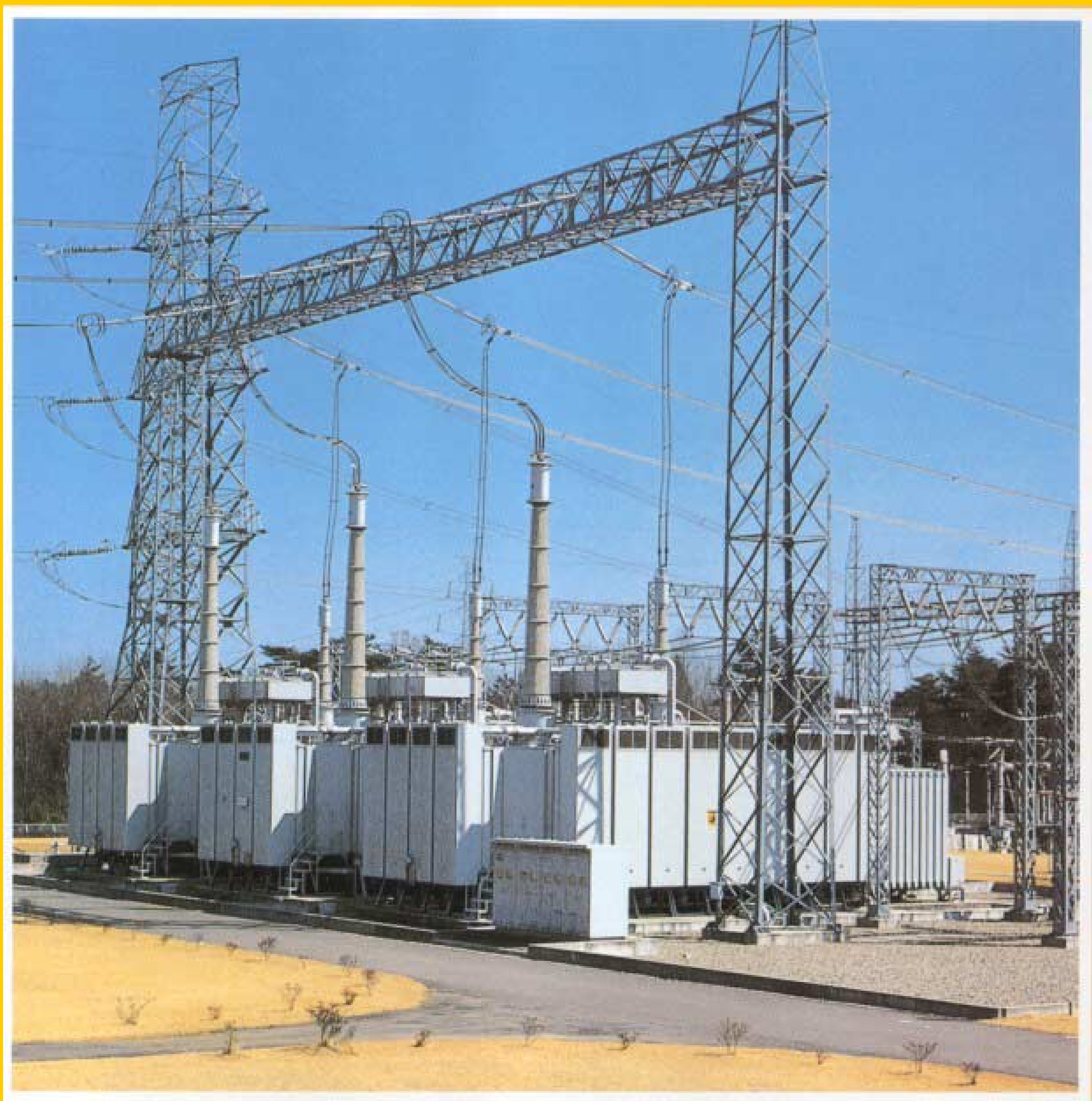
TOSHIBA

POWER TRANSFORMERS



TOSHIBA POWER TRANSFORMERS

In 1894 Toshiba started producing transformers. Since then, we have successively completed the following power transformers, each epoch-making when considering Japan's industrial level in those years.

1909	44kV, 4.5MVA Bank	Hodogaya Substation, Yokohama Electric Co., Japan
1917	110kV, 13.2MVA Bank	Inawashiro Hydroelectric Power Co., Japan
1926	154kV, 20MVA Bank	Gifu Substation, Nihon Electric Power Co., Japan
1939	220kV, 80MVA	Xu Chuna Jiang Power Station, Chang Jin Jiang Hydroelectric Power Co.,China
1952	275kV, 117MVA	Shin-Aimoto Substation, Kansai Electric Power Co., Japan
1958	275kV, 200MVA	Chiba Thermal Power Station, Tokyo Electric Power Co., Japan
1960	275kV, 300MVA	Yokosuka Thermal Power Station, Tokyo Electric Power Co., Japan
1961	330kV, 300MVA Bank	Electricity Commission of New South Wales Substation, Australia
1963	275kV, 430MVA	Owase-Mita Thermal Power Station, Chubu Electric Power Co., Japan
1967	275kV, 680MVA	Anegasaki Thermal Power Station, Tokyo Electric Power Co., Japan
1967	512.5kV, 600MVA Bank	B.C. Hydro & Power Authority Power Station, Canada
1968	525kV, 1200MVA Bank	Bonneville Power Administration Substation, U.S.A.
1971	500kV, 1000MVA Bank	Shin-Koga Substation, Tokyo Electric Power Co., Japan
1973	275kV, 1100MVA	Kashima Thermal Power Station, Tokyo Electric Power Co., Japan
1974	275kV, 450MVA	Sunen Substation, Chubu Electric Power Co., Japan
1974	525kV, 1100MVA	Sodegaura Power Station, Tokyo Electric Power Co., Japan
1977	500kV, 1500MVA Bank	Shin-Koga Substation, Tokyo Electric Power Co., Japan
1977	500kV, 680MVA	Okuyoshino Pumped Storage Power Station, Kansai Electric Power Co.,
1977	525kV, 1200MVA	Fukushima 1st Nuclear Power Station, Tokyo Electric Power Co., Japan
1982	765kV, 805.5MVA Bank	EDELCA Guri Power Station, Venezuela
1985	515kV, 1260MVA	Tsuruga 2nd Nuclear Power Station, Japan Atomic Power Co., Japan
1988	765kV, 1650MVA Bank	Furnas Foz do Iguacu Substation, Brazil

Fig. 1 515kV, 1260MVA Three-phase Transformer

Recently, with the sharp increase in demands for electric power, power transformers have grown in scale while unit capacity has shown as increasing tendency.
Especially, thermal/nuclear power plant transformers have displayed a notable tendency toward large capacity. Toshiba has successively renewed its records on unit capacity such as 200MVA in 1958, 300MVA in 1960, 430MVA in 1963, 680MVA in 1967, 1100MVA in 1973, 1200MVA in 1977. In 1985 we manufactured a world-record product of 60Hz, 515kV, 1260MVA delivered to Tsuruga 2nd Nuclear Power Station, Japan Atomic Power Co., Japan.
While substation transformers are mostly equipped with on-load tap changers, based on technical know-how under license of Maschinenfabrik Reinhausen GmbH, Germany, Toshiba developed a resistance-type on-load tap changer, which was promptly standardized to ensure high reliability. A large number of transformers providing on-load tap changers up to 800 VIVA are being produced, and many auto-transformers up to 765 kV-1650 MVA bank are being manufactured by Toshiba.
Recently, transformers connected to gas-insulated switchgear (GIS) are being broadened in application.
As to all voltage classes no larger than 500kV, Toshiba established a G IS connection technique, resulting in the successful manufacture and delivery of 500kV, GIS direct-coupled transformers. Transformers for pumped-storage power stations and underground substations are subject to strict restrictions on transport dimensions and weight. Through adopting an innovative method of dividing components to facilitate transportation and assembly technique, Toshiba manufactured and delivered three-section type 275kV, 300MVA transformers to underground substations, 345kV, 300MVA transformer to pumped-storage power station and a nine-section type 500kV, 680MVA transformer to an underground power station, whose equivalent cannot be seen in any part of the world.
By initiating research on 500kV transformers early in 1955, and through exerting efforts subsequently several times in related research and development activities, in 1967 Toshiba successfully completed and delivered a 500kV transformer to the B.C. Hydro & Power Authority, Canada. This was the first practical model ever built in Japan for an ultra high-voltage power transformer. Further, in 1971, 500/275kV-1000MVA auto-transformer-banks were completed as the first 500kV transformer product to be delivered for domestic use. In 1977, Toshiba also delivered 1500MVA-bank autotransformers.
In 1988, 765/525kV1650MVA auto-transformer-banks were delivered to Brazil as the first 765kV autotransformer product.
Supported by such technology, Toshiba successively manufactured and delivered the aforementioned gigantic thermal, nuclear power station transformers and hydroelectric power station transformers which requires the difficult transportation with strict transport restrictions.
Regarding transformers of the 500kV and above, Toshiba boasts one of the world's largest supply record, having exceeded 120,OOOMVA in total capacity of supplied transformers (330 units).


Fig. 2 500kV 1500MVA Auto-transformer Bank

Features

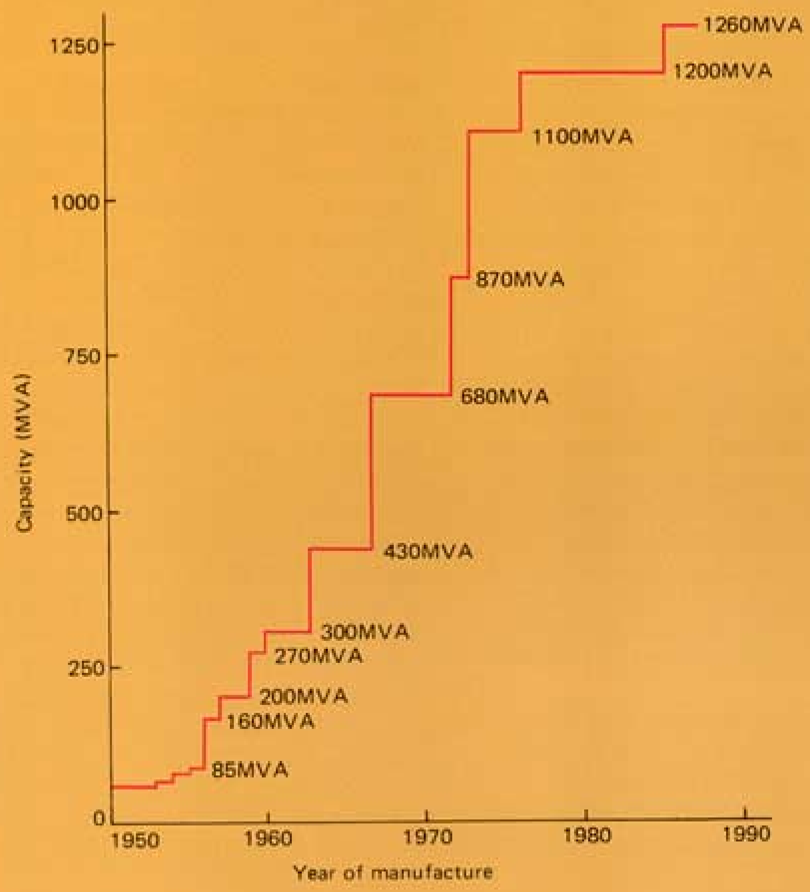


Fig. 3 Changes in Capacity of Thermal and Nuclear Power Station Transformers Produced by Toshiba

- High Reliability
- Core Structure Offers Splendid Characteristics
- Advanced Winding Application
- Perfect Drying Process
- Sufficient Mechanical Strength against Short-circuiting
- Highly Efficient Cooling
- Perfect Measure against Leakage Flux
- Adequate Oil-leakage Preventive Structure
- Simplified Installation Work

The high reliability of Toshiba products is widely recognized by users in Japan and abroad. It is backed up by an accumulation of technology, which has been carefully achieved by adding new technologies to conventional technologies, the ability to design capable transformers, an excellent working environments and facilities, and thorough use of inspection and testing system.

Adopting of a miter-joint core, in which the characteristics of grain-oriented silicon steel are fully utilized, displays with Toshiba transformers less no-load loss and no-load current, as well as low noise.

Toshiba adopts the disk windings with optimum insulation design based on the voltage oscillation analysis by computer in high voltage winding. The windings are manufactured by highly skilled workers in a dust-proofed room.

Toshiba transformers are of the core type, in which the core-and-coil assembly is independent of the tank, so that the core-and-coil assembly can be completely dried through our unique vapor phase drying method. Toshiba transformers offer excellent insulation, and are free from shrinkage caused by aging.

Efforts are now being exerted to ensure sufficient short-circuit strength by maintaining a balance of ampere-turns between windings, determining materials to be used on the basis of mechanical force calculated by computers, and exercising adequate care in the pretreatment fastened by applying pressure with a hydraulic jack on a thick annular insulating plate set on the top thereof. Further more, a perfectly dried, precompressed, pressboard is used, so that the winding is provided with adequate strength to withstand short-circuit mechanical force.

Forced-cooling is used on the winding and inside the core, with oil kept circulating through its interior in order to achieve a large cooling effect. Since the windings are effective in voltage distribution, the winding conductors are uniformly insulated, and no reinforcement of insulation is necessary. Because of this favorable voltage distribution, the rise of temperature is uniform.

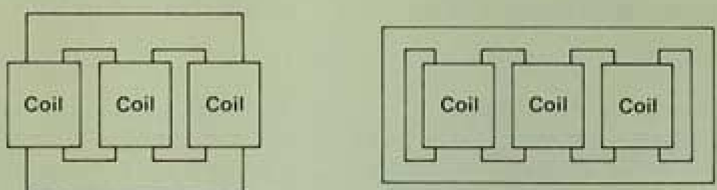
In a large-capacity, high-impedance transformer, probable leakage flux is calculated by computers on each part so that a magnetic shield, corresponding to the result of each calculation, is provided on the inner surface of the tank and the clamp surface opposite of the coil, to prevent a large amount of leakage flux. Slits are provided on core-leg clamping plates and so on, in order to reduce stray loss as a prevention against local overheating. Further more, nonmagnetic steel is used as necessary in large-current bushing pockets and parts, in the vicinity of large-current lead.

The tank is of all-welded construction in which there is no possibility of oil leakage. Nitrile rubber gaskets, excellent in oil resistance and weather resistance, are used in such openings as manholes and accessory mounting parts.

Since the transformer is transported with its core-and-coil assembly kept in the factory-assembled stage, high reliability is maintained and installation in the field is simplified. Further more, by utilizing its advantage of being a built-in type, it is a standard practice to transport the on-load tap changer as assembled in the main tank.

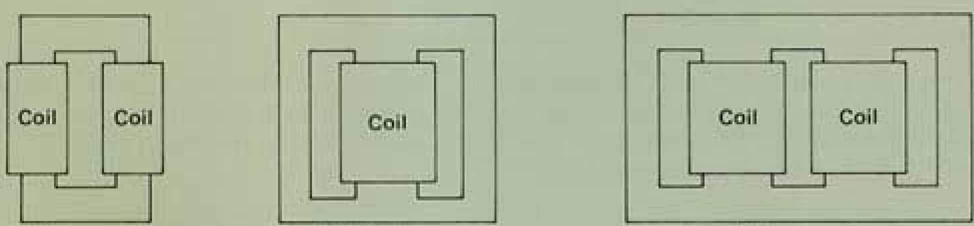
Core

Three-phase transformers usually employ three-leg core. Where transformers to be transported by rail are large capacity, five-leg core is used to curtail them to within the height limitation for transport.
Even among thermal/nuclear power station transformers, which are usually transported by ship and freed from restrictions on in-land transport, gigantic transformers of the 1000MVA class employ five-leg core to prevent leakage flux, minimize vibration, increase tank strength, and effectively use space inside the tank.
Regarding single-phase transformers, two-leg core is well known. Practically, however, three-leg core is used; four-leg core and five-leg core are used in large-capacity transformers. The sectional areas of the yoke and side leg are 50% of that of the main leg; thus, the core height can be reduced to a large extent compared with the two-leg core.
For core material, high-grade, grain-oriented silicon steel strip is used.
The steel strip surface is subjected to inorganic insulation treatment. All cores employ miter-joint core construction. Yokes are jointed at an angle of 45 − to utilize the magnetic flux directional characteristic of steel strip.
A computer-controlled automatic machine cuts grain-oriented silicon steel strip with high accuracy and free of burrs, so that magnetic characteristics of the grain-oriented silicon steel remains unimpaired. (Fig. 6)
Silicon steel strips are stacked in a circle-section. Each core leg is fitted with tie plates on its front and rear side, with resin-impregnated glass tape wound around the outer circumference. Sturdy clamps applied to front and rear side of the upper and lower yokes are bound together with glass tape.
And then, the resin undergoes heating for hardening to tighten the band so that the core is evenly clamped (Fig. 7).
Also, upper and lower clamps are connected by a core leg tie plate; fore and hind clamps by connecting bars. As a result, the core is so constructed that the actual silicon strip is held in a sturdy frame consisting of clamps and tie plates, which resists both mechanical force during hoisting the core-and-coil assembly and short circuits, keeping the silicon steel strip protected from such force.
I n large-capacity transformers, which are likely to invite increased leakage flux, nonmagnetic steel is used or slits are provided in steel members to reduce the width for preventing stray loss from increasing on metal parts used to clamp the core and for preventing local overheat. The core interior is provided with many cooling oil ducts parallel to the lamination to which a part of the oil flow forced by an oil pump is introduced to achieve forced cooling.
When erecting a core after assembling, a special device shown in Fig. 8 is used so that no strain due to bending or slip is produced on the silicon steel plate.



(a) 3-leg core (b) 5-leg core

Fig. 4 Three-phase Transformer Cores



(a) 2-leg core (b) 3-leg core (c) 4-leg core

Fig. 5 Single-phase Transformer Cores

Fig.6 Computer-controlled Core Lamination Line

Fig.7 Bind-type Core

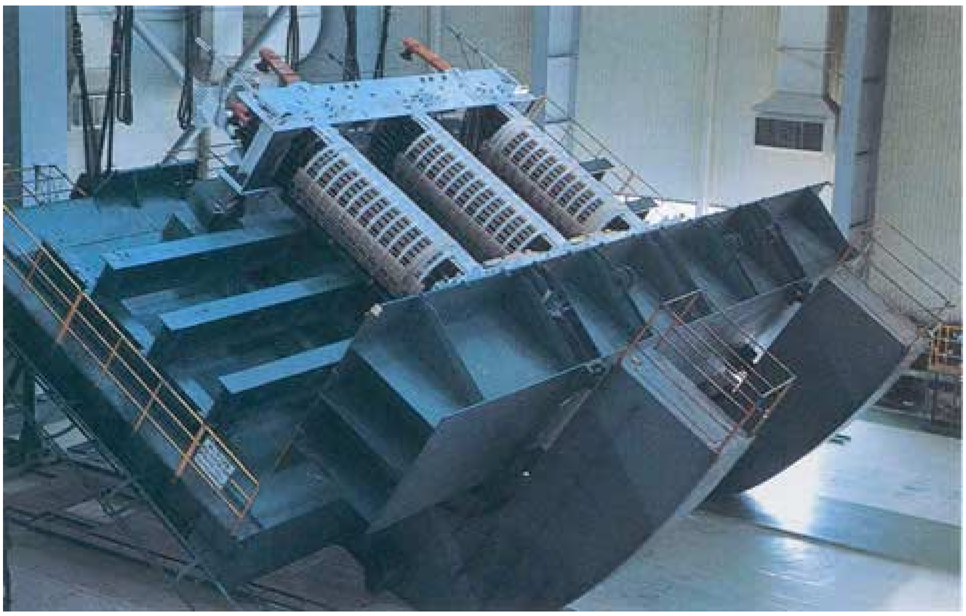


Fig.8 Core Erecting Cradle

Winding

Various windings are used as shown below. According to the purpose of use, the optimum winding is selected so as to utilize their individual features.

Hisercap Disk Winding (Interleaved disk winding)

In hisercap disk winding, electrically isolated turns are brought in contact with each other as shown in Fig. 9.
Thus, this type of winding is also termed "interleaved disk winding." Since conductors 1 - 4 and conductors 9 - 12 assume a shape similar to a wound capacitor, it is known that these conductors have very large capacitance.

This capacitance acts as series capacitance of the winding to highly improve the voltage distribution for surge.
Unlike cylindrical windings, hisercap disk winding requires no shield on the winding outermost side, resulting in smaller coil outside diameter and thus reducing transformer dimension.
Comparatively small in winding width and large in space between windings, the construction of this type of winding is appropriate for the winding, which faces to an inner winding of relatively high voltage. Thus, general EHV or UHV substation transformers employ hisercap disk winding to utilize its features mentioned above.

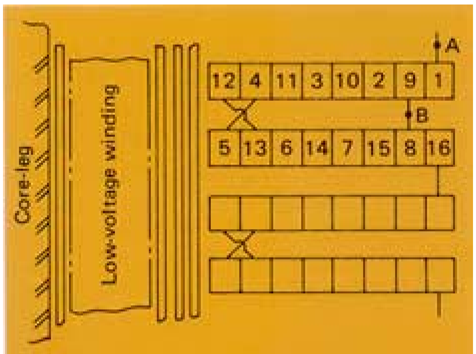


Fig. 9 Hisercap Disk Winding (Conductor Arrangement Diagram)

Continuous Disk Winding

This is the most general type applicable to windings of a wide range of voltage and current (Fig.10). This type is applied to windings ranging from BI L of 350kV to BI L of 1550kV.
Rectangular wire is used where current is relatively small, while transposed cable is applied to large current. When voltage is relatively low, a transformer of 100MVA or more capacity handles a large current exceeding 1000A. In this case, the advantage of transposed cable may be fully utilized.
Further, since the number of turns is reduced, even conventional continuous disk construction is satisfactory in voltage distribution, thereby ensuring adequate dielectric characteristics. Also, whenever necessary, potential distribution is improved by inserting a shield between turns.

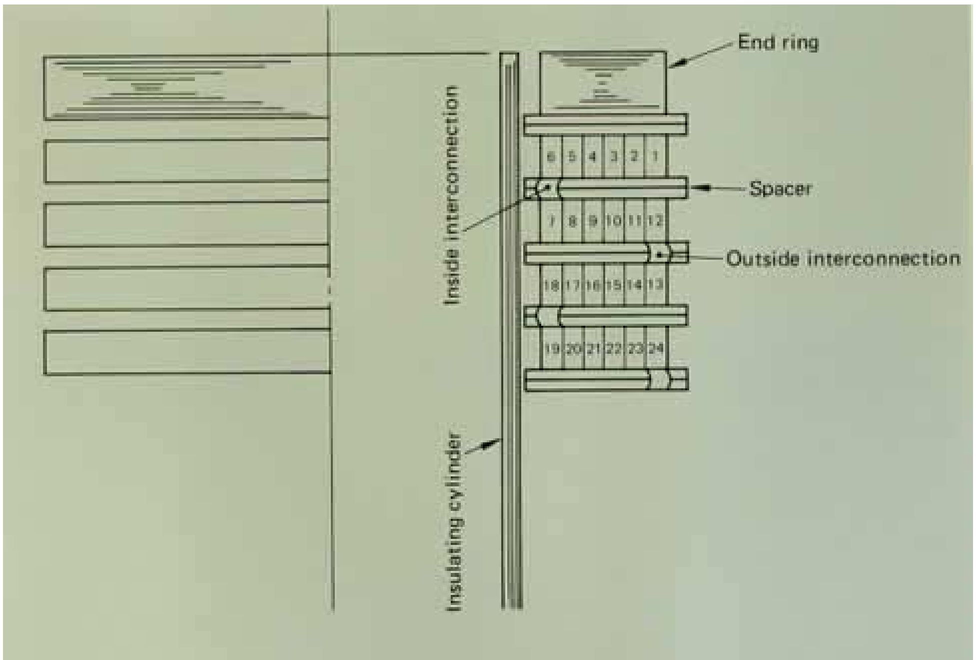


Fig. 10 Continuous Disk Winding

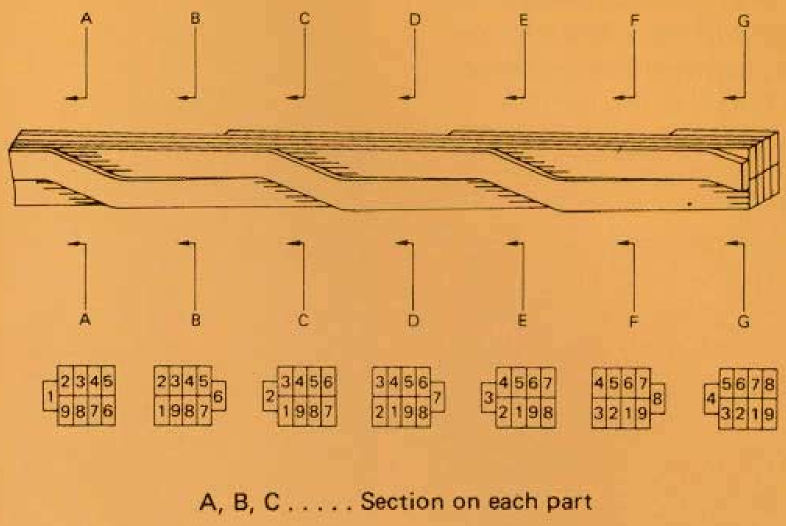


Fig. 11 Transposed Cable Construction Diagram

Helical Coil

For windings of low voltage (20kV or below) and large current, a helical coil is used which consists of a large number of parallel conductors piled in the radial direction and wound. Adequate transposition is necessary to equalize the share of current among these parallel conductors.
Figure 12 illustrates the transposing procedure for double helical coil. Each conductor is transposed at intervals of a fixed number of turns in the order shown in the figure, and as a result the location of each conductor opposed to the high voltage winding is equalized from the view point of magnetic field between the start and the end of winding turn.

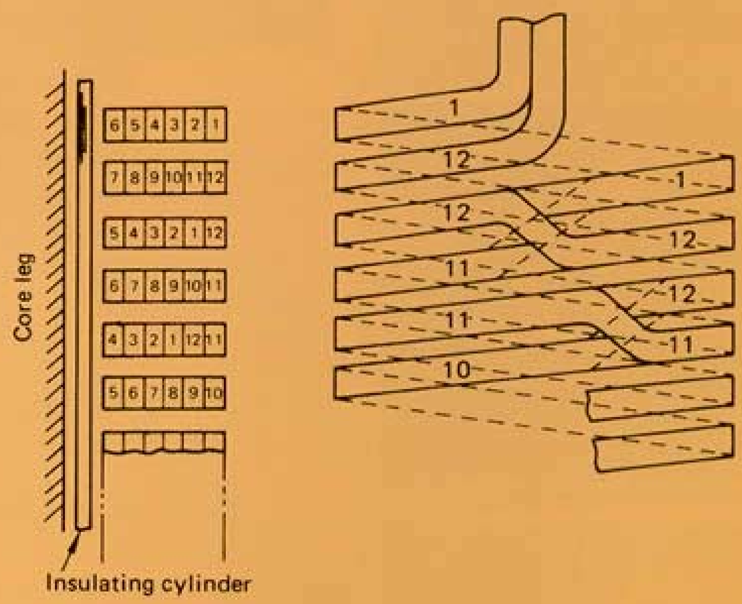


Fig. 12 Double Helical Coil (Hobert Helical Coil)

Insulation Structure

On parts where the electric field is liable to be concentrated, such as the winding ends of disk windings, detailed electric field analysis by computer determines the optimum shield shape and the insulation distance so that the surrounding oil is kept free from excessive electric stress (Fig. 13).
Further, spaces between windings close to a uniform field employ a barrier insulation structure in which an oil gap is formed by pressboard (Fig. 14), so that partial discharge characteristics and dielectric strength are improved through an adequate barrier arrangement, resulting in stabilized insulating performance. The windings are clamped according to the following steps.
When the annular, thick insulating plate placed on the coil top has been clamped by a hydraulic jack, insulator wedges and blocks are inserted between the insulating plate and the underside of the upper yoke and clamp, so that each coil is clamped uniformly and completely.
Regarding pressboard to be used for spacers and duct pieces on the coil, precompressed pressboard is used. Coils maintaining adequate short-circuit strength for many years and free from shrinkage through aging have been realized through uniformly, completely clamped construction and insulating materials excellent in compressive characteristics combined with adequate drying.
Further, all insulating materials used for clamping these coils are oil impregnable and the optimum type for applications under high electric fields.
The connective parts of coil leads are likely to invite electric field concentration as a result of the edges of terminals and clamping bolts. To alleviate stress concerntration, each connection is wound with aluminum-foil-laminated crepe paper into a streamlined shape and completely covered with insulating paper.

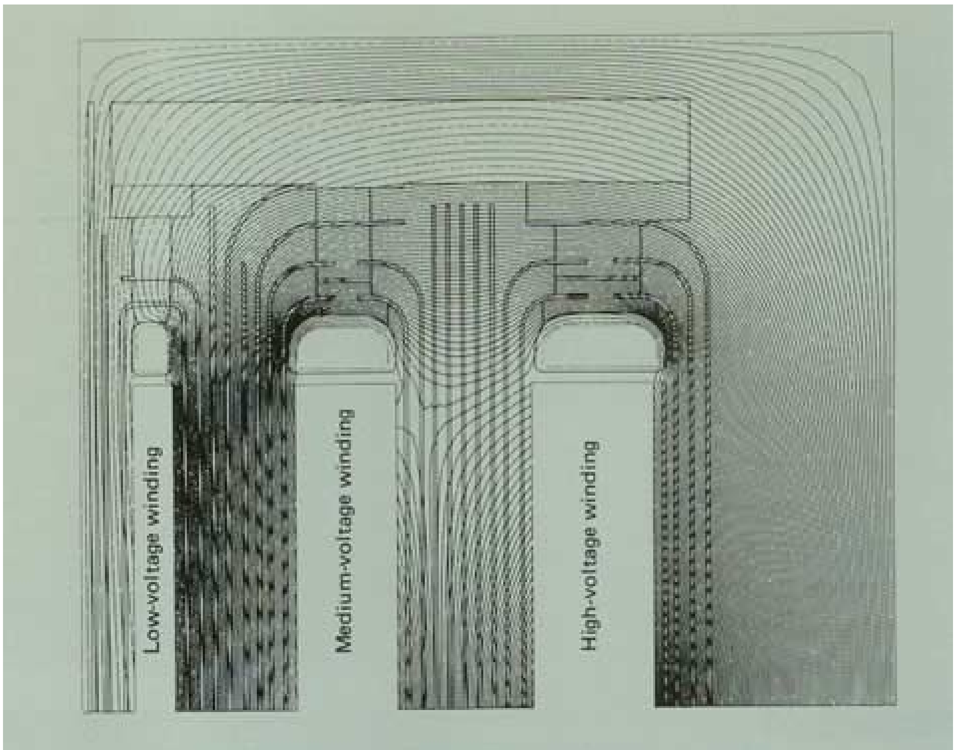


Fig. 13 Example of Electric Field Analysis by a Computer

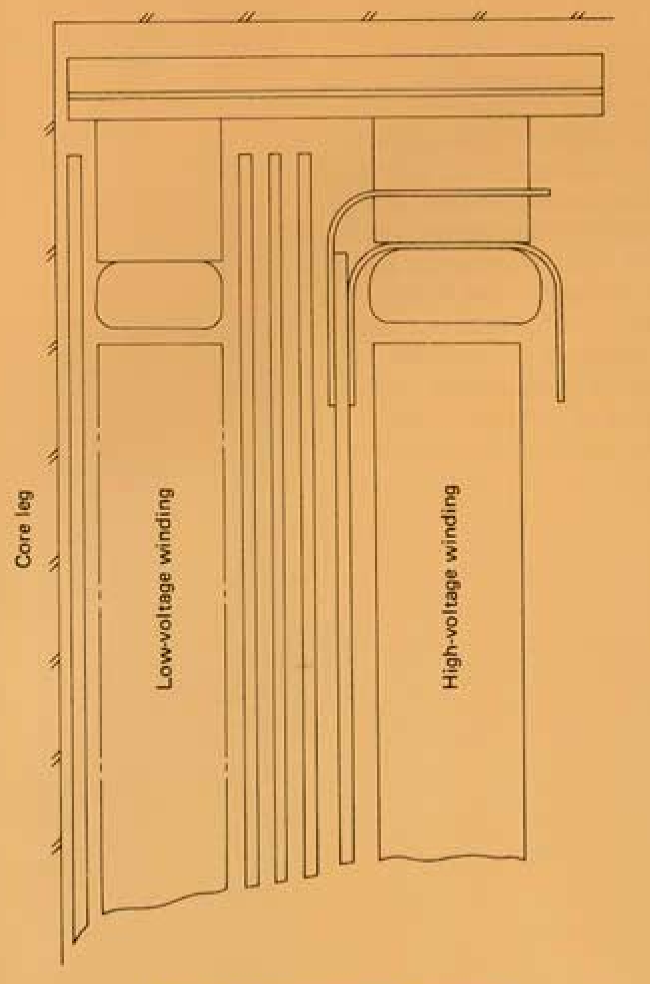


Fig. 14 Barrier Insulation Structure

Prevention of Internal Partial Discharge and Insulation Treatment

In the case of transformers specified with several reduced-insulation levels, such as EHV or UHV transformers, the ratio between testing voltage and operating voltage is small. To ensure high reliability in extended operation under high voltage, thorough quality control must be effected to prevent dangerous partial discharge. Main causes of partial discharge include:

- Incompletely dried insulations
- Voids in insulations
- Electrically floating metals and incomplete contact under electric field of high intensity
- Edged electrodes
- Concentrated electric stress applied to oil gap
- Intermixed foreign matter or dust

To eliminate these causes, the following measures are taken in the process of design and manufacture; to confirm reliability, a partial discharge test is conducted at the final stage.

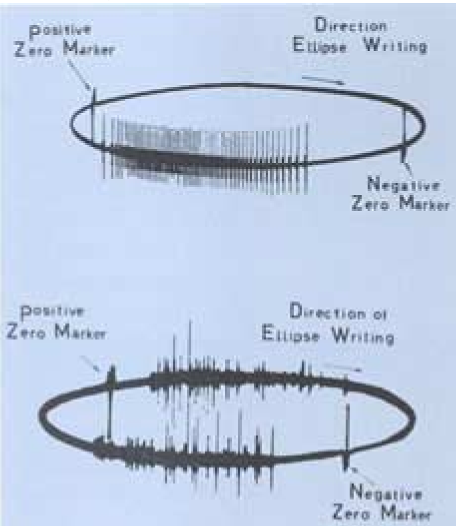


Fig. 15 Wave Form of Partial Discharge

Drying/Oil Filling Treatment

I n the core-type transformer, the core-and-coil assembly is independent of the tank, so that the assembly is allowed to completely dry. When drying the core-and-coil assembly, Toshiba's innovative vapor phase drying method is used, in which special oil vapor is sprayed on the assembly to utilize latent heat produced when the oil vapor condenses.
Since heating is effected deep inside evenly and quickly, the assembly can be completely dried without causing damage to the insulations.
Upon completion of drying, the coil is clamped in a low-humidity room adjusted to 5% or below relative humidity to prevent any reabsorption of humidity (Fig. 17).
When a core-and-coil assembly has been installed in a tank, the tank is evacuated to a high vacuum state to remove reabsorbed humidity on the insulations surface and voids in impregnated insulation; then deaerated oil is filled under the high vacuum.
Upon completion of a factory test, the transformer is transported to the site (with its accessories disassembled and packed as required) for installation and assembly. During installation and assembly at site, adequate care is taken to dehydration and the prevention of water absorption as in the case of factory

Removing Voids

Voids in impregnated insulation such as paper and pressboard can be completely removed by oil filling under a vacuum. Depending on the glue material and the using method, there is a possibility of creating voids inside. Thus, oil-impregnable glue is used and due care is exercised to avoid using excessive glue.

Electric Field Control

Insulation between high- and low voltage windings, between windings and the tank/core, and between coil layers depends mainly on the oil impregnated paper and oil gaps. Unless voids are created in layers of insulation paper, partial discharge occurs first on oil gaps. The electrode shape and insulation dimensions must be carefully selected to keep the oil free from excessive stress.
The electric field tends to concentrate on the small shaped lead wires from coils and lead wire connections, edges of terminals and clamping bolts, and metal structures such as cores, clamps, and the tank which are facing these high-voltage electrodes.
As to parts liable to invite electric field concentration, detailed electric field analysis is conducted by computer to determine the optimum electrode shape, insulation construction, and insulation dimensions to ensure careful control of the electric field.

Dust Control

The penetration of all sorts of dust and foreign matter, as well as metallic particles, is unfavorable to transformers; such matter incurs partial discharge. To avoid this penetration, the transformer core-and-coil is assembled in a dust-controlled dust-proofed room; winding operations are performed in a double-ceiling room -a dust-proofed room provided with an additional ceiling (Fig. 16).
Dust is further controlled by coating metal structures of the core-and-coil assembly and the tank interior with white paint; should dust or foreign matter penetrate from the exterior, it can be readily detected.

Fig.16 Dust-proofed Workshop

Fig.17 Vapor-phase Drying Oven

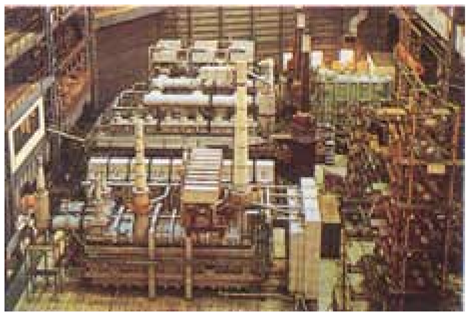


Fig.18 Transformer Final Testing

Measures against Leakage Flux

With the increase in transformer capacity, the leakage flux also rises, so that stray loss is increased or local overheat is caused. For large-capacity transformers, it becomes very important from the standpoint of improved reliability to thoroughly comprehend leakage flux and to take measures to minimize stray loss.
At Toshiba, careful measures against leakage flux are taken on the basis of the results of computer-aided analysis on leakage flux distribution and eddy current loss on each part of the transformer, fully utilizing our rich experience in producing a huge number of large-capacity transformers.
As to eddy current loss in coil conductors, the loss of each coil part is determined from leakage flux distribution. Transposed cable and various types of transposition are applied in accordance with results of the above-mentioned loss analysis to prevent local overheat from being caused by excessive loss.
Generally made of mild steel, tanks and other structural members are high in permeability and liable to invite leakage flux concentration.
Thus, the tank inner surface is provided with a shield made of conductor plate such as aluminum or a laminated shield made of silicon steel strips to prevent leakage flux from penetrating the tank, thus reducing a large eddy current loss created on steel members.
As to other structural members, efforts are exerted to prevent local overheat or excessive deterioration of adjacent insulation from being caused by eddy current loss, while employing nonmagnetic materials in accordance with leakage flux on each part, providing slits in steel members to narrow the width as described in the section on "Core " and adopting other measures appropriate for respective parts.

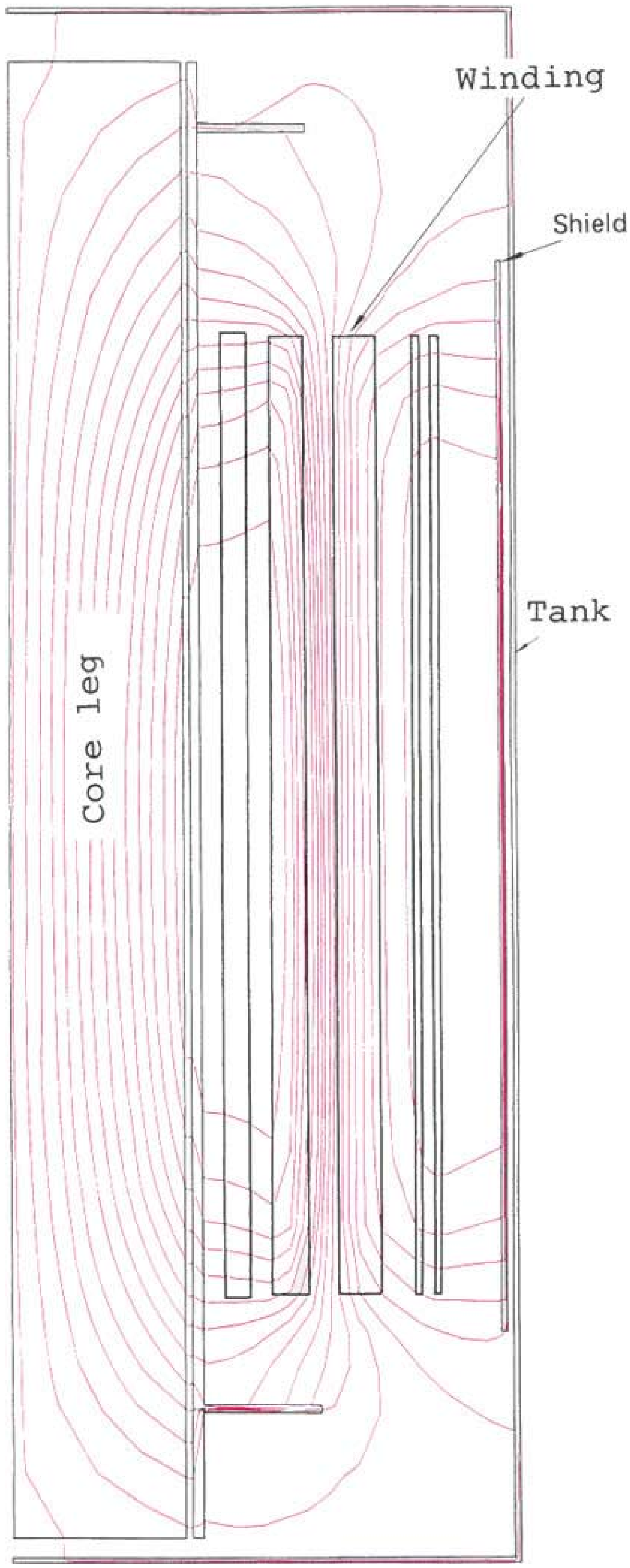


Fig.19 Example of Leakage Flux Distribution Analysis by a Computer

Tank

The tank is manufactured by forming and welding steel plate to be used as a container for holding the core and coil assembly together with insulating oil. The Toshiba transformer tank offers the following features:

- Subjected to automatic beam welding machine (Fig. 20) and other special facilities, the tank possesses high quality and strength.
- Transformers to be transported by ship are structured in a semioval shape on both ends of the tank and provided with reinforcement members rationally arranged, resulting in increased strength and decreased weight.
- The tank bottom is fitted with a skid base by welding and provided with pull lugs to facilitate rolling in the longitudinal and transverse directions.
- Capable of withstanding a high vacuum of 0.1 torr or below, the tank can be filled with oil under a vacuum; to thoroughly remove gases and moisture from the insulation.
- The tank is of completely enclosed, welded construction.
  Oilproof nitrile rubber gaskets are used on those parts which must be removed from the standpoint of assembly in the field or during maintenance; flanges thereon are provided with accurately machined grooves or gasket retainers to ensure proper tightening of gaskets. Consequently, there is no possibility of oil leakage over an extended period (Fig. 21, 22).
- The tank internal surface and the metallic part of the core-and-coil assembly are coated with white paint to help observe dust accumulation.

Fig.20 Automatic beam welding machine

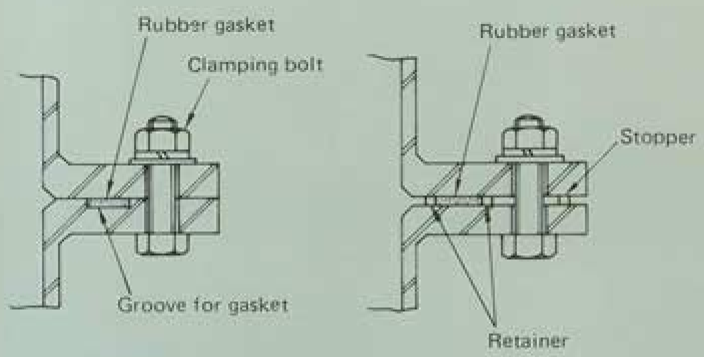


Fig. 21 Oiltight Flange Construction

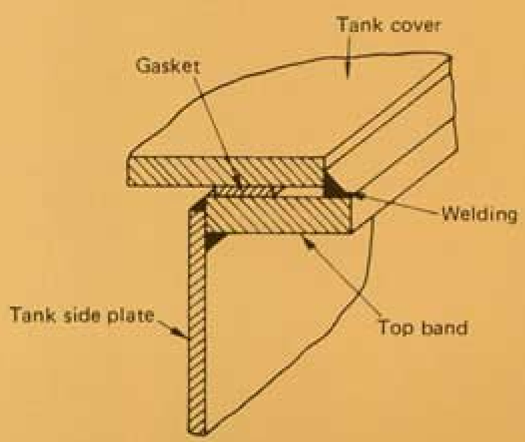


Fig. 22 Welded Oiltight Construction

Cooling System

Self-cooled Type

Panel type radiators are mounted on the tank.
Since any cooling fans and oil pumps are not used, this type is widely applied owing to its facilitated maintenance, Panel type radiators have features of decreasing oil volume and withstanding a vacuum (Fig. 23).

Air-cooled-air-cooled

Cooling fans are installed on the radiators to increase the cooling effect. Usually, the cooling fans will be put into service when natural cooling becomes inadequate to maintain the oil and/or winding temperature within the specified limit under a heavy load (Fig. 24).

Forced-oil, Forced-air-cooled Type

This is a system in which unit coolers, each consisting of a cooling tube, fan, oil-submerged pump, and oil flow indicator assembled as a unit, are arranged around the tank in the necessary amount. Steel pipe fitted with fins and dipped in zinc, with an excellent corrosionproof characteristics, is adopted as cooling pipe.
In the tank cooled oil is delivered to the windings and ducts on the core, so that each part is cooled uniformly and effectively (Fig. 25).
In some cases, a cooling device consisting of a combination of oil-submerged pumps and radiators with cooling fans is used as a cooling device for multirating of a forced-oil, forced-aircooled/forced-aircooled/self-cooled transformer (Fig. 26).

Forced-oil, Water-cooled Type

In case that a large amount of cooling air is unavailable such as in underground substations, water cooled type is applied. The oil circulates through the casing outside the water tubes, and the water circulates through the water to be.
Where the cooling water pressure is maintained at a higher level than oil pressure, a double-tube-type cooler is applied (Fig. 27).

Table 1 Standard design of cooling system

Cooling System	Capacity	Cooling equipment
Self-cooling type (ONAN)	30,000kVA or below	Panel-type radiators
Forced-air-cooled type (ONAF)	30,000kVA~150.000kVA	Panel-type radiators and cooling fans
Forced-oil, forced-air-cooled type (OFAF)	150,000kVA or more	Unit cooler or panel-type radiator, and Installation of cooling fans and pumps

In addition to the above, a forced-oil, water-cooled type (OFWF) and forced-oil, self-cooled type (OFAN) are available.

Fig.23 Self-cooled type Transformer

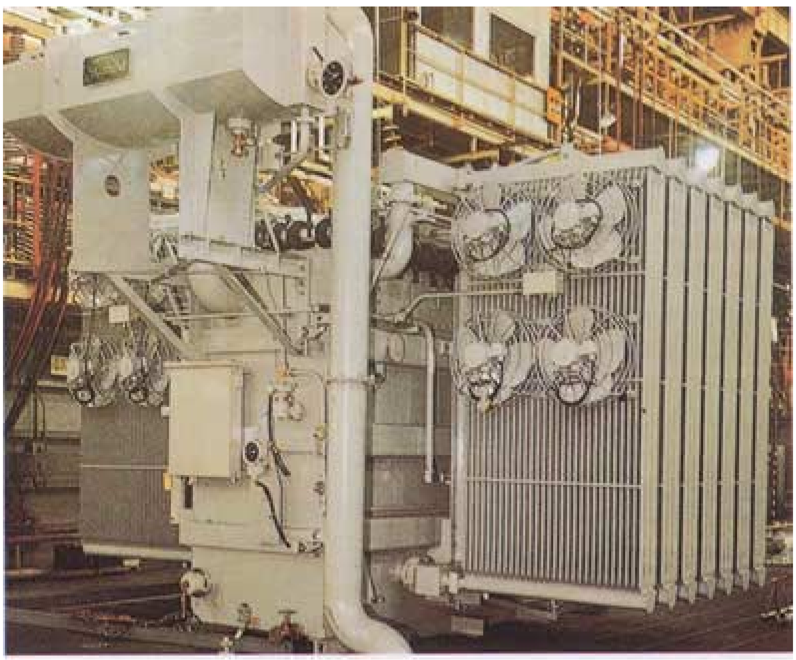


Fig.24 Forced-air-cooled type Transformer

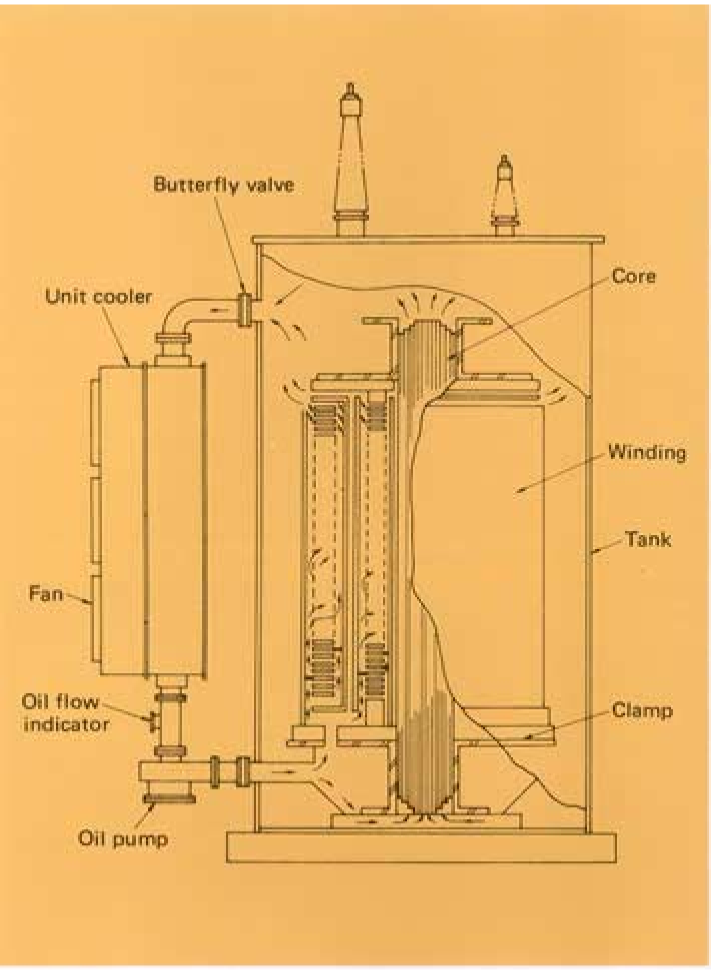


Fig.25 Forced-oil, Forced-air-cooled type Construction

Fig.26 345kV-75MVA Forced-oil, Forced-air-cooled type Transformer

Accessories

Oil Preservation System

Oil conservator type, nitrogen-enclosed type, and diaphragm type (Type OH-D), are employed for the oil preservation system.

Diaphragm-type Oil Preservation System (Type OH-D)

The oil preservation system Type OH-D is provided with a synthetic rubber air cell stretched over the oil surface in the conservator to completely isolate the insulating oil from outside air. This is most suitable for high-voltage, large-capacity transformers (Fig. 28).
Since air in the air cell is connected to the open atmosphere through a dehydrating breather, the air cell shape varies according to expansion and contraction of the oil, keeping pressure in the air cell at the atmospheric pressure.
Diaphragm-type oil preservation system Type OH-D offers the following features:

- Oil can be filled into the transformer tank without being exposed to the air.
- Since insulating oil is completely isolated from the atmosphere by an air cell, there is no possibility of oxygen or moisture penetrating the oil.
- Pressure on the surface of the oil is constantly maintained at the atmospheric pressure, offering no possibility of the oil becoming supersaturated and forming bubbles; thus, high dielectric strength can be maintained.
- No need to refill nitrogen gas or measure the gas purity simplifies maintenance.
- No need of attachments to be separately installed results in less floor area.
- The air cell is made of nitrile rubber reinforced with nylon cloth, ensuring splendid oil-proofing and high strength.

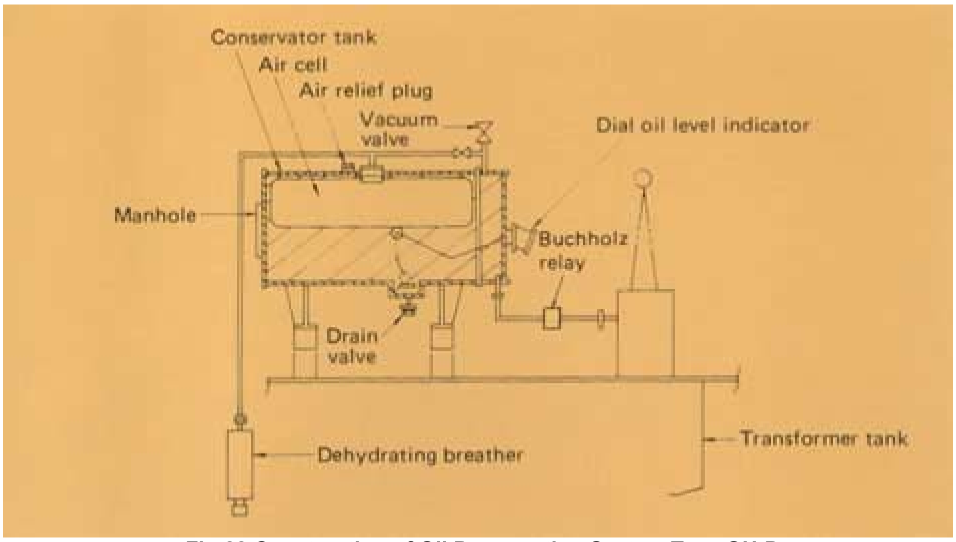


Fig.28 Construction of Oil Preservation System Type OH-D

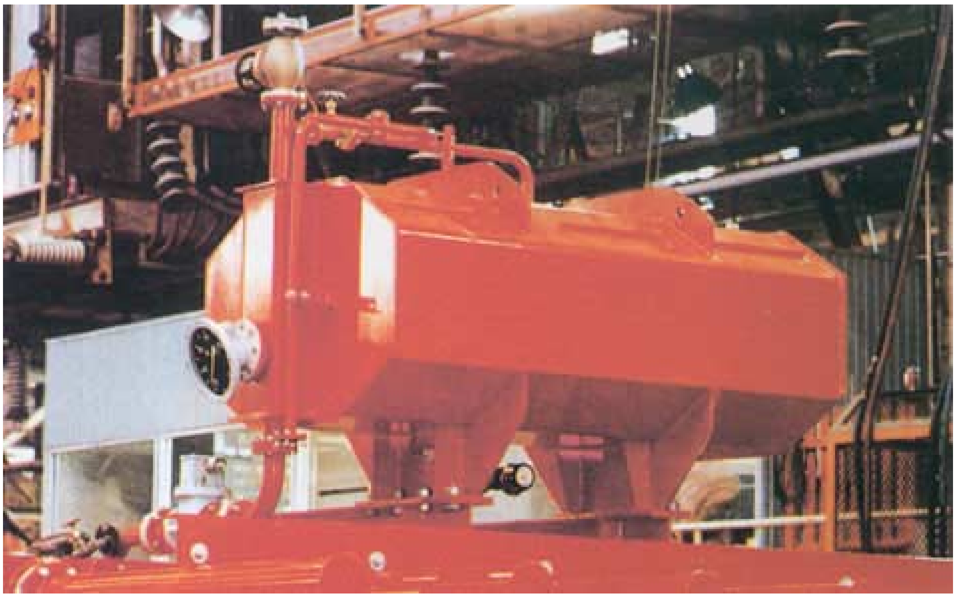


Fig.29 Oil Preservation System Type OH-D

Fig.30 Dehydrating Breather

Dehydrating Breather (Types FG, FP, FS)

Air in the air cell of conservator Type OH-D is exposed to the open atmosphere through a dehydrating breather to prevent dew condensation.
Regarding moisture absorbent, a granular type free from deliquescence is used.
To display the extent of moisture absorption of the moisture absorbent, it is also mixed the kind of moisture absorbent which is blue color under a dry state and changes to pink as moisture absorption progresses. When no breathing is conducted, the breather is isolated from the open air by oil to prevent the moisture absorbent from needlessly absorbing moisture (Fig. 30).

Dial Oil Level Indicator

For indicating on the dial a change of oil in the conservator, the indicator is tilted downward to permit easy supervision of the oil level even if it is installed at a high level. Any change in the oil level is detected by a float, converted into rotary motion by a gear, and transmitted to the external pointer through a magnet. The float side is completely isolated from the pointer side by a partition through which the rotary shaft does not pass, preventing oil leakage. The pointer side is of airtight construction with moisture absorbent contained therein to prevent the glass inner side from clouding (Fig. 31).

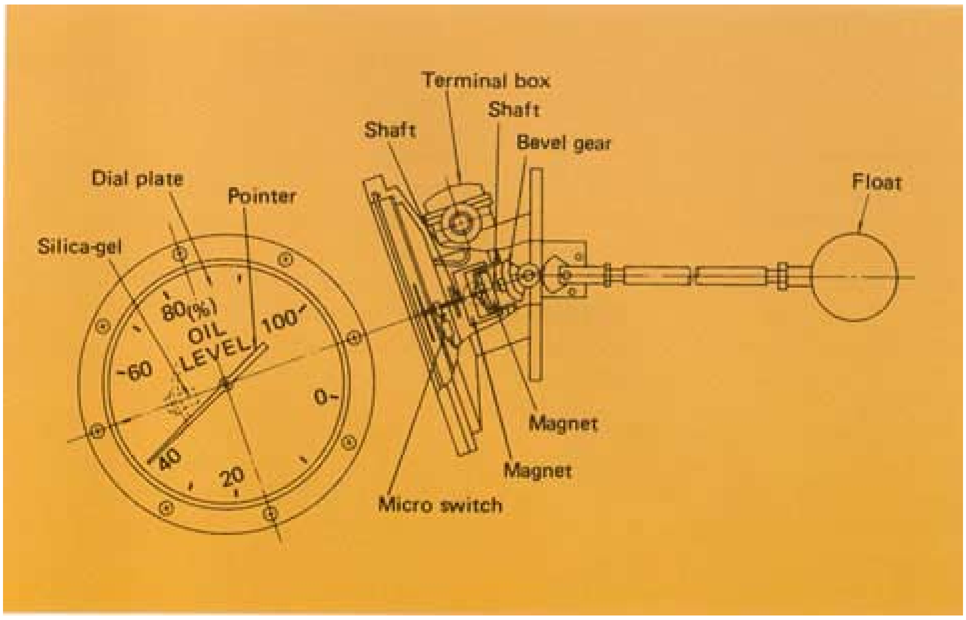


Fig.31 Construction of Dial Oil Level Indicator

Protective Relays

The following protective devices are used so that, upon a fault development inside a transformer, an alarm is set off or the transformer is disconnected from the circuit. In the event of a fault, oil or insulations decomposes by heat, producing gas or developing an impulse oil flow. To detect these phenomena, a Buchholtz relay is installed.

Buchholtz Relay

The Buchholtz relay is installed at the middle of the connection pipe between the transformer tank and the conservator. There are a 1st stage contact and a 2nd stage contact as shown in Fig. 32.
The 1st stage contact is used to detect minor faults. When gas produced in the tank due to a minor fault surfaces to accumulate in the relay chamber within a certain amount (0.3Q-0.35Q) or above, the float lowers and closes the contact, thereby actuating the alarm device.
The 2nd stage contact is used to detect major faults. In the event of a major fault, abrupt gas production causes pressure in the tank to flow oil into the conservator. In this case, the float is lowered to close the contact, thereby causing the circuit breaker to trip or actuating the alarm device.

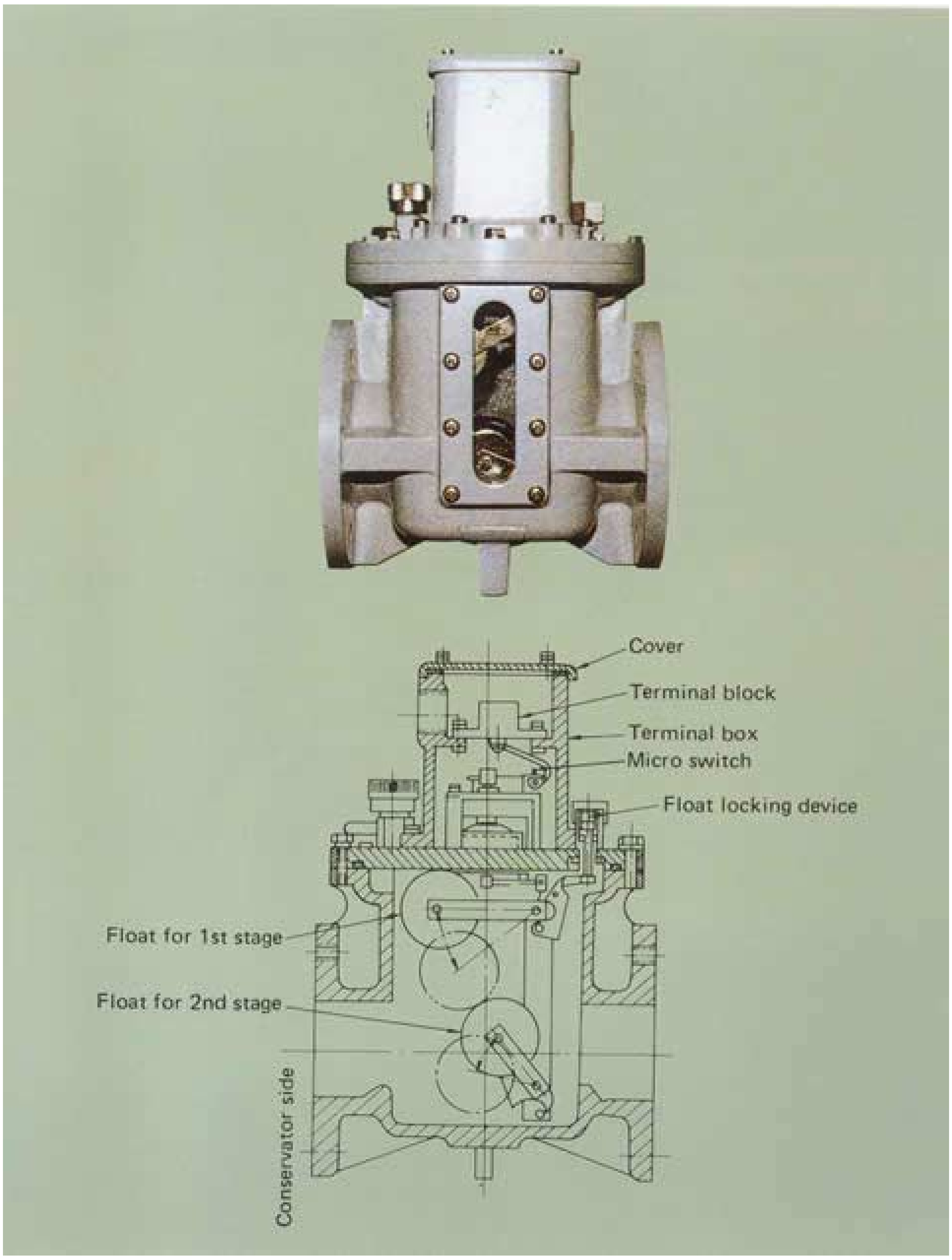


Fig.32 Buchholtz Relay

Temperature Measuring Device

Liquid Temperature Indicator
Liquid temperature indicator (BM SERIES) is used to measure oil temperature as a standard practice. With its temperature detector installed on the tank cover and with its indicating part installed at any position easy to observe on the front of the transformer, the dial temperature detector is used to measure maximum oil temperature. Thanks to its double construction, the indicator can be removed regardless of oil in the transformer tank. The indicating part, provided with an alarm contact and a maximum temperature pointer, is of airtight construction with moisture absorbent contained therein; thus, there is no possibility of the glass interior collecting moisture whereby it would be difficult to observe the indicator (Fig. 33).
Further, during remote measurement and recording of the oil temperatures, on request a search coil can be installed which is fine copper wire wound on a bobbin used to measure temperature through changes in its resistance.

Winding Temperature Indicator Relay (BM SERIES)

The winding temperature indicator relay is a conventional oil temperature indicator supplemented with an electrical heating element. The relay measures the temperature of the hottest part of the transformer winding. If specified, the relay can be fitted with a precision potentiometer with the same characteristics as the search coil for remote indication. The temperature sensing system is filled with a liquid, which changes in volume with varying temperature. The sensing bulb placed in a thermometer well in the transformer tank cover senses the maximum oil temperature. The heating element with a matching resistance is fed with current from the transformer associated with the loaded winding of the transformer and compensate the indicator so that a temperature increase of the heating element is thereby proportional to a temperature increase of the winding-over-the-maximum-oil temperature. Therefore, the measuring bellows react to both the temperature increase of the winding-over-the-maximum-oil temperature and maximum oil temperature. In this way the instrument indicates the temperature in the hottest part of the transformer winding.
The matching resistance of the heating element is preset at the factory.

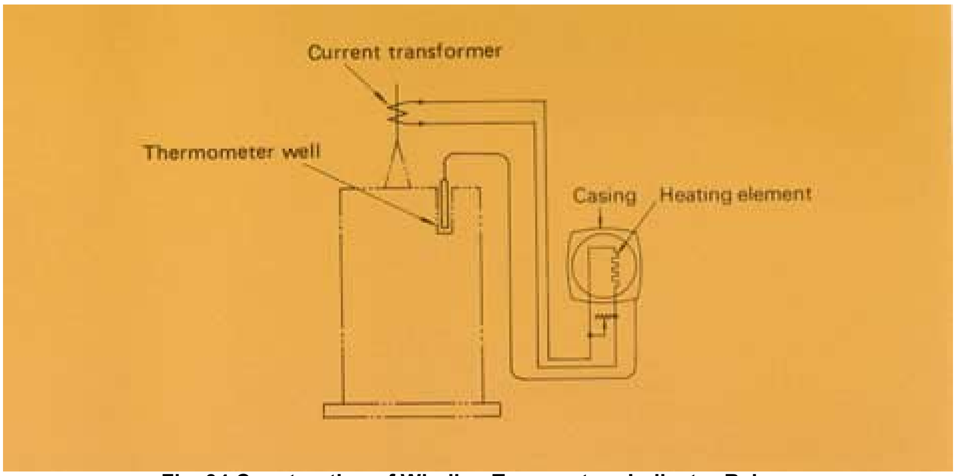


Fig. 34 Construction of Winding Temperature Indicator Relay

Fig.33 Oil Temperature Indicator

Fig.35 Winding Temperature Indicator

Pressure Relief Device

When the gauge pressure in the tank reaches abnormally to 0.35-0.7kg/c m2 the pressure relief device starts automatically to discharge the oil. When the pressure in the tank has dropped beyond the limit through discharging, the device is automatically reset to prevent more oil than required from being discharged.

Tap Changer

Off-circuit Tap Changer

Off-circuit tap changer is used for regulating the voltage after the transformer has been completely de-energized.

At Toshiba, two standard types of off-circuit tap changers are available: a wedge-type off-circuit tap changer and a slide-type off-circuit tap changer. The wedge-type is used when taps are provided halfway on the winding; the slide-type is used when taps are provided on the end of the winding. The wedge-type is shown in Fig. 37. The spring, which applies a contact pressure to the contact piece, is most highly compressed at its regular position. Thus, in conjunction with wedge action of the contact piece, a sufficiently high amount of contact pressure can be obtained, negating the possibility of incomplete contact. To prevent oil leakage, an oil seal is used on that part of the tank cover through which the operating shaft passes.

Fig.36 Pressure Relief Device

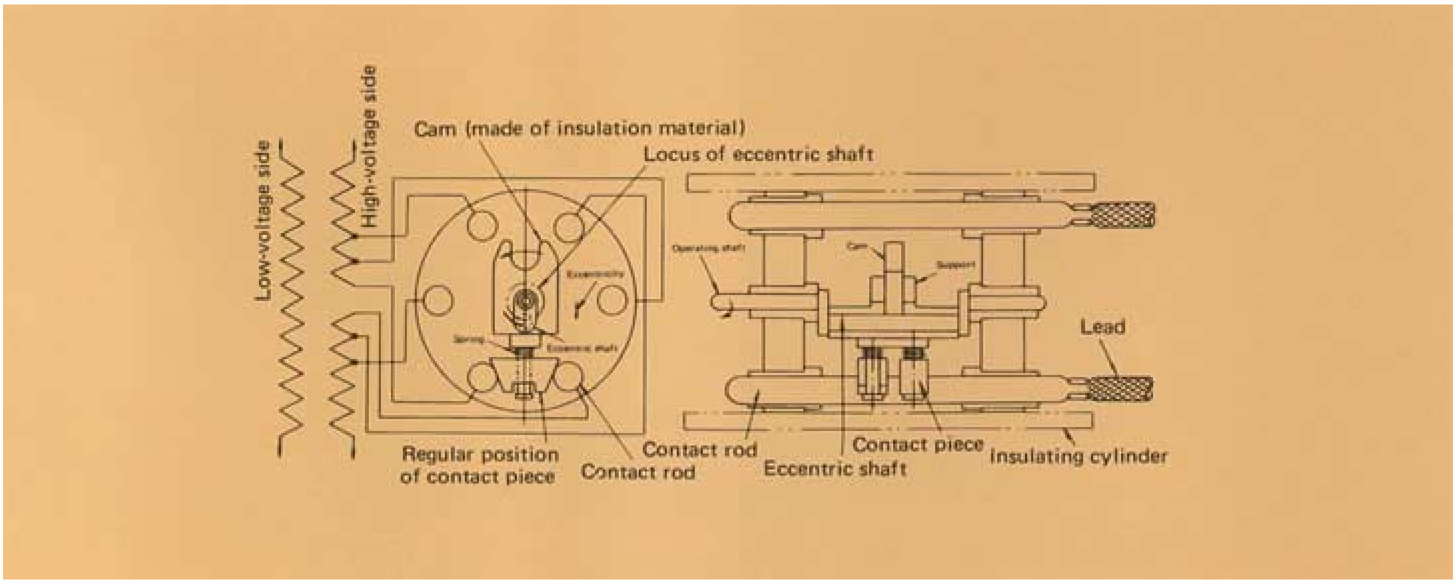


Fig.37 Construction of Wedge-type Off-circuit Tap Changer

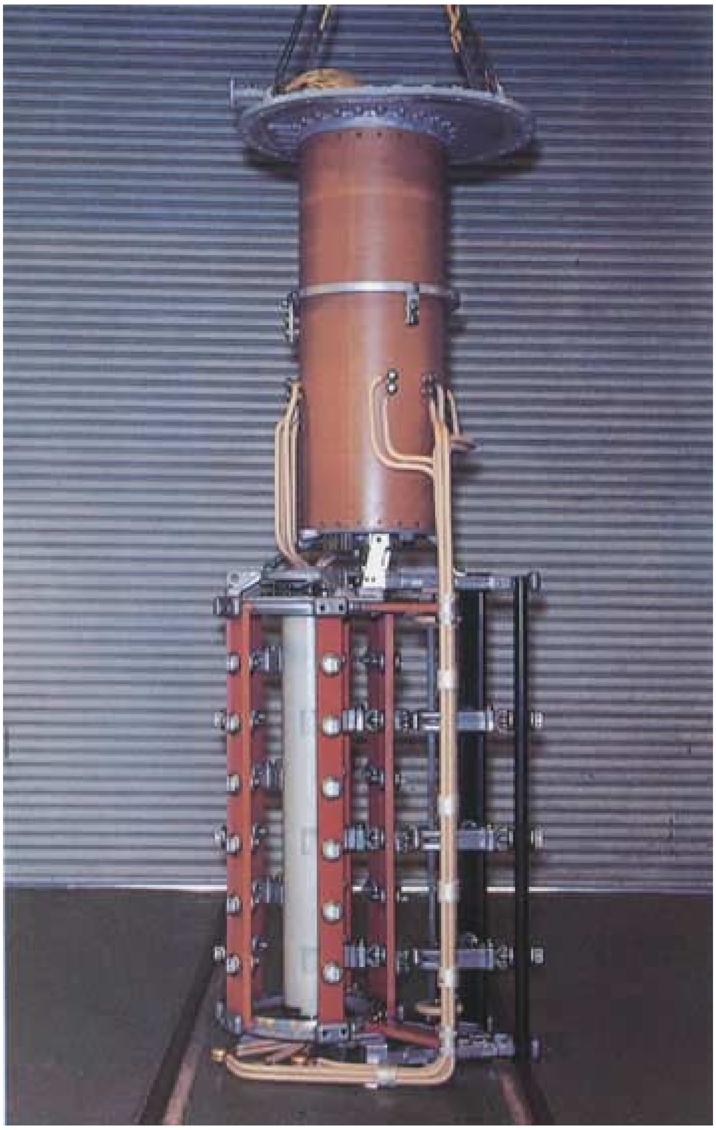
On-load Tap Changer

Developed on the basis of technical license from MR Co., Germany, Toshiba On-load Tap Changer FK Series boasts the following features:

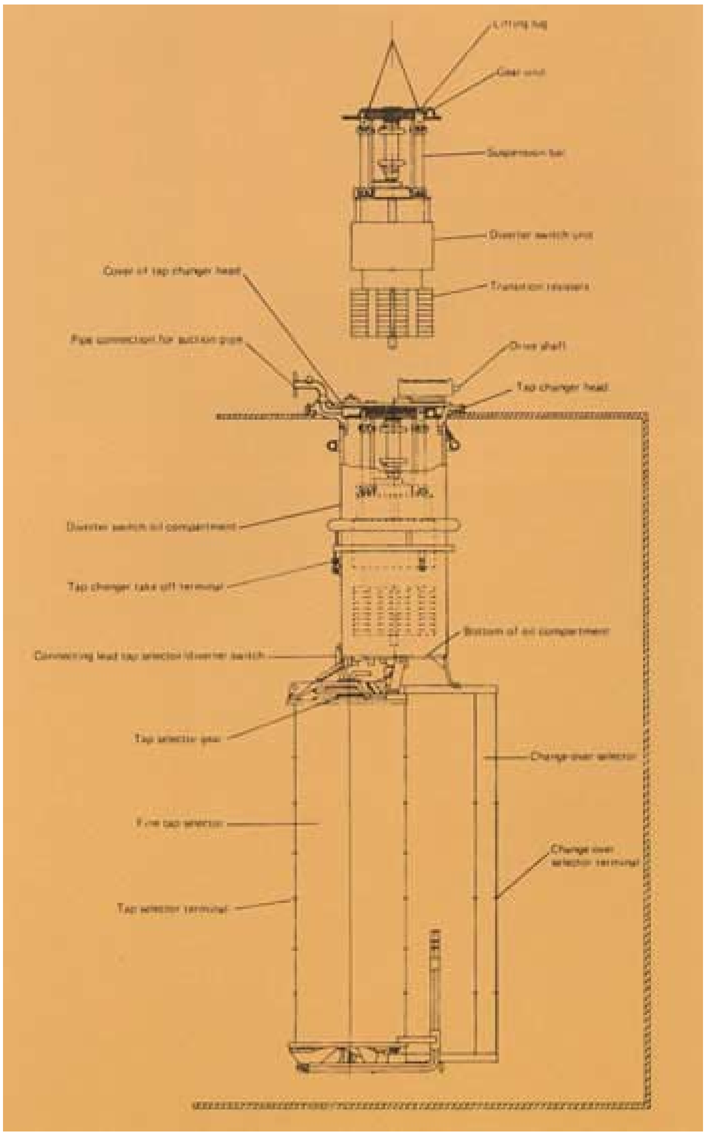
- The entire on-load tap changer can be built in a tank to facilitate assembly and transport of the transformer.
- By performing resistance-type breaking, arcing time is short, and both oil contamination and contact wear can be considerably reduced. Further, this tap changer ensures high reliability and long life.
- The tap selector is provided with contact pieces structured to permit conducting large current; each contact piece is provided with a shield electrode on its upper and lower sides for needs of insulation.
- The mechanical parts are provided with adequate strength to meet torque as required, thus ensuring high reliability during extended operation.
- The three-phase tap changer is split into three segments, becoming suitable for changing the neutral-point tap on star-connection winding. This type of tap changer can also be used as a large-capacity, single-phase tap changer with current shunted by impedance of the transformer windings.
- The diverter switch can be lifted from the tap changer, offering maintenance ease.

Table 2 Standard Types of On-load Tap Changers

Type	Max, step voltage (V)	Max, load current (A)
FKT-M100J	3,300	550
FKT-T100M	4,000	1,120



Fig, 38 On-load Tap Changer Type FKT-T100M



Fig, 39 Section of On-load Tap Changer

Bushing

Having manufactured various types of bushings ranging from 6kV-class to 800kV-class, Toshiba has accumulated many years of splendid actual results in their operation.

Plain-type Bushing

Applicable to 24kV-class or below, this type of bushing is available in a standard series up to 25,OOOA rated current. Consisting of a single porcelain tube through which passes a central conductor, this bushing is of simplified construction and small mounting dimensions; especially, this type proves to be advantageous when used as an opening of equipment to be placed in a bus duct (Fig. 40).

Oil-impregnated, Paper-insulated Condenser Bushing

The oil-impregnated, paper-insulated condenser bushing, mainly consisting of a condenser cone of oil-impregnated insulating paper, is used for high-voltage application (Fig. 41, 42). This bushing, of enclosed construction, offers the following features:

- High reliability and easy maintenance.
- Partial discharge free at test voltage.
- Provided with test tapping for measuring electrostatic capacity and tan δ.
- Provided with voltage tapping for connecting an instrument transformer if required.

Fig. 40 24kV-25000A Plain-type Bushing

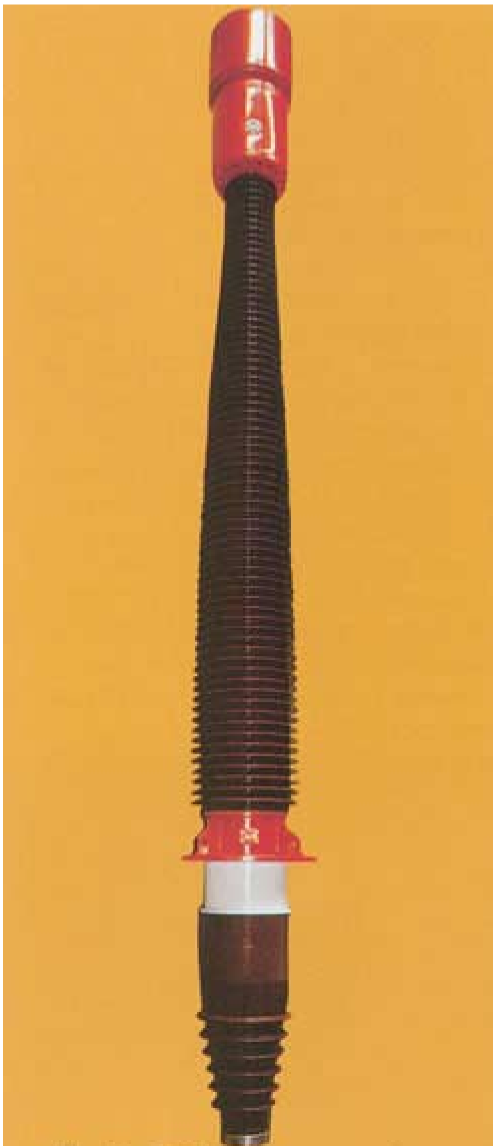


Fig. 41 800kV Oil-impregnated Paper-insulated Condenser Bushing (Air–Oil)

Fig.42 345kV Oil-impregnated Paper-insulated Condenser Bushing (SF_6 Gas-Oil)

Low-noise Transformer

From the standpoint of protecting the surrounding living environment, the problem of noise is attached much importance.
Thanks to a combination of Toshiba's excellent core construction and assembling technique, our large-capacity transformers are manufactured at lower noise level than the standard level for transformers specified in NEMA-TR1.
However, when a transformer is installed close to the boundary line of a power station/substation, or when several transformers are installed at the same station, it may be necessary to employ transformers with even less noise.
According to the required decrease of noise, large-capacity transformers are decided the combination of various noise enclosed constructions and cooler.

Construction of Noise Enclosure

Curtain-type enclosure
The transformer tank side walls are covered with steel plate panels around their outer circumference. The steel plate interiors are lined with sound-absorbent material to prevent noise from built-up.

Steel-panel noise enclosure
The transformer tank side walls and covers are entirely covered with steel plate panels. Welded construction is used in all assembly of steel plate panels to minimize noise, resulting in a high noiseproofing effect.

Concrete-panel noise enclosure
The transformer tank side walls and covers are entirely covered with a noise enclosure consisting of concrete and steel plate combined. Since mass of concrete-panel is greater than that of steel plate, the concrete-panel noise enclosure achieves greater noise reduction than the steel-panel noise enclosure.

Concrete noise enclosure
The transformer tank side walls and covers are entirely covered with a reinforced concrete wall. This construction achieves the greatest noise-reducing effect.

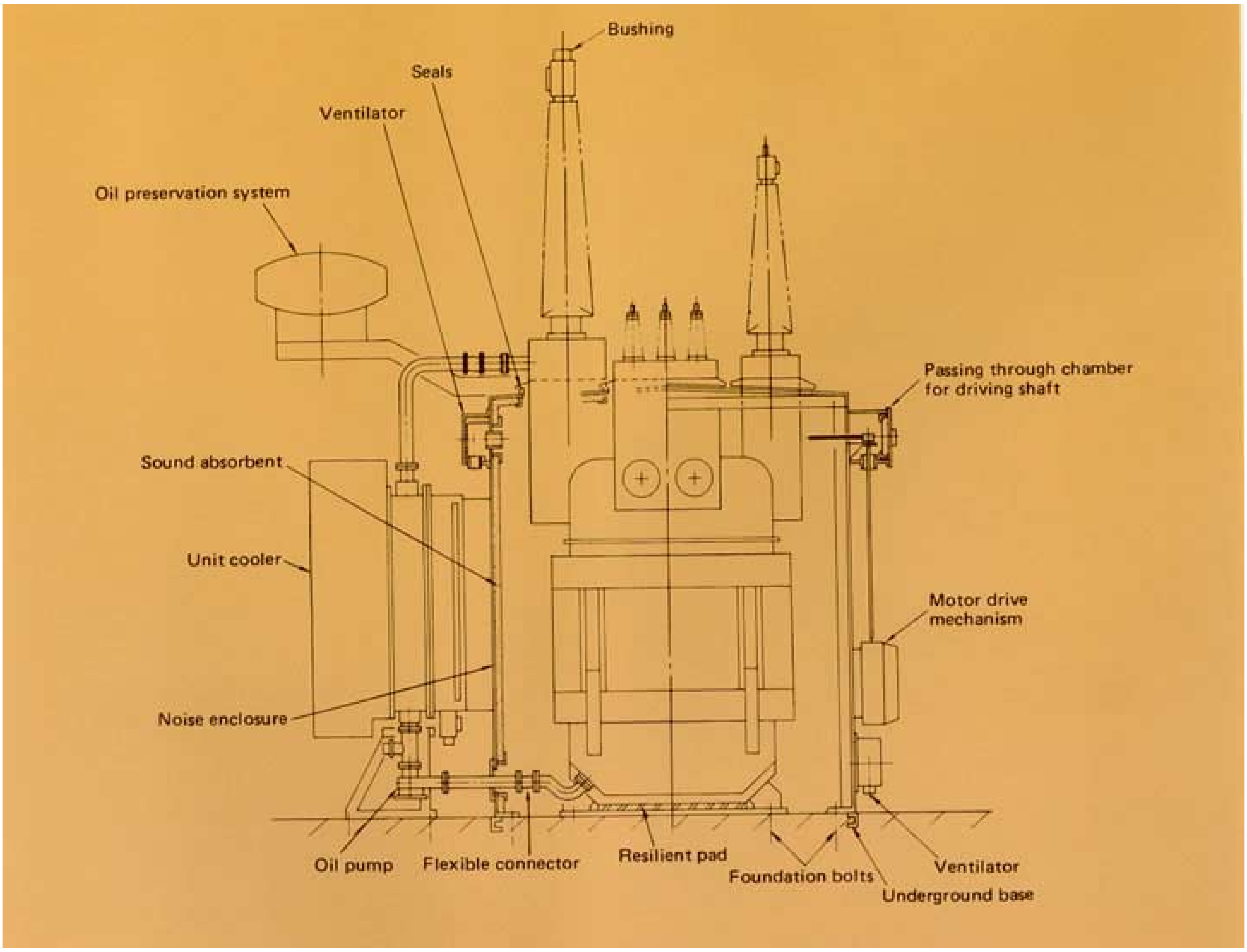


Fig.43 Construction of Low-noise Transformer

Low-noise Cooler

Typical coolers applicable to low-noise transformers include the followings:

- Low-noise unit cooler with low-speed cooling fan
- Low-noise unit cooler with sound-absorbing duct on the front of cooling fan
- Independent radiator of self-cooled type or forced-oil, self-cooled type
- Water-cooled unit cooler

Low-noise Combination of Transformer

Large-capacity transformers of the 100-300MVA class adopt the following various types of combination in accordance with noise level requirements:

- Noise level: 70-80 dB
  The transformer tank side walls are covered with a curtain-type enclosure; a low-noise unit cooler with low-speed cooling fan is installed.
- Noise level: 60-70 dB
  The transformer tank is covered with a steel-panel noise enclosure; a low-noise unit cooler with low-speed cooling fan or noise-absorbing duct is installed.
- Noise level: 55-65 dB
  The transformer tank is covered with a concrete-panel noise enclosure; a radiator bank or low-noise unit cooler with noise-absorbing duct is installed.
- Noise level: 50- 60 dB
  The transformer tank is placed in a concrete noise-enclosure. Generally, an forced-oil, self-cooled system is employed with the radiator bank installed outside the concrete noise-enclosure. If circumstances require, a unit cooler of the water-cooled type or super low-noise type is installed.

Fig.44 Steel-panel Noise Enclosure

Fig.45 Concrete-panel Noise enclosure

Construction of Cable Connection And GIS Connection

Cable Connection

In urban-district substations connected with power cables and thermal power stations suffered from salt-pollution, cable direct-coupled construction is used in which a transformer is direct-coupled with the power cable in an oil chamber. Toshiba employs an indirect connection system in which, with a cable connecting chamber attached to the transformer tank, a coil terminal is connected to the cable head through an oil-oil bushing in the cable connection chamber. Construction of the connection chamber can be divided into sections. Cable connections and oil filling can be separately performed upon completion of the tank assembling.

GIS (Gas Insulated Switchgear) Connection

There is an increasing demand for GIS in substations from the standpoint of site-acquisition difficulties and environmental harmony. In keeping with this tendency, G IS connection-type transformers are ever-increasing in their applications.
At Toshiba, the SF6 gas bus is connected directly with the transformer coil terminal through an oil-gas bushing.
Toshiba's oil-gas bushing support is composed of a transformer-side flange and an SF6 gas bus-side flange, permitting the oil side and the gas side to be completely separated from each other.

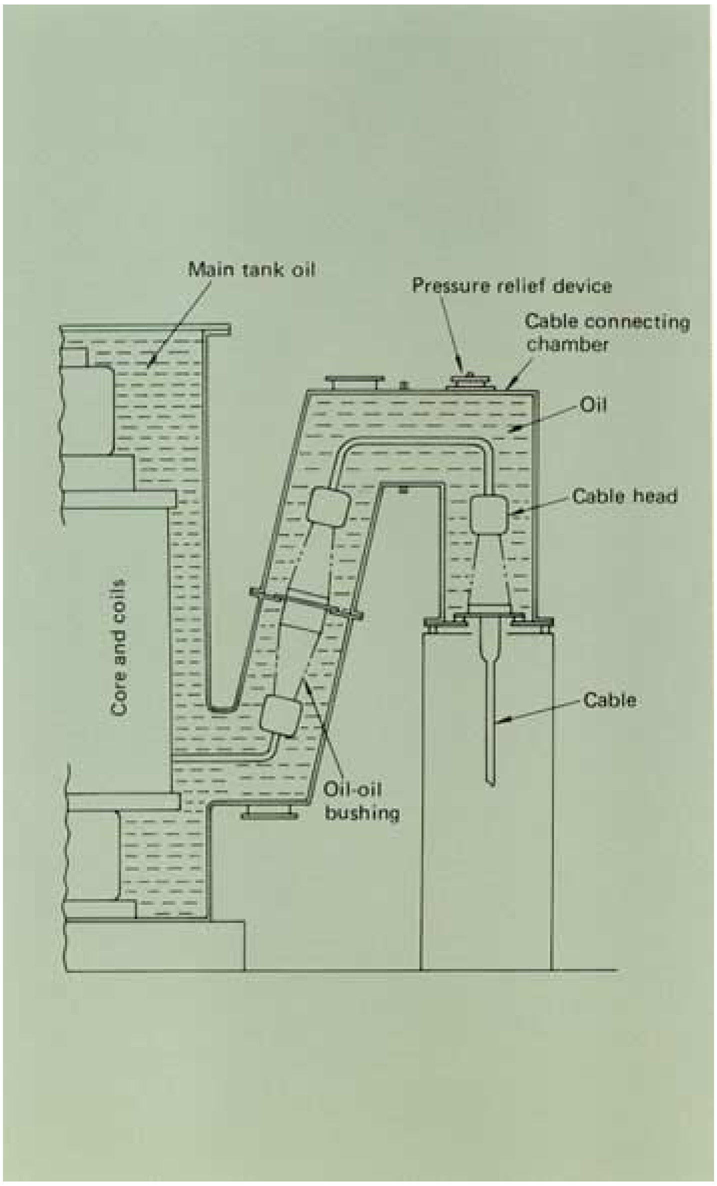


Fig.46 Indirect Cable Connection

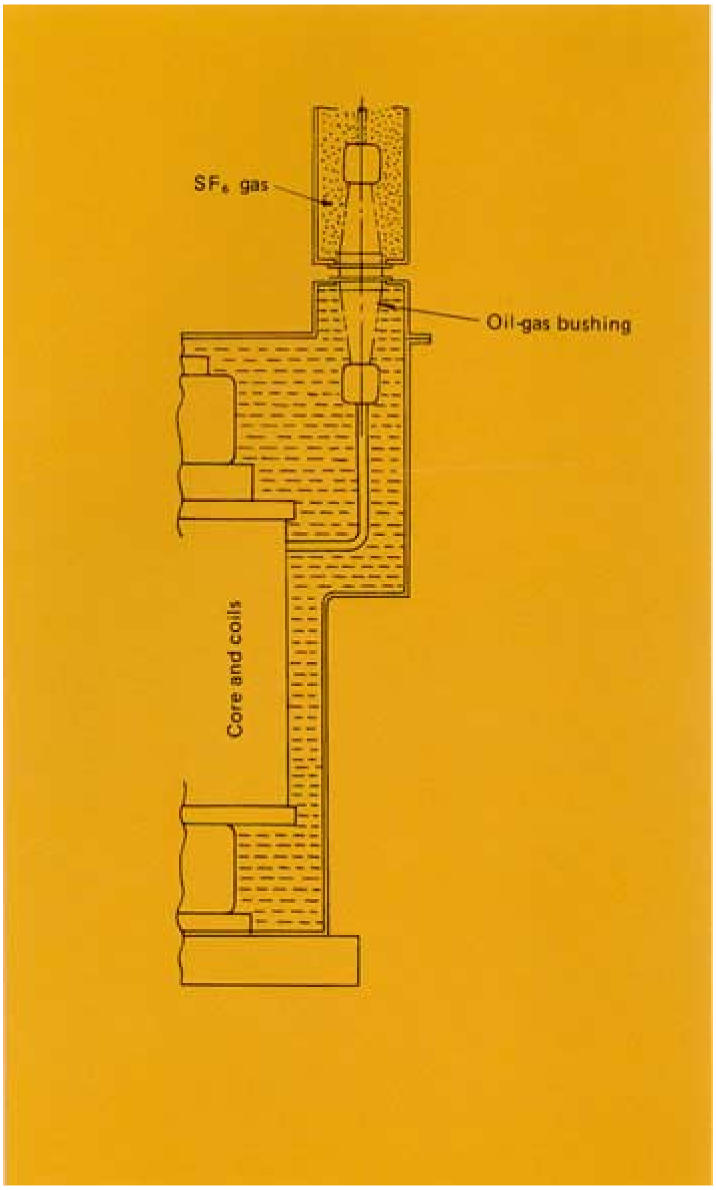


Fig.47 Direct GIS Connection

Transportation

It is important to transport a transformer in the same condition as it was completely assembled, dried and tested at the factory. This makes it possible to ensure high reliability and to shorten the period for on-site installation.
A Toshiba transformer is transported in the same upright position as it was in final assembling so that on-site installation becomes very simple, requiring no special operations.
While a transformer is in transportation, its main tank is filled with dry air or dry nitrogen to completely prevent the core and coils from absorbing moisture until final on-site oil filling.
When extreme transport restrictions are imposed, as in the case of power stations in mountains or when roads are subjected to weight restrictions or when the entrance for underground hoisting is narrow in the case of installation with urban underground substation, the following transport procedure is employed: A three-phase transformer is divided into sections so that one-phase section housed in a tank is carried into the site at a time, and the three sections are assembled into the original three-phase transformer at the site.
The transformer core and coils are transported to the site in the same condition as it was assembled and tested at the factory, and they are joined to each other using special ducts and leads submerged in oil.
When further strict transport restrictions are imposed, a single-phase unit may be divided into two or three sections. Toshiba delivered a 500kV, 680MVA three-phase transformer in nine sections - a record-breading product!

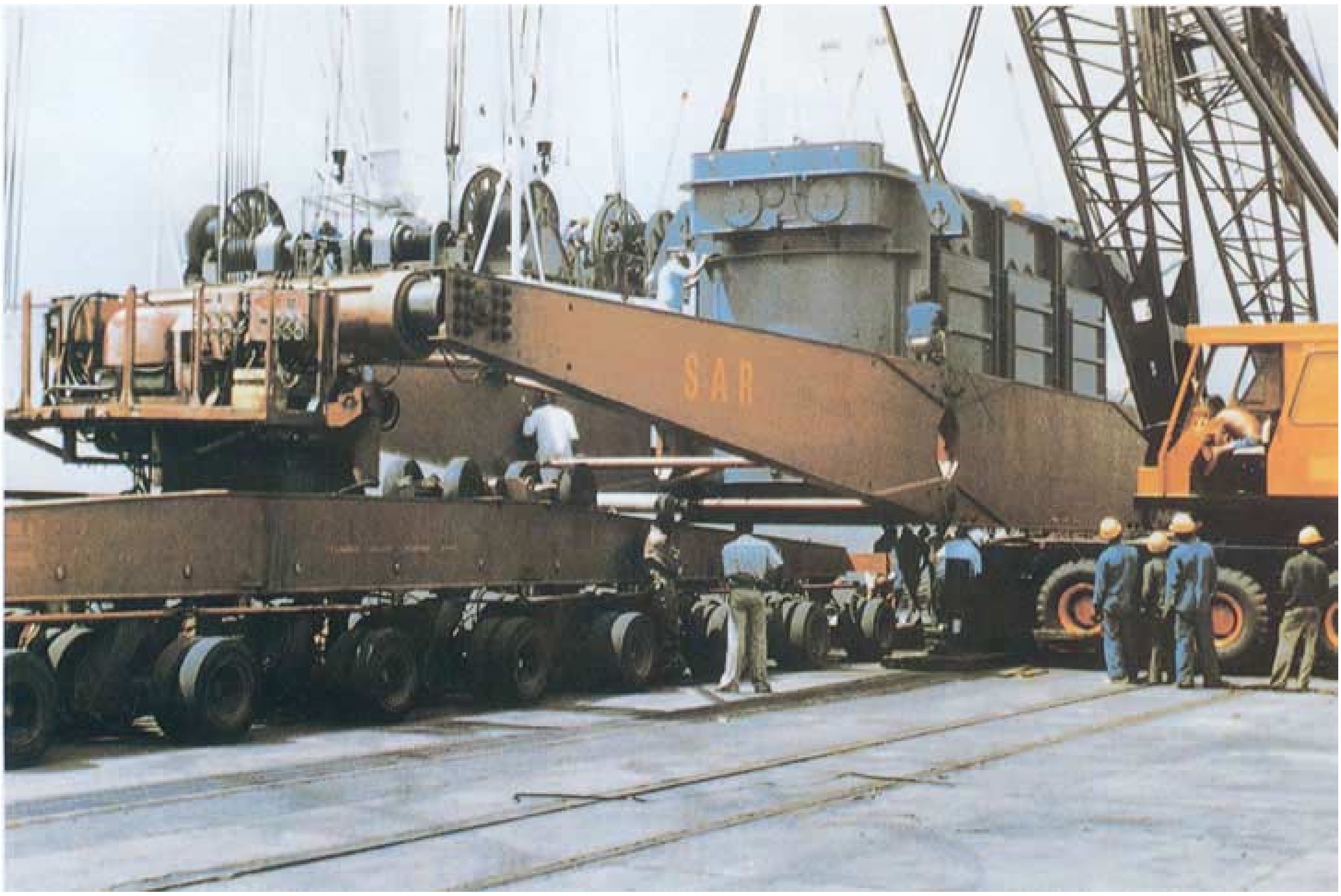


Fig.48 Loading a 50Hz, 420kV, 700MVA Transformer

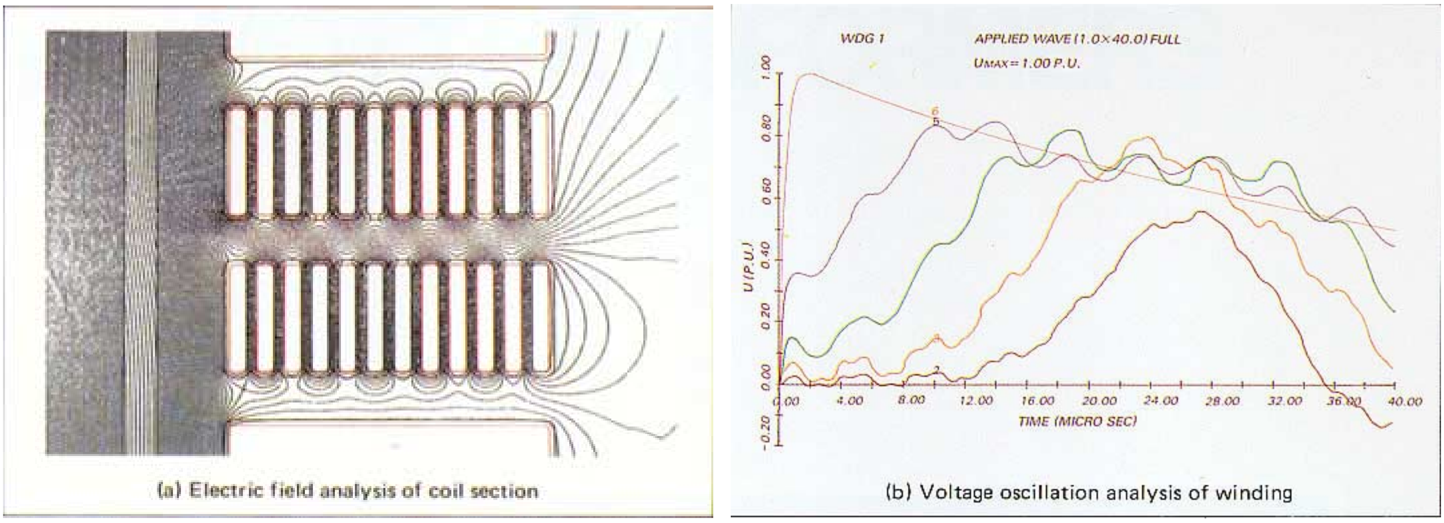
Research and Development

For the research and development of equipment coping with the tendency toward high voltage and large capacity, the cooperation of engineers in every field is necessary -such as electrical, mechanical, chemical and metal engineering, as well as statistics. Toshiba Heavy Apparatus Engineering Laboratory is exerting efforts to cultivate basic techniques covering various fields in close cooperation with the manufacturing department including the design, production, and test/inspection sections, thereby playing a major role in new product development, improved product performance, and enhanced reliability. The world-prominent, latest testing facilities in this Laboratory are fully utilized in the development of ultrahigh-voltage insulation structures represented by Toshiba UHV transformers and 500kV transformers, as well as in fundamental research concerning various types of discharge and breakdown, including breakdown in oil which supported development. Further, all possible efforts are exerted by the staff of this Laboratory in basic to applied research on extensive engineering fields ranging from electromagnetic phenomenon, structural strength, heat transfer and cooling, noise, vibration, and earthquake proofing -including insulation and metallic materials.

Fig.49 UHV Laboratory

Fig.50 2300kV AC Testing Facilities

Fig.51 6000kV Impulse Generator



(a) Electric field analysis of coil section

(b) Voltage oscillation analysis of winding

Fig.52 Analysis with Computer

Fig.53 UHV Prototype Auto-transformer 500/3MVA-1200/√3kV-50Hz

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