.

If a transformer were required to work on full load all the time it was in circuit P_i would naturally be made equal to P_c when $x = 1$ and the maximum efficiency would occur at the full working load. In practice such a loading is rarely obtainable, and the load for maximum efficiency is less than full load.

2.14 CALCULATION OF EFFICIENCY

The formula for efficiency of a transformer at any power factor $\cos \phi$ and load X (KVA) is given by

$$\begin{aligned} &= \frac{\text{output}}{\text{Input}} = \frac{\text{output}}{\text{output} + \text{losses}} \\ &= \frac{X (\text{KVA}) \cos \phi}{X (\text{KVA}) \cos \phi + \text{iron loss} + X (\text{load loss on full load})} \end{aligned}$$

Where

KVA : total KVA rating of the transformer

X : fraction of full load KVA at which efficiency is calculated

The load loss occurring at any load is proportional to square of the current and hence equal to X^2 (load loss on full load). Maximum efficiency shall occur when iron loss equals the load loss.

(i.e) iron loss = X^2 (load loss on full load)

The maximum efficiency occurs at X (full load KVA) where X is found from the relation

$$X = \frac{\text{iron loss}}{\text{losses on full load}}$$

4.2.15 CALCULATION OF NO LOAD CURRENT

The no load current I_0 consists of two components

(i) magnetizing current I_m

(ii) loss component I_l and its value is given by

$$I_0 = \sqrt{(I_m^2 + I_l^2)}$$

Thus the estimation of no load current I_0 requires the calculation of its two components I_m and I_l .

Let l_c, l_y = length of flux path through core and yoke respectively ($l_c = Hw, l_y = W$)
 a_{tc}, a_{ty} = mmf / metre for flux densities in core and yoke respectively .

Total magnetizing mmf

$$A_{T0} = 2a_{tc} l_c + 2a_{ty} l_y + \text{mmf required for joints.}$$

The calculation of total mmf is based upon the maximum value of density.

$$\text{rms value of magnetizing current } I_m = \frac{A_{T0}}{2T_p}$$

But the magnetizing is not sinusoidal and therefore the peak factor K_{pk} should be used in place of 2.

$$I_m = A_{To} (K_{pk} T_p)$$

Let the iron losses be P_t the loss component

$$I_t = P_i / V_p$$

The iron losses are calculated by finding the weight of cores and yokes.

No load current of three phase transformers,
 Total magnetizing mmf required for the transformer =
 $3 a_{tc} l_c + 2 a_{ty} l_y + \text{mmf required for joints.}$

Total magnetising mmf required per phase

$$A_{To} = 3 a_{tc} l_c + 2 a_{ty} l_y + \text{mmf required for joints.}$$

$$\text{Magnetising current per phase } I_m = A_{To} / (2 T_p)$$

Let P_i be the total iron loss for the three phases.

$$I_t = P_i / 3 V_p$$

It is not usual to calculate the no load current in transformers as in a normally designed transformers, the no load current would be below 5% and a considerable variation can be made in its value without affecting the transformer performance.

$$\text{Magnetising Volt ampere } E_p = 4.44 f T_p B_m A_T$$

$$\begin{aligned} \text{Magnetising Volt ampere (VA)}_m &= E_p I_m \\ &= 4.44 f T_p B_m A_T \left(\frac{A_{To}}{2T_p} \right) \end{aligned}$$

$$= 4.44 f B_m A T_o A_i / 2$$

Now $A T_o$ = magnetizing mmf per metre x length of iron path

$$VA (m) = \frac{4.44 f B_m A_i \text{ atm } l_i}{2}$$

Weight of iron = $A_i l_i \times 7.8 \times 10^3$, if the density of iron is assumed as $7.8 \times 10^3 \text{ kg/m}^3$

$$\begin{aligned} \text{Magnetizing volt - ampere / kg} &= \frac{4.44 f B_m \text{ atm}}{2 \times 7.8 \times 10^3} \\ &= 0.4 f B_m \text{ atm} \times 10^{-3} \end{aligned}$$

Magnetizing current

$$I_m = \frac{\text{Magnetizing VA / kg} \times \text{weight of core}}{\text{Number of phases} \times \text{voltage / phase}}$$

4.2.16 TEMPERATURE RISE OF TRANSFORMERS

The losses developed in the transformer cores and windings during conversion are converted into thermal energy and cause heating of corresponding transformer parts. From its source the heat is directed, due to thermal gradients, to the places where it may be transferred to a cooling medium (i.e) to air, or water, depending upon the method of transformer cooling. Heat dissipation occurs in the same way as in electrical machines (i.e) by way of radiation and convection. The path of heat flow is :

(i) From the internal most heated spots of a given part (of core or winding) to their outer surfaces in contact with the oil.

(ii) From the outer surface of a given transformer part to the oil that cools it.

(iii) From the oil to the walls of a cooler, for instance of the tank.

(iv) From the walls of the cooler to the cooling medium - air or water.

In section (i) the heat is transferred by conduction. In sections (ii) and (iii) the heat is transferred by convection of the oil.

In section (iv) the heat is dissipated by both convection and radiation.

Temperature rise in plain walled tanks

The walls of tank dissipate heat by both radiation and convection.

$$\begin{aligned} \text{Temperature rise } \theta &= \frac{\text{Total loss}}{\text{Specific heat dissipation} \times \text{surface}} \\ &= \frac{P_i + P_c}{12.5 St} \end{aligned}$$

where St = heat dissipating surface of tank. The surface, to be considered in applying the above formula, is the total area of the vertical sides plus one half area of the cover, unless the oil is in contact with the cover in which case whole area of the lid should be taken. The area of bottom of the tank should be neglected as it has very little cooling effect.

For transformers of low output, the plain walled tanks are large enough to accommodate the transformer and oil have sufficient surface to keep the temperature to rise within limits. But for transformers of large output, the plain walled are not sufficient to dissipate losses. This is because volume and hence losses increases as cube of linear dimensions while the dissipating surface increases as the square of linear dimensions. Thus an increase in rating results in an increase in loss to be dissipated per unit area giving a higher temperature rise.

Modern oil immersed power transformers with natural oil cooling and a plain tank may be produced for outputs not exceeding 20 - 30 KVA transformers rated for larger outputs must be provided with means to improve the conditions of heat dissipation. This may be done by providing corrugations, tubing or radiators where feasible.

4.2.17 DESIGN OF TANK WITH TUBES

If the temperature rise as calculated with plain tank exceeds the specified limits, it can be brought down by provision of the tubes. The provision of tubes increases the dissipating area but the increase in dissipation of heat is not proportional to area because the tube screen some of the tank surface preventing radiation from there. So there is no change in surface as far as dissipation of heat due to radiation is concerned. But the increase in dissipation of

heat is more than what is justified by the increase in surface area. The circulation of oil is improved due to more effective heads of pressure produced by columns of oil in tubes. An addition of about 35% should be made to tube area in order to take in to account this improvement in dissipation of loss by convection.

Let the dissipating surface of tank be St .

It will dissipate $(6 + 6.5) St = 12.5 St w/c$

Area of tubes = $X St$

Loss dissipated by tubes by convection = $1.35 \times 6.5 \times St$
 $= 8.8 \times St w/c$

Total loss dissipated by tank walls and tubes
 $= 12.5 St + 8.8 \times St$
 $= St (12.5 + 8.8X)w/c$

Total area of tank walls and tubes = $St + X St$
 $= St (1 + X)$

Loss dissipated = $\frac{12.5+8.8X}{X + 1} w/m^2-c$

Temperature rise with tubes = $\frac{Pi + Pc}{St (12.5 + 8.8 X)}$

$$X = \frac{1}{8.8} \left(Pi + Pc - \frac{12.5}{Sto} \right)$$

Total area of tubes = $1 \left(\frac{Pi+Pc}{Sto} - 12.5 Si \right)$

Let lt and dt be length and the diameter of each tube respectively.

$$\text{Area of each tube} = 3.14 dt lt$$

$$\text{Hence number of tubes } nt = \frac{l}{8.8 dt lt} \left\{ \left(\frac{Pi + Pc}{O} - 12.5 St \right) \times \left(\frac{Pi + Pc}{O} - 12.5 St \right) \right\}$$

The area of the tubes can be found out by using the above expression. The diameter of tubes normally used is 50 mm and they are spaced at 75mm. Elliptical tubes with pressed radiators are increasingly being used as they give a greater dissipating surface for smaller volume of oil.

The inner dimensions of the transformer tank are fixed by the active dimensions of the transformer and clearances between windings and grounded parts of transformer.

$$\begin{aligned} \text{Width of tank } Wt &= 2D + De + 2b && \text{(for three phase)} \\ &= D + De + 2b && \text{(for single phase)} \end{aligned}$$

where D = distance between adjacent limbs

De = external diameter of h.v winding

b = clearance between h.v winding and tank

$$\text{length of the tank } Lt = De + 2l$$

l = clearance on each side between the width

$$\text{Height of transformer } Ht = H + h$$

where H = height of transformer frame and

h = clearance (height) between the assembled transformer and the tank

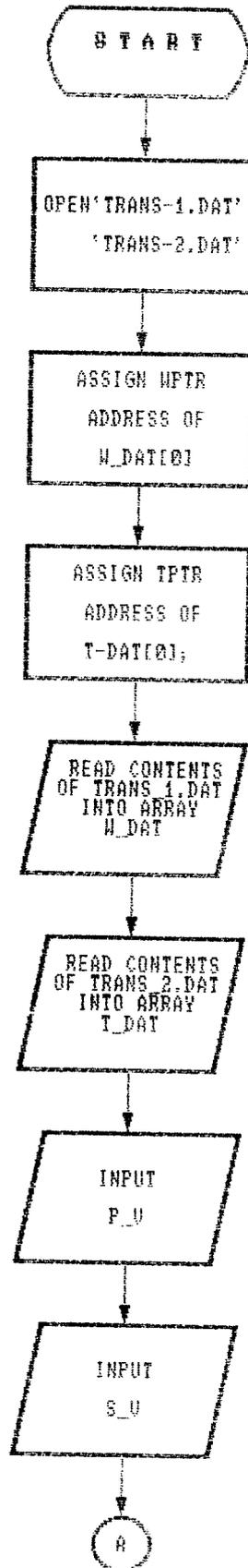
This includes the clearance at the base, oil height above the assembled transformer space for terminals and tap changing gear. l and h are given in the tables.

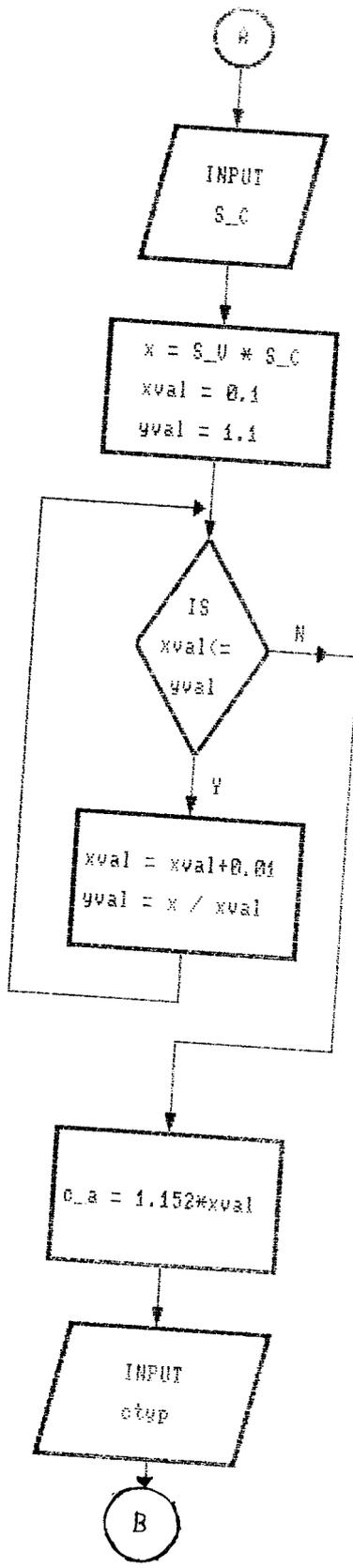
V. ALGORITHM AND FLOWCHART

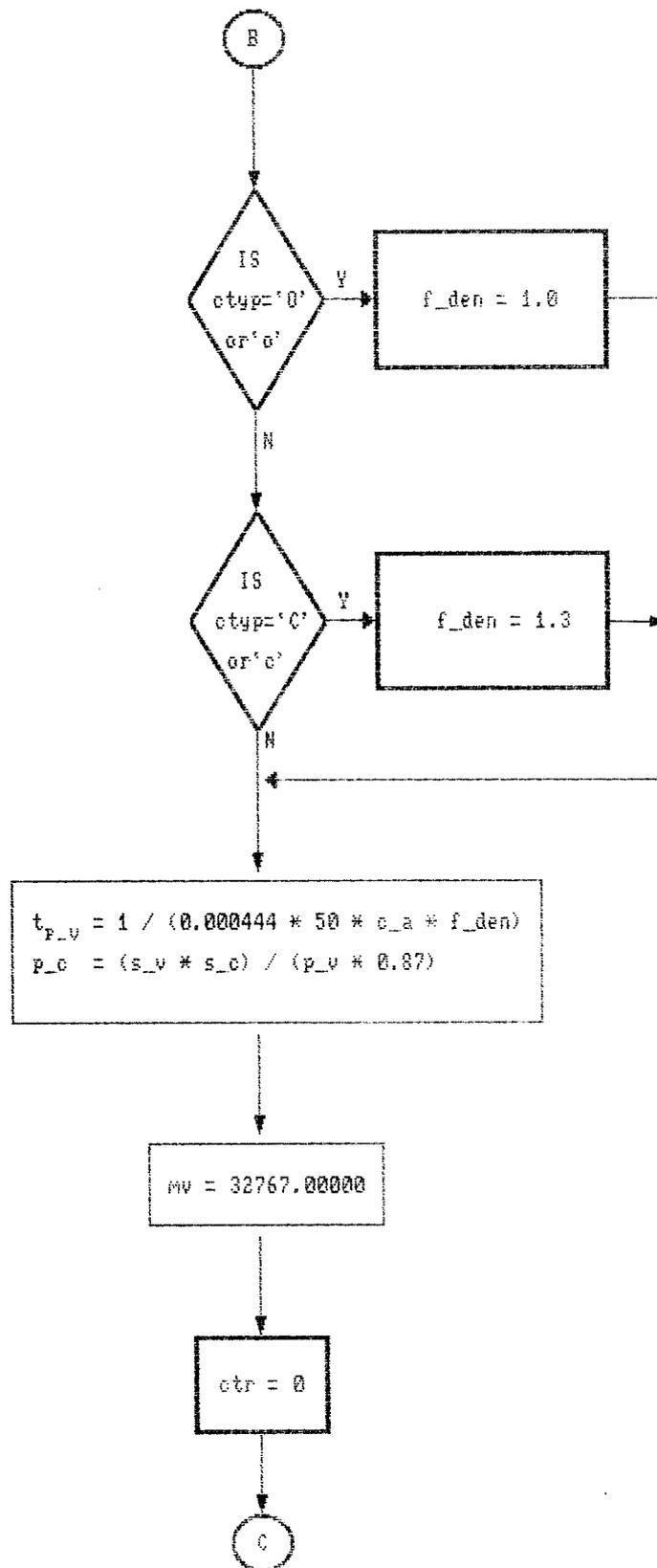
5.1 ALGORITHM FOR DESIGN OF 230/24V-1 A TRANSFORMER

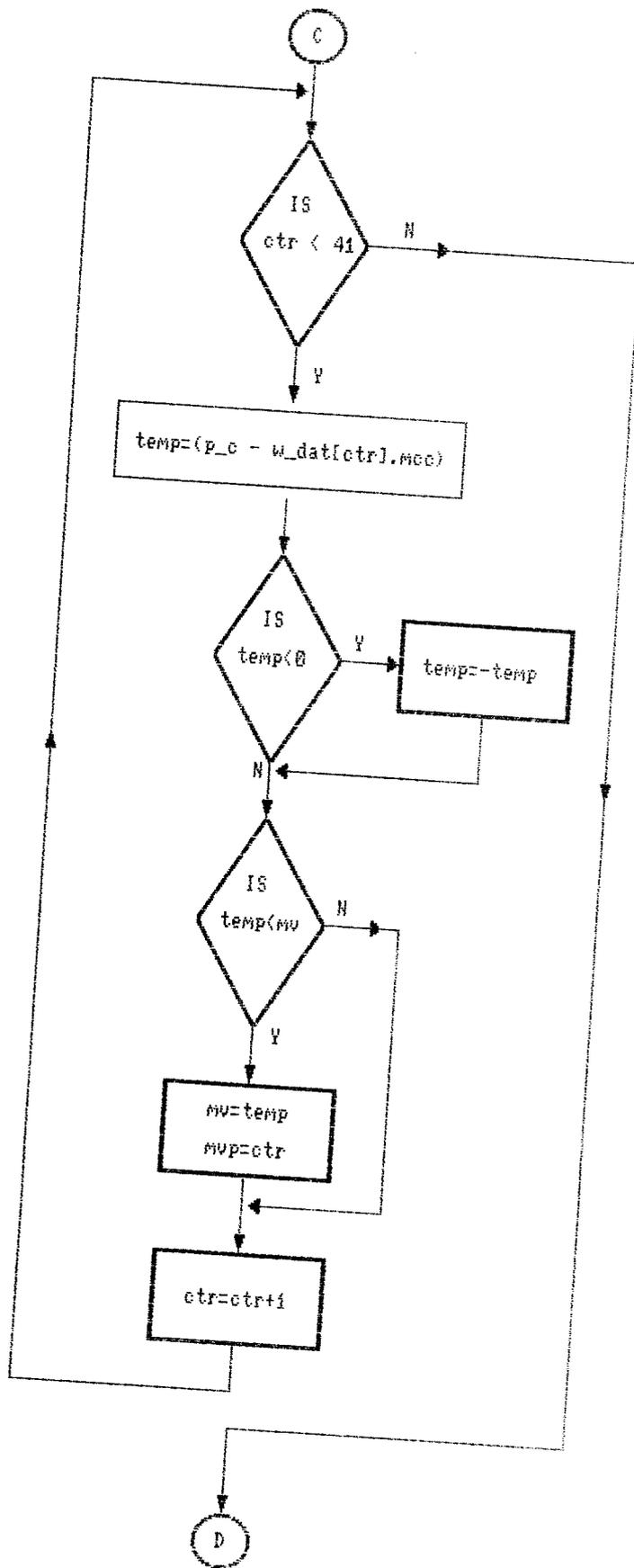
The input data is first stored in the memory, (i.e) primary voltage, secondary voltage and current. Now core area is calculated and the primary current, primary and secondary winding area, number of turns in primary and secondary, tongue width, core size and stack height are computed with standard formula.

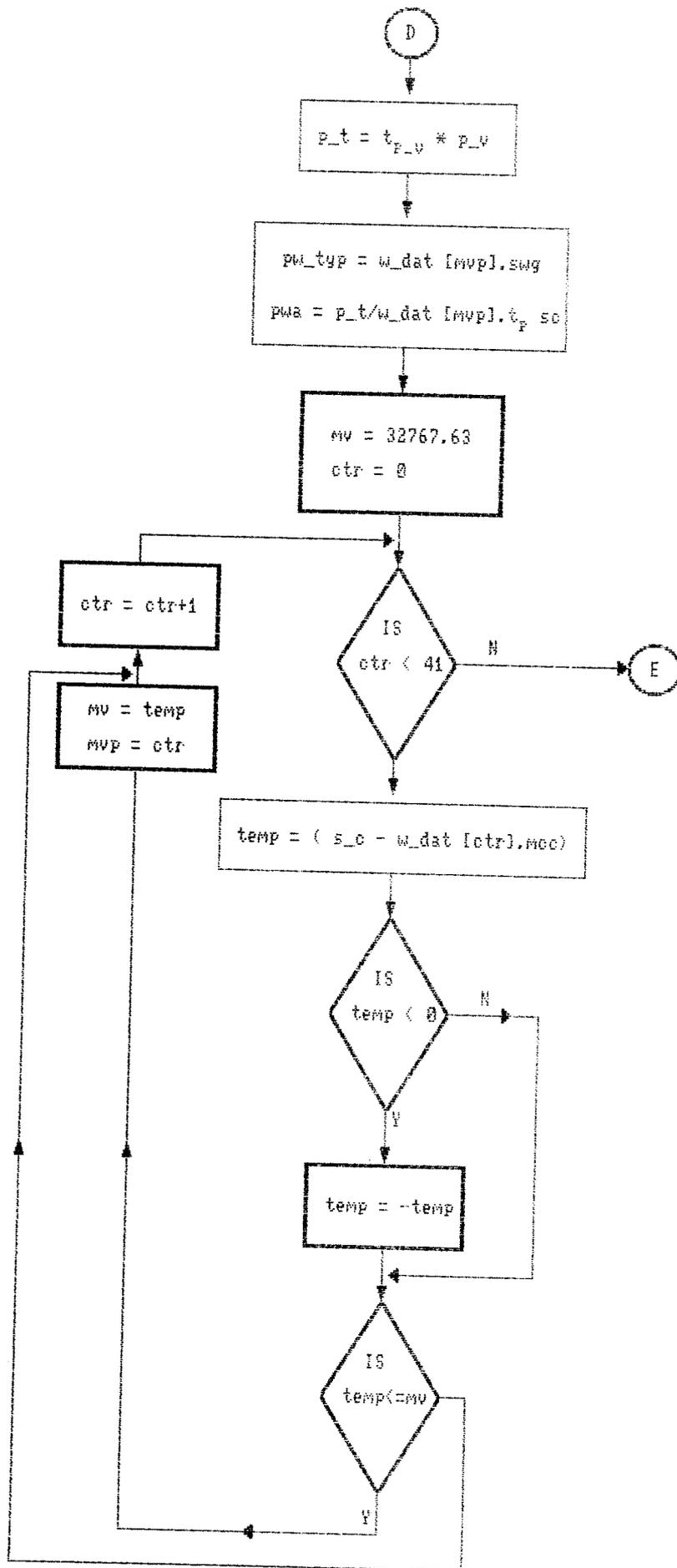
5.1 TO DESIGN SMALL TRANSFORMER

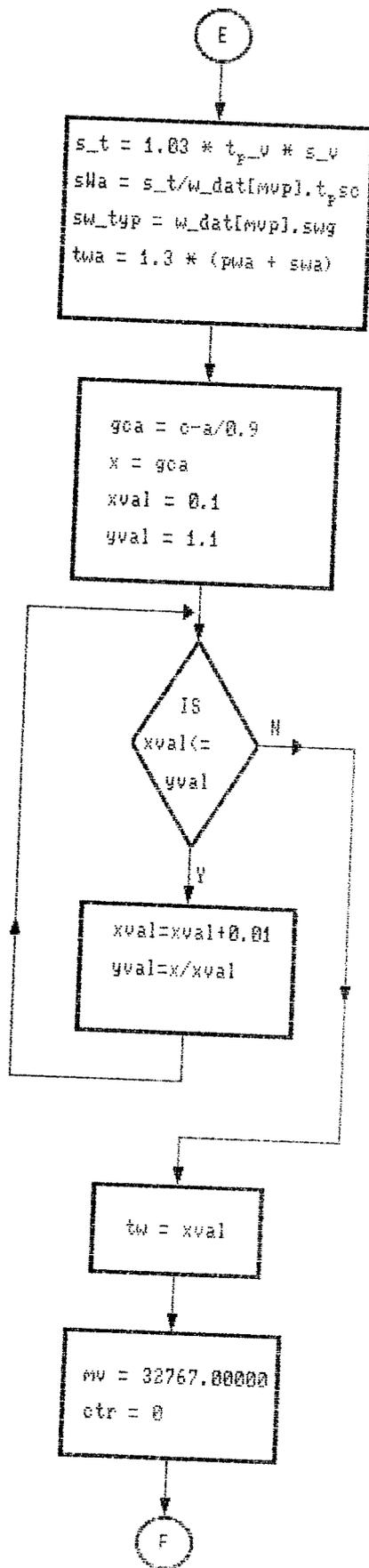


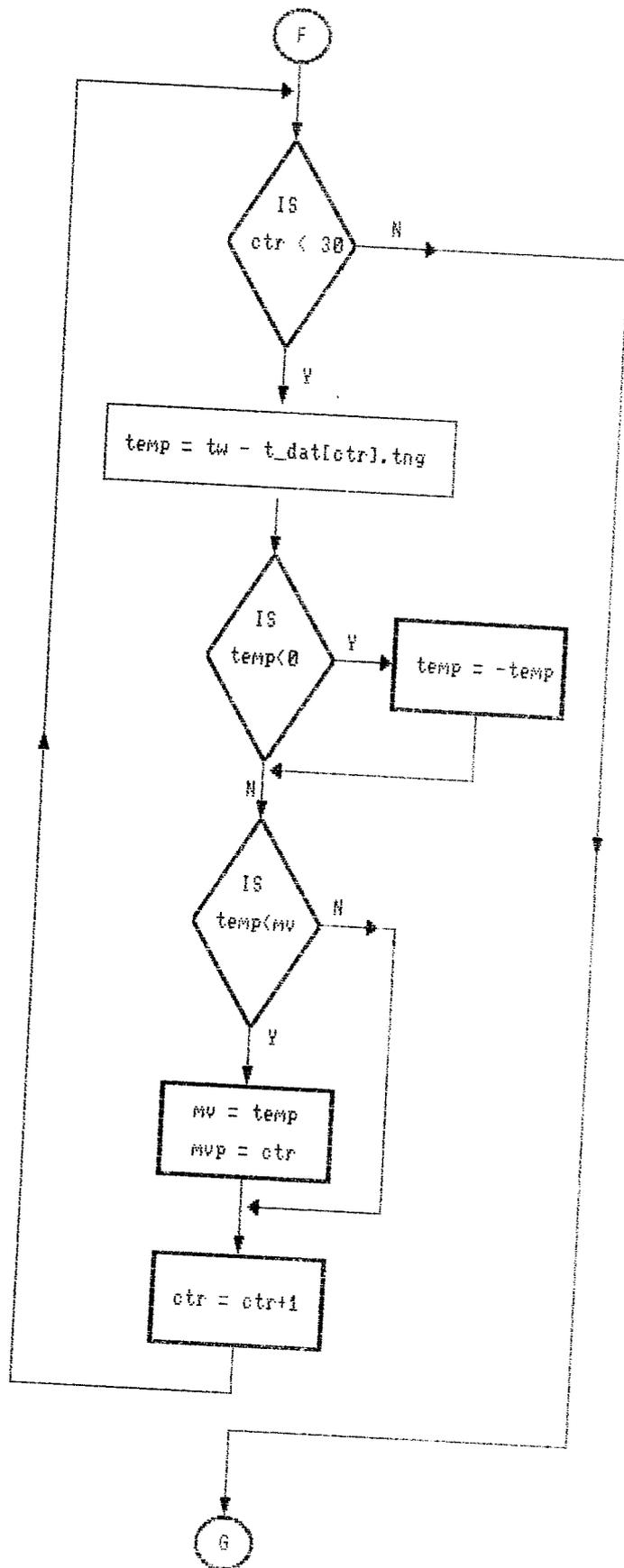


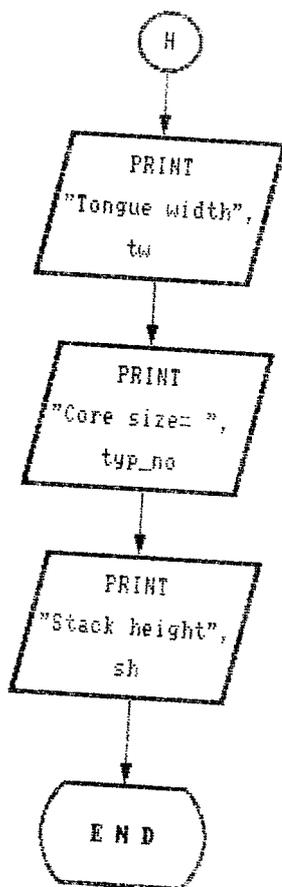


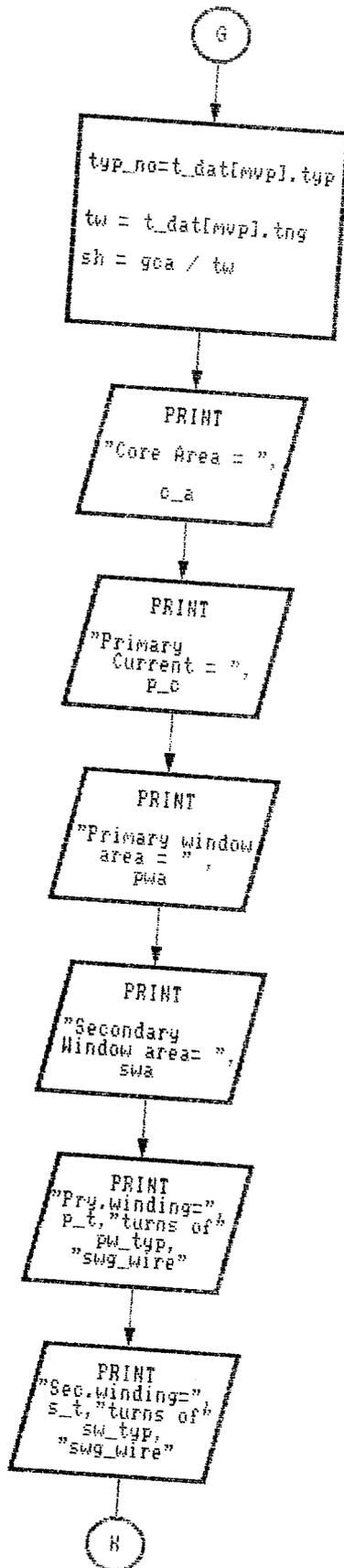








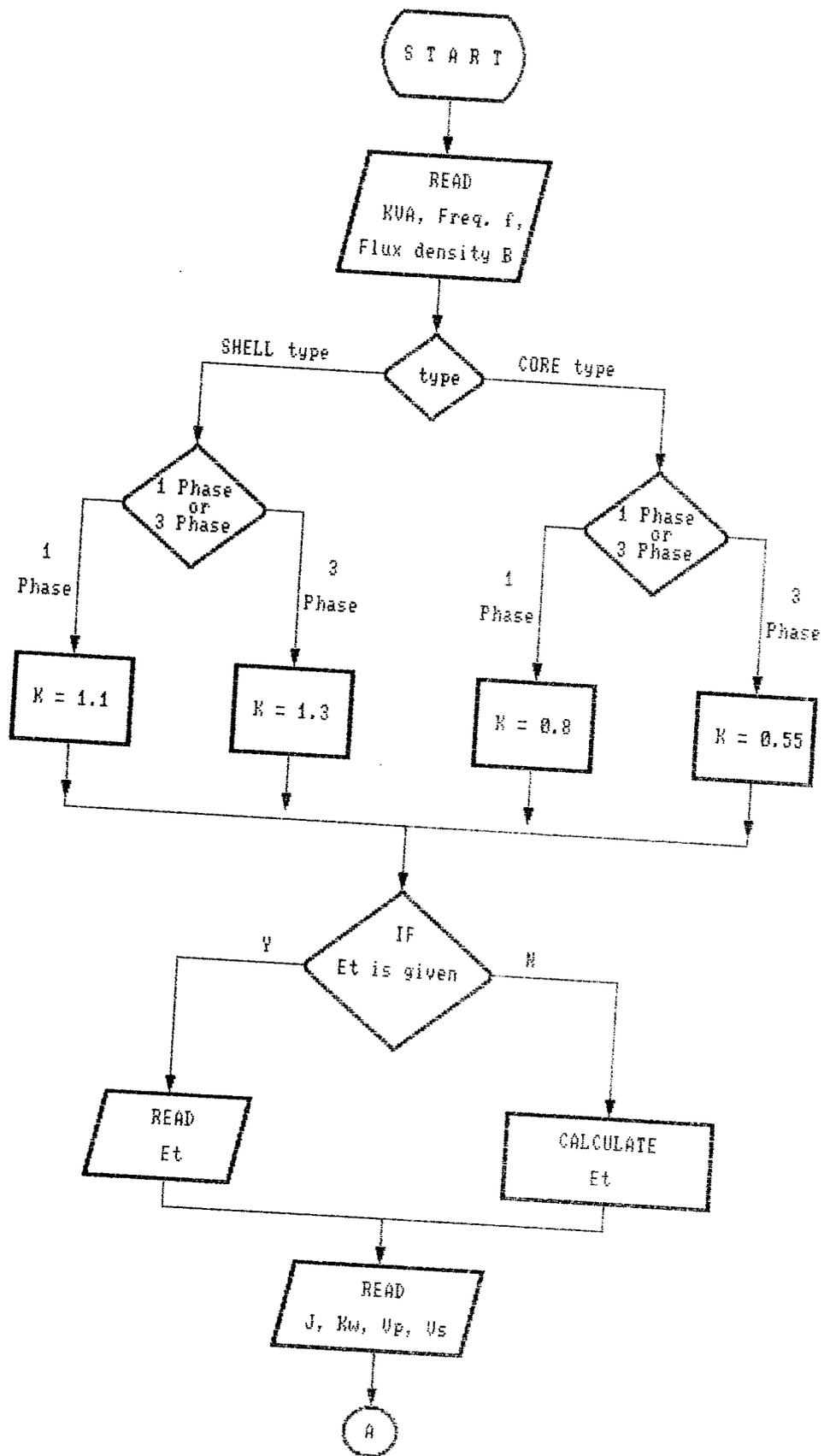


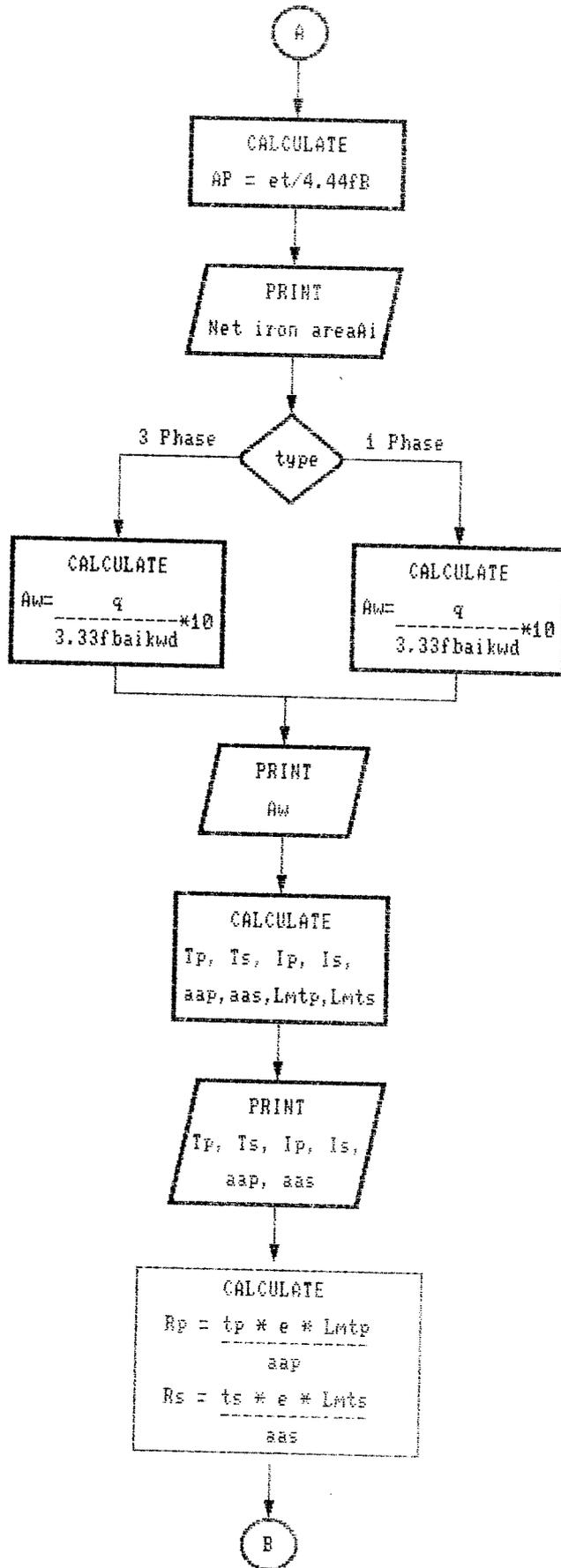


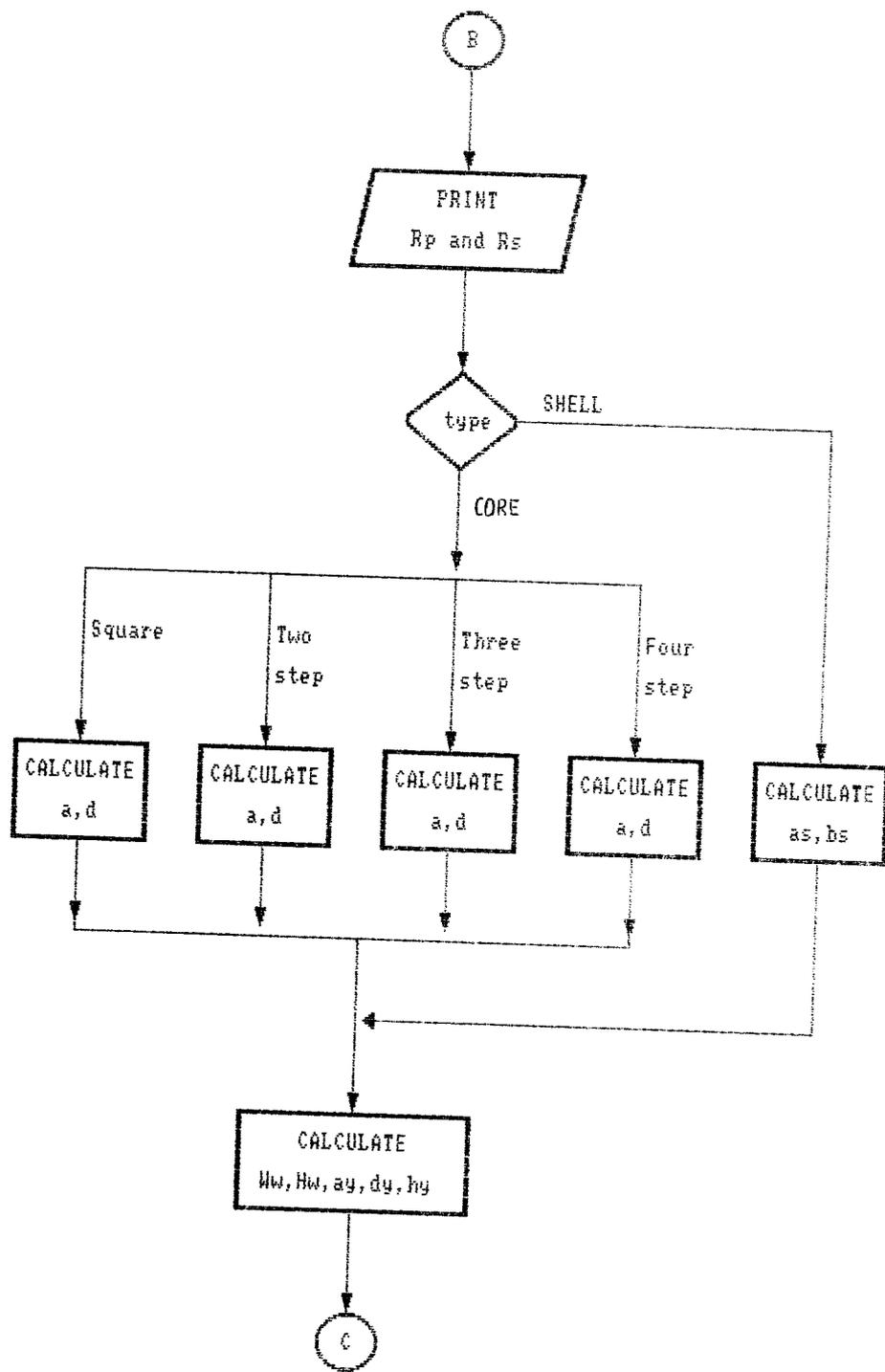
5.2 ALGORITHM FOR LARGE CAPACITY TRANSFORMER DESIGN

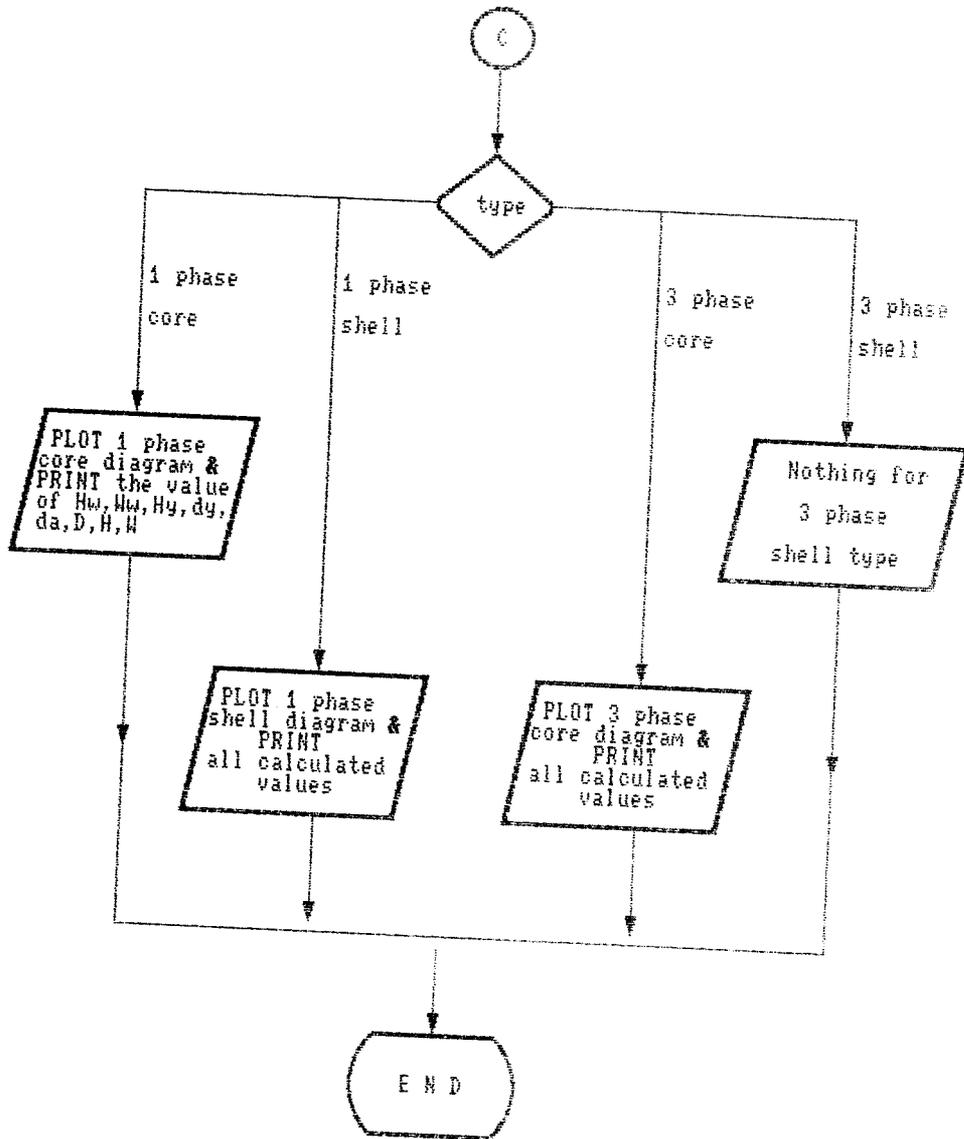
Transformer KVA rating, frequency, flux density, emf per turn, current density, window space factor, primary voltage and secondary voltage are given as input data. Emf per turn is now computed. Now compute net iron area and window area, Primary & secondary turns, primary & secondary current and primary & secondary core area with standard formulae. With these results calculate primary and secondary resistance. From the above results we can find the area of the circumscribing circle of core material, window height & width, yoke height & width and overall height & width. Now plot the diagram according to the given data and print the values of overall dimension.

5.2 TO DESIGN POWER AND DISTRIBUTION TRANSFORMER





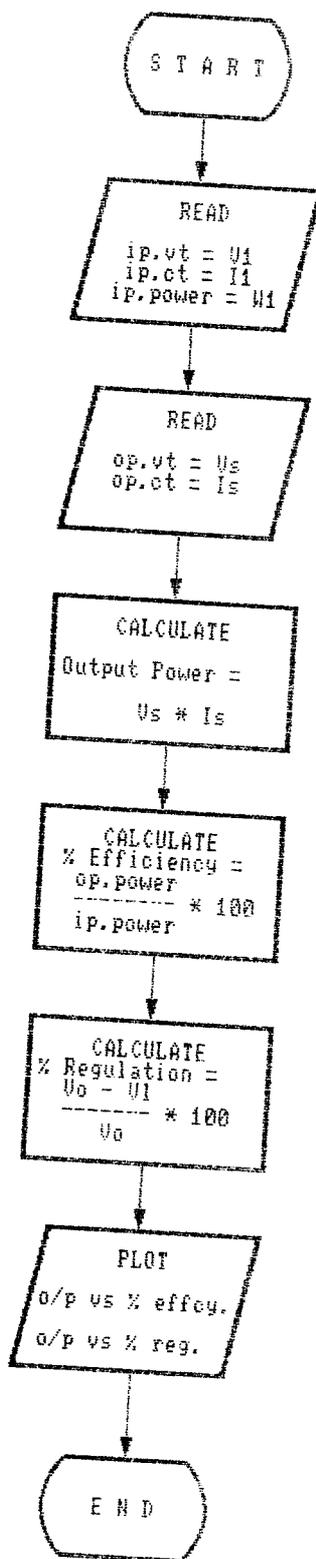




5.3 ALGORITHM TO PLOT PERFORMANCE CHARACTERISTIC OF A 230/24V - 1A TRANSFORMER

The fabricated transformer is tested by loading it up to 125% of the rated. The test data is stored as a lookup table in the computer. Now a software is developed to calculate the efficiency and regulation of lookup table. So this will plot the performance characteristic of the designed transformer. This performance plot enables the designer to check the suitability of the designed transformer for a particular application.

5.3 TO PLOT PERFORMANCE CHARACTERISTICS OF THE TRANSFORMER



```

/*****
/*
/*          DESIGN OF SMALL TRANSFORMERS
/*****
#include<stdio.h>
#include<string.h>
#include<math.h>

main()
{
struct w_data
{
int swg;
float mcc;
float tpsc;
};
struct t_stamp
{
char typ[41];
float tng;
float wind;
};

char ctyp, typ_no[41];
int.mvp,ctr,pwtyp,swtyp,pw_typ,sw_typ;
float s_c,s_v,c_a,p_v,f_den,p_c,temp,mv,p_t,pwa,s_t,swa;
float twa,tw,gca,sh;
float x,xval,yval;
double tp_v;
FILE *fp1,*fp2;

struct w_data *wptr,w_dat[41];
struct t_stamp *tptr,t_dat[30];

fp1=fopen("trans_1.dat","r");
fp2=fopen("trans_2.dat","r");

wptr=&w_dat[0];
tptr=&t_dat[0];
system("cls");
printf("*****\n");
printf("*****DESIGNING OF SMALL TRANSFORMER*****\n\n");
fread(wptr,sizeof(struct w_data),41,fp1);
fread(tptr,sizeof(struct t_stamp),30,fp2);

printf("****DATA ENTRY...\n\n");
printf("enter the Primary voltage (in volts):");
scanf("%f",&p_v);
printf("enter the secondary voltage (in volts):");
scanf("%f",&s_v);
printf("enter the secondary current (in Amps):");
scanf("%f",&c_c);

x=s_v*s_c;
xva=0.1;
yval=1.1;
while(xval<=yval)
{
xval=xval+.01;
yval=x/xval;
}
c_a=1.152 * xval;

```

```

printf("\n Enter the core material [0.SS/CRGO1 : ");
scanf("%c",&ctyp);
scanf("%c",&ctyp);

switch(ctyp)
{
case '0':
case 'O': f_den=1.0;break;
case 'C': f_den=1.3;break;
}

tp_v=1/(0.0004444 * 50 * c_a * f_den);
p_c=(s_v*s_c)/(P_v*0.87);
mv=32767.00000;
for(ctr=0;ctr<41;ctr++)
{
temp=abs(p_c-w_dat[ctr].mcc);
if(temp<mv)
{
mv=temp;
mvp=ctr;
}
}

```

```

p_t=tp_v*p_v;
pw_typ=w_dat[mvp].swg;
pwa=p_t/w_dat[mvp].tpsc;

mv=32767.6300;
for (ctr=0;ctr < 41;ctr++)
{
temp=(s_c-w_dat[ctr].mcc);
if (temp < 0) temp = -temp;
if(temp < mv)
{
mv=temp;
mvp=ctr;
}
}

p_t = tp_v * p_v;
pw_typ = w_dat[mvp].swg;
pwa = p_t/w_dat[mvp].tpsc;
mv = 32767.63;
for (ctr = 0; ctr < 41; ctr++)
{
temp = (s_c - w_dat[ctr].mcc);
if (temp < 0) Temp = -temp;
if (temp <= mv)
{
mv = temp;
mvp = ctr;
}
}

s_t=1.03 * tp_v * s_v;

```

```

swa = t/w_dat[mvp].tpsc;
sw_typ = w_dat[mvp].swg;
twa = 1.3 * (pwa + swa);

gca = c_a/0.9;
x = gca;
xval = 0.1; yval = 1.1;
while (xval <= yval)
{
xval = xval + 0.01;
yval = x / xval;
}
tw = xval;

mv = 32767.00000;
for(ctr = 0; ctr < 30; ctr++)
{
temp = (tw - t_dat[ctr].tng);
if(temp < 0) temp = -temp;
if(temp < mv)
{
mv = temp;
mvp = ctr;
}
}

strcpy (typ_no, t_dat[mvp].typ);
tw = t_dat[mvp].tng;
sh = (gca/tw);
printf("\n*****RESULTS*****\n\n");
printf("Core area = %3f sq.cm.\n", c_a);
printf("Primary current = %3f amps\n", p_co);
printf("Primary window area = %3f sq.cm.\n", pwa);
printf("secondary window area = %3f sq.cm.\n", swa);
printf("primary turns = %0.0f.\n", p_t);
printf("secondary turns = %0.0f.\n", s_t);
printf("tounge width = %3f cm.\n", tw);
printf("Core size = %s\n", typ_no);
printf("Stack Height = %0.2f cm.\n", sh);
printf("\n*****\n\n");

```

*****DESIGNING OF SMALL TRANSFORMER*****

****DATA ENTRY...

Enter primary voltage [volts]: 230
Enter secondary voltage [volts]: 24
Enter secondary current [amps]: 1
Enter core material [O.SS/C.RGO] : C

*** RESULTS...

Core Area	= 5.645 sq.cm.
Primary Current	= 0.120 amps
Primary Window Area	= 1.242 sq.cm.
Secondary Window Area	= 1.108 sq.cm.
Primary Winding	= 1412 turns of 32 SWG wire.
Secondary Winding	= 152 turns of 21 SWG wire.
Tounge Width	= 2.540 cm.
Core Size	= 15.
Stack Height	= 2.47 cm.

```

#include <stdio.h>
#include <string.h>
#include <graphics.h>
#include <conio.h>
#include <math.h>
#include "gra.c"
main()
{
    int f, ch, cho, choi;
    float k=0.0, kw=0.0, aw=0.0, at=0.0, q;
    float ai, b, delta, ww, hw, as, bs, aas, aap, ls, lp;
    float vp, vs, a, d, ay, hy, dy, ts, tp, ip, is;
    char ee;

    menu();
    clrscr();
    gotoxy(30, 1);
    printf("DESIGN OF POWER TRANSFORMER");
    box(1, 1, 1, 24, 79);
    gotoxy(4, 3);
    printf("Enter the transformer rating(Q in kva):");
    scanf("%f", &q);
    gotoxy(4, 4);
    printf("Enter the value of the frequency(f in Hz):");
    scanf("%d", &f);
    gotoxy(4, 5);
    printf("Enter the flux density(B in tesla):");
    scanf("%f", &b);
    clrscr();
    gotoxy(30, 1);
    printf("DESIGN OF POWER TRANSFORMER");
    box(1, 1, 1, 24, 79);
    gotoxy(4, 3);
    printf("Transformer types are.....");
    gotoxy(4, 4);
    printf("*****");
    gotoxy(4, 6);
    printf("1. 1-Phase shell type");
    gotoxy(4, 7);
    printf("2. 1-Phase core type");
    gotoxy(4, 8);
    printf("3. 3-Phase shell type");
    gotoxy(4, 9);
    printf("4. 3-Phase core type");
    gotoxy(4, 10);
    printf("Enter your choice.....");
    scanf("%d", &choi);

    switch(choi)
    {
        case 1: k = 1.1; break;
        case 2: k = 0.8; break;
        case 3: k = 1.3; break;
        case 4: k = 0.55; break;
    }

    gotoxy(4, 11);
    printf("Do you want to give EMFperturn(Et in volts/turn);

```

```

printf(" (y/n)");
flushall();
scanf("%c",&ee);
if (ee == 'y')
{
gotoxy(4,12);
printf("Enter EMF per turn(Et in volts/turn):");
scanf("%f",&et);
}
else {
et = k * sqrt(3);
gotoxy(4,13);
printf("EMF per turn is(Et in volts/turn) :%Of",et);
gotoxy(4,14);
printf("The value of current density is(%fA/Sq mm)",
scanf("%f",&delta));
delta = delta*1000000;
gotoxy(4,15);
printf("Enter the value of window space factor(Kw):");
scanf("%f",&kw);
gotoxy(4,16);
printf("The value of primary voltage is(vpinvolts)");
scanf("%f",&vp);
gotoxy(4,17);
printf("The value of secondary voltage is(vsinvolts)");
scanf("%f",&vs);
}

```

```

/*Calculating Net Iron Area(Ai)*/
clrscr();
gotoxy(30,1);
printf("DESIGN OF POWER TRANSFORMER");
box(1,1,1,24,79);
ai = et/(4.44*f*b);
gotoxy(4,3);
printf("NET IRON AREA VALUE");
gotoxy(4,4);
printf("*****");
gotoxy(4,5);
printf("Net iron area is(Ai) = ; %f sq m",ai);
gotoxy(10,13);
printf("Press any key to continue...."); getch();
/* Window area calculation(Aw) */

```

```

clrscr();
gotoxy(30,1);
printf("DESIGN OF POWER TRANSFORMER");
box(1,1,1,24,79);
gotoxy(4,3);
printf("Your phase choice is....");
gotoxy(4,4);
printf("1. Single phase");

```

```

gotoxy(4, 11);
printf("Enter Phase");
gotoxy(4, 12);
printf("Enter your choice....");
scanf("%d", &cho);
gotoxy(10, 0);
printf("WINDOW AREA CALCULATION & WINDING DESIGN");
gotoxy(10, 11);
printf("*****");
switch(cho)
{
    case 1:
        aw = q/(12.22*f*b*ai*kw*delta*0.001);
        gotoxy(4, 12);
        printf("Window area is(Aw) %3f sq m",aw);
        gotoxy(10, 13);
        printf("Press any key to continue....");
        getch();
        break;

    case 2:
        aw = q/(13.33*f*b*ai*kw*delta*0.001);
        gotoxy(4, 12);
        printf("Window area is(Aw):%3fSq m",aw);
        gotoxy(10, 13);
        printf("Press any key to continue....");
        getch();
        break;
}

Flushall();
tp = vp/et; ts = vs/et;
qp = q*1000/vp; qs = q*1000/vs;
esp = tp/delta; ess = ts/delta;
ip = (ip * sqrt(esp*0.14));
is = (is * sqrt(ess * 3.14));

gotoxy(10, 15);
printf("WINDING DESIGN");
gotoxy(10, 17);
printf("Primary turns(Tp) = %f", (vp/et));
gotoxy(10, 18);
printf("Secondary turns(Ts) = %f", (vs/et));
gotoxy(10, 19);
printf("Primary current(in Amps) = %f", (q*1000/vp);
gotoxy(10, 20);
printf("Secondary current(in Amps) = %f", (q*1000/vs);
gotoxy(10, 21);
printf("Primary core area /in sq m = %f", esp);
gotoxy(10, 22);
printf("Secondary core area /in sq m) = %f", ess);
gotoxy(10, 23);
printf("Press any key to continue...."); getch();

clrscr();
gotoxy(30, 1);
printf("DESIGN OF POWER TRANSFORMER");

```

```

box(1,1,1,24,79);
gotoxy(14,2);
printf("RESISTANCE CALCULATION");
gotoxy(10,4);
printf("Primary ResistanceRp(in ohms):%f", (tp*lp/aap));
gotoxy(10,5);
printf("Secondary ResistanceRs(inohms):%f", (ts*ls/aas));
gotoxy(10,7);
printf("Press any key to continue.....");
getche();

```

```

/* WINDOW DESIGN CALCULATION */

```

```

if ((ch01 != 1) && (ch01 != 3))

```

```

{
clrscr();
gotoxy(30,1);
printf("DESIGN OF POWER TRANSFORMER");
box(1,1,1,24,79);
gotoxy(14,3);
printf("WINDOW DESIGN");
gotoxy(14,4);
printf("*****");
gotoxy(4,5);
printf("Type of the cores are.....");
gotoxy(4,5);
printf("*****");
gotoxy(4,7);
printf("1. Square core");
gotoxy(4,9);
printf("2. Two step (or) Cruciform");
gotoxy(4,10);
printf("3. Three step core");
gotoxy(4,11);
printf("4. Four step core");
gotoxy(4,12);
printf("Enter your choice ,please.....");
scanf("%d",&ch);

```

```

switch(ch)

```

```

{

```

```

case 2;

```

```

d = sqrt((ai/0.56));
a = ai/0.71;
break;

```

```

case 3;

```

```

d = sqrt((ai/0.6));
a = ai/0.75;
break;

```

```

case 4;

```

```

d = sqrt((ai/0.62));
a = ai/0.78;
break;

```

```

    )
    gotoxy(4,14);
    printf("Dia of the circumscribing circle(d):%3fmm",d);
    gotoxy(4,15);
    printf("Area of the circumscribing circle(a):%3fsq(mm)",a);
    gotoxy(4,16);
    printf("Press any key to continue.....:"); getch();
}
else {
    as = sqrt(ai/4.5);
    bs = 5 * as;
}

ww = sqrt(aw/2.5);
hw = 2.5*ww;

ay = ai/0.9;
dy = a;
hy = ay/dy;

switch(choi)
{
    case 3:
        gotoxy(14,4);
        printf("NO DIAGRAM IS AVAILABLE");
        break;
    case 2:
        clrscr();
        gotoxy(30,1);
        printf("DESIGN OF POWER TRANSFORMER");
        box(1,1,1,24,79);
        gotoxy(14,3);
        printf("WINDOW DESIGN");
        gotoxy(14,4); printf("*****");
        box(2,13,26,16,37); box(2,13,63,16,72);
        box(1,10,30,19,70); box(1,12,35,17,65);
        gotoxy(28,10); printf(":-> d <-");
        gotoxy(30,21);
        printf(":-> a <-");
        gotoxy(75,11); printf("-----> ww <-----");
        gotoxy(75,12); printf("Hy");
        gotoxy(75,20); printf("Hy");
        gotoxy(75,13); printf("-----");
        gotoxy(75,18); printf("-----");
        gotoxy(75,15); printf("Hw");
        gotoxy(75,19); printf("Hy");
        gotoxy(5,11);
        printf("d(in mm) = %f",d);
        gotoxy(5,12);
        printf("a(in mm) = %f",a);

```

```

gotoxy(5,13);
printf("Hw(in m) = %f",hw);
gotoxy(5,14);
printf("Ww(in m) = %f",ww);
gotoxy(5,15);
printf("Hy(in m) = %f",hy);
gotoxy(5,16);
printf("D(in m) = %f",d+ww);
gotoxy(5,17);
printf("H(in m) = %f",hw+2*hy);
gotoxy(5,18);
printf("W(in m) = %f",d+ww+a);
gotoxy(5,23);
printf("press any key to continue....");
getche();
break;

```

case 4:

```

clrscr();
gotoxy(30,1);
printf("DESIGN OF POWER TRANSFORMER");
box(1,1,1,24,79);
gotoxy(14,3); printf("WINDOW DESIGN");
gotoxy(14,4); printf("*****");
box(2,13,27,16,37); box(2,13,42,16,57);
box(2,19,63,16,72); box(1,10,30,19,70);
box(1,12,35,17,45); box(1,12,55,17,55);
gotoxy(28,10); printf("d = ");
gotoxy(30,21); printf("a = ");
gotoxy(75,11); printf("-----> ww <-----!");
gotoxy(75,12); printf("Hy");
gotoxy(75,20); printf("-----");
gotoxy(75,19); printf("-----");
gotoxy(75,18); printf("-----");
gotoxy(75,17); printf("Hw");
gotoxy(75,16); printf("Hy");
gotoxy(5,11); printf("d(in mm) = %f",d);
gotoxy(5,12); printf("a(in mm) = %f",a);
gotoxy(5,13); printf("Hw(in m) = %f",hw);
gotoxy(5,14); printf("Ww(in m) = %f",ww);
gotoxy(5,15); printf("Hy(in m) = %f",hy);
gotoxy(5,16); printf("D(in m) = %f",d+ww);
gotoxy(5,17); printf("H(in m) = %f",hw+2*hy);
gotoxy(5,18); printf("W(in m) = %f",d+ww+a);
printf("press any key to continue....");
getche();
break;

```

case 1:

```

clrscr();

gotoxy(30,1);
printf("DESIGN OF POWER TRANSFORMER");
box(1,1,1,24,79);
gotoxy(14,3); printf("WINDOW DESIGN");
gotoxy(14,4); printf("*****");

```


DESIGN OF POWER TRANSFORMER

```
Enter the transformer rating (P in VA): 700
Enter the value of the frequency (f in Hz): 50
Enter the flux density (B in Tesla): 1.5
```

DESIGN OF POWER TRANSFORMER

```
Transformer types are:
*****
1. 1 phase shell type
2. 1 phase core type
3. 3 phase shell type
4. 3 phase core type
Enter your choice: 1
Do you want to give EMF per turn (Et in volts/turn): Yes (y/n): N
```

```
EMF per turn is (Et in volts/turn) : 24.586746
The value of current density is (A/m2/CC) : 3.75
Enter the value of window space factor (Kw) : 0.27
The value of primary voltage is (Vp in volts) : 0
The value of secondary voltage is (Vs in volts) : 0
```

DESIGN OF POWER TRANSFORMER

NET IRON AREA VALUE

Net Iron area is (Ai) = 0.1101 sq m

Press any key to continue.....

DESIGN OF POWER TRANSFORMER

Vol. ratio choice is....

1. Single phase

2. Three phase

Enter your choice.....11

WINDOW AREA CALCULATION & WINDING DESIGN

Window area is (Aw) = 0.004785 sq m
Press any key to continue.....

WINDING DESIGN

primary turns (Tp) = 246.322151
Secondary turns (Ts) = 16.242312
primary current (in Amps) = 75.757574
secondary current (in Amps) = 1250.000000
primary core area (in sq m) = 0.000000
secondary core area (in sq m) = 0.000000
Press any key to continue.....

DESIGN OF POWER TRANSFORMER

RESISTANCE CALCULATION

primary Resistance (in ohm) = 280.407200
secondary Resistance (in ohm) = 17.2224

Press any key to continue.....

DESIGN OF POWER TRANSFORMER

WINDOW DESIGN

a (in m) = 0.149610

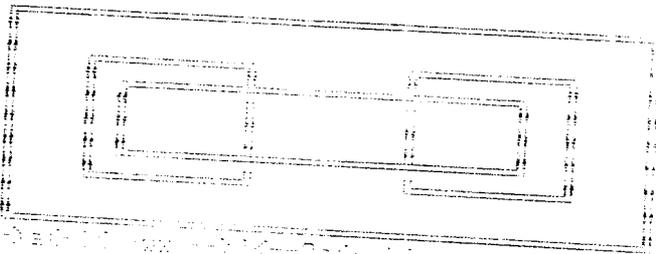
MW (in m) = 0.147994

W_1 (in m) = 0.029984

W (in m) = 0.894424

H (in m) = 0.249203

Core depth b (in m) =
0.074034



[Dashed lines representing the window and core geometry]

press any key to continue.....

DESIGN OF POWER TRANSFORMER

Enter the transformer rating (S in kVA):500
Enter the value of the frequency (f in Hz):50
Enter the flux density (B in Tesla):1.1

DESIGN OF POWER TRANSFORMER

Transformer types are.....

- 1. 1-phase shell type
- 2. 1-phase core type
- 3. 3-phase shell type
- 4. 3-phase core type

Enter your choice.....:2

Do you want to give EMF per turn (E_t in volts/turn [say (y/n)]):N

EMF per turn is (E_t in volts/turn) :17.888544
The value of current density is (j in A/SQ mm) 2.75
Enter the value of window space factor (K_w):0.27
The value of primary voltage is (V_p in volts) 6600
The value of secondary voltage is (V_s in volts) 400

DESIGN OF POWER TRANSFORMER

NET IRON AREA VALUE

Net Iron area is (A_i) = : 0.079 sq m

Press any key to continue.....

DESIGN OF POWER TRANSFORMER

Your phase choice is....
1. Single phase
2. Three phase
Enter your choice.....1

WINDOW AREA CALCULATION & WINDING DESIGN

Window area is (Aw) 0.075288 sq m
Press any key to continue.....

WINDING DESIGN

Primary turns (Tp) = 368.951211
Secondary turns (Ts) = 20.240479
primary current (I_p Amps) = 75.757574
secondary current (in Amps) = 1250.000000
Primary core area (in sq m) = 0.000028
secondary core area (in sq m) = 0.000455
Press any key to continue.....

DESIGN OF POWER TRANSFORMER

RESISTANCE CALCULATION

Primary Resistance R_p (in ohms) : 520.140020
Secondary Resistance R_s (in ohms) : 7.000475

Press any key to continue.....

DESIGN OF POWER TRANSFORMER

WINDOW DESIGN

type of the cores are.....

1. Square core
2. Two step (or) Cruci form
3. Three step core
4. Four step core

Enter your choice ,please.....:2

Dia of the circumscribing circle (d):0.361677m
 Area of the circumscribing circle (a):0.103174sq m
 Press any key to continue.....:

DESIGN OF POWER TRANSFORMER

WINDOW DESIGN

d (in m) = 0.361677
 a (in m) = 0.103174
 Hw (in m) = 0.488845
 Ww (in m) = 0.173538
 Hy (in m) = 0.788889
 D (in m) = 0.535215
 H (in m) = 2.011622
 W (in m) = 0.638389

l -> d <- l



press any key to continue.....:

DESIGN OF POWER TRANSFORMER

Enter the transformer rating (P in kVA):500
Enter the value of the frequency (f in Hz):50
Enter the fill density (D in %):1.1

DESIGN OF POWER TRANSFORMER

Transformer types are....

1. 1 Phase shell type
2. 1 Phase core type
3. 3 Phase shell type
4. 3 Phase core type

Enter your choice.....:4

Do you want to give EMF per turn (Et in volts/turn) say (y/n)IN

EMF per turn is (Et in volts/turn) :12.238374
The value of current density is (in A/SQ mm):2.75
Enter the value of window space factor (Kw):0.27
The value of primary voltage is (vp in volts):6600
The value of secondary voltage is (vs in volts):1400

DESIGN OF POWER TRANSFORMER

NET IRON AREA VALUE

Net Iron Area is (A_{net}) = : 0.050 sq m

Press any key to continue....

DESIGN OF POWER TRANSFORMER

Your phase choice is....
1. Single phase
2. Three phase
Enter your choice.....:2

WINDOW AREA CALCULATION & WINDING DESIGN

Window area is (Aw):0.0730079sq m
Press any key to continue.....

WINDING DESIGN

Primary turns (Tp) = 536.656302
Secondary turns (Ts) = 32.524624
primary current (in Amps) = 75.757576
secondary current (in Amps) = 1250.000000
Primary core area (in sq m) = 0.000028
secondary core area (in sq m) = 0.000455
Press any key to continue.....

DESIGN OF POWER TRANSFORMER

RESISTANCE CALCULATION

Primary Resistance (Rp) (in ohms):740.963256
Secondary Resistance (Rs) (in ohms):11.058709

Press any key to continue.....


```

/*****
/****GRAPH FOR EFFICIENCY & REGULATION OF TRANSFORMERS****
/*****
#include <stdio.h>
#include <graphics.h>
#include <conio.h>
#include <dos.h>
#include "window.c"
main()
{
    int gd=DETECT, gm,n,i,ro,col,x1,y1,x2,y2,y12,y22,key;
    float vpf[10],ipf[10],wpt[10],vst[10],ist[10],opt[10],eff[10],reg[10];
    do{
        clrscr();
        box(2,10,4,35,54,95,' ',2,10);

        textbackground(BLACK);
        textcolor(WHITE);

        gotoxy(11,3); cprintf("Enter the # input : ");
        scanf("%d",&n);
        box(6,5,20,76,54,10,' ',1,10);
        horline(8,5,74,54,1);
        gotoxy(6,7); cprintf("Sl.No.");
        verline(10,6,18,54,1);
        gotoxy(12,7); cprintf("Vp");
        gotoxy(13,8); cprintf("volts");
        verline(16,6,18,54,1);
        gotoxy(20,7); cprintf("Ip");
        gotoxy(21,8); cprintf("amps");
        verline(26,6,18,54,1);
        gotoxy(26,7); cprintf("Wp");
        gotoxy(29,8); cprintf("watts");
        verline(34,6,18,54,1);
        gotoxy(36,7); cprintf("Vs");
        gotoxy(37,8); cprintf("volts");
        verline(42,6,18,54,1);
        gotoxy(44,7); cprintf("Is");
        gotoxy(45,8); cprintf("amps");
        verline(50,6,18,54,1);
        gotoxy(52,7); cprintf("O/P");
        gotoxy(53,8); cprintf("watts");
        verline(56,6,18,54,1);
        gotoxy(60,7); cprintf("Eff");
        gotoxy(62,8); cprintf("%");
        verline(66,6,18,54,1);
        gotoxy(68,7); cprintf("Reg");
        gotoxy(70,8); cprintf("%");
        textbackground(50);
        textcolor(YELLOW);
        gotoxy(11,9); cprintf("+");
        gotoxy(19,9); cprintf("+");
        gotoxy(27,9); cprintf("+");
        gotoxy(35,9); cprintf("+");
        gotoxy(43,9); cprintf("+");
        gotoxy(51,9); cprintf("+");
        gotoxy(59,9); cprintf("+");
        gotoxy(67,9); cprintf("+");
        textbackground(0);
        textcolor(WHITE);
        ro=10;
        for(i=0;i<n;i++)
        { col=4;
          gotoxy(7,ro); cprintf("%d",i+1);
          col+=8;
          gotoxy(col,ro); scanf("%f",&vpf[i]);

```

```

col+=8;
gotoxy(col,ro); scanf("%f",&ipfil);
col+=8;
gotoxy(col,ro); scanf("%f",&wpfil);
col+=8;
gotoxy(col,ro); scanf("%f",&vsfil);
col+=8;
gotoxy(col,ro); scanf("%f",&isfil);
opfil=vsfil*isfil;
efffil=(opfil/wpfil)*100;
regfil=(vsfil-vstfil)/vsfil*100;
col+=8;
gotoxy(col,ro); printf("%4.2f",opfil);
col+=8;
gotoxy(col,ro); printf("%4.2f",efffil);
col+=8;
gotoxy(col,ro); printf("%4.2f",regfil);
ro+=1;
}
cursor(80);
gotoxy(10,23);

```

```

printf("Press Esc to return/F1 to reenter");
printf("the i/p data/Enter to continue...");
key=getch();
if(key==0) key=getch();
if(key==27) ro=0;
if(key!=59) ro=0;
if(key==13){
initgraph(&gd,&gm," ");
setbkcolor(54);
setcolor(10);
line(50,10,50,170);
line(40,160,600,160);
line(100,10,100,170);
settextstyle(DEFAULT_FONT,HORIZ_DIR,1);
outtextxy(110,5,"PERFORMANCE CHARACTERISTICS OF A TRANSFORMER");
settextstyle(DEFAULT_FONT,VERT_DIR,1);
outtextxy(10,20,"% EFFICIENCY/% REGULATION");
settextstyle(DEFAULT_FONT,HORIZ_DIR,1);
outtextxy(200,160,"OUTPUT (Watts)");

/*Points for y-axis*/
line(98,145,102,145);
line(98,130,102,130);
line(98,115,102,115);
line(98,100,102,100);
line(98,85,102,85);
line(98,70,102,70);
line(98,55,102,55);
line(98,40,102,40);
line(98,25,102,25);
line(98,10,102,10);

/*Points for 2nd y-axis*/
line(48,145,52,145);
line(48,130,52,130);
line(48,115,52,115);
line(48,100,52,100);
line(48,85,52,85);

```

```

line(48,70,52,70);
line(48,55,52,55);
line(48,40,52,40);
line(48,25,52,25);
line(48,10,52,10);

/*Points for x-axis*/
line(150,158,150,162);
line(200,158,200,162);
line(250,158,250,162);
line(300,158,300,162);
line(350,158,350,162);
line(400,158,400,162);
line(450,158,450,162);
line(500,158,500,162);
line(550,158,550,162);
line(600,158,600,162);
settextstyle(DEFAULT_FONT,HORIZ_DIR,1);
outtextxy(30,145,"10");
outtextxy(30,130,"20");
outtextxy(30,115,"30");
outtextxy(30,100,"40");
outtextxy(30,85,"50");
outtextxy(30,70,"60");
outtextxy(30,55,"70");
outtextxy(30,40,"80");
outtextxy(30,25,"90");
outtextxy(27,10,"100");

outtextxy(70,145,"0.7");
outtextxy(70,130,"1.4");
outtextxy(70,115,"2.1");
outtextxy(70,100,"2.8");
outtextxy(70,85,"3.5");
outtextxy(70,70,"4.2");
outtextxy(70,55,"4.9");
outtextxy(70,40,"5.6");
outtextxy(70,25,"6.3");
outtextxy(70,10,"7.0");
outtextxy(140,170,"3");
outtextxy(190,170,"6");
outtextxy(240,170,"9");
outtextxy(290,170,"12");
outtextxy(340,170,"15");
outtextxy(390,170,"18");
outtextxy(440,170,"21");
outtextxy(490,170,"24");
outtextxy(540,170,"27");
outtextxy(590,170,"30");
rc=180; col=50;

for(i=0;i<n-1)
{
x1=(int )(cp[i]/3)*50+100;
y1=160-(int )(ef[i]/10)*15;
y2=160-(int )(reg[i]/0.7)*15;
i++;
x2=(int )(cp[i]/3)*50+100;
y2=160-(int )(ef[i]/10)*15;
}

```

```

y22=160-(int )(ray[i]/0.7)*15;
setcolor(BLUE);
line(x1,y1,x2,y2);
setcolor(GREEN);
line(x1,y1,x2,y22);
}
key=getch();
if(key==0) getch();
clrscr();
cursor(6);
gotoxy(10,10);
printf("Press Esc to return to Prompt/Enter to continue..");
key=getch();
if(key==0) key=getch();
if(key==27) ro=0;
}
}while(ro!=0);
cursor(6);
}

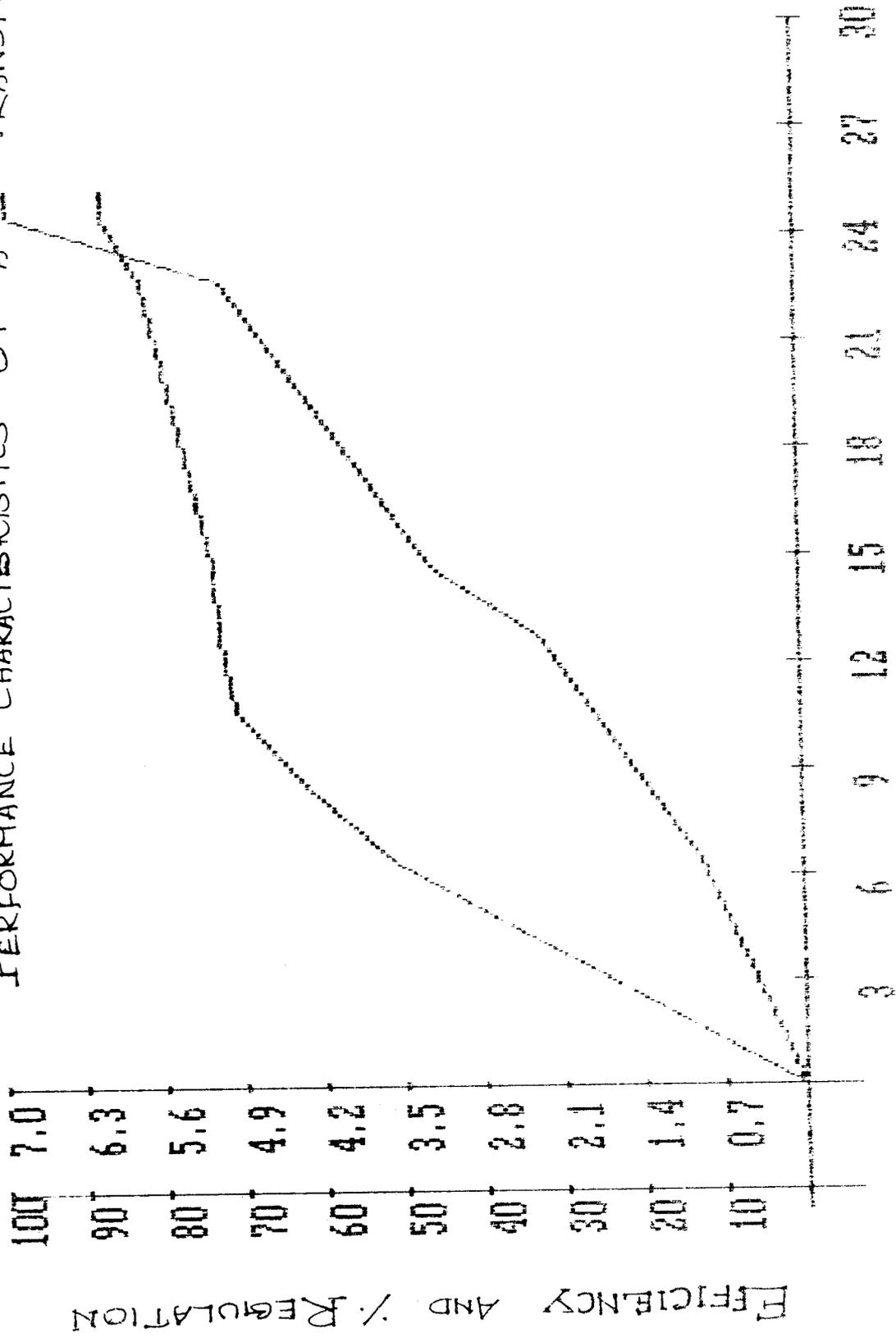
```

Enter the # input : 09

Sl.No	Vp volts	Ip amps	Wp watts	Vs volts	Is amps	O/P watts	Eff %	Reg %
1	230	0.15	9.5	21.7	0	0.00	0.00	0.00
2	230	0.16	12.5	21.5	0.3	6.45	51.60	0.92
3	230	0.16	13.75	21.4	0.4	8.56	62.25	1.38
4	229	0.165	15	21.3	0.5	10.65	71.00	1.84
5	229	0.17	17.5	21.2	0.6	12.72	72.69	2.30
6	229	0.175	20	21.0	0.7	14.70	73.50	3.23
7	228	0.195	27.5	20.6	1.1	22.66	82.40	5.07
8	227	0.198	28	20.2	1.21	24.44	87.29	6.91
9	227	0.2	29	20.2	1.25	25.25	87.07	6.91

Press Esc to return/F1 to reenter the i/p data/Enter to continue.

PERFORMANCE CHARACTERISTICS OF A TRANSFORMER



VII. TESTING AND PERFORMANCE CHARACTERISTICS OF SMALL TRANSFORMERS

7.1 FABRICATION OF POWER SUPPLY TRANSFORMER

1 phase and 3 phase power and distribution transformer can be designed using the developed software. Given the name plate details (ie.) input voltage, output voltage and o/p current of a transformer, the design parameters core area, primary current, primary window area, secondary window area, primary winding, secondary winding, tongue width, core size, stack height can be obtained on execution of the software.

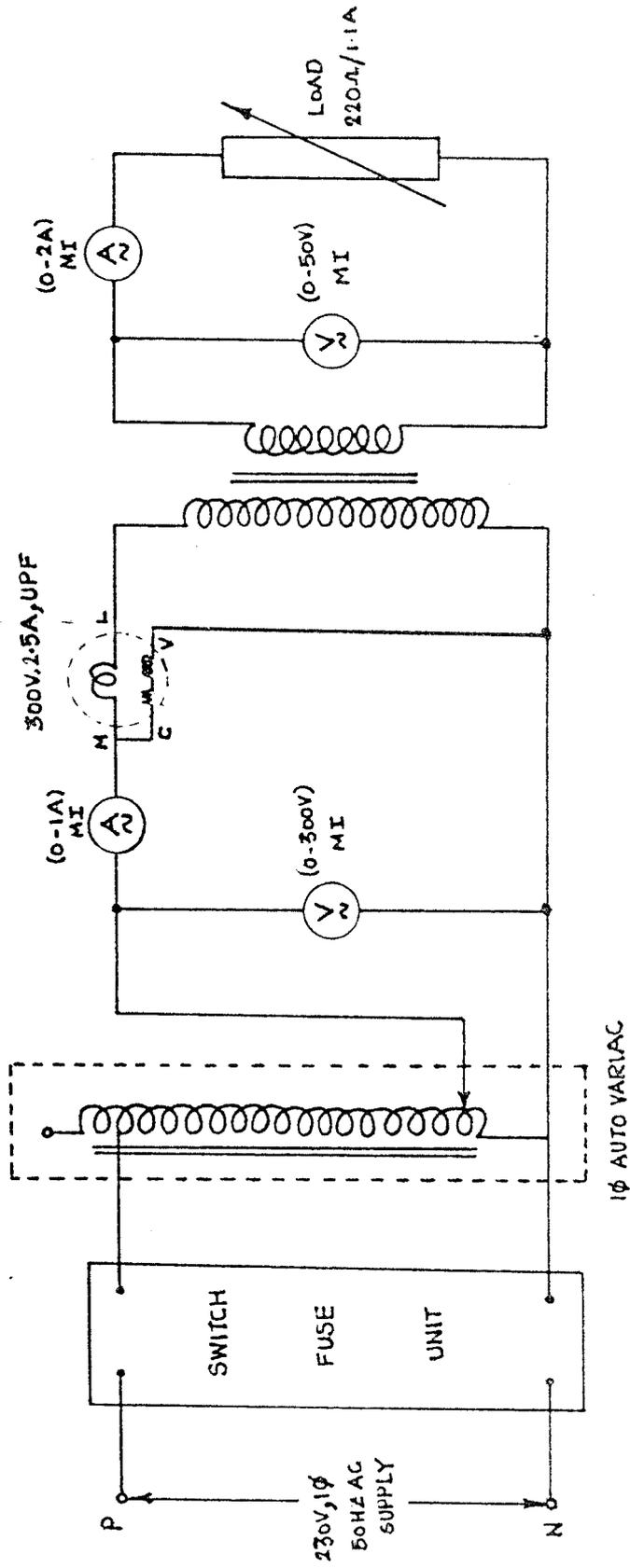
Power supply transformer find wide application in INDUSTRIAL and CONSUMER field. The software package can be used to design single phase or three phase transformer. 230V/24V transformer is most widely used in various application as in Timer circuit and counters.

Given the input data of 230V/24V with 1 amp secondary current the software lists the following design parameter values.

The design output from software

The primary voltage	= 215 volts
The secondary voltage	= 22.5 volts
The secondary current	= 1 amps
The core area	= 5.472 sq.cm
The primary current	= 0.120 amps

LOAD TEST ON TRANSFORMER:-



7.2 TESTING OF TRANSFORMER

The software developed enables to determine the efficiency and regulation of fabricated power supply transformer. An additional software enables to plot the performance characteristics of fabricated transformer.

The power supply transformer fabricated is loaded and the parameters necessary to calculate the efficiency and regulation and various load condition are tabulated.

The connections for the testing of fabricated power supply transformer is given as per the circuit diagram. The primary voltage is gradually increased to the rated voltage 230V by adjusting the auto transformer. The output from the auto transformer is given to the primary of power supply transformer. The output of the secondary of power supply transformer is 24V and 1 amp. The primary voltage, primary current, input power, secondary voltage and secondary current are noted at no load condition. Loading of transformer is done by varying the rheostatic load. The transformer is loaded gradually and for each load condition the primary voltage (V_1), primary current (I_1), secondary voltage (V_s), and secondary current (I_s) are noted down. The output power, efficiency and regulation are calculated using software. Performance characteristics for output V_s efficiency and output V_s regulation are plotted using software.

VIII. CONCLUSION

The greatness of any existing system depends upon its adaptability. This software package is in such a manner that its versatility is enviable. The software package has been formed in keeping in mind the requirements of the transformer designers and manufacturers.

The software is flexible enough to give design parameters of any power or distribution transformers. A 230V/24V, transformer has been successfully designed and its performance characteristics are obtained using an additional software.

The software can be slightly modified for the design of current transformer and welding transformer. This project provides a software which minimizes the time and man power for design of any transformer for any specific applications.

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Table 1: WINDING DATA ON ENAMELLED COPPER WIRE(@ 200 Amp/Sq.cm.)

SWG	Max current capacity (Amp)	Turns per sq.cm.	SWG	Max. current capacity (Amp)	Turns per sq.cm.
10	16.60	8.7	30	0.1558	881
11	13.638 10.961	10.4	31	0.1364	997
12	10.961	12.8	32	0.1182	1137
13	8.579	16.1	33	0.1013	1308
14	6.487	21.5	34	0.0858	1608
15	5.254	26.8	35	0.0715	1902
16	4.151	35.2	36	0.0586	2286
17	3.178	45.4	37	0.0469	2800
18	2.335	60.8	38	0.0365	3507
19	1.622	87.4	39	0.0274	4838
20	1.313	106	40	0.0233	5595
21	1.0377	137	41	0.0197	6543
22	0.7945	176	42	0.0162	7755
23	0.5838	242	43	0.0131	9337
24	0.4906	286	44	0.0104	11457
25	0.4054	341	45	0.0079	14392
26	0.3284	415	46	0.0059	20223
27	0.2726	504	47	0.0041	27510
28	0.2219	609	48	0.0026	39706
29	0.1874	711	49	0.0015	62134
			50	0.0010	81242

TABLE 2

TABLE DIMENSIONS OF TRANSFORMER STAMPINGS

Type No.	Tongue width (cm.)	Window area (sq.cm.)	Type No.	Tongue width (cm.)	Window area (sq.cm.)
17 (E-1)	1.270	1.213	9 (U-T)	2.223	7.865
12A (E-1)	1.588	1.897	9A (U-T)	2.223	7.665
7A (E-1)	1.748	2.284	11A (E-1)	1.905	9.072
23 (E-1)	1.905	2.723	4A (E-1)	3.335	10.284
30 (E-1)	2.000	3.000	2 (E-1)	1.905	10.891
21 (E-1)	1.588	3.329	16 (E-1)	3.810	10.891
31 (E-1)	2.223	3.703	5 (E-1)	3.810	12.704
10 (E-1)	1.588	4.439	4A (U-T)	2.383	13.039
15 (E-1)	2.540	4.839	13 (E-1)	3.175	14.117
33 (E-1)	2.800	5.880	75 (U-T)	2.540	15.400
1 (E-1)	2.461	6.555	4 (E-1)	2.540	15.865
11 (E-1)	2.540	6.555	7 (E-1)	5.080	18.969
11 (E-1) 1.905	1.905	7.259	6 (E-1)	3.810	19.356
3A (U-T)	1.588	7.259	35A (U-T)	3.810	29.316
3 (E-1)	3.175	7.562	8 (E-1)	5.080	49.803