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PRODUCTION OF DISTRIBUTION TRANSFORMERS IN DEVELOPING COUNTRIES

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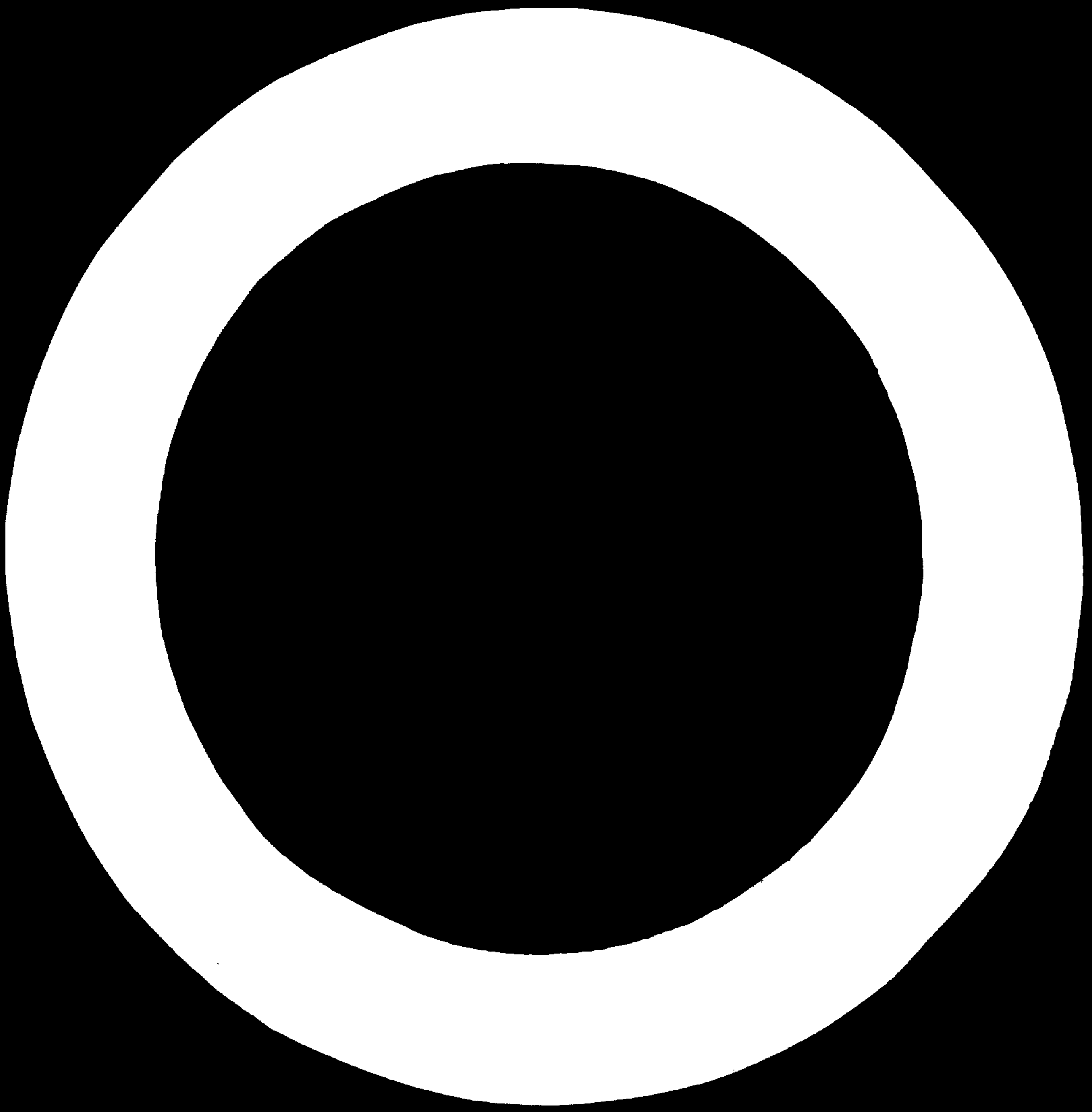
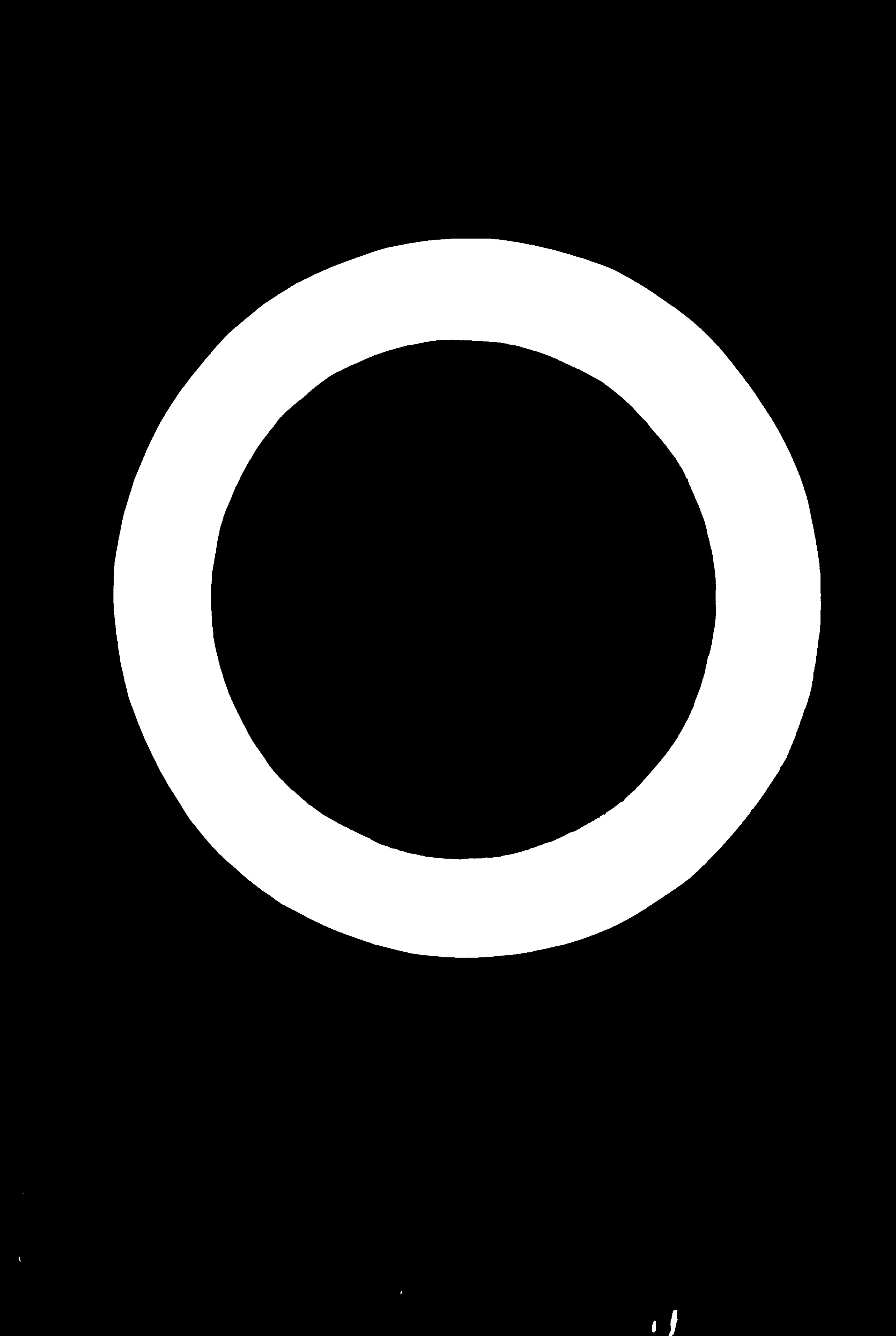
UNITED NATIONS





UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION, VIENNA

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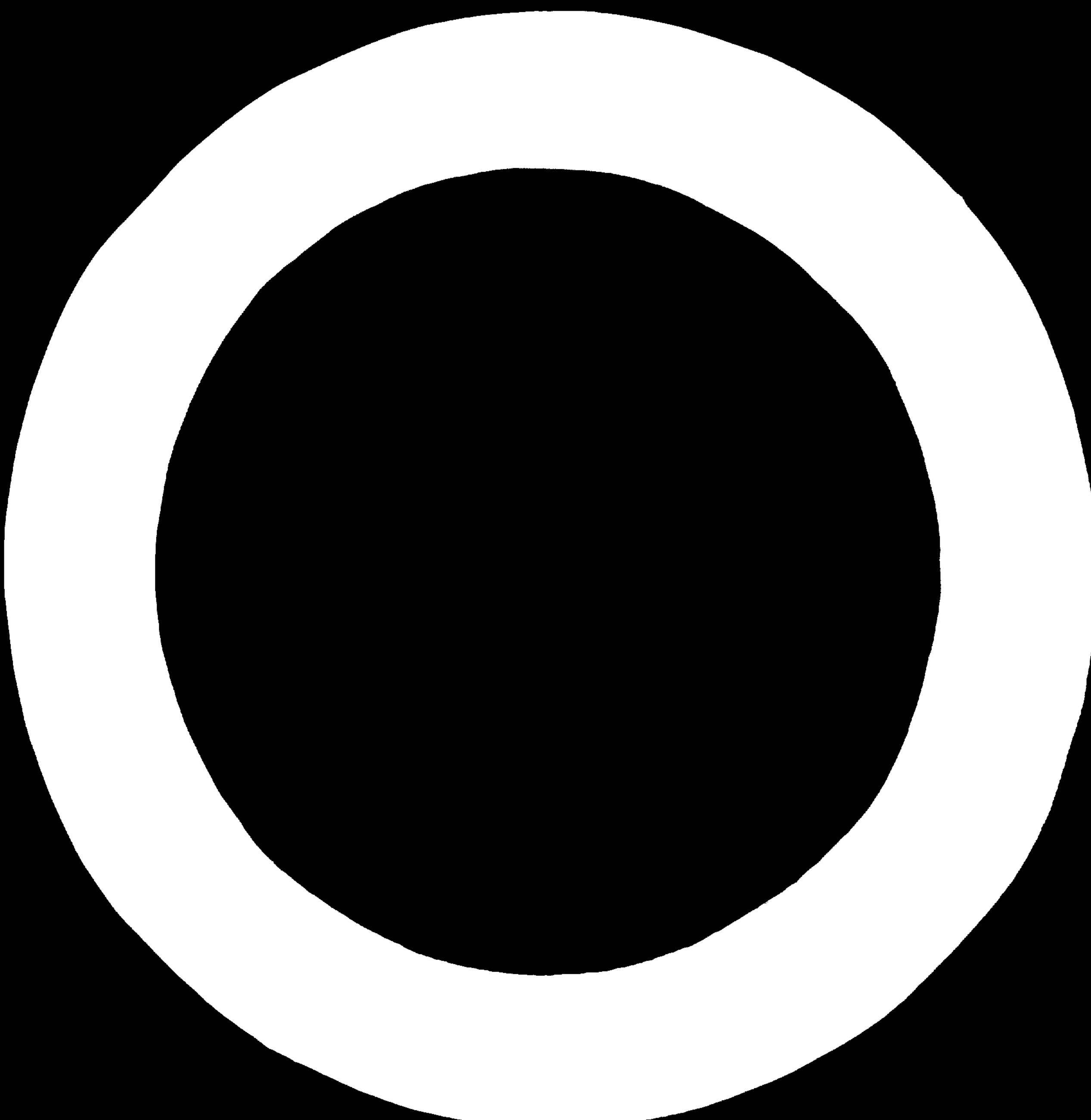
Annexes

Explanatory notes

Dollar ($) refers to US dollars unless otherwise indicated.
Ton refers to metric ton (1,000) unless otherwise indicated.

The following abbreviations are used in this publication:

ASA	American Standards Association
cm	centrimetre
cps	cycles per second
DBPC	ditertiary-butyl-para-cresol
kg	kilogram
kV	kilovolt
kVA	kilovolt ampere
kW	kilowatt
mm	millimetre
MVA	megavolt ampere
POC	paper oil-condenser
V	volt
VDE	Verband Deutscher Elektrotechniker
W	watt

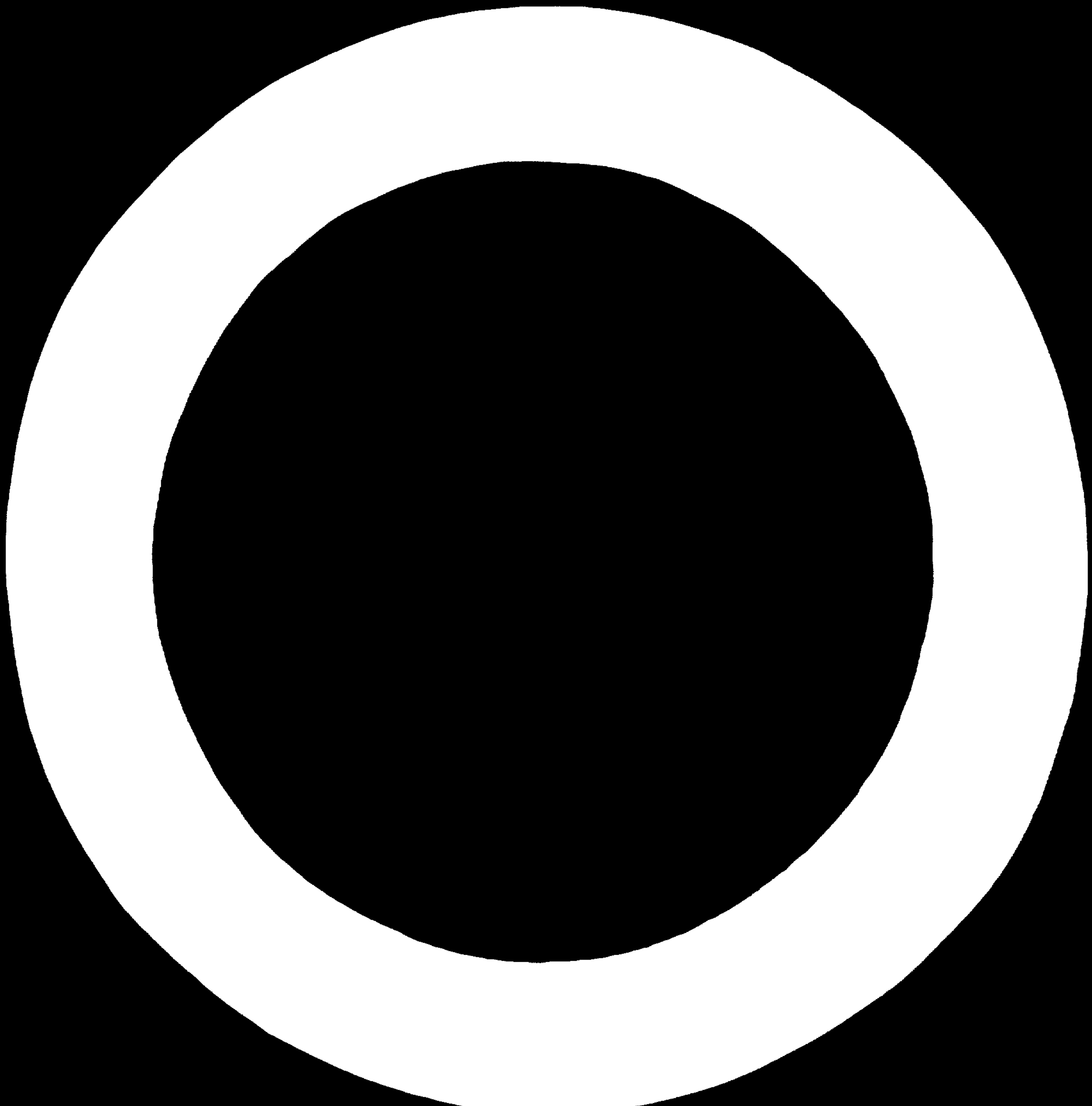


Introduction

The increasing demand for electrical energy in developing countries makes it desirable and advisable for many of these countries to plan their own industrial production of distribution transformers. The present study assumes a sound financial base for such a project and focuses mainly on the actual planning of distribution transformer, production, including the construction of plants and equipment installations, personnel recruitment and training and the creation of a successful sales programme. Discussion of these points is based on the normal standard practices with respect to working conditions, equipment, etc. of a similar plant in any industrially developed country.

The statements in this paper are general only and should be modified according to the actual conditions of individual developing countries.

The present publication was prepared by Mr. K. Rothaler of Elin-Union, Austria in the capacity of consultant to UNIDO. The views and opinions expressed in this publication are those of the consultant and do not necessarily reflect the views of the secretariat of UNIDO.



I SELECTING THE TYPE OF PRODUCTION TO BE ESTABLISHED

The basic types of distribution transformer production that may be established in a developing country are as follows:

(a) Production that is completely independent from other countries and from other manufacturers of the same product;

(b) Production using design and construction licences from another manufacturer of the same product;

(c) Production consisting of assembly of main components which are supplied by another manufacturer of the same product.

When selecting the type of production most suited to the developing country in question, the specific requirements of each type must be considered. For instance, completely independent production requires a certain minimum market to absorb the products and a staff of specialists, skilled workers and trained employees. Also essential is the availability of machinery and additional technical equipment and facilities for economic distribution transformer production.

The success of the project would be promoted by securing information about potential suppliers for the main raw materials. These suppliers need not necessarily be located in the same country as the plant. Co-operation with foreign producers may be profitable to both parties and the cheap supply of all required materials could be assured by favourable long-term supplying contracts. This is especially suitable for the purchase of core-lamination steel, copper for windings, construction steel etc. In general, insulating materials such as oil, cable paper, bakelite and other phenolic parts, varnishes and porcelain will eventually be available domestically. In some cases, however, even these materials will have to be obtained from foreign manufacturers.

Considering the conditions existing in most developing countries, completely independent distribution transformer production is not a very likely choice at this time; production under foreign design and construction licences will probably prove more suitable. The number of licences required depends on the resources and capabilities of the developing country; these must be examined in each case by experts. The essential licences seem to be those for design information and construction and they must allow for the remaining domestic fabrication possibilities.

It is evident that there must not be any procedures in the calculations for and design of transformers, which afterwards, during production, cannot be followed owing to lack of qualified personnel and equipment. The quality of the product therefore depends on existing capabilities. Comparison of the currently possible and the desired quality of the transformers may show the necessity to use other licences in addition to those for design and construction. Alternatively, it should be possible by greater investment to improve the quality of the final product.

If finances are limited as well, the remaining alternative plan to be followed in establishing the production of distribution transformers will be that of assembling foreign-supplied main components. The production experience to be gained in this case by a developing country is less than with the other types of production described above. On the other hand this assembly experience may be part of a long-term programme which will eventually develop into the completely independent manufacture of distribution transformer.

II ASPECTS OF PRODUCTION PLANNING

When the most suitable type of production has been selected, planning can proceed to the considerations described below.

Limitation of the range for sale and use of planned product

This refers to choosing the domestic market sector to be supplied by the planned production facilities. In nearly all cases, the export of transformers may be excluded from production planning.

The production programme

When the market sector has been selected, it should be possible to determine the expected demand and plan a production programme. This programme should include figures for distribution transformers of different ratings and voltage classes.

The economic structure of the developing country will influence these determinations decisively. The demand in an agricultural economy will be mainly for distribution transformers with low ratings to supply small settlements. Districts of low industrialization, such as villages and small towns, will require transformers with nominal ratings of several hundreds of kilovolt amperes. Ratings of 1,000 kVA and more will be necessary for the larger towns and more important industrial plants. (The term "distribution transformer" in this study refers to transformers with ratings limited to 1,600 kVA. Transformers with greater nominal ratings are not considered distribution transformers.)

Technical details and requirements of transformer design

The next step in production planning is to work out the electrical and mechanical design of the transformer.

The elements of electrical design, such as rating, voltage ratio, losses and the tolerances applied to the guaranteed values of these design characteristics are fairly well standardized. For this reason, it is unlikely that a developing country would determine its own standards to define these data. Rather, it is advisable that each developing country conform to the standards prescribed for the economic area to which the country belongs. This will guarantee that difficulties with respect to co-operation with neighbouring countries are kept to a minimum. Furthermore, these standards are geared to the geographic situation of the country, its climate (e.g. tropical, subtropical etc.), prevailing ambient temperatures, height above sea level, risk of lightning and other factors.

On the other hand, the selection of standards for the mechanical design (e.g. with respect to machining tolerances, threads, nominal diameters of pipes, standard sizes of rolled steel, sizes of plates, copper cross-sections, insulating materials, manufacturing tolerances in series production etc.) will primarily depend on the country supplying these materials. This applies especially to production under licences and to production consisting of the assembly of main components. The great dependence on foreign standards in these cases must be carefully considered in any plan to expand production in future to a partially or completely independent stage. Selection of fundamental standards with this eventuality in mind is therefore of great importance.

The selection of electrical design characteristics

In addition to nominal rating and voltage ratio, the loss-ratio of distribution transformers is an important design value. This ratio is the relation of the no-load losses to the copper or on-load losses of a transformer. No-load losses always exist during the operation of a transformer. On-load losses are proportional to the square of the actual load. A criterion for fixing the loss-ratio is therefore the expected average load of the transformer during operation.

Transformers of low nominal ratings, i.e. from 50 to several hundred kVA, installed for the power supply of small settlements, will have long operation periods during the year with a very low load or even at no-load. For this reason, these transformers must be dimensioned to ensure iron losses as low as is economically possible, while the value of the copper losses is of less importance. An extended lay-out of the magnetic circuit (large iron cross-section, small flux density) is therefore necessary.

Transformers of a medium or high rating (630 to 1,600 kVA, as far as this study is concerned) are installed in the more densely populated areas with more important industrial activity. With proper selection of transformer ratings and a degree of flexibility in the operation of the available transformer units, it should be possible to reach a high degree of loading for each transformer, preferably close to the nominal rating. The importance of iron losses will thereby decrease, while the value of the copper losses will become decisive. This will make it necessary to pay more attention to the selection of the cross-section of the copper windings and the best method of heat removal in order to keep within the permissible limits of temperature increases for oil and windings and to give the maximum possible overload capacity.

The loss-ratios of modern European distribution transformers range from 1:6 to 1:9 for nominal ratings from 50 to 1,600 kVA and primary voltages up to 36 kV. Depending on the impedance voltages selected, the conditions of the transmission network and operation in parallel with existing transformer units will determine the appropriate values. The short-circuit capacity of the grid and the voltage drop allowed in the supply and consumption sections of the network determine the limits at which, according to the applied standards, the mechanical and thermal stresses under short-circuit conditions must be guaranteed.

III THE MECHANICAL AND ELECTRICAL DESIGN OF A MODERN DISTRIBUTION TRANSFORMER

Even if general knowledge of transformer design is assumed, it seems useful to give a short description of the main components of modern distribution transformers in order to show the present standard of development for these products in developed countries. Although the following description presents mainly the elements of the "core-type" construction because this is the most widely used type, it is also valid in general for the "shell-type" transformer construction. The general lay-out of a distribution transformer is shown in figure 1 below.

Construction of the core

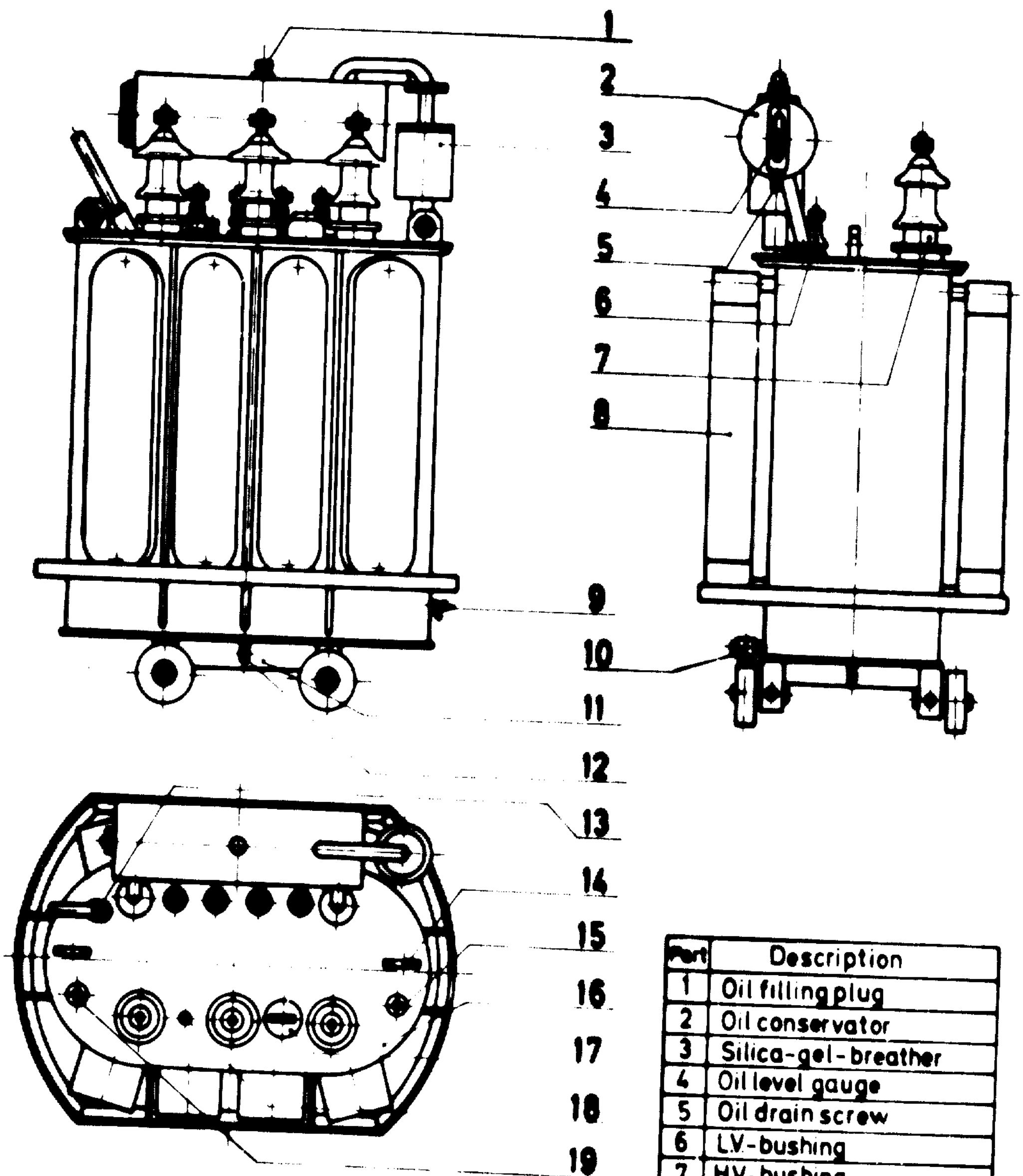
The core is built up with laminations of high-grade, non-aging, electrical silicon steel, of low hysteresis loss and high permeability, especially developed for transformer construction. The best quality material recently available consists of laminations 0.28 mm (0.011 inches) thick, with guaranteed losses of 0.4 W/per kg at 1,000 lines per cm^2 and 50 cps.

Magnetic characteristics are at the optimum parallel to the direction in which the lamination is rolled. For this reason, holes for clamping bolts, which cause deflection of the magnetic flux and therefore increase losses, should be avoided wherever possible. Special methods of fixing the laminations are used instead, in order to connect the core legs to the yokes. The outer legs are diagonally cut at an angle of approximately 45^o.

There are various solutions to the problem of assembling the centre leg with the yokes. Figure 2 below shows two successive layers of steel laminations. The advantage of this method is its complete avoidance of waste. Figure 3 below shows the application of the diagonal cutting, also for the centre leg. This method reduces excitation losses, but there is a 4 to 6 per cent waste of sheet material.

Figure 1

Drawing of the lay-out of a distribution transformer



Part	Description
1	Oil filling plug
2	Oil conservator
3	Silica-gel-breather
4	Oil level gauge
5	Oil drain screw
6	LV-bushing
7	HV-bushing
8	Radiator
9	Oil sampling cock
10	Oil drain valve
11	Undercarriage
12	Haulage eyes
13	Thermometer
14	Lifting eyes
15	Connection to vacuum syst
16	Earthing terminal
17	Tap changer drive
18	Air relief vent
19	Valve to oil purifying plant

Figure 2

Two successive layers of steel laminations

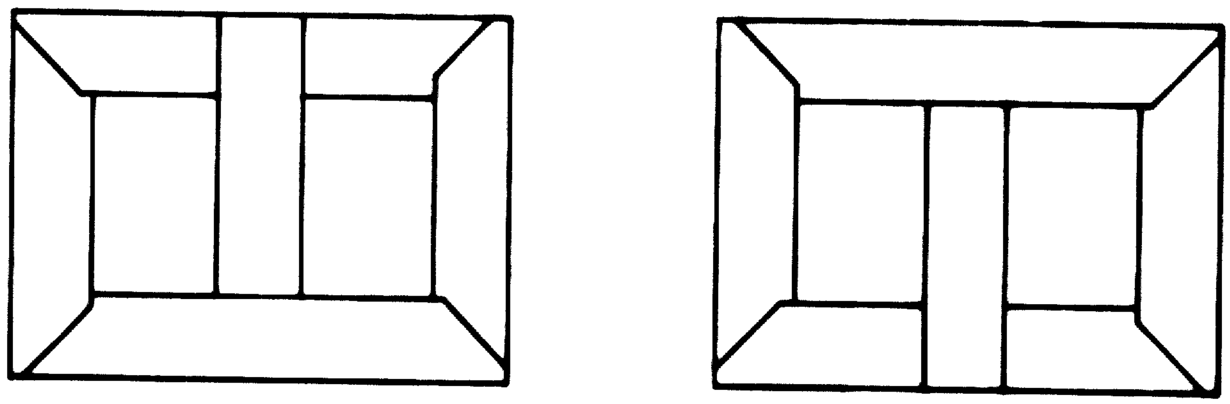
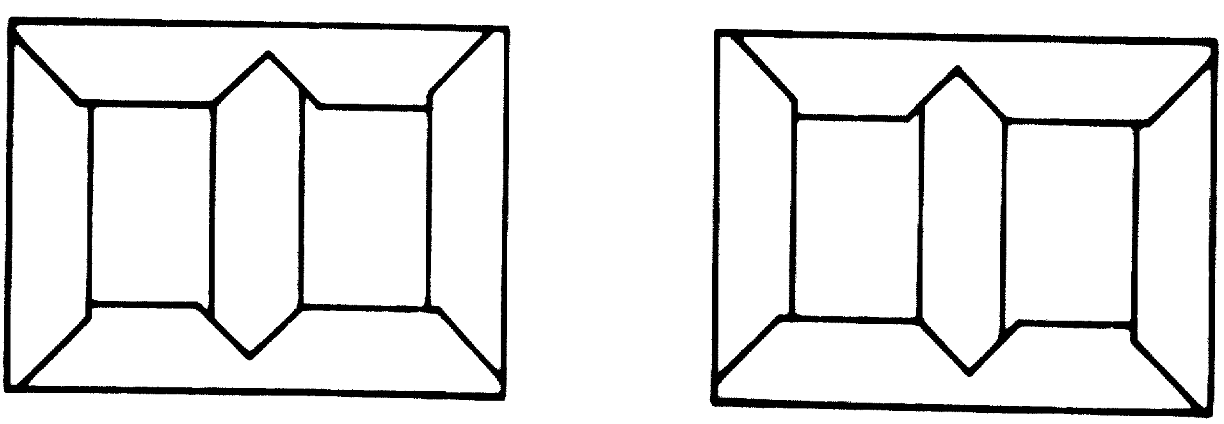


Figure 3

Application of the diagonal cutting



The oompletely out laminations of the core are coated with a heat-resistant varnish, which has been aged at room temperature and agglutinated. The upper and lower yokes are securely held by means of a wooden or steel framework which also ensures the proper compression of the windings.

Construction of windings

The winding nearest to the core leg is the low-voltage winding. Transformer-board insulating cylinders and craft paper prevent flash-overs from the windings to the core. Conductors are made of electrolytic copper of nearly 100 per cent chemical purity. Wires of round and rectangular cross-sections are used. Conductor insulation consists of special varnishes or cable paper.

Windings were formerly exclusively of the coil type. Today, manufacturers increasingly prefer layer windings because of their greater ability to withstand test impulse voltages. Taps are often provided on the high-voltage winding. These taps, generally for ±5 per cent or ±2 x 2.5 per cent are connected to a manually controlled ratio-adjuster within the transformer tank. The tap changes are made at no voltage and no load.

All windings must be capable of withstanding short-circuit stresses without deflection and test impulse voltages according to the specified basic impulse level.

Tank and oover

The tank is normally oonstruoted of welded steel plates with welded oonnexions from radiators, valves and other required devices. The tank is usually designed to withstand a 50 per cent vacuum without distortion or leakage. For the dissipation of heat caused by the transformer losses, the surface area of the tank is increased by incorporating radiators or by folding the tank walls.

For a new production plant, tanks with folded walls will prove more practioal beoause the folding of walls only a few millimetres thick can be done by a single machine. The production of radiators, on the other hand, requires a much greater investment while production costs remain approximately the same.

In some countries transformers are usually installed simply on prepared foundations. In Europe the transformers are normally equipped with four steel single-flanged or plain steel wheels. These wheels are interchangeable for directions of motion parallel to the centre lines of the transformer.

The cover is made of commercial low-carbon steel and is securely gasketed and bolted to the tank flange. Practically speaking, the cover, core and windings form a single mechanical unit. This construction allows the core and coils to be removed from the tank without dismantling of the bushings.

In accordance with applicable standards, all bushings are plainly marked by welding, soldering or pasting labels or letters on the cover for easy identification of connexions. A name-plate and rating-plate (also according to the applicable standards) are affixed to the transformer and include all important information and data.

Bushings

Distribution transformers with nominal voltages of up to 36 kV are usually equipped with oil-filled bushings. The oil in the bushings is directly connected to the oil in the transformer tank. The bushing must always be filled completely with oil and, for this reason, the oil level in the expansion tank must never be lower than the top of the highest bushing. The porcelain of the bushing is wet-process and homogeneous with a uniform, preferably brown glaze. The connexion of the lower bushing stud to the winding is made by means of flexible connectors, since expansion due to heat could otherwise cause oil leakages.

Expansion tank and insulating liquid

The insulating liquid is normally straight-run mineral oil obtained by fractional distillation of crude petroleum and refined specifically for use as an insulating and cooling medium in transformers. It is sometimes requested that the oil contain oxidation inhibitors such as ditertiary-butyl-para-cresol (DEPC). The oil must be treated by purification and evacuation equipment before it is used for filling. The availability of such equipment of proper capacity is one of the fundamental requirements for transformer production.

Because of fluctuations in oil volume caused by changes in temperature it is necessary to provide an expansion tank, preferably mounted with consoles on the tank cover. An oil-level gauge is required for proper control of the oil level. The air cell of the expansion tank is connected to the ambient atmosphere by a container with a suitable desiccant. Because of this oil-preservation system, the tank is never subjected to undue pressures. A disadvantage of this system is the continuous contact of oil with the atmosphere which may cause the accumulation of a certain amount of humidity in the transformer oil. This effect, combined with the influence of the oxygen in the air, accelerates the aging process of the oil. In spite of these flaws, however, the life expectancy of high-quality transformer oil has recently been 18 to 25 years and this period is sufficient under normal conditions.

In some cases, the inflammability of oil is a disadvantage. The use of non-flammable insulating liquids such as clophen and pyralen is often necessary, especially for transformers installed in densely populated areas or in industrial plants with combustible or explosive atmospheres. However, the fumes of these liquids are sometimes toxic and have a very unpleasant odour; therefore, these transformers must be hermetically sealed. This causes the internal pressure to vary with the temperature of the insulating liquid. The maximum pressure permissible affects the size of the expansion chamber and pressure is limited by a relief valve.

Figure 4 below is a schematic drawing of a hermetically sealed transformer without expansion tank. For this system, condenser-type bushings with adequate ground-sleeve length are used instead of normal, oil-filled bushings. These expensive bushings and the necessary enlargement of the transformer tank result in a considerable increase in price. The long delay in delivery involved in such special constructions is a further disadvantage.

Figure 5 below shows a hermetically sealed transformer with two expansion chambers, where space is too limited to accommodate a single large expansion tank. The upper chamber accommodates the normal expansion of the insulating liquid and the lower chamber contains the air or nitrogen necessary for pressure limitation. This tank is not mounted on the transformer cover but on one of the walls of the transformer tank. It should be remembered that some non-flammable insulating liquids attack insulating material and even corrode metals.

Figure 4

Schematic drawing of a hermetically sealed transformer without expansion tank

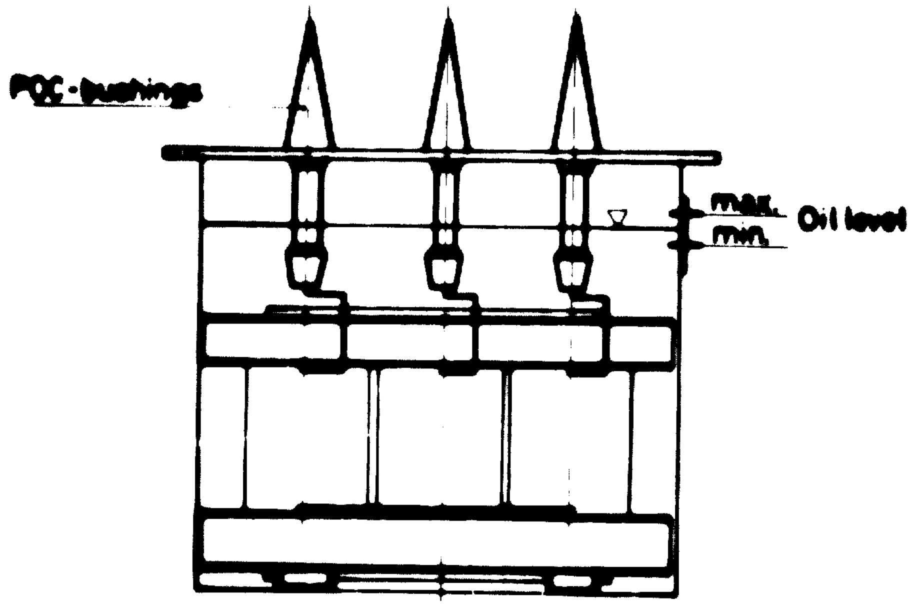
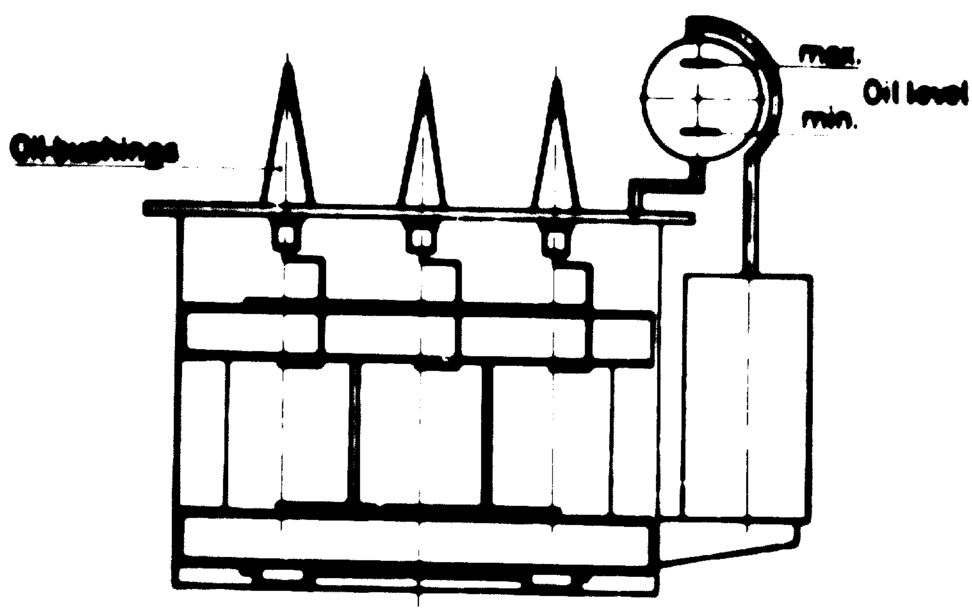


Figure 5

Schematic drawing of a hermetically sealed transformer with two expansion chambers



Surface treatment

For transformers used in areas with normal unpolluted atmospheric conditions, sand-blasting of all outside metallic surfaces is satisfactory. This treatment should be followed immediately by the application of one priming coat and two or three finish coats of synthetic resin varnish. The best method of protection for radiators built of only 1-mm-thick steel sheet is hot-dip galvanization.

In areas with corrosive atmospheres, for instance at coastal locations or in areas close to chemical plants, it may be worth while to hot-dip galvanize all outside surfaces. This is an expensive process, however, and may not be feasible in developing countries where proper equipment may not be available. In these cases, a spray method of galvanization is probably more economical. After sand-blasting treatment, several layers of zinc (up to an average thickness of 50 to 80 microns) are applied by a spray gun. Then one sealing coat, one priming coat and several finishing coats are applied. This type of surface protection is also suitable in tropical climates. The application procedure is simple, does not require expensive investment and may be performed by unskilled personnel. The inner surfaces of the tank, cover and expansion chamber are thoroughly cleaned and thereafter remain unpainted.

Accessories

A gas detector relay should be provided for the protection of transformers rated 250 kVA or more. This type of relay is actuated by oil surges (caused by internal electric arcs) or by gas accumulation due to other internal faults. In both cases separate alarm contacts may be used for de-energizing the transformer.

Indicating thermometers of the dial type are provided for the control of transformer-oil temperature. The temperature-sensitive element is located in the path of the hottest oil. A thermal well is provided in order that the thermometer bulb may be removed without lowering the oil level in the tank. This instrument is equipped with one or more alarm contacts which are normally open.

Temperature control of windings is possible only by provision of the appropriate current transformers, heating elements and temperature relays. Such equipment is not used for transformers of small nominal ratings.

IV ESTABLISHING A COMPLETELY INDEPENDENT PRODUCTION PLANT

The various divisions of this type of plant are described in detail in this section. The organization chart presented in figure 6 below shows the possible structure of such an organization.

Design and construction departments

The manufacture of distribution transformers takes place for stock, unlike that of large power transformers. In order to meet the customers' requirements, the plant should be able to provide an assortment of transformers with a great variety of ratings, voltage classes, impedance voltages, winding connexions etc.

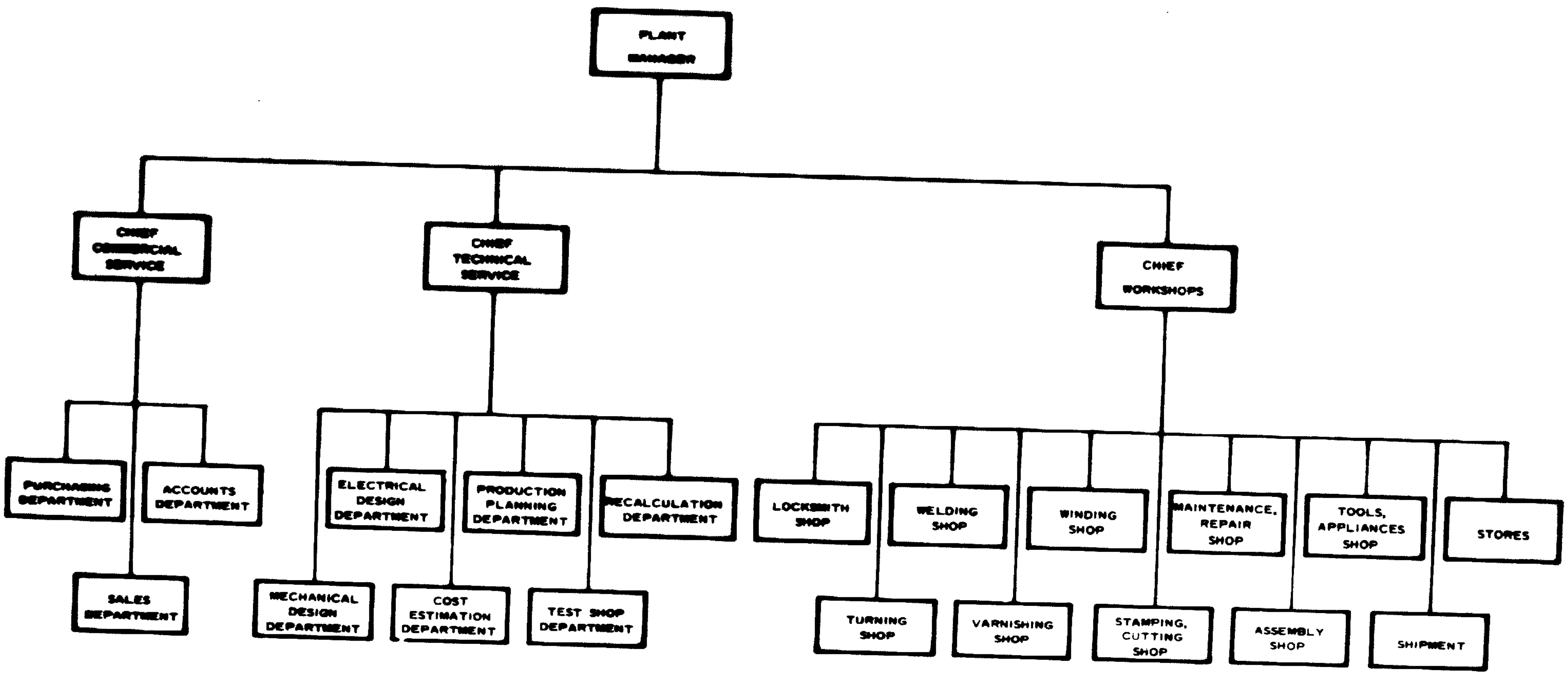
The electrical design engineer must decide whether special requirements can be met with standardized transformer models. He is responsible for the product's competitiveness, and sales success depends on his work. The design engineer's background should include at least five to eight years of practical working experience to ensure his detailed understanding of the complete field and related areas.

In close co-operation with the electrical design engineer, the mechanical design engineer is responsible for the physical design of all transformer types built for stock. In addition, he must determine all details of quantities required, so that cost calculations can be made. This engineer should have at least seven to ten years' experience in his field. He must define all components and is therefore also responsible for production methods, quality and product competitiveness.

The price situation on the world market will not allow design costs to be charged as a flat percentage of sale prices. In the case of special requirements for the construction of distribution transformers, the fundamental drawings may be supplemented, but not superseded, by new drawings. The design effort for a completely new type of distribution transformer may represent approximately 30 to 35 per cent of the total production cost. In this case it would not be possible to offer the usual six to ten weeks for delivery.

Figure 6

Organisation chart



A computer is valuable in the preparation of design and construction data for economical production. The design procedure can be programmed completely. In particular, the lay-out of the magnetic circuit and the calculation of field distributions and mechanical strength can be done very economically by a computer. In addition computers are used for recalculations and for calculating payrolls.

Production planning department

After the calculation and design work for the transformers has been completed, there are some further intermediate steps before workshop production actually begins. Production planning personnel prepare working documents for each transformer component which prescribe the methods used and the sequence of production processes in the various workshops. At the same time, a stock check must be made to determine whether material on hand is available in sufficient quantity. The purchasing department, in co-operation with the mechanical design department, is responsible for seeing that special materials and equipment are ordered and that they are available when required. Production planning personnel must check the delivery in due time of all bought-out components, and that the product itself moves from one workshop to the next according to programme.

Cost estimation department

On the basis of statistical data, this branch calculates the cost of production for special transformers not produced in series. The prices of the latter have been established previously, normally by the design engineers, not by a separate department, using data of actual costs in the past made available by the cost accounting department.

Cost accounting department

This branch collects records of all expenditure incurred in the production of the individual transformers. A comparison with the price quoted yields the profit or loss. If a computer is available, this task requires only one worker.

Stock control department

This department checks the materials on hand and is responsible for supplementary supplies when required. If a computer is available, this task can be handled by the cost estimation department.

Purchasing department

This branch handles all procurements of material and is responsible for the prompt delivery of all materials and equipment ordered.

Printing shop

This shop prepares documents for all departments. After reproduction, all drawings must be classified and stored so that they are available at any time. It is recommended that the drawings be kept for a period of approximately 40 to 50 years. The storage space required can be kept to a minimum by the use of a microfilm file.

V ESTABLISHING A SEMI-INDEPENDENT PRODUCTION PLANT

If completely independent production is not practicable because of insufficient industrialization in a developing country, the use of licences acquired from a well-known transformer manufacturer is recommended.

The most economical procedure to be followed in order to reach completely independent production is described step by step below.

Assembly of purchased main components

This type of production begins with the delivery by the licenser, according to the framework of a contract agreement, of all the active transformer components, i.e. the core and windings and a partly finished tank without oil. The manufacture of some minor components, such as the wheel truck, the expansion tank and pipe connexions, may be carried out in advance by the licensee in the initial phase of this production programme. In this way the workshop personnel become familiar with the fabrication of these parts and may learn to improve their own capabilities in some basic working procedures.

Oil impregnation and all standard tests should at first take place at the plant of the licenser. After completion of the transformer in the plant of the developing country, all tests should be repeated with full test voltages applied. This guarantees the proper functioning of the product in every way and prevents controversies between licenser and licensee.

A welding shop, an assembly shop for main components, oil-treatment equipment and a testing shop are the basic facilities that must be established at the beginning of the project.

During this phase of manufacture, three of the licenser's consulting engineers should be at the disposal of the licensee. One of these engineers should be responsible for all problems of design and construction, for the training of personnel who deal with customers and for production planning and purchasing. Another engineer should assist the licensee in solving fabrication and workshop problems. Finally, a field test engineer should instruct customer personnel in all testing procedures, the connexion of test circuits and, in the interests of accident prevention, all safety regulations.

The training of personnel who will eventually have key positions in the plant of the licensee should be performed at the production plant of the licenser. This instruction should consist of several short training periods, rather than a single longer session.

Independent production of main components

When the assembly of purchased main components has been mastered, and after the products have been on the market for a certain period of time, the second step in establishing completely independent production may be initiated.

At first, the complete tank and cover and the core should be fabricated, although it is recommended that the windings be purchased still from the licenser. At this stage, the developing country's share in transformer production may already reach 80 to 90 per cent of the total production cost.

At this stage of development, the demand for skilled workers increases. All personnel who have proved themselves to be competent workers should now be given positions of responsibility as foremen, charge hands etc. These individuals should also train new employees.

After all problems involved in the fabrication of main components have been solved, the developing country may begin the final step of completely independent production, including the manufacture of windings.

VI WORKSHOP AND TESTING FACILITIES REQUIRED FOR THE PRODUCTION OF DISTRIBUTION TRANSFORMERS

In order to discuss and describe the fabrication of the main components and groups of components of these transformers, it seems necessary first to outline the proper flow of material and arrangement of the various workshops and production lines. The lay-out shown in figure 7 below guarantees a minimum of interdepartmental costs, such as those for transport, waiting periods caused by non-availability of material and equipment, and for cranes, machinery etc.

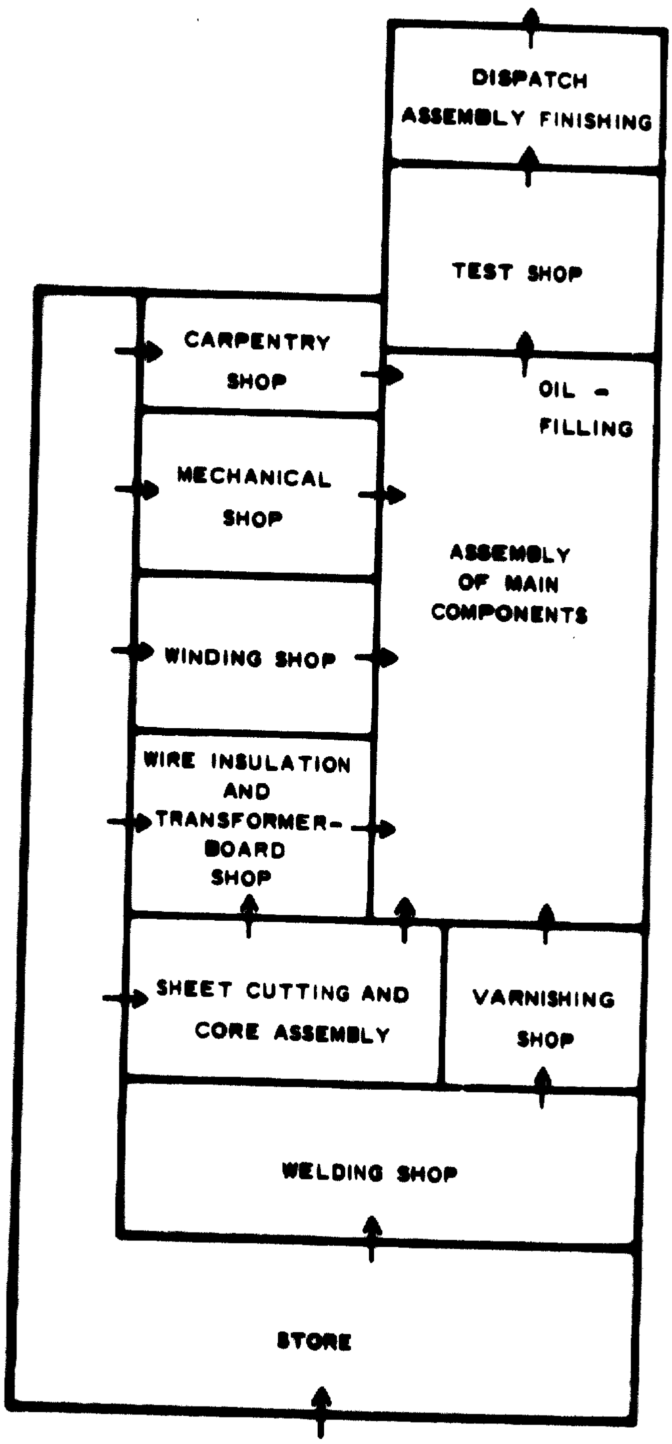
The arrangement of fabrication facilities is partially influenced by the degree of production independence in the factory in question, i.e. completely independent production, construction under licences, or parts assembly only. The scheme described below is suitable if production is to be completely independent. In the case of semi-independent production, or even of parts assembly, however, this scheme may be simplified and used for future expansion.

Store

In order to control the flow of material, the first step in the production of distribution transformers is the arrangement of an adequate store. The store holds the appropriate quantities of all material required for complete production, such as sheet steel, insulating paper for copper wires, bakelite, and finished parts such as instruments, valves, bushings, clamps and bolts. The amount of stock held of the various items should be fixed as a function of the delivery time by subcontractors and the actual rate of consumption. The arrangement of storage bays for materials such as oil, paper and varnishes depends on local safety regulations.

Figure 7

Shop lay-out of a transformer factory



Welding shop

The welding shop should be located next to the store. The main components (e.g. tank, cover, expansion tank, wheeltruck etc.) will be manufactured here. The equipment of this shop generally consists of the normal production facilities for regular welded-steel constructions, the essential items being as follows:

(a) One or more marking plates, plate size approximately 2,000 x 1,000 mm, with ancillary equipment for metering and marking;

(b) Flame-cutting machines for cutting by hand; or, depending on the scale of production, one or two copying flame-cutting machines, each with one or more cutting tips and equipped with a mechanical or photoelectric scanner for processing the bottom, wall and cover plates;

(c) One form-cutting machine for steel plates up to a thickness of approximately 6 mm for cutting special constructions;

(d) One hammer shears and one loose coiler with horizontally arranged rollers, able to handle material of approximately 1,500 mm. The diameter of the rollers should not exceed 120 mm for easy rolling of the shell plate of the expansion tank;

(e) Cold saws (belt saws or circular saws) for cutting to length the tank flanges and stiffening the ribs of the tank, wheel-truck or cover, pipes etc;

(f) One loose coiler with vertically arranged rollers for easy and economic upright rolling of tank flanges. The rollers are provided with grooves which prevent distortion of the flange during the rolling process;

(g) Special shaping machines for processing of edges for x- or v-welding seams. These machines allow fabrication at a low noise level;

(h) Direct-current welding machines with appropriate electrodes for manual welding of walls up to at least 3 mm thickness;

(i) One or more resistance welding machines for welding tanks for small distribution transformers or tanks made from corrugated sheet iron. These machines are similar to those used for the production of radiators or barrels;

(j) Auxiliary equipment for manual welding such as a horizontal welding plate (approximately 1,000 x 2,000 mm in size), a lifting device for hoisting and turning the workpiece, screw clamps and one or more water balances. The latter are indispensable during stitching of single parts.

In order to keep distortion of the main parts during the welding process to a minimum, certain instructions must be observed. First, the individual parts of a main component should be fixed in the correct position by welding stitches only a few millimetres in length at intervals of approximately 100 mm. For bigger tanks and shrinkage of about 2 per cent should be considered. Secondly, the proper choice of welding current and electrode diameter for the sheets to be connected is an important factor. Thirdly, the welding should be done in steps to avoid heat accumulation and increased warping. After completion of the welding process and alignment and cleaning of the welded workpiece, and after the common drilling of holes on the tank flange and cover, the surface of the parts should be thoroughly cleaned by sand-blasting.

A column type drilling machine with a swivelling beam and radially adjustable sliding drill-head should be available for drilling flange holes. This machine would also be suitable for threading operations. The column height of the drilling machine must be matched to the tank height of the largest transformer model.

If domestic manufacture of radiators or tanks from corrugated sheet iron is undertaken, a folding press with a capacity of approximately 100 tons is necessary. The insertion in the press of special stamping dies must be possible. The subsequent operations on the radiator parts require the use of resistance or oxyacetylene welding machines.

A manually or remote-controlled tilting turnstile to facilitate welding in an ideal position may usefully complete the welding shop. The size of this turnstile must match the maximum possible diameter of pieces to be welded.

Miscellaneous welding shop equipment includes portable grinding machines, chisels, files and metal handsaws.

Sheet cutting and core assembly

The cores of modern transformers have cross-sections of approximately circular shape. This shape may be fabricated by using a large number of lamination stacks of varying length and width for the core legs and core yokes. These different steel laminations are cut by the hammer shears and then stamped out. The raw material consists of coils of lamination steel of a suitable width. Modern manufacturing plants use special automatic cutting machines which electronically control and programme the production of these laminations. In the stamping process the edges of the laminations are treated to remove all burrs and sharp projections.

When the required quantity of laminations has been completed, the core will be stacked in a horizontal position and will lie under the lower yoke press plates according to a special stacking plan. The upper yoke laminations will not be inserted before the windings are mounted. This procedure is only possible, however, if a special device is available which prevents changes in the positions of the core laminations during transport to the erecting shop and during the assembly of the windings in an upright position. Base plates should be used for the storage and transport of assorted core laminations after sorting, to avoid mechanical shocks which cause deterioration of loss characteristics.

The loss quality of ordinary transformer steel laminations can be improved by treating the ready-cut laminations in an annealing furnace. The capacity necessary for this furnace depends on the production capacity of the plant and the annealing cycle. The furnace may operate under normal atmospheric conditions or with a layer of protective gas.

Wire insulation and transformer-board shop

Two major tasks are handled in this shop. First, the winding copper (of rectangular or circular cross-section) is insulated with sufficient cable paper. This is performed by insulating machines similar to those used in cable manufacturing plants. The size of these machines depends on the required thickness of the insulation. The application of insulation to internal transformer conductors is also performed by this insulating machine.

Secondly, this shop manufactures all other insulating materials required for the windings, such as insulating cylinders, distance strips and associated spacers, shield rings, parts of the yoke end-supports and all other parts of switches, and supporting structures.

Additional machines are necessary for the fabrication of these parts. Linear cutting of thicker materials is performed by a circular saw. Form cuts are made by a belt saw with a vertical running belt of the usual construction. A punch press of approximately 20 tons capacity is necessary for stamping spacers. A belt sander is used for the manual removal of burrs from cutting edges. Additional miscellaneous equipment consists of a small column type drilling machine, a cutter for insulating materials of a thickness not exceeding 4 mm and a small splicer.

Winding shop

Windings are made on simple machines driven by electric motors. The special features of these machines are their capacity for intermittent control and a device for counting the revolutions of the main shaft that bears the winding.

For production of distribution transformers of ratings up to 1,600 kVA and voltages not exceeding 36 kV, the maximum length of the winding, including the required space for connexions, may be 1,200 mm. The distance from the centre line of the shaft to the table of the machine should be approximately 600 mm, but no less.

The winding is constructed according to the technical design sheet and drawing showing the design. Because of the wide variety of winding constructions, the procedure to be followed can be described only in general.

The inner or low-voltage winding is applied to a supporting cylinder, which is subsequently applied directly to the core legs. This cylinder is fastened to the shaft of the winding machine and is centred by wooden or metallic discs. If required, distance strips are arranged on the cylinder and are connected to spacers by means of a dovetailed connexion. The winding process then begins, including all twists and taps. The connexions of conductors must be done with special care.

The manufacture of the outer or high-voltage winding is similar to that of the inner or low-voltage winding. Each of the completed windings is then compressed separately to a predetermined extent. Then the windings are pre-dried in a drying furnace for several hours at an ambient temperature of approximately 95°C.

During the manufacture of windings and related accessories great care must be taken to assure maximum cleanliness in order that the dielectric and creepage strength of the insulating material is not decreased by contamination.

Mechanical shop

This workshop may be divided into three major sections. One section manufactures all parts that require machining, such as studs of bushings, protective spark gaps, flexible connectors, contacts of no-load tap changers, facing flanges, parts of switch gear, clamping devices and supporting structures and parts of the wheeltruck.

Another section manufactures all auxiliary production equipment such as welding, stamping and assembly fixtures and templates. This section is also partly responsible for the maintenance of tools.

The third section is equipped for the maintenance and repair of the installed machinery and equipment, including electrical installations, motors, cables, switches, lighting etc. The equipment required for this section comprises several turning lathes with a distance between centres of approximately 1,600 mm, one milling machine, one shaping machine, one drilling machine, some small stamping machines with a 10 to 20-ton capacity, one hydraulic press, one soldering installation, some special dies for making contacts, portable manually operated oxyacetylene welding equipment, one electrical furnace for heat treatment of tool steel, measuring instruments cylindrical gauges and calibre gauges for control of fits, surface plates and miscellaneous manual tools for metal machining, small manually operated grinding machines, and tools and instruments for the repair of electrical workshop installations. As the production of the plant expands, it may also be necessary to procure a small jig drill for this section.

Carpentry shop

The equipment of the carpentry shop of a transformer production plant is quite conventional. For making wooden clamping devices, a circular saw, a planing and thicknessing machine, a belt saw and a column type drilling machine are satisfactory. This equipment is also used for the production of all wooden parts required, such as base supports, storage bay racks and crates.

Assembly of main components

When all transformer parts have been delivered to the erection shop, the assembly work may begin. The first step is to apply the inner low-voltage windings to the core legs. Care is necessary in this procedure in order not to damage the insulating cylinder as it slides along the core edges. The next step is to mount the outer high-voltage windings. The methods used in clamping the core and in fixing the core cylinder depend on the mechanical design of the transformer. When clamping has been completed the upper yoke laminations are inserted and the yoke is clamped and compressed. Next is the location of the functional part of the transformer in the tank, aligning the cover support construction to the cover and the bushings.

After attachment of the no-load tap changer, the switch gear parts and the appropriate connexion circuits, the completed functional part of the transformer is placed in a vacuum drying furnace where, at a temperature of approximately 95° to 100°C under high-vacuum conditions, the accumulated moisture is removed during one to two days (according to transformer size). The amount of water extracted from the insulating material is measured by measuring glasses located outside on the furnace walls. Periodic measurements of the power factor of the winding insulation provide a check on the progress of the drying process. Meanwhile, the tank is equipped with all required fittings, armatures and accessories.

After this main drying period and before the functional part of the transformer is inserted in the tank, all joints, screws, bolts etc. are retightened and equipped with proper screw-locking devices. Then the completely assembled transformer is filled with oil that has been purified in an oil-separating plant. At the same time, the tank is evacuated and the oil is sucked into the transformer tank by this vacuum. The vacuum applied depends on the insulation class of the transformer: for distribution transformers, the upper limit is approximately 40 per cent vacuum. After a rest period of about twelve hours, the transformer is ready for testing.

The oil is purified by circulating it through a filter press. Using modern devices, the oil is heated to a temperature of 90°C during circulation when it passes through very fine plastic filters. Connected to this equipment is an oil container under vacuum, which separates moisture from the warm oil. Another connexion between the bottom of the container and the inlet of the purification plant allows a circulating heating process to continue until a certain value of dielectric strength is attained. This value depends upon the test electrodes used. According to the Institution of German Electrical Engineers (VDE) the dielectric strength should reach 220 kV/cm.

<u>Test shop</u>

The duties of the test shop are, on the one hand, to carry out all tests and measurements required during manufacture and assembly and, on the other hand, to devise measurements for the further development of the product.

Transformers of the rating range mentioned above require the tests and measurements described below. The instruments to be used in these procedures have already been discussed.

Resistance measurements. For transformers with a resistance of up to 10 ohms, a Thompson bridge is used (measuring range: 10^{-5} to 10 ohms). Resistances exceeding 10 ohms are determined by the usual measurement of voltage and current using a direct current source of 24 or 60 V.

Measurement of turn ratio. This measurement is made by means of a special ratio meter that permits direct readings of the ratio and per cent ratio error. The vector group of the transformer is simultaneously checked.

Measurement of insulation resistance. This measurement is made with Megger testing equipment with a nominal voltage of 2.5 to 5 kV.

Low-frequency dielectric tests. The applied potential test requires a potential transformer with a voltage range of up to 100 kV and a rating of 50 kVA. The test voltage is determined by a normal electrostatic voltmeter with measuring ranges of 25 to 50 kV to 100 to 250 kV, or by crest voltmeters.

The induced potential test requires a frequency converter with a rating of about 30 kVA and 1,000 V, 150 cps. The duration of this test is fixed by the standards used. The measurement of voltage and current is made by the use of highly accurate instrument transformers.

Measurement of losses and impedance voltage. Determination of excitation and load losses requires a generator with a sine-wave voltage characteristic. The readings are obtained by means of precise, light spot galvanometers connected to instrument transformers for metering of current, voltage and power.

All the above-mentioned tests are performed on each transformer. In addition to the normal shop tests, the following tests may occasionally be required.

Temperature test (heat run). This test is normally made at a load equivalent to the rated load, and one winding of the transformer is short-circuited.

Impulse test. This test requires the purchase of an impulse generator of ample capacity and all appropriate accessories.

In addition to the normal and additional tests described above, the test shop must be able to perform functional tests of transformer accessories such as gas-detection relays and thermometers. This department is also responsible for the proper functioning and accuracy of metering instruments used in other sections of the plant.

Finishing and despatch section

After satisfying all required tests the transformer is given the finishing coats. It is advisable that this process be carried out in spraying cells with spray guns of the usual design. The ratings and nameplates, terminal markings and protecting instruments are also attached in this division. The transformers are then packed in crates and are ready for despatch.

Estimated power demand of the main equipment in a distribution transformer production plant

The power demand of all electrical equipment in the factory should be calculated and summarized. Estimated values for individual items are given in table 1 below.

Table 1

Estimated power demand in a transformer factory

Equipment	Power demand
Welding machines, according to rating	10-25 kW
Loose coiler with vertically arranged rollers	8 kW
Loose coiler with horizontally arranged rollers	4 kW
Drilling machines, according to rating	4-10 kW
Autogenous cutting machines	2 kW
Power press (100 tons) with large fly-wheel mass	8 kW
Manually operated grinding machines	2 kW
Shaping machines	5 kW
Stamping machines, according to capacity	2.5-6 kW
Sand-blasting equipment	15 kW
Insulating machine	6 kW
Hammer shears	8 kW
Roll-welding equipment with two rollers	38 kVA
Roll-welding equipment with one roller	24 kVA
Tilting turnstile, with large gear ratio	1.5 kW

Table 1 (continued)

Equipment	Power demand
Annealing furnace	40-60 kW
Hydraulic press	2-3 kW
Turning bench for windings	5-8 kW
Planing machine for wood-working	3 kW
Thicknessing machine for wood-working	4 kW
Belt saw for wood and insulating material	2 kW
Circular saw for wood and insulating material	2 kW
Potential transformer for testing	50-100 kVA
Frequency converter	20-40 kVA
Impulse generator	Approx. 600 kVA
Oil-separating plant	20 kW
Drying furnace	Economical heating only with oil- or steam-heat generation
Lighting	15 kW
Compressed air plant	5 kW
Cranes and hoists	20 kW

VII ANALYSIS OF PRODUCTION COSTS

A detailed breakdown of the capital costs of production equipment is contained in Annex 2.

For competitive production of distribution transformers the cost of every single component of this product should also be determined as exactly as possible. This cost breakdown will vary according to the position, size and mechanization of the transformer plant. Costs will also vary according to the materials used and the manufacturing processes adopted.

The quality of transformers may be measured by comparing the weights of products with the same losses. Transformers with lower weights but the same losses as other transformers are of higher quality. Since transformers of lower weight are also cheaper under nearly all circumstances, they are more competitive. There is, in fact, a connexion between losses and active weights, which is related to technical design, but the relationship is complex and is therefore not discussed in this study.

Production costs may be analysed from the points of view described below.

Commercial cost analysis

An important factor here is the evaluation of the overhead costs of the manufacturing shop. Basically, there are two overhead systems - the wages overhead system and the cost centre overhead system. In the former system the hourly wages are charged with amounts corresponding to the cost of the various workshops. In the latter system, the overheads are determined for each single cost centre and charged to the product pro rata.

In the following example of cost analysis the wages overhead system is applied. The various costs (as percentage of total production cost) involved in the series production of a transformer with insulation class 10 kV (maximum high voltage 12 kV) and a nominal rating of 250 kVA are approximately as follows:

Item	Cost (per cent of total)
Wages	11
Wages overhead costs	26
Material	36
Material overhead costs	2
Intermediate products	19
Design costs	1
Sales overhead costs	5
Total production costs	100

The figures in this example are determined on the assumption that no administration centre exists, i.e., the sales department is located at the factory site. On this basis, 5 per cent for sale overhead costs should be sufficient.

Technical cost analysis

The cost breakdown below is of special interest to the design engineer. Again, a series production transformer with insulation class of 10 kV and a nominal rating of 250 kVA is assumed.

Item	Cost (per cent of total)
Design	1
Core	28
Windings	34
Tank, cover and expansion tank	14
Radiators	6
Bushings and tap-changer	3
Connexions and minor parts	3
Oil	3
Gaskets, finishing and assembly	8
Total production costs	100

VIII ACTUAL ESTABLISHMENT OF A PRODUCTION PLANT FOR THE ASSEMBLY OF PURCHASED MAIN COMPONENTS

Some years ago a developing country in Asia decided to install a production line for the assembly of foreign-supplied main components. A well-known Austrian transformer manufacturer was engaged to help establish this transformer production by delivering the main components, by helping to install all the equipment required for the assembly process and by providing personnel to supervise production. The share of domestic production in the total was in this case only about 10 per cent.

Factory, personnel and labour efficiency

Before beginning transformer assembly, this factory was a mechanical workshop with a group of about 50 workers skilled in metalworking. During a period of approximately seven months, about 300 transformers were assembled, filled with oil, tested under the supervision of a European testing field engineer experienced in workshop problems, and shipped.

Production equipment

The workshops were already equipped with the required metal-working machines such as lathes, hammer shears, drilling machines and electric and autogenous welding facilities. A crane with a 2.5-ton capacity was available, but its lifting power proved to be insufficient. A vacuum furnace, an oil-treatment plant, a stacker truck and some other trucks had to be provided to supplement equipment already on hand. The trucks were necessary because the plant had no junction with railway lines. A completely new installation of testing field equipment was also necessary. The supply of the necessary electrical power, 250 kW, was guaranteed and new storage bays with lean-to roofs were built.

Experience gained

Heavy plates, gas cylinders for welding purposes and transformer oil were easily obtained. On the other hand, the procurement of screws and nuts with metric and even with inch threads was difficult as was the replacement of machine parts.

Attention is drawn to the fact that requirements of miscellaneous materials can always be satisfied. If there should be any lack of material, however, the purchase of the required supplies must not be delayed by unnecessary "paper shuffling".

From a long-range viewpoint, it seems advantageous for the manufacturing company to train its own personnel by giving apprentices special courses of instruction during their apprenticeship. These courses should be given by skilled personnel within the company. With such a programme, a crew of well-trained workers should be available in a few years' time and there will then be a corresponding increase in production efficiency.

Maintenance and repair

Assuming that a properly tested transformer is shipped from the factory and properly erected at the site, special maintenance should not be necessary for at least ten years, although the oil level in the expansion tank should be checked occasionally. When the transformer has been in operation for ten years, replacement of all gaskets and renewal of paint or corrosion protection may be necessary. The oil should also be analysed at this time and should be exchanged or reprocessed if the dielectric strength is below 80 to 100 kV/cm (according to VDE testing standards) or if moisture content is excessive.

Damage to the transformer may occur during transport by rail, truck or ship, and during unloading or handling at the site. Even under the most favourable conditions, damage to the active parts of the transformer is possible. For quick repair of the unit the plant of the licensee should be equipped with a winding machine. A specially trained worker should also be available who is able to produce a partly or completely new winding. An adequate supply of the required winding material should be on hand for this purpose.

It is usually the bushings that are damaged, resulting in a loss of oil. If the windings have not been exposed to the atmosphere the repair of this damage should be very simple. After replacement of the bushings, the oil level has to be brought back to normal under a slight vacuum. Before shipment of the transformer it is recommended that the insulation be checked by an applied voltage test using 80 per cent of the normal test voltage.

Replacement of material

Defective material in a modern transformer cannot be substituted by material of similar but not identical specification. This is especially true of the functional parts and the oil. If core laminations of the required quality and thickness are not available, the guaranteed values of the transformer, as well as the construction of the core, are changed by use of substitute material with other characteristics. For similar reasons the winding copper cannot be replaced by aluminium, not to mention the fact that the technological treatment of aluminium is much more complicated than that of copper.

If low-grade insulating materials are used instead of high quality papers, transformer-board and oil, failure of the transformer even during the tests may be expected. Despite their good dielectric strength, low-grade oils have a tendency to quick tarring at operating temperatures. As a result flash-overs occur, often destroying the transformer.

Replacement possibilities do exist for inactive iron materials and for sheet steel for the tank. These commercial materials are available on the market under normal conditions, however, and it is therefore not ordinarily necessary to look for substitutes.

Because the proper transformer materials are essential, all basic supplies necessary for a two-to-three months' transformer production period should be on hand. Neglect in this area may result in delivery difficulties or in failures during testing. Either situation entails expenses that are normally higher than the total cost of adequate material supplies.

IX SUMMARY AND POSSIBILITIES FOR FUTURE DEVELOPMENT

Although transformer parts are made to normal industrial standards of accuracy, many problems with respect to electrical and mechanical design and proper workmanship are involved in transformer production. Often a compromise must be found between the contradictory requirements of the electrical and mechanical points of view. The merit of a compromise solution may always be judged in a practical way according to the market success of the product and its operating reliability over a period of years.

In view of the difficulties involved in transformer production, the assistance of an experienced and well-known company is essential if such an undertaking is to be successful. Close co-operation with such a company during a period of at least ten years should enable the licensee to expand production gradually. Even after this initial period, consultation with experienced advisers and construction under licences may be advantageous.

When a plant progresses to the construction of transformers with ratings of up to 10 or 20 MVA, new problems will arise. Some of the areas of difficulty are as follows:

(a) Nominal voltages up to 150 kV;

(b) Complicated winding connexions required by customers;

(c) Transformers with on-load tap changing devices;

(d) Transformers with cable-end boxes;

(e) Difficulties during assembly at the plant due to handling of many large transformer parts.

The selection of a licenser should not be made only according to financial considerations. Confidence in the licenser's product and in his administrative personnel should be determining factors as well.

Annex 1

RELATIONSHIP OF CERTAIN DESIGN DATA TO THE NOMINAL RATING OF THE TRANSFORMER

Figures 1 through 6 below show the relationship of some important design data to the nominal rating of the distribution transformer. These data were supplied by a well-known European transformer manufacturer. As is usual, the data refer to transformers with a nominal rating of up to 630 kVA and an impedance voltage of 4 per cent, and to transformers with nominal ratings from 250 to 1,600 kVA and an impedance voltage of 6 per cent.

Additional parameters used in these figures are the primary voltages of transformers most used in practice for installation in smaller distribution grid systems, i.e. maximum voltages of 12, 24 and 36 kV. In addition to no-load and copper losses, these curves show the change in total weights and in the over-all dimensions of such transformers, as nominal rating increases. All these data should be used mainly to record the present state of distribution transformer design technique, mechanical and electrical, and to show the attainable limits.

Figure 7 below shows the relative costs of distribution transformers in the rating range from 50 to 1,600 kVA for primary voltages of up to 36 kV and secondary voltages of up to 6.3 kV. This curve is based on recent information supplied by a leading European company which manufactures all types of transformers.

The width of this cost band results from the variations encountered in primary and secondary voltages and the application of different winding connexions (wye/wye, wye/zig-zag and delta/wye). The costs were recorded not as actual money values but as percentages, 100 per cent corresponding to the average cost of a transformer with rating of 630 kVA. The advantage of this type of presentation is that it is independent of actual cost variations from country to country and is not much influenced by probable future cost increases.

Figure 1

Losses and total weight versus nominal rating, maximum primary voltage = 12 kV

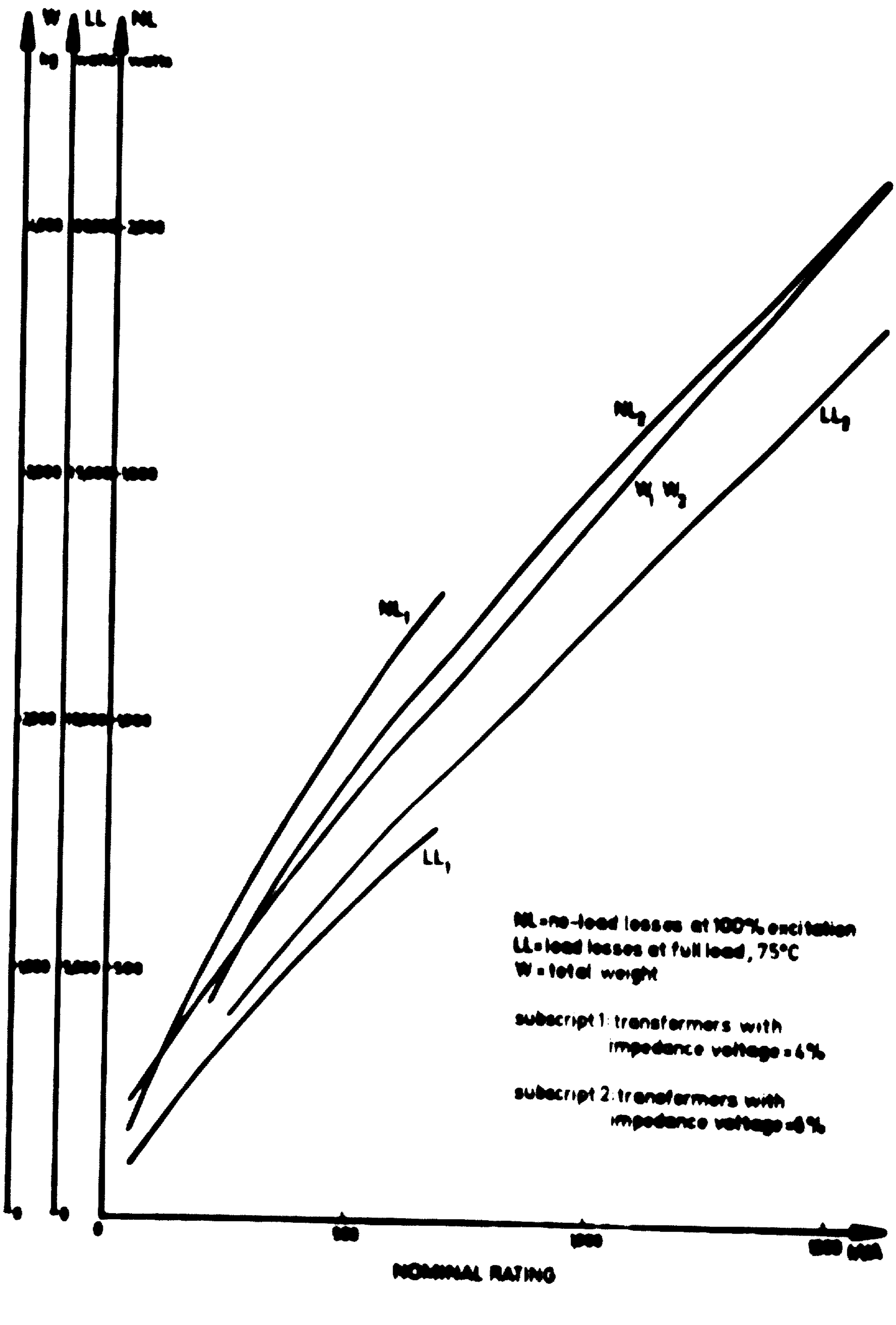


Figure 2

Losses and total weight versus nominal rating, maximum primary voltage = 24 kV

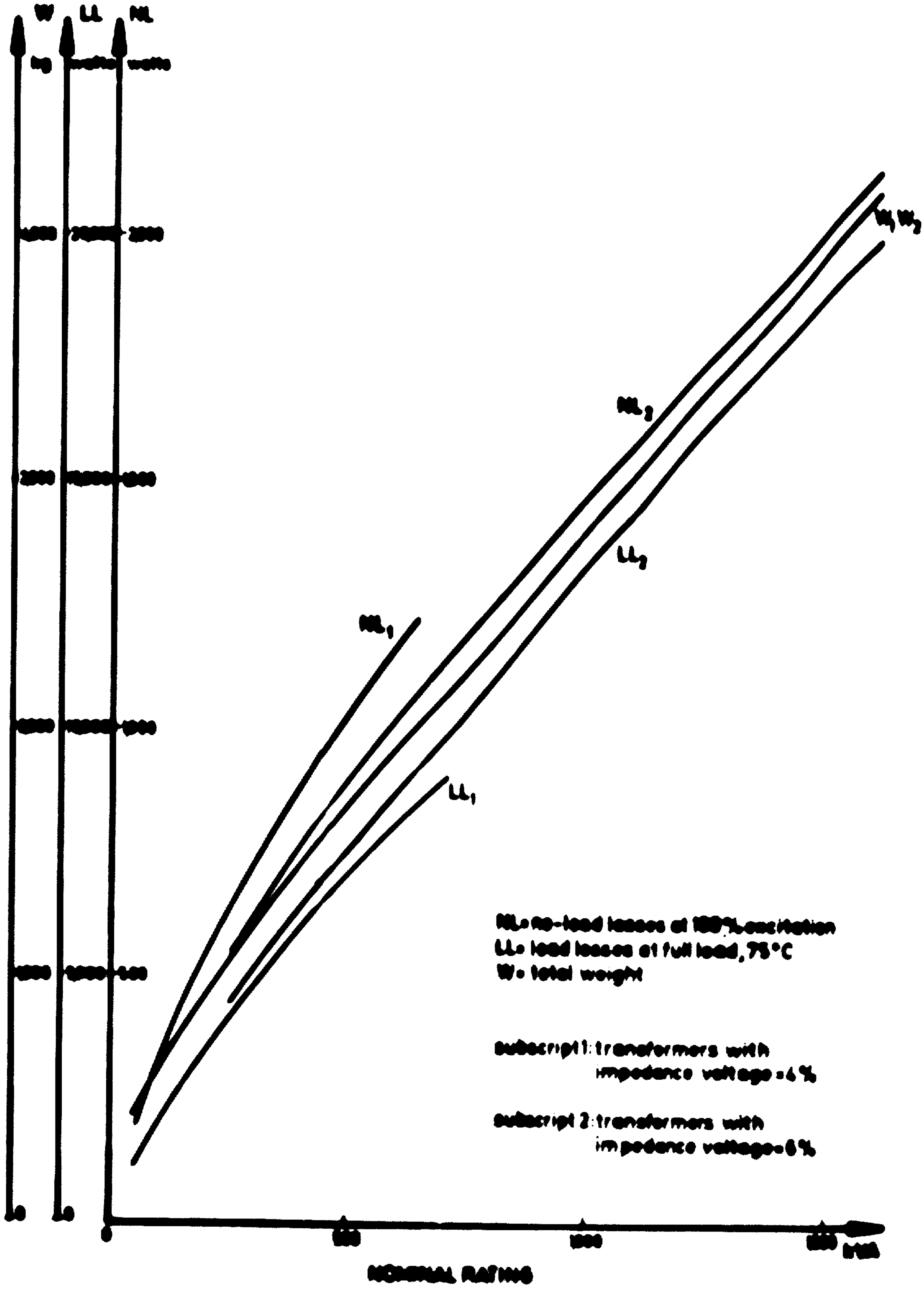


Figure 3

Losses and total weight versus nominal rating, maximum primary voltage = 36 kV

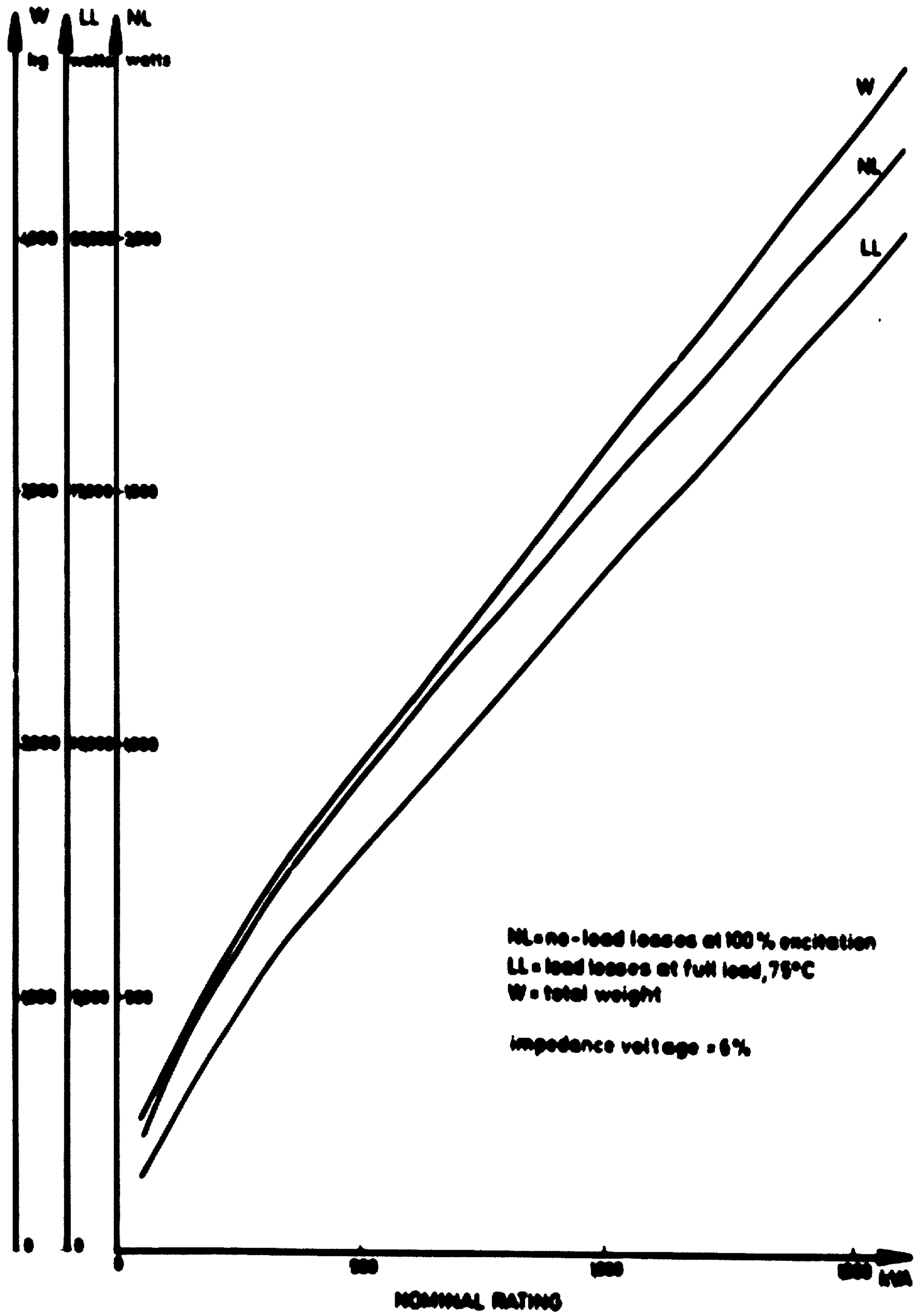


Figure 4

Length, width and height versus nominal rating, maximum primary voltage = 12 kV

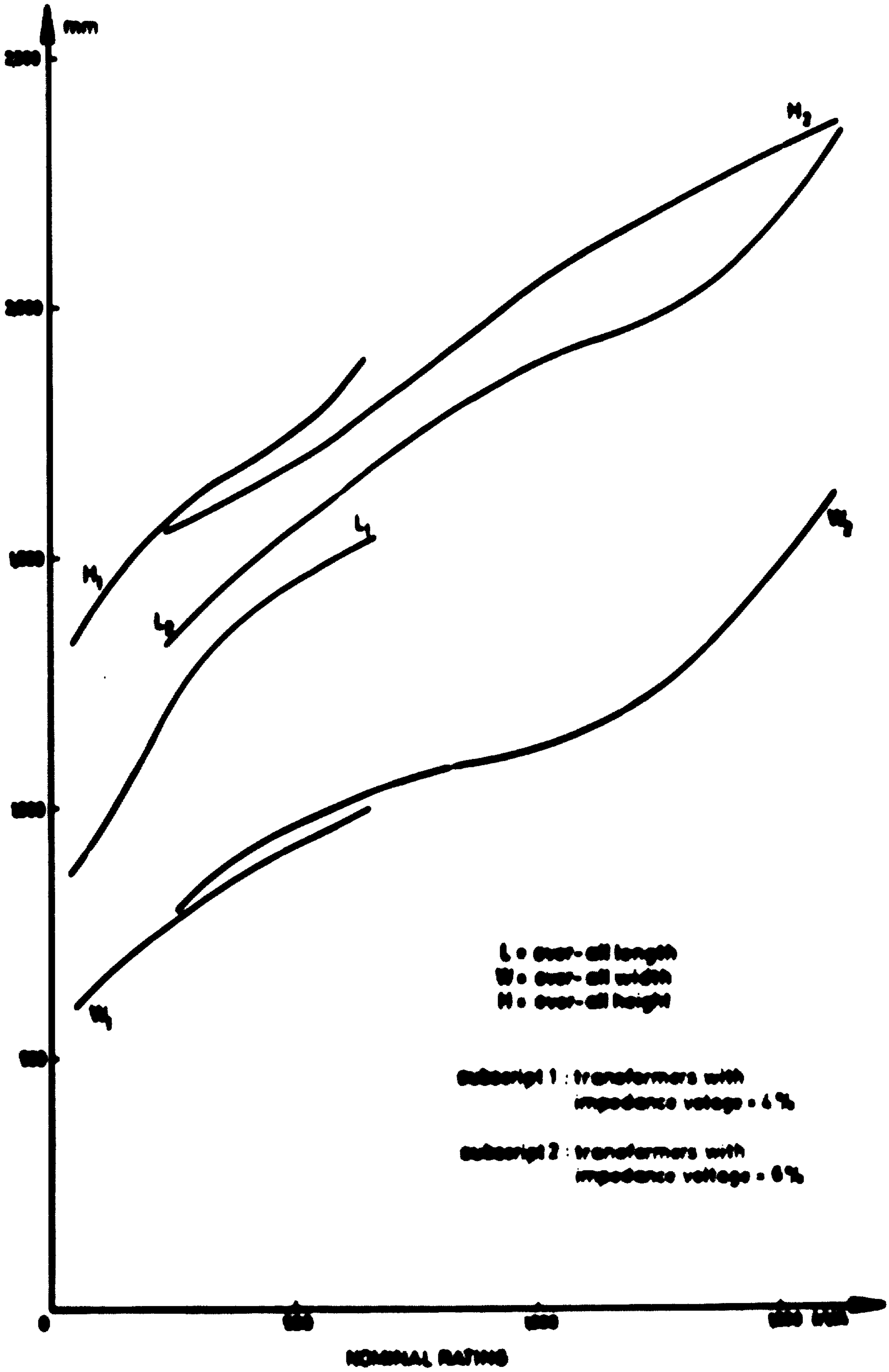


Figure 5

Length, width and height versus nominal rating, maximum primary voltage = 24 kV

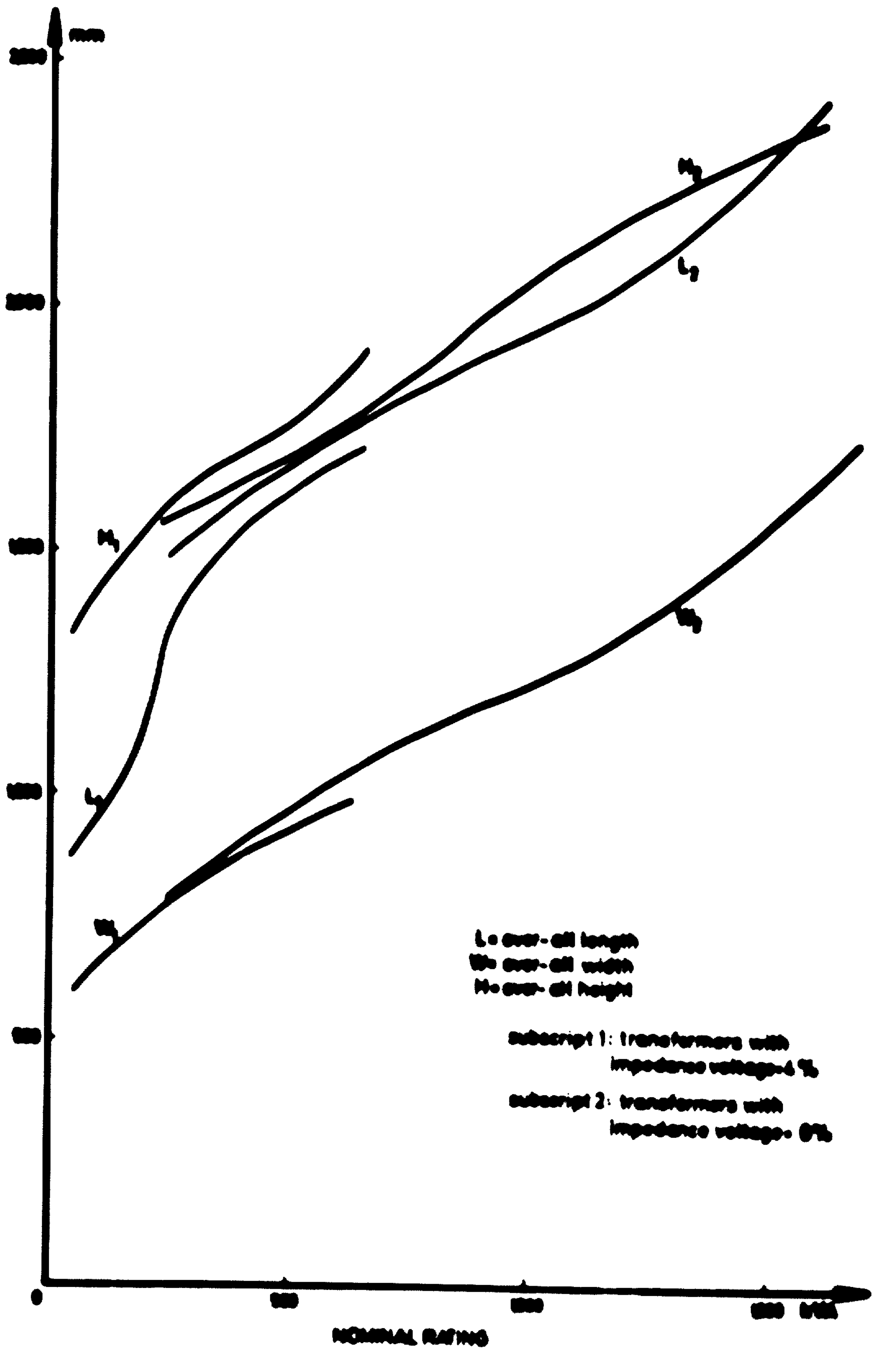


Figure 6

Length, width and height versus nominal rating, maximum primary voltage = 36 kV

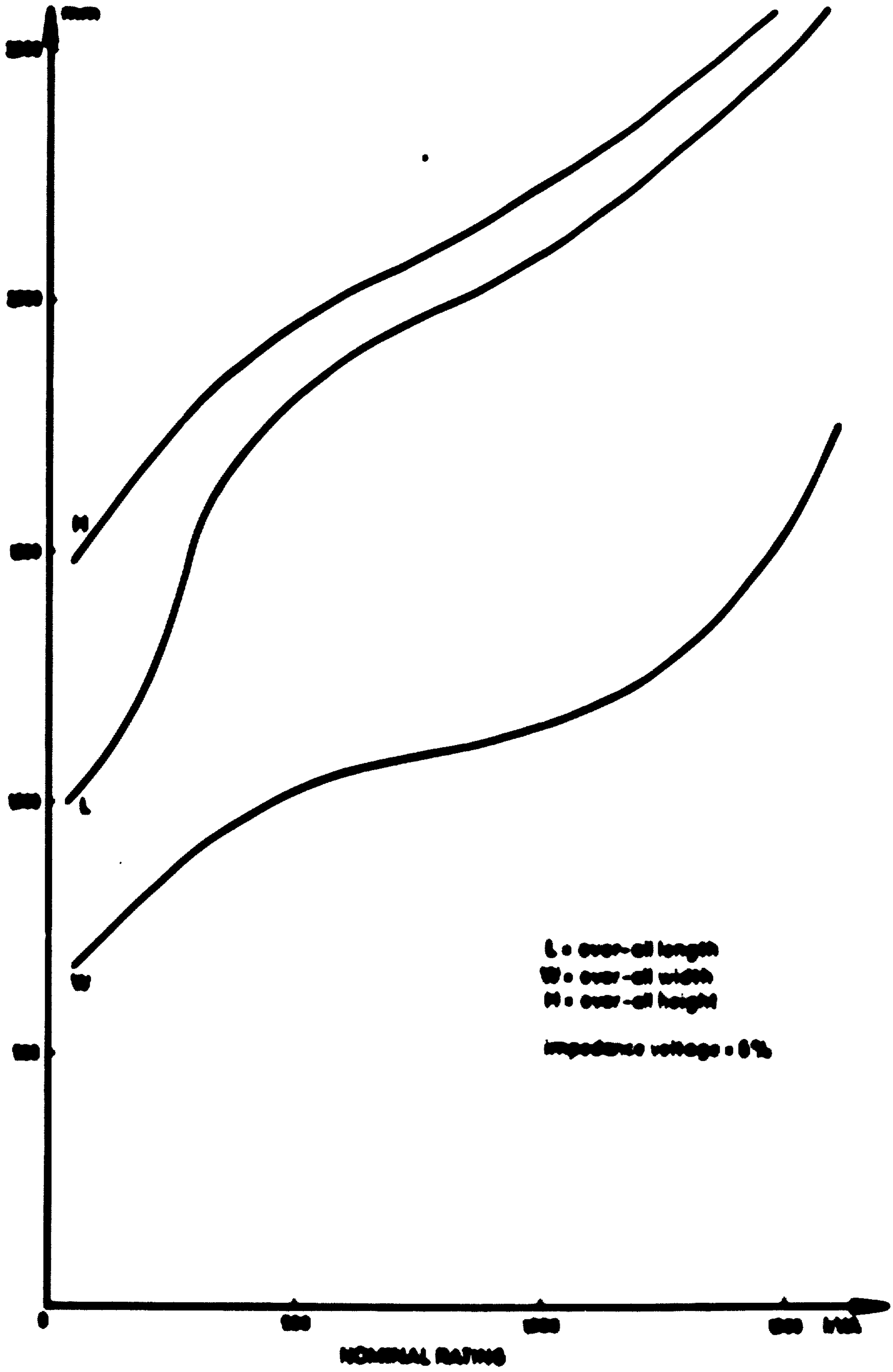
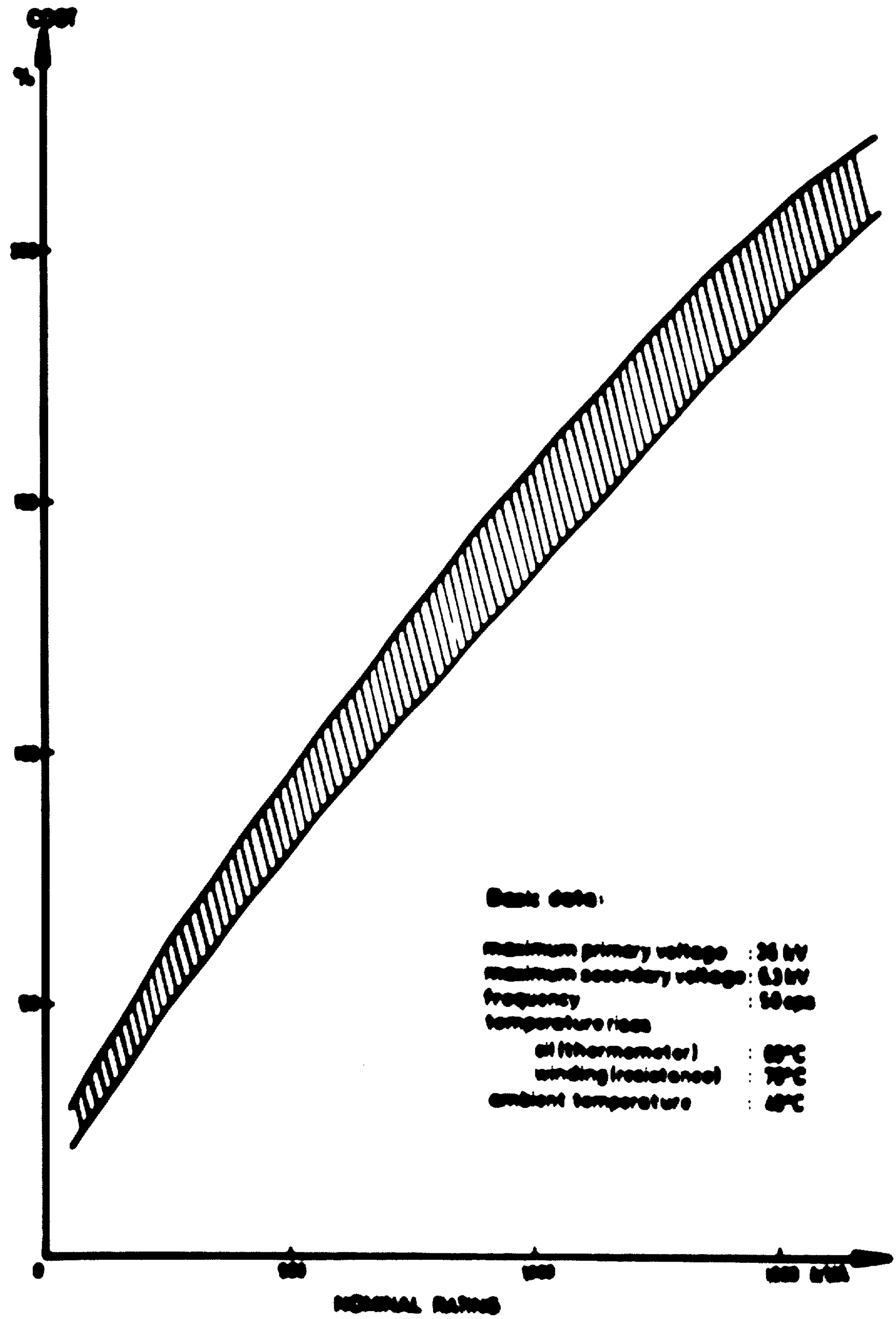


Figure 7

Capital costs versus nominal rating
(cost of 630 kVA transformer = 100%)



Annex 2

ROUGH ESTIMATE OF COSTS OF PRODUCTION EQUIPMENT

The following breakdown of costs should be considered only as a rough estimate because the costs may vary within a certain range according to the varying capacities, methods of control etc. of the machinery and equipment selected. The assumed production capacity is 100 transformers per month, completely manufactured at the domestic plant, but under licences from a well-known foreign transformer company. The cost breakdown does not include the construction of the buildings required and other civil engineering work such as roads. The items in the cost estimate are grouped in a sequence similar to that of the various workshop facilities described in section VI above.

In addition to these costs, some expenditure is necessary for design projects to supplement the manufacturing process and for special arrangements, maintenance etc. This expenditure includes the cost of installing four working areas with equipment for draughtsmen (drawing board size approximately 1,100 x 800 mm). The purchase price of this equipment is approximately $4,000.

Welding-shop equipment

Quantity	Item	Cost (dollars)
1	Oxyacetylene flame-cutting machine approx. 2,000 x 1,000 mm	3,200
2	Surface plates, 1,000 x 2,000 mm each	480
1	Cold circular saw	5,700
1	Plate shears, clearance 3,000 mm	14,000
1	Plate shears, clearance 1,500 mm	4,900
1	Profile shears	190
1	Column type drilling machine	3,900
1	Loose coiler with horizontally arranged rollers	4,200
1	Loose coiler with vertically arranged rollers (approx. 1,100 x 1,000 mm)	4,100
3	Oxyacetylene welding machines for manual operation	930
4	Electric welding machines, 25 kW each	3,960

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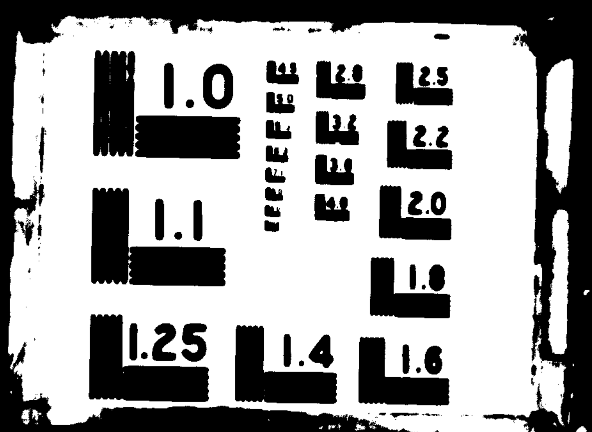

Welding-shop equipment (cont'd)

Quantity	Item	Cost (dollars)
1	Metal saw, belt-driven	3,200
3	Manual grinding machines	400
1	Sandblasting equipment	6,400
2	Welding tables	250
2	Sets of marking tools	150
	Various tools such as hammers, chisels, files, screw clamps, drills, threading tools	2,100
1	Crane installation, capacity approx. 5 tons	20,000
1	Power press, capacity 100 tons	17,000
1	Column type grinding machine	510
	Total	95,570

In addition, the following items are required if domestic production of radiators is planned:

Quantity	Item	Cost (dollars)
1	Equipment for stamping profiles	1,100
1	Equipment for stamping radiator head	400
1	Roll-welding equipment with 2 rollers	24,000
1	Roll-welding equipment with 1 roller	4,400
2	Welding tables	250
1	Container and additional equipment for pressure test	360
1	Eccentric press, capacity approx. 20 tons	1,550
2	Oxyacetylene welding machines for manual operation	620
	Total	32,680

Equipment for sheet-cutting and core assembly shop

Quantity	Item	Cost (dollars)
2	Plate shears	26,000
2	Hammer shears	4,800
1	Eccentric press, capacity approx. 20 tons	1,600
15	Pallets	50
	Total	32,450

Equipment for wire insulation and transformer-board shop

Quantity	Item	Cost (dollars)
1	Belt saw	1,150
1	Circular saw	850
1	Compass saw	1,950
1	Grinding machine with short belt drive	380

Equipment for wire insulation and t~ansformer-board shop (cont'd)

Quantity	Item	Cost (dollars)
1	Drilling machine	1,100
1	Drying furnace with recirculating air system	4,300
1	Machine for processing overlaps	2,800
1	Crank press, capacity approx. 15 tons	1,500
1	Circular shears	1,300
1	Insulating machine for round wire, 0.4 to 1.3 mm in diameter, with 4 bobbins	3,700
1	Insulating machine for round wire, 0.8 to 4 mm in diameter, with 8 bobbins	14,000
1	Insulating machine for flat copper wire, with 4 discs and 8 bobbins	6,100
1	Insulating machine for flat copper bars, with 1 disc and 3 bobbins	4,100
1	Marking table and 1 set of marking tools	160
	Various tools such as drills, cutters, scrapers	620
1	Chip exhaust system	2,200
	Total	46,210

Winding shop equipment

Quantity	Item	Cost (dollars)
8	Winding machines for flat copper wires	12,000
6	Winding machines for round copper wires	6,300
1	Round copper wire welding transformer equipment	1,000
1	Hand lever shears	450
1	Vacuum-drying furnace	6,400
	Total	26,150

Mechanical shop equipment

Quantity	Item	Cost (dollars)
1	Column type drilling machine	2,000
1	Centre lathe	5,500
1	Circular metal saw	3,100
1	Vertical milling machine	9,000
1	Bench lathe for smaller parts	3,200
1	Column type grinding machine	510
1	High-speed planing machine	4,900
2	Manual grinding machines	270
1	Spot welding machine	310
1	Eccentric press, capacity approx. 20 tons	1,550
1	Small stamping machine	1,100
1	Hard soldering installation	600
2	Oxyacetylene welding equipment for manual operation	620
5	Work benches with vices	1,000

Mechanical shop equipment (cont'd)

Quantity	Item	Cost (dollars)
	Various tools such as hand saws, files, screw-drivers, screw-spanners, chisels	2,000
5	Soldering coppers (sizes from 100 W - 1,000 W) with accessories	120
	Cylindrical gauges, controlling instruments	580
	Various instruments and tools for repair and maintenance of electrical equipment	1,000
	Total	37,360

Carpentry shop equipment

Quantity	Item	Cost (dollars)
1	Thicknessing machine for wood-working	1,300
1	Planing machine for wood-working	1,300
2	Circular saws for wood material	1,800
1	Wood-milling cutter machine	2,900
1	Column type drilling machine	1,100
1	Belt saw	1,050
	Handplanes, chisels, hammers etc.	250
1	Chip exhaust system	2,200
	Total	11,900

Assembly shop equipment

Quantity	Item	Cost (dollars)
4	Work benches with vices	800
1	Crane installation, capacity approx. 5 tons	20,000
1	Oil treatment plant	7,800
1	Vacuum furnace	10,400
2	Oil pumps, capacity approx. 120/min each	520
1	Sheet iron shears for manual operation	370
2	Vacuum pumps	2,600
	Total	42,490

Test shop equipment

Quantity	Item	Cost (dollars)
1	Testing transformer	14,000
1	Impulse generator	13,500
1	Testing generator	7,400
	Various metering instruments and instrument transformers	14,500

Test shop equipment (cont'd)

Quantity	Item		Cost (dollars)
	High-voltage switchgear with 4 panels		7,100
1	Frequency converter		6,400
1	Oil testing equipment		200
	Various cables, instrument leads and accessories		400
		Total	63,500

Equipment for finishing and despatch section

Quantity	Item		Cost (dollars)
2	Spraying cells with spray guns and exhaust equipment (1 cell for priming coat, 1 cell for finishing coat)		10,400
	Various manual tools for shipment preparation		100
		Total	10,500

Additional equipment

Quantity	Item			Cost (dollars)
1	Compressed air plant		(approx.)	2,000
1	Truck		(approx.)	8,000
1	Stacker truck		(approx.)	4,600
1	Electric general utility truck		(approx.)	3,400
		Total	(approx.)	18,000

Electrical station service equipment

Quantity	Item		Cost (dollars)
2	Transformers, approx. 250-300 kVA each, with disconnecting and circuit breakers, instrument transformers etc.		6,900
	High-voltage switchgear		6,100
	Low-voltage switchgear		5,200
		Total	18,200

Total expenditure (by major cost grouping)

Cost grouping	Cost (dollars)
Construction of working areas	4,000
Welding shop equipment (without radiator production)	95,570
Additional equipment for radiator production	32,680
Sheet-cutting and core assembly shop equipment	32,450
Wire insulation and transformer-board shop equipment	46,210
Winding shop equipment	26,150
Mechanical shop equipment	37,360
Carpentry shop equipment	11,900
Assembly shop equipment	42,490
Test shop equipment	63,500
Finishing and despatch section equipment	10,500
Additional equipment	18,000
Electrical station service equipment	18,200
Total cost (with radiator production)	**439,010**
Total cost (without radiator production)	**406,330**

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