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1 INTRODUCTION

Since the commencement of transformer production in Japan, Mitsubishi Electric Corporation has held a leading position in the fields of large power transformer design and manufacture. A distinguishing feature of Mitsubishi large power transformers is shell-form construction, which in combination with rectangular sandwich coils and Form-Fit tank construction, has resulted in excellent performance and high reliability proven by an operational record of many years duration.

Mitsubishi large power transformers are manufactured on the basis of over 70 years of transformer manufacture. And continuous research efforts toward improvement of technical skills and materials has earned for these products a high reputation and wide acceptance.

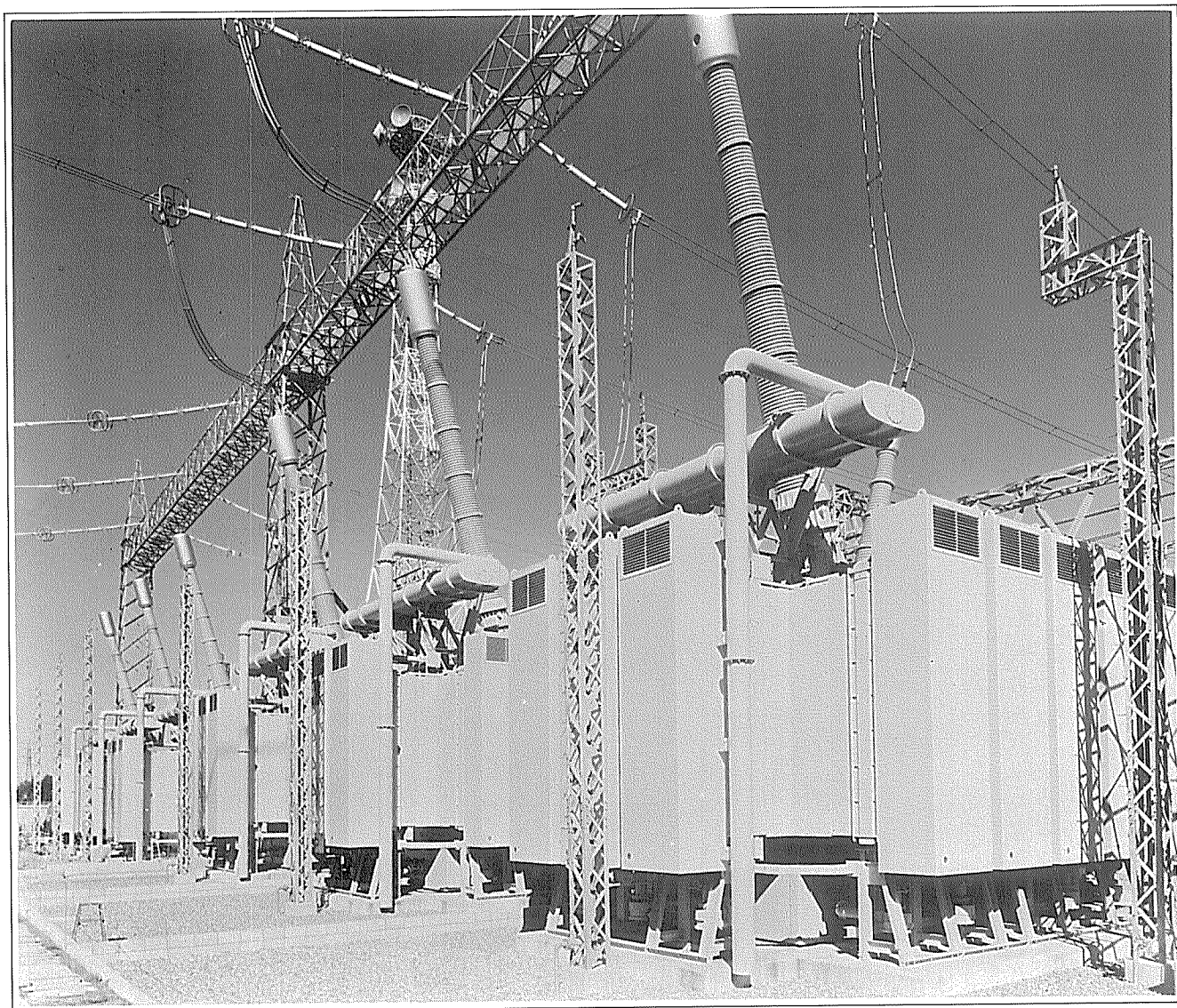
2 TYPES

Mitsubishi large power transformers are designated according to the method of cooling, as follows:

SR	Oil-immersed, self-cooled (ONAN)
SRB	Oil-immersed, forced-air-cooled (ONAF)
SUB	Forced-oil, forced-air-cooled (OFAF)
SUW	Forced-oil, water-cooled (OFWF)
SUR	Forced-oil, self-cooled (OFAN)

Transformers of double rating having a combination of these cooling systems (e.g., SR/SRB) or of triple rating (e.g., SR/SRB/SUB) are manufactured to order. When a transformer is equipped with an on-load tap changer, a tap-changer denotation is suffixed (e.g., SUB-MRM).

This catalog describes in detail cooling systems (p. 8 ~ 12) and an on-load tap changer (p. 19).



Mitsubishi Extra-High-Voltage Transformers

This 1000MVA 500/275/63kV 50Hz low-noise-level 3-phase bank with on-load voltage regulators is installed at the Shin-Sahara Substation of Tokyo Electric Power Co., Japan

3 FEATURES

The construction of the shell-form transformer is best suited to high-voltage, large-capacity power transformers. These transformers offer the following advantages:

3.1 Surge-Proof Insulation

The shell-form transformer uses a small number of coils having large coil surfaces so that series capacitance between the coils is large, providing a good voltage distribution when a surge is applied. Recently, even core-form transformers have tended to replace the conventional disk coil with a cylindrical coil similar in construction to this "surge-proof" coil, for improvement of surge-voltage distribution. This fact is ample proof of the wide acceptance of the design principle of this coil construction. The coil is entirely insulated with pressboard, which increases impulse ratio and provides high dielectric strength against impulse voltage.

Furthermore, it is so constructed that graded insulation can easily be applied.

3.2 High Mechanical Strength

In shell-form, Form-Fit transformers, the coil is entirely covered by the insulation, and all the sides are firmly clamped by the core and tank. Mechanical force is distributed over a large area, with the obvious result that mechanical strength is high.

The coil is held in place vertically, with wooden wedges inserted between it and the core, to prevent displacement.

All sides of the rectangular sandwich coil employed in Mitsubishi shell-form transformers are clamped by the core and tank, for greater mechanical strength.

The additional fact that in shell-form construction the mechanical force resulting from unbalance due to taps, etc. has virtually no influence upon coil strength is one of the advantages of the shell form over the core form, in transformers having a wide tapping range.

3.3 Efficient Cooling

Shell-form transformers use a small number of widely spaced coils. The oil ducts are arranged vertically, facilitating convection and flow speed, and minimizing the temperature gradient in both the coils and the oil. If a forced-oil system is employed, the Form-Fit construction is especially effective in that the pumped oil flows mainly through the coils, and cooling efficiency is thus extremely high (Fig. 1).

In core-form transformers it is usually necessary to provide a means to guide the oil through the coils, but with the Form-Fit tank, the structure serves as the guide.

3.4 Form-Fit Construction

Features inherent to the Form-Fit construction are as follows:

1. The size, mass, and oil quantity required are all reduced.
2. Lifting of the assembled core and coils is not needed and the on-site crane-capacity requirement is reduced.
3. Transportation with the unit laying on its side is possible.
4. If required (e.g., for a portable substation), design for laying-down operation is possible.
5. No oil leakage: the tank is a fully welded construction, and uses no gaskets.

3.5 Other Advantages

Other points of particular note are as follows:

1. It is easy to lead out taps, due to the sandwich arrangement of the coils.
2. It is easy to provide a small-capacity tertiary winding.
3. It is easy to build coils of high current capacity, so that the design is especially suitable for transformers of ultralarge-current capacity.
4. The noise level is low.

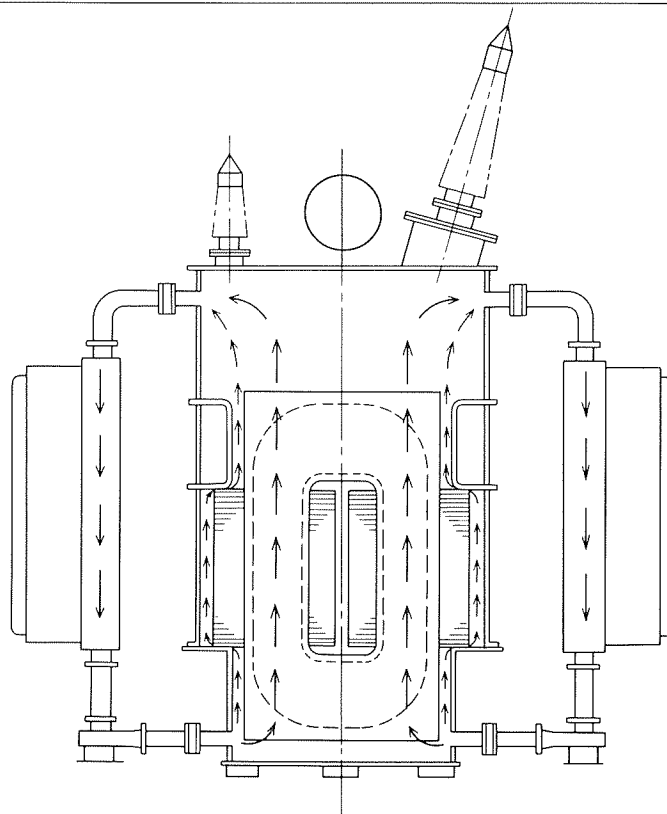


Fig. 1 Oil-circulation path in a Form-Fit transformer

4 INTERNAL CONSTRUCTION

4.1 Core

The shell-form transformer has two parallel magnetic circuits and the core is arranged horizontally so as to surround the coil. The shell-form Form-Fit transformer (Fig. 2) has a core composed of silicon steel punchings of common width (Fig. 3), laminated to form lapped joints on the flange of the lower tank. The upper tank is lowered onto the core and coil assembly and welded to the lower tank so that secure clamping of the core is obtained.

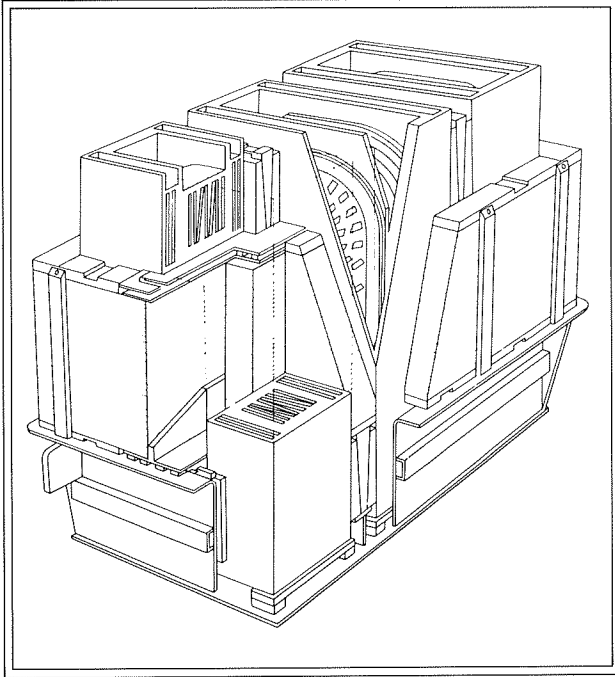


Fig. 2 Construction of Form-Fit transformer

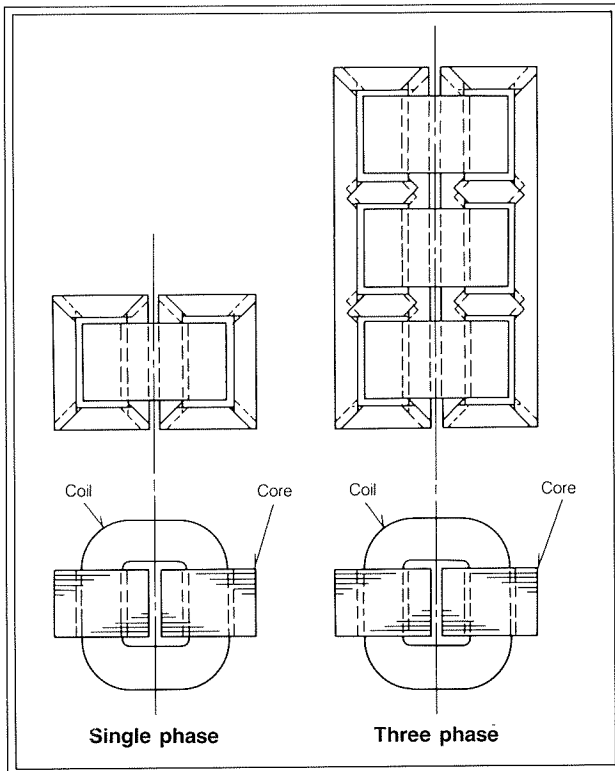


Fig. 3 Core arrangement

The core is thus firmly clamped over its entire periphery by the tension of the tank side plate, reducing the noise level to a minimum and eliminating fear of loosening during operation. Since it is evenly held around the entire periphery without the use of clamping bolts, there is no possibility of deterioration of the characteristics due to bolt holes and uneven clamping, and no fear of trouble due to deterioration of clamping-bolt insulation. The narrowness of the core enhances core cooling efficiency, so that even in transformers of extremely large capacity there is no need to split the core to improve cooling. This makes core construction very simple.

Cold-rolled, grain-oriented silicon steel having excellent magnetic properties is extensively used. In order to take full advantage of these characteristics, the joint of the core is lapped with the punchings bevelled at 45° so that the magnetic flux flows in the direction of rotation over the whole magnetic circuit.

Thus the Form-Fit construction used in Mitsubishi large power transformers, while simple, makes full use of the characteristics of high-grade silicon steel.

4.2 Coils

Conductor elements of the coils are made up of rectangular (almost square) cross-sectioned copper wire insulated with two layers of kraft paper.

Several wires are wrapped together as a coil element with successive layers of insulation paper, the number depending upon the working voltage, to give sufficient dielectric strength to the layer insulation. Adhesive solvent is applied to the extreme outside layer of the insulation paper so that coil-forming is made easy and each layer adheres firmly to form strong coils. For the purpose of reducing eddy-current losses, transposition is made at predetermined positions of the conductor elements, and in coils of large current capacity a number of coil elements are used in parallel.

Figs. 4 and 5 show the winding construction and Fig. 6 the cross-section of a coil. The end coils close to the line terminal are more strongly insulated, depending on requirements, and the coil is made slightly smaller to improve distribution of the electrostatic field. The completed coils are enclosed with pure insulating pressboard of channel or angle section. Between each coil, insulating washers of the same material are inserted and the whole is then assembled so that none of the individual

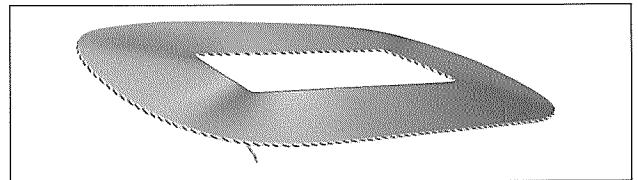


Fig. 4 Coil

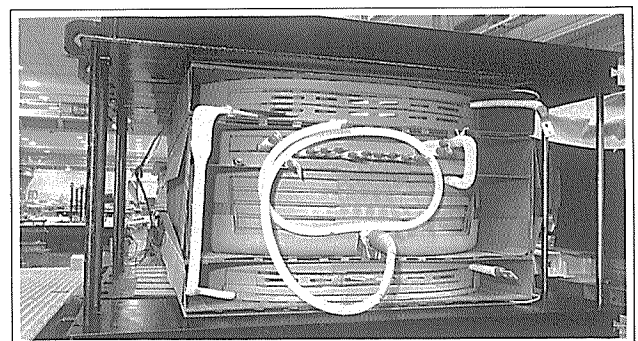


Fig. 5 Surge-Proof coil assembly

coil surfaces are exposed. These coil groups are completely enveloped with pressboard in a similar manner. Low- and high-voltage coil groups thus finished are stacked alternately and pressed to predetermined dimensions.

In conformity with customer requirements for overload capacity, Mitsubishi Electric can supply upon request HI-L heat-resistant paper for the turn insulation. As the capacity of a transformer is limited by the permissible temperature limits of its paper insulation (which has the lowest thermal capability among the materials of which the transformer is composed), it can be substantially increased if the thermal resistance of the paper insulation can be improved. HI-L heat-resistant paper consists of conventional paper insulation to which melamine dicyandiamide and polyacrylic amide are added in order to provide greatly extended life. This HI-L paper is used for insulating those conductors which operate at the highest temperatures.

Testing has proved that this HI-L paper has the same life as untreated paper, even when used at about 30°C higher temperatures, and up to eight times the life of untreated paper at the same working temperature. The additives in the HI-L paper have no effect on the other materials used in the transformer or the paper's own dielectric properties.

Transformers with HI-L paper have far higher short-time overload capability, and units having a small continuous rating can be run at peak load. Moreover, if load increases become necessary, there will be no need to increase the number of transformers or to replace the transformer with a unit of large capacity. Thus replacement or installation of additional units can be delayed. Conversely, when used at the same working temperature, they outlast conventional transformers considerably.

4.3 Surge-Proof Insulation

The Mitsubishi shell-form transformer uses a surge-proof coil with high dielectric strength against impulse voltage. The Surge-Proof coil is a non-oscillatory winding which limits the voltage oscillation due to impulse voltage and makes optimal use of the insulating materials. Since this Surge-Proof type was first adopted as standard for shell-form transformers a half-century ago, it has maintained a high reputation for faultless operation.

In considering the impulse voltage characteristics, the winding can be taken as a circuit composed of inductances and capacitances, as shown in Fig. 7. When a steep-front surge voltage is applied to the front of the winding, the initial voltage distribution is given (in case of a grounded neutral) by the equation:

$$E_n = E \sinh \alpha \frac{n}{N} / \sinh \alpha$$

where

E_n = Voltage between the n 'th coil from neutral and ground

E = Applied voltage

N = Number of coils

n = n 'th coil

$\alpha = \sqrt{C_p/C_s}$

$C_p = C_g \times N$

$C_s = C_c \times \frac{1}{N}$

C_g = Capacitance of each coil to ground

C_c = Capacitance between coils

As is obvious from this equation, the larger the capacitance between the coils as compared to the capacitance of each coil to ground (i.e., the smaller the value of α), the straighter the voltage distribution (Fig. 8) becomes. The initial voltage distribution changes and finally reaches a value determined by resistance and inductance with the voltage of each part of the winding oscillating at the resonance frequency of the whole winding during this distribution change. The closer the initial and final voltage distributions are, the smaller the amplitude of the oscillating voltage and the smaller the abnormal voltage developed in each part of the winding.

Generally, the shell-form winding consists of a small number of coils having large coil surfaces, but a small surface between the coil and ground. For this reason, C_s becomes large and C_g becomes small. Similarly, the value of α is 0.5 ~ 1.5, which is considerably smaller than the 10 ~ 30 range of the conventional core-form winding. The shell-form transformer thus has excellent impulse voltage characteristics.

Surge-Proof construction incorporates the following further improvements.

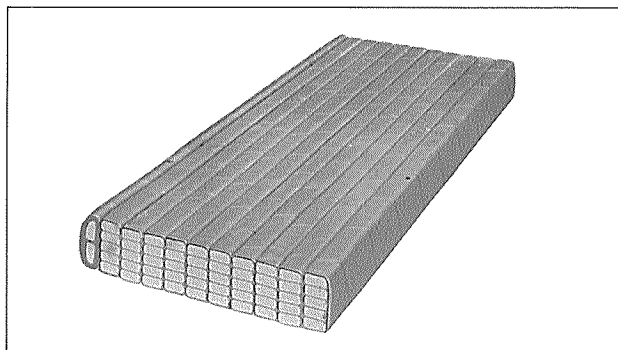


Fig. 6 Cross section of a coil

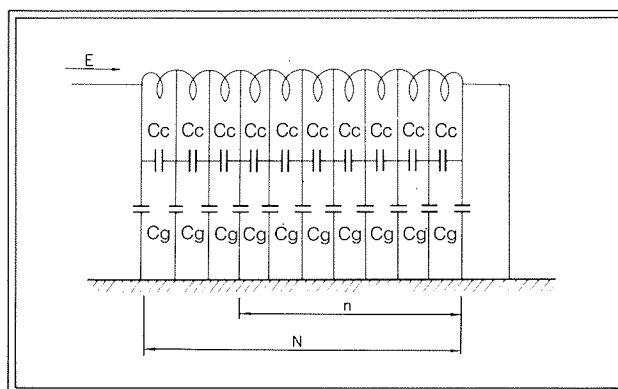


Fig. 7 Equivalent circuit of transformer winding for initial surge-voltage distribution

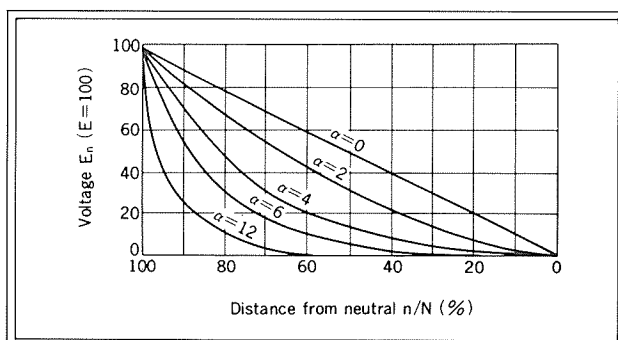


Fig. 8 Initial surge-voltage distribution (neutral grounded)

4.3.1 Static Plate on Line-End Coil

A static plate is arranged on the outside of the line-end coil of the transformer, to control the voltage distribution curve in that area. Without this plate, voltage distribution in the line coil is curved initially (line A in Fig. 9), but with it, distribution becomes almost straight (line B in Fig. 9), thus preventing the subsequent oscillation.

Another effect of the static plate is to introduce a large, concentrated capacitance at the terminal of the transformer, which plays an important role in smoothing the steep front of the impulse wave.

4.3.2 Solid Insulation along Equipotential Surfaces

The characteristics of breakdown due to impulse voltage are quite different from that due to power-frequency voltage. As creep insulation strength is considerably lower for the impulse voltage than for low-frequency voltage, it is not effective to increase creepage distance above a certain limit.

Based on this fact, Surge-Proof transformers have solid insulation arranged along the equipotential surfaces so that breakdown cannot develop unless the solid insulation is punctured.

Fig. 11 shows a cross section of the Surge-Proof coil. All inside and outside surfaces are fully enclosed in insulation angles and channels so that no part remains exposed. Fig. 12 shows the insulation assembly of the winding of a 333MVA, 500kV autotransformer assembled and laid down.

4.3.3 Inclination of Coils

As shown in Fig. 11, the 2nd and 4th coils are inclined. This inclination of some of the coils is useful in preventing irregular harmonic oscillation. In the Surge-Proof type, the end of one coil is connected to the start of the next coil, and the start to the start (Fig. 11), so that very reliable connecting-lead insulation is easily obtained.

Since the voltage across the insulation between adjacent coils is increased with this connection, ample insulation strength between coils is maintained by inclining the coils, and designing the insulation arrangement in such a way as to eliminate unnecessary increase of insulation clearances.

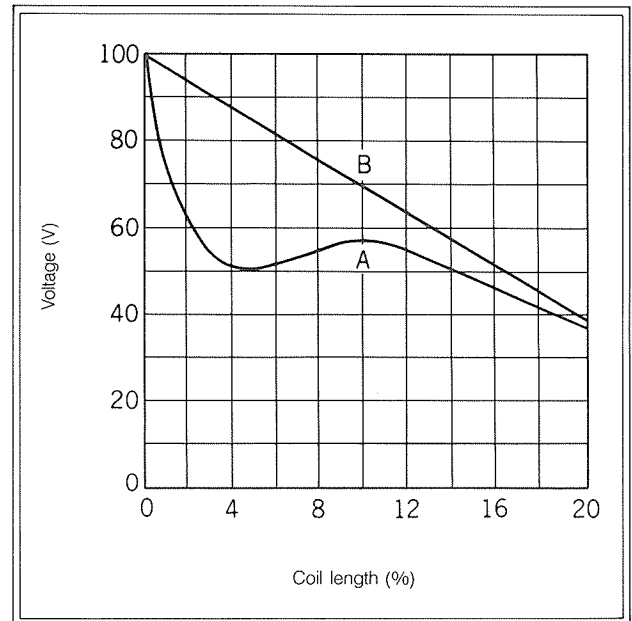


Fig. 9 Initial surge-voltage distribution at the line end of a shell-form transformer

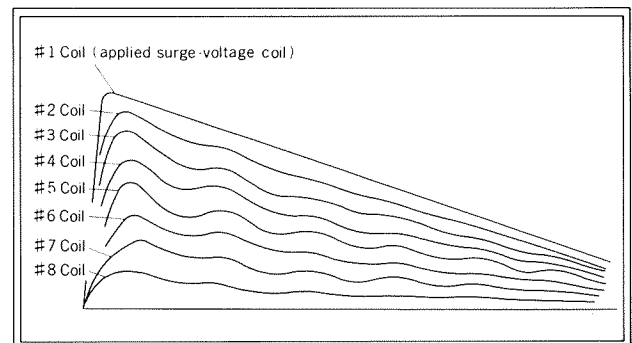


Fig. 10 Oscillogram showing the surge-voltage distribution in a Surge-Proof transformer winding

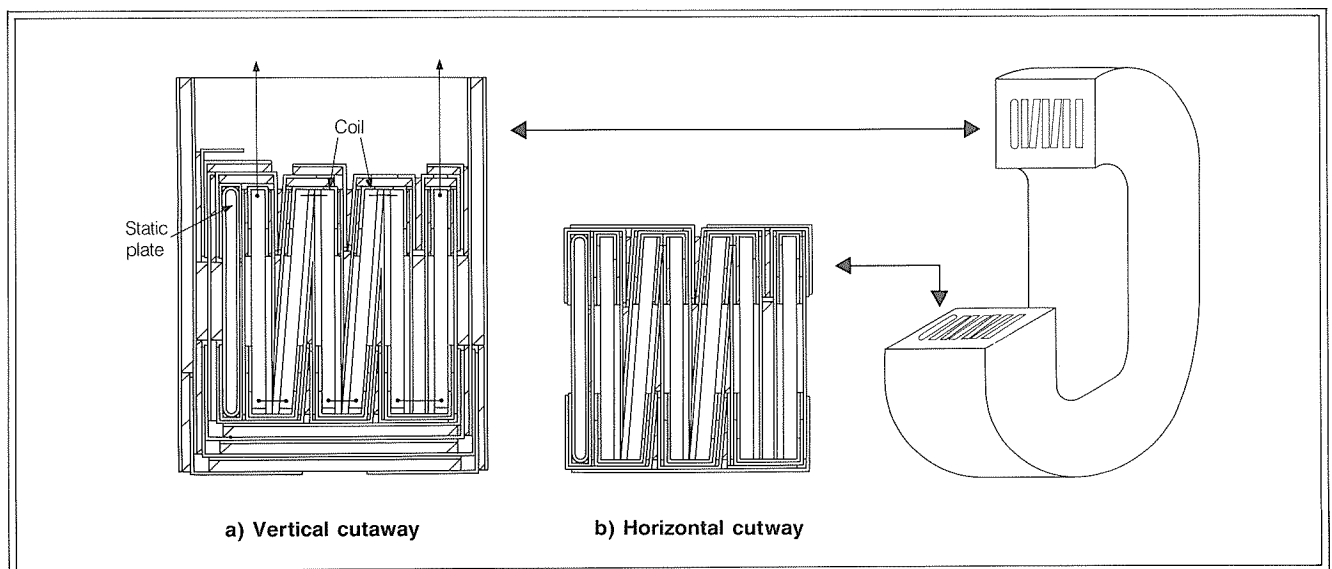


Fig. 11 Cross sections of Surge-Proof coil

4.4 Graded Type

As noted above, shell-form Surge-Proof construction gives a very low value of α (i.e., $\sqrt{C_p/C_s}$) so that when an impulse voltage enters the line end and the other terminal is grounded, the initial voltage distribution comes very close to the final voltage distribution (i.e., approaches a straight line) and the voltage oscillation in each part of the winding is markedly reduced. Accordingly, in a solidly grounded system, so-called graded insulation is possible, whereby insulation is gradually reduced from the line end to the neutral end.

Fig. 13 shows the coil arrangement of one phase of a transformer having graded insulation, and Fig. 14 the coil construction of a high-voltage winding having graded insulation. The high-voltage windings are each of a different size. Close to the neutral end, the coil is larger, and the insulation distance between it and the surrounding core is smaller. Other construction features are exactly the same as those of the conventional full-insulation Surge-Proof type.

An advantage of shell-form transformers is that graded insulation is easily applied and extremely effective.

4.5 Reduced Neutral Type

In transformers used in noneffectively grounded systems, the insulation at the neutral end can be reduced to about $1/\sqrt{3}$ of the insulation at the line end. Unlike graded insulation, the insulation in the winding is almost the same as that for the full-insulation type. The reduced neutral insulation that corresponds to the graded insulation shown in Fig. 13 is illustrated in Fig. 15. They are similar, except where marked with an asterisk and except that the insulation between the high-voltage winding and the core inclines in Fig. 13 but is straight in Fig. 15.

In shell-form transformer windings, only a small number of coils having large coil surfaces are used. Therefore, even limited reduction of insulation at the neutral end produces considerable effect, making it possible to save material and reduce mass, as well as to decrease impedance.

As a general rule, the neutral end with reduced insulation is protected by a lightning arrester, but where an arrester cannot be used, a protective gap is incorporated in the neutral bushing.

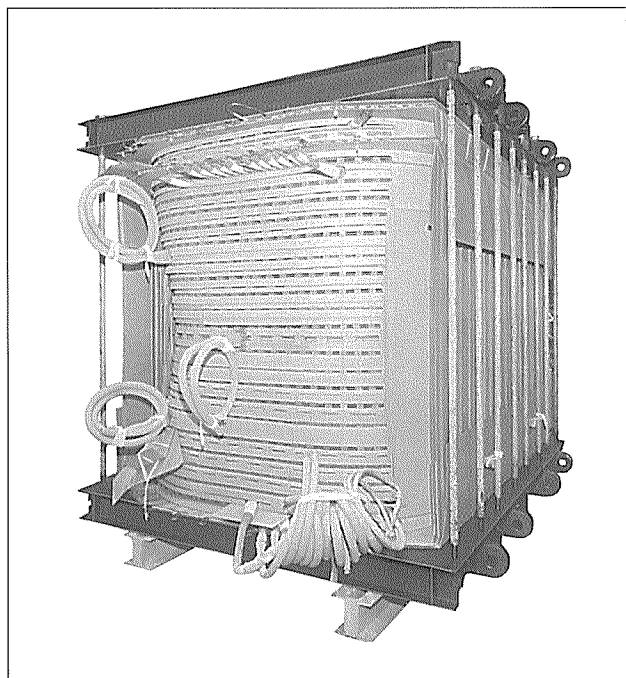


Fig. 12 Shell-form transformer coil assembly

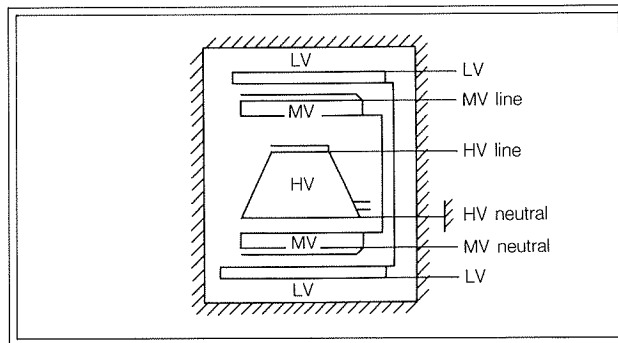


Fig. 13 Typical coil arrangement for graded insulation

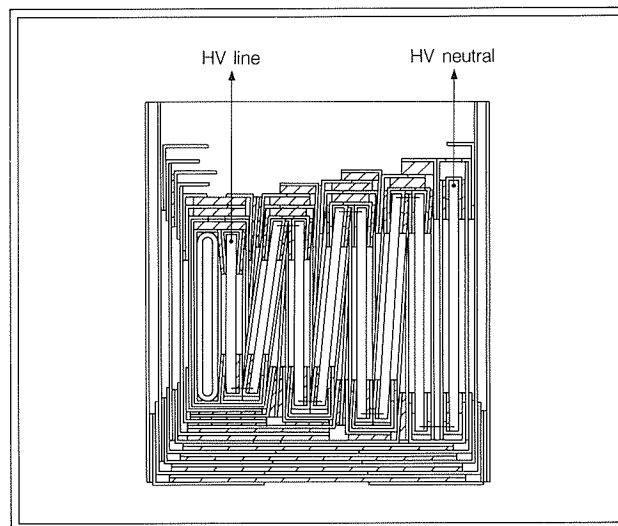


Fig. 14 Coil insulation assembly of graded-insulation winding

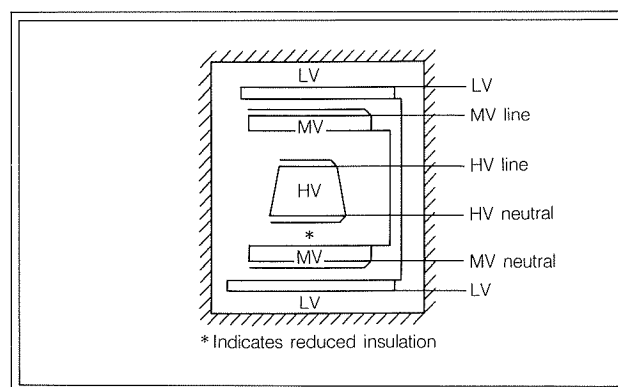


Fig. 15 Typical coil arrangement for reduced neutral insulation

5 FORM-FIT TANK CONSTRUCTION

The Form-Fit transformer represents the latest advances in shell-form construction. The tank is constructed to fit the core and coil assembly closely, for the fullest utilization of the features of the shell-form transformer.

The coil of the shell-form transformer is entirely wrapped with insulation and this in turn is surrounded by the core. There is, therefore, no fear of damage due to external influences, and it is unnecessary to provide insulation spacing. For this reason, no clearance other than that required for assembly is needed between the core and the inside of the tank. In Form-Fit transformers, this clearance is further reduced, and the core, coil and tank are assembled in one piece.

Fig. 16 shows a cross section of a conventional shell-form transformer, and of a Form-Fit transformer. The end frames of the conventional type are made of steel channel and steel angles (Fig. 16a), to support the core and winding, but the tank of the Form-Fit transformer is made in two sections, upper and lower (Fig. 16b). The lower tank section supports the coil and winding, serving at the same time as the lower-end frame into which the insulated coil is placed upright with the core stacked up around it.

After the completion of internal-lead connection, the upper tank is lowered onto the core and coil assembly, and welded to the lower tank at the flange. In the conventional type, upper- and lower-end frames are clamped with bolts, but the core of Form-Fit transformers is clamped by the side plate of the tank eliminating the need for bolts while saving space.

In order to let a small quantity of oil also flow to the outside of the core, all four sides are provided with spacers, as shown in Fig. 16b, which allows adjustment of the gap between the tank and core when the upper tank is lowered onto the assembly.

In rare case, the vibration or creak noise of spacers, which doesn't disturb the transformer normal operation, may occur due to the manufacturing tolerances of spacer itself and upper tank.

The construction advantages of Form-Fit over conventional types may thus be summarized as follows:

1. The tank is built to fit the core-coil assembly very snugly.
2. The lower tank supports the core and winding, serving as the lower-end frame.
3. No bolts are used to clamp the coil and core.
4. Completely welded construction is used.

Coil and core construction of the Form-Fit type are exactly the same as those of the conventional type.

The features of the Form-Fit type are :

1. As will be apparent from the above, reductions of both mass and installation space are possible, and in particular, the oil quantity is reduced by more than 30%.
2. It is easy to transport the transformer on its side. Since all four sides of the core are firmly clamped by the tank, the two reinforce each other and prevent the core and winding from slipping out during transportation, and since the mass and dimensions are considerably reduced, even a large-capacity transformer can be transported either upright or on the side without disassembly.
3. In erecting the transformer, a small-capacity crane well serves the purpose. The assembly of a conventional-type transformer requires that the whole core and coil assembly be lifted up, while the Form-Fit type can be built up in order from the bottom. The upper tank can be placed without the necessity of lifting the entire core-coil assembly; the maximum single lift being generally the mass of the coil of one phase. Fig. 17 shows the inside assembly of a Form-Fit transformer.

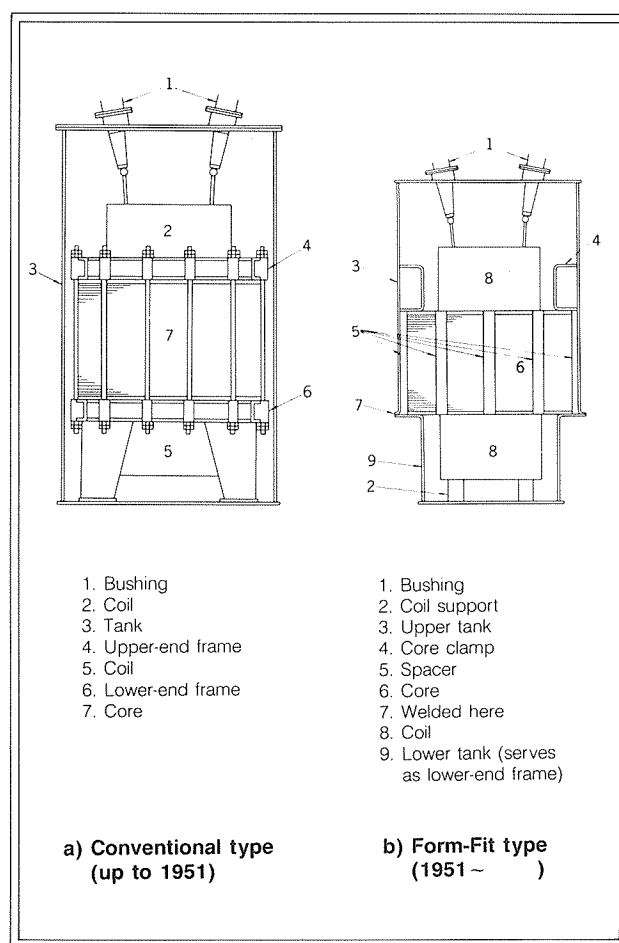


Fig. 16 Cross sections of conventional and Form-Fit transformers

4. As the tank is of completely welded construction, no gaskets are necessary and there is no fear of oil leakage.
5. The cooling effect has been improved. As explained above, the shell-form coil is suited to cooling. In the Form-Fit type, however, the space between the tank wall and the core is extremely small, so that most of the oil flows inside the winding to cool it. Therefore, in spite of the small quantity of oil, Form-Fit construction provides an improved cooling effect over the conventional shell-form type, proving an advantage in forced-oil cooling.

Form-Fit transformers were first built in 1951, and since then this construction has been adopted as standard for Mitsubishi shell-form transformers. Up to the present, more than 1,700 such transformers have been turned out and the superior features of this design are widely recognized.

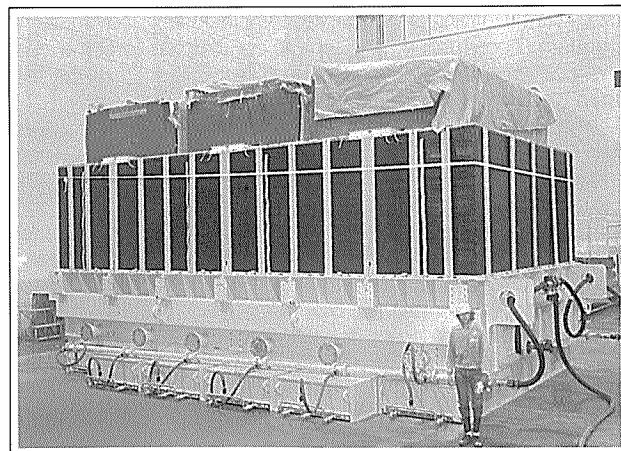


Fig. 17 Inside assembly of Form-Fit transformer

6 COOLING SYSTEMS

6.1 Oil-Immersed, Self-Cooled (SR)

The simple construction, ease of operation, high reliability and excellent durability of the oil-immersed self-cooled system makes it the most generally used in present-day transformers.

Units can be manufactured up to 50,000kVA capacity, but larger capacity transformers require a number of radiators, causing increases in oil quantity, cost, and floor space. Thus for transformers larger than 30,000kVA, self-cooling is not recommended and is only supplied when specifically requested. A seam-welded radiator is standard. This radiator, shown in Fig. 18, is composed of two polished steel plates welded together at both edges and on four lines in the middle, and inflated with compressed air to take its characteristic form. The upper and lower edges are bent into flanges and welded

to the adjacent radiating tubes to form one side of a header with a suitable slope, providing for easy inspection and maintenance, and preventing corrosion.

These seam-welded radiating tubes have the advantages that the amount of oil in the radiator can be considerably reduced in relation to the cooling surface, and that the mechanically rugged construction is capable of withstanding a full vacuum.

Since valves are provided at the upper and lower parts, the radiator can be removed for transportation or replacement, without draining the oil from the tank. As shown in Fig. 19, the radiator valve is a butterfly type and is operated from the outside. An operating tool is supplied with each transformer.

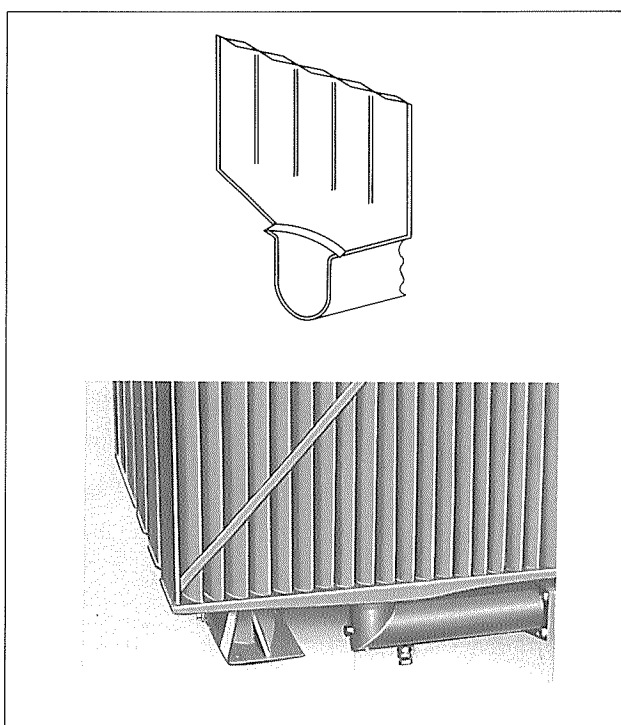


Fig. 18 Seam-welded radiator

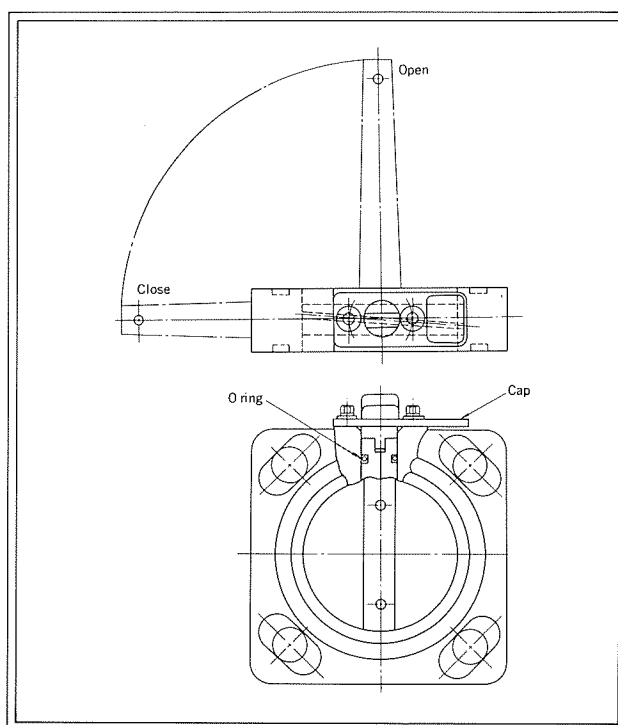


Fig. 19 Radiator valve

6.2 Oil-Immersed, Forced-Air-Cooled (SRB)

The use of cooling fans in conjunction with the seam-welded radiator characterizes oil-immersed forced-air cooling. The cooling effect is increased 150~200% over self-cooling, corresponding to an increase of 20~40% in transformer output.

The Form-Fit tank is rectangular and is equipped with radiators in parallel.

The standard arrangement of cooling fans is 2 fans or more for each group of radiators, arranged to blow air from the side. Fig. 20 shows a transformer of this type. Seam-welded radiators are best suited to this application. A powerful, rugged cooling fan driven by a 550W 3-phase motor is used (Fig. 21).

6.3 Forced-Oil, Forced-Air-Cooled (SUB)

Designed for large power transformers, the Type NEFP forced-oil, forced-air cooler (Fig. 23) is far superior to the self-cooling type in that its cooling efficiency is high and yet the weight and space factors per unit of cooling capacity are lower.

Mitsubishi forced-oil, forced-air-cooled transformers have the coolers required for the capacity directly attached to the transformer main body.

As shown in Fig. 22, steel fins are attached to the outer circumference of the tubes at optimum pitch, and both the tube and fins are hot-dip-galvanized to provide ample corrosion resistance. Both ends of the cooling tube are welded to the upper and lower parts of the inner shell; thus there is no fear of oil leakage. The standard arrangement is in four staggered lines.

There are five cooler units offered, differing according to the number of cooling fans attached: Types NEFP-1, NEFP-2, NEFP-3, NEFP-4, and NEFP-5. An oil pump is attached to the lower part of the cooler, forcing the oil to circulate downward from the top.

Cooling fans are attached in the cooling fan box, and are installed so as to draw hot air out of the cooler element.

An oil-flow indicator, attached to the lower part of the cooler in an easily visible position, controls oil-pump operation. Table 1 shows the standard specifications of the cooler auxiliaries.

The oil pump, shown in Fig. 24, is constructed integrally with an oil-immersed motor in a single totally enclosed welded-metal-plate casing. Thus oil can never leak from the shaft or other parts. An oil-flow indicator (Fig. 25) is interposed between the cooler and the pump. The angular displacement of the vane in the case is transmitted by means of a magnetic coupler to an external pointer, which shows the volume and direction of the oil flow, acting as a check on pump operation.

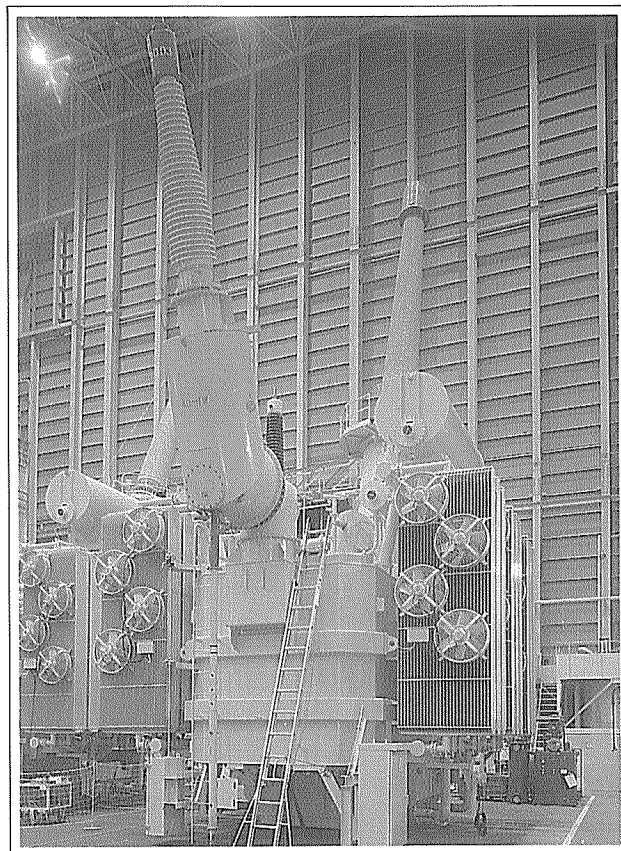


Fig. 20 300-400-500/3MVA, 500kV, single-phase, ONAN-ONAF-ONAF autotransformer

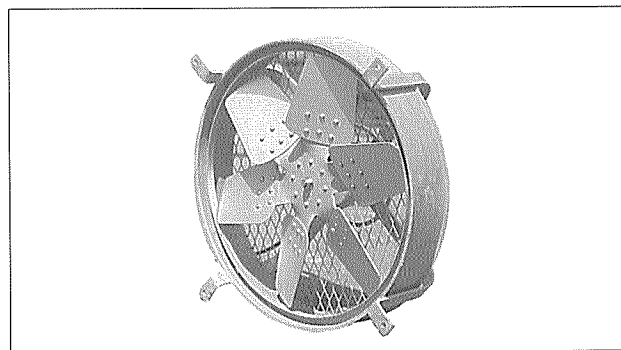


Fig. 21 Type KBW fan

Table 1 Standard Specifications of Type NEFP Cooler Auxiliaries

Type			NEFP-1	NEFP-2	NEFP-3	NEFP-4	NEFP-5
Oil pump	Output (kW)		2.0		3.7	5.5	5.5
	Oil flow (ℓ/min.)		2000		3000	4500	4500
Cooling fan	Number per unit		1	2	3	4	5
	Output (kW)	50Hz	1.0	2.0	3.0	4.0	5.0
		60Hz	0.75	1.5	2.25	3.0	3.75
	Output airflow (m ³ /min.)	50Hz	220	440	660	880	1100
		60Hz	200	400	600	800	1000

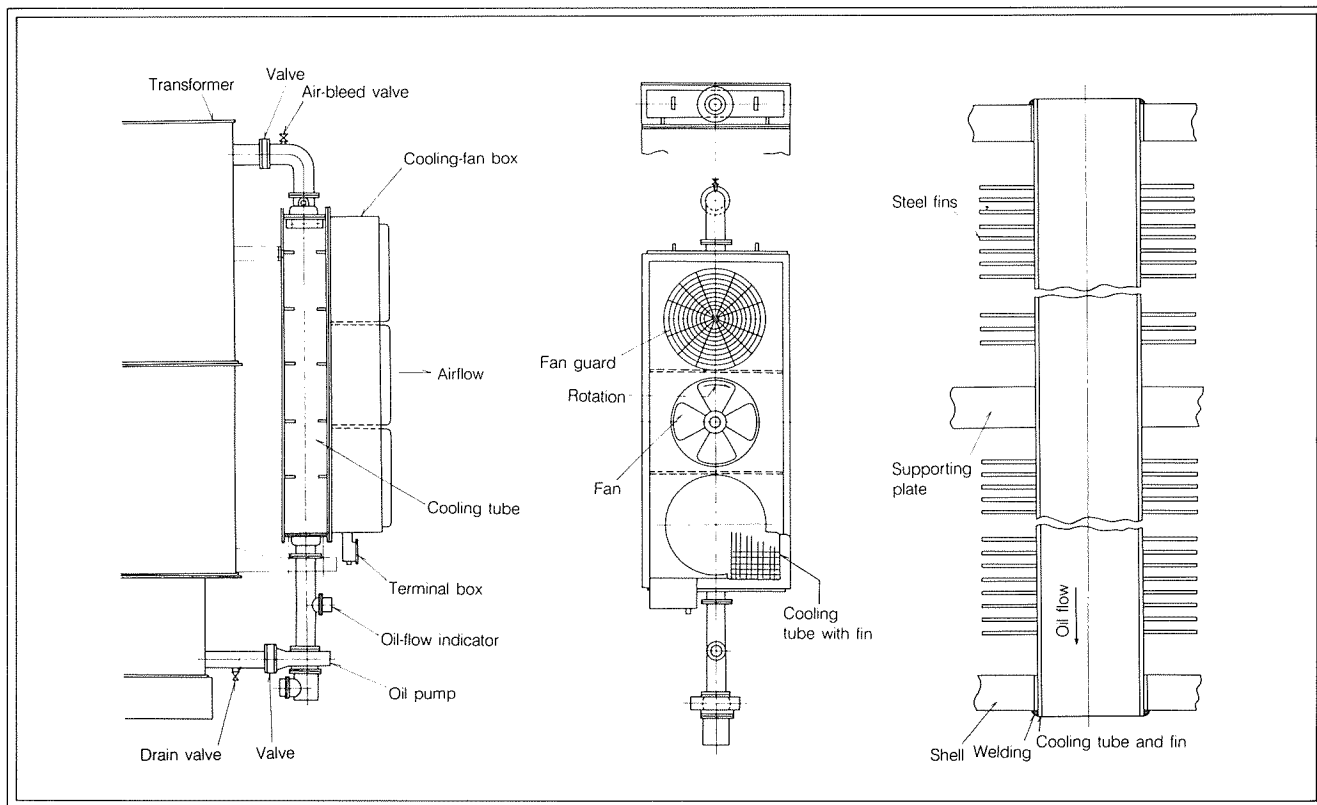


Fig. 22 Construction of Type NEFP forced-air forced-oil cooler tube and fin details

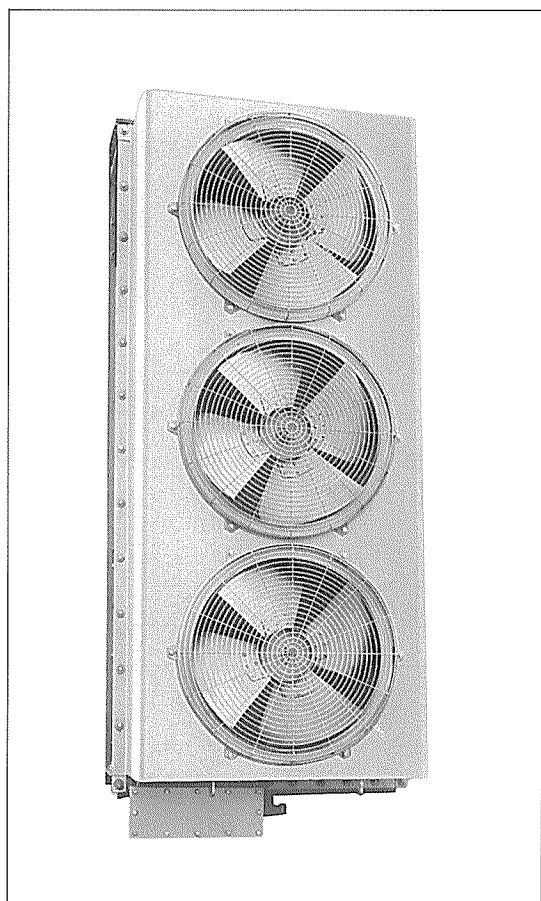


Fig. 23 Type NEFP cooler unit



Fig. 24 Oil pump

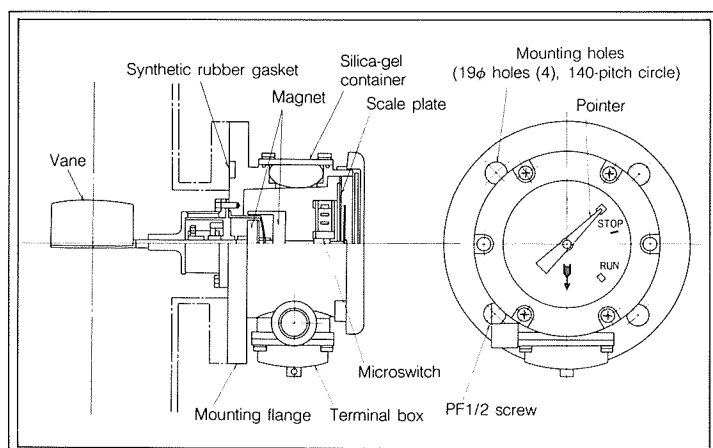


Fig. 25 Type OR oil-flow indicator (inner mechanism)

Type NEFP coolers are equipped with 1 ~ 5 powerful fans (Fig. 27) each driven by a 0.75~1.0kW motor.

Type NEFP coolers lose most of their cooling effect if the pump or fans stop, and the transformer has no continuous capacity in this case. However, since the transformer can generally continue for 1/2 hour at full load or for 1 hour at 75% load, during which period it may be possible to restore pump and fan operation, it is not necessary to disconnect the transformer from the line immediately.

When a continuous self-cooling capacity is required, however, seam-welded radiators equipped with oil pumps and fans are adopted (Fig. 26).

In such cases, it is common practice to give the transformer a double rating (self-forced-oil, forced-air) or a triple rating (self-forced-air/forced-oil/forced-air), the ratios running in the area of 60/100 and 60/80/100.

When forced cooling is used, the cooling equipment can be controlled to change the cooling method in double- or triple-rated transformers, or to stop some of the cooler units according to the transformer load or temperature. Such control can be accomplished either manually or automatically, by the cooler control panel (Fig. 28).

With newer cooling devices having high reliability and improved efficiency, however, it is preferable to operate the transformer at low temperature with all the coolers operating, thus

extending transformer life, rather than to attempt to reduce an already small auxiliary loss with a complicated control device. In fact the reduction of copper loss due to lowered operating temperature is sometimes larger than the increase in auxiliary loss.

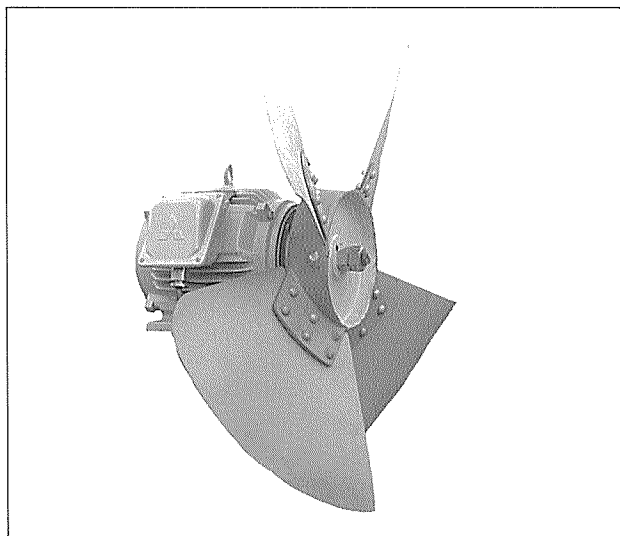


Fig. 27 Fan for Type NEFP cooler

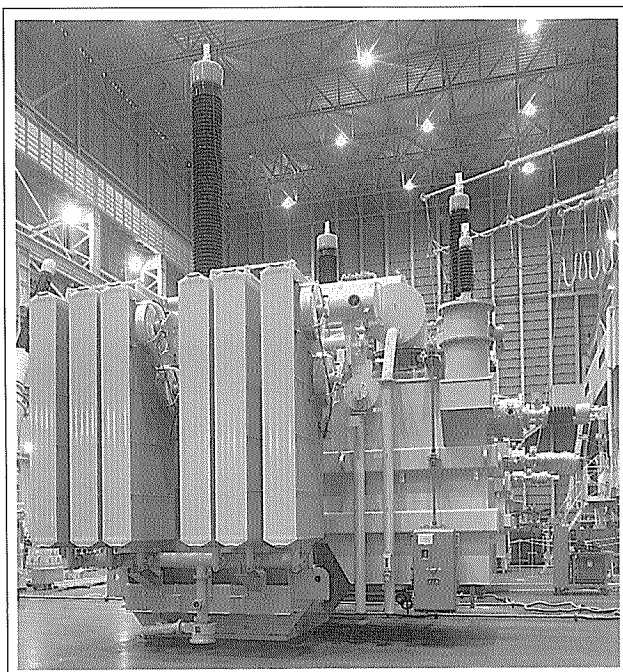


Fig. 26 450-600-750/3MVA, 500kV, single-phase, ONAN-ONAF-OFAP autotransformer



Fig. 28 Cooler control panel

6.4 Forced-Oil, Water-Cooled (SUW)

This system is used when water is the coolant. The high specific heat and heat conductivity of water make it a superior cooling medium, and water-cooled transformers can get by with the smallest coolers.

In this system, the oil pump is located between the transformer and the cooler, and the oil is cooled by the water (Figs. 29 and 30).

Coolers are directly mounted on the side of the transformer tank, the number being determined by requirements. As in SUB cooling (§6.3), an oil-immersed pump is used and it is generally mounted on the oil-inlet side of the cooler so as to increase transformer oil pressure.

The outside appearance of a cooler is shown in Fig. 29. This cooler consists of a single or a double cooling tube (the outer tube and the inner tube), the tube plates, the shell, the water compartment, the leak detector, and other parts.

The hot oil within the transformer flows from the oil-inlet flange into the cooler, flows along the baffle plates that are provided outside the cooling tube, and re-enters the transformer from the oil-outlet flange.

Simultaneously with the circulation of the oil, the cooling water enters from the water-inlet flange into the water compartment, flows through the cooling tube at a speed of about 1 meter per second, and flows from the water-outlet flange to the water piping outside the cooler.

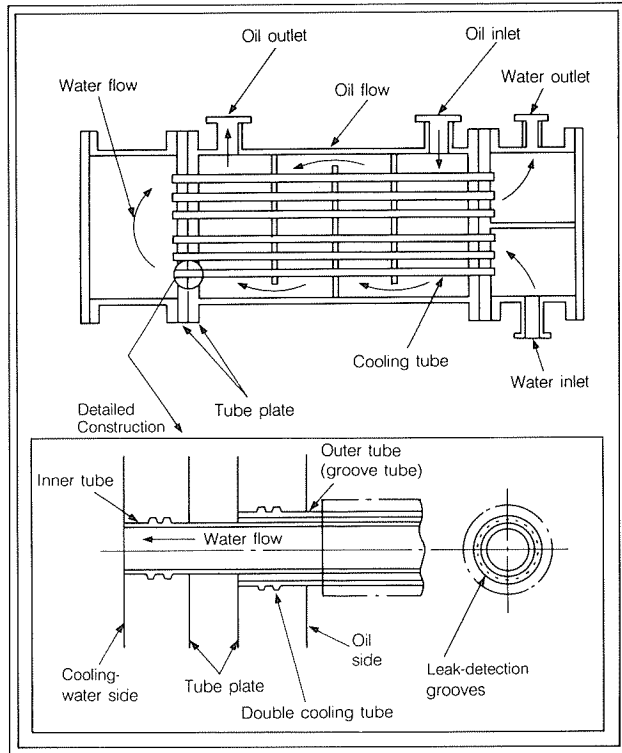


Fig. 30 Construction of Type DW oil-to-water cooler

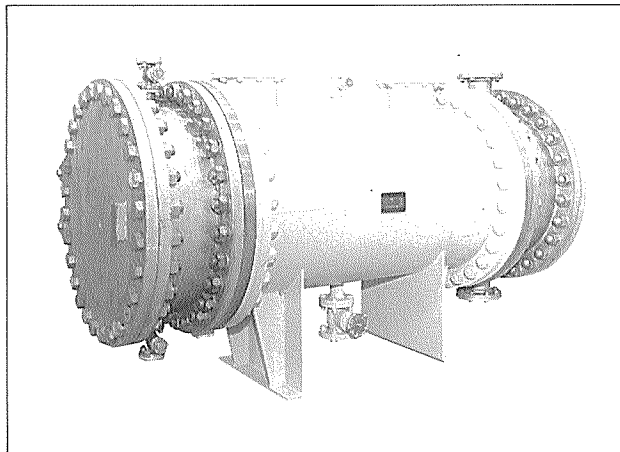


Fig. 29 Oil-to-water cooler

6.5 Forced-Oil Self-Cooled (SUR)

For reduction of noise, as in substations located in the center of a city, the main body of the transformer is sometimes installed indoors, and the radiators are grouped separately outdoors. In such cases, forced-oil self-cooling is employed, with an oil pump installed between the transformer and the radiator banks, instead of depending upon natural convection.

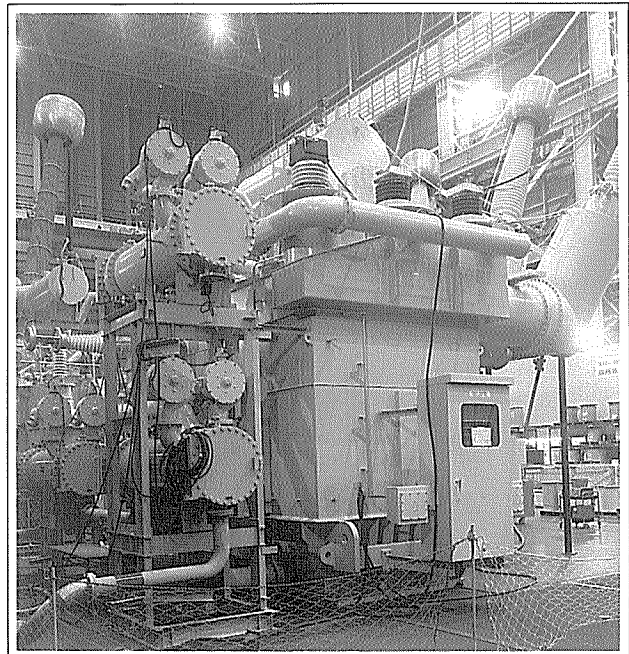


Fig. 31 437.5MVA, 275kV, three-phase, OFWF generator transformer

7 TRANSPORTATION AND ERECTION

7.1 Transportation

7.1.1 General

The mass and size of large power transformers always present a transportation problem. The transformer can be strictly tested at the factory on completion, and if it can be installed on-site as is, the highest reliability will be obtained. For this reason, it is Mitsubishi standard practice to transport transformers already assembled.

If, however, there are mass or size limitations, accessories such as bushings, coolers, conservator, etc., are removed, so that high reliability is maintained, yet on-site erection is accomplished easily.

The Form-Fit construction is best suited to pre-assembled transport because: 1) the transformer can be laid on its side, 2) outline dimensions and mass are small, and 3) design freedom is high. Form-Fit transformers can thus be designed to meet almost all transportation limitations, and can easily be adapted to any of the types of freight cars commonly used in transporting heavy machinery (Figs. 32 ~ 34).

7.1.2 Special Three-Phase Transformers

Where standard vehicles are not big enough to allow ordinary pre-assembled transport, the special three-phase design is adopted, which enables any transformer to be shipped in three pre-assembled units.

The special three-phase transformer is exactly the same as the ordinary type in characteristics, appearance and operation, save that its shipping mass is considerably less. In the standard construction, the lower and middle tanks of each phase

are separate, and the upper tank is common for all three phases, which are connected internally. It is possible to separate each phase up to the upper tank if necessary, and to accomplish interphase connection in oil through a window provided on the connection part, thus requiring no more bushings than are used in the ordinary three-phase type.

The special three-phase construction is shown in Fig. 35, and Fig. 36 shows the special features of the core configuration. The shaded portions shown in Fig. 36 b are added to the ordinary three-phase core, and each phase is separated and acts as single-phase unit. The increase in overall final dimensions incidental to this convenient construction is negligible.

7.2 Erection

Shipping the transformer pre-assembled does involve the tasks of righting it if shipped on its side, or of assembling the three phases of the special three-phase type, but these can be carried out using temporary support beams, and there is no need for inspection or drying of the core and coil. It is also unnecessary to provide an assembling room and crane.

Normally, vacuum filling with de-aerated oil is carried out after assembly.

For details of erection at site, refer to the instruction book for Form-Fit shell-form transformers (IB-66280).

In the event that pre-assembled transport is impossible and it is necessary to disassemble the transformer into coil, core, and other sections, the assembly procedure is exactly the same as that employed at the factory, including drying after assembly. Since it is unnecessary to lift up the entire core and coil assembly, the mass of the coil of one phase is the maximum mass to be lifted, and a small-capacity crane suffices.

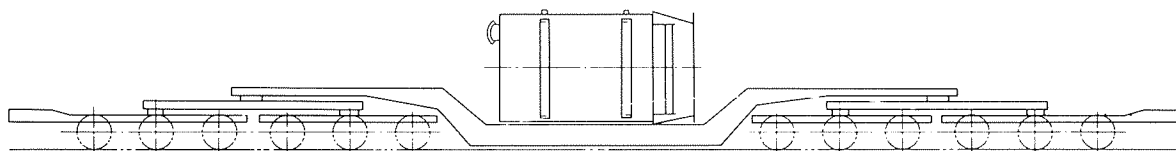


Fig. 32 Well wagon

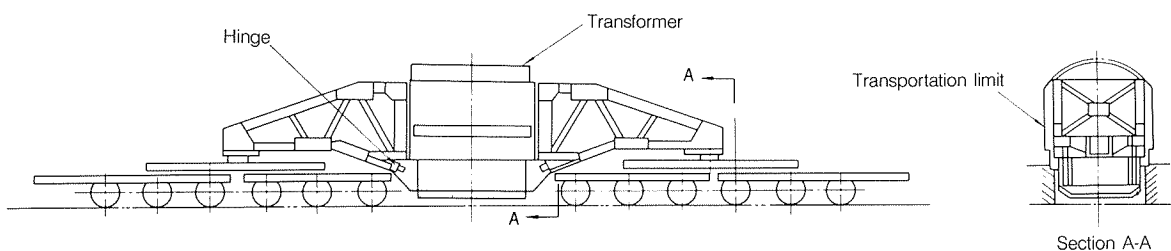


Fig. 33 Schnable-type wagon

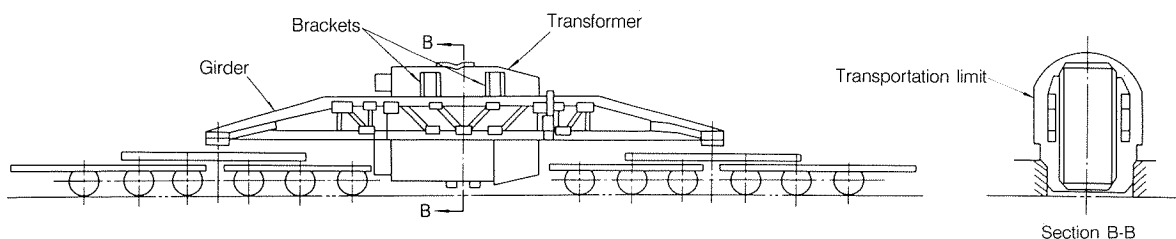


Fig. 34 Girder wagon

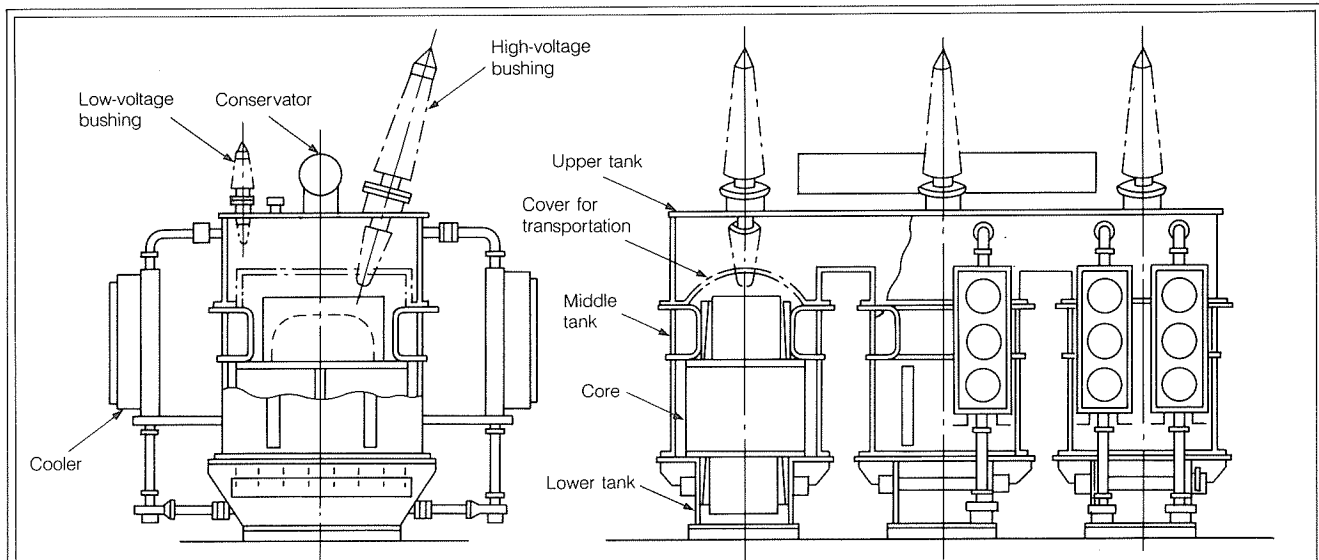
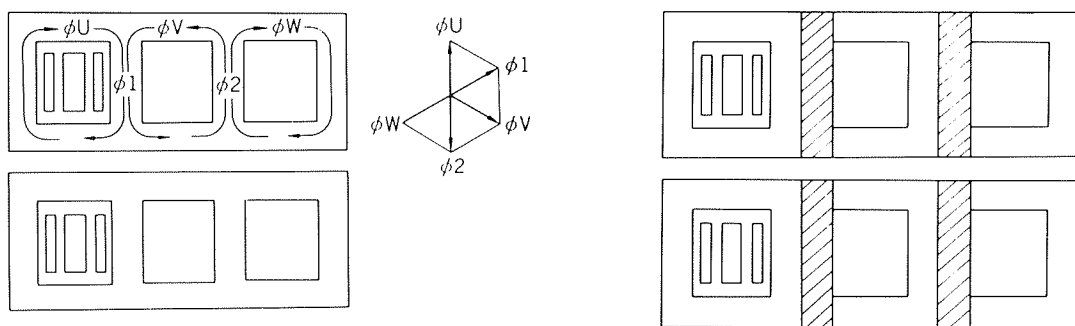


Fig. 35 Special three-phase Form-Fit transformer



a) Ordinary three-phase core

b) Special three-phase core (the shaded areas show added portions)

Fig. 36 Magnetic circuit of three-phase shell-form transformer

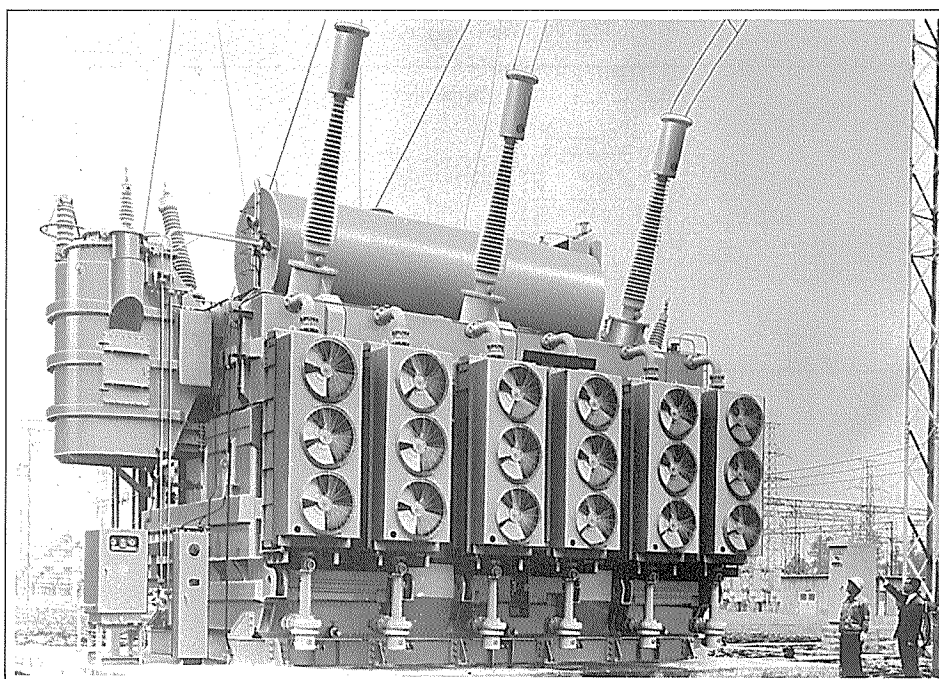


Fig. 37 275/147/63kV, 300/300/90MVA special three-phase transformer

8 STANDARD ACCESSORIES

8.1 Bushings

Type OT perfectly sealed condenser-type oil-filled bushings are standard for transformers above 34.5kV, and plain bushings are standard for those under 25kV.

OT condenser-type bushings are an exclusive product of Mitsubishi Electric. They are made with alternate layers of insulating paper and aluminum foil on a copper or brass core, forming cylindrical concentric capacitors of identical static capacity that give uniform potential distribution from the center to the grounded end of the flange. Though narrower, this bushing has very high dielectric strength compared to oil-filled or compound-filled bushings, which have a marked potential gradient near the center.

Mitsubishi Electric has been making condenser-type bushings for over 60 years, during which time vast improvements have been made. The present OT bushing is wound, like a power capacitor, with the highest-quality kraft paper and is vacuum-filled with quality condenser oil, so that its dielectric strength is very high.

In addition, the main element is encased in upper and lower porcelains, which are filled with oil and tightly sealed. This virtually precludes deterioration of the bushing characteristics.

The porcelains use no cemented flange, a mechanical defect of conventional types. The upper and lower porcelains are fastened with upper, center and lower flanges provided with gasketed joints by means of powerful springs.

This is called the center-clamp method and gives the strongest mechanical properties. There is an expansion chamber at

the top to provide for expansion and contraction of the oil and for differences in expansion coefficients, so that the bushing will undergo no mechanical strain. Both corkprene and hard neoprene gaskets are used, and constant spring pressure ensures that there will be no oil leakage from these gasket joints.

In comparatively low-voltage circuits, up to 20kV, there is little restriction on bushing insulation, so that the Type PO plain bushing without capacitor is employed as standard.

Even in this type of bushing, the rolling-fit method is adopted, whereby the flange is fixed to the porcelain by means of roller fitting through the gasket material without cementing the flange, in order to prevent stress concentration on the porcelain part. Thus the bushing has high mechanical strength and withstands impact well.

8.2 Conservator and Pressure-Relief Device

Insulating oil has a large expansion-coefficient, and its level rises and falls considerably with changes in temperature. However, if a large cavity is provided inside the upper part of the tank, the area of contact between the oil and air increases, causing faster deterioration of the oil.

To minimize this effect, a separate tank having a capacity of a very small amount of the oil in the main tank is connected to the transformer via narrow piping. This tank, called a conservator (Fig. 40), reduces the area of contact between oil and air, thus minimizing deterioration of the oil, and also preventing the

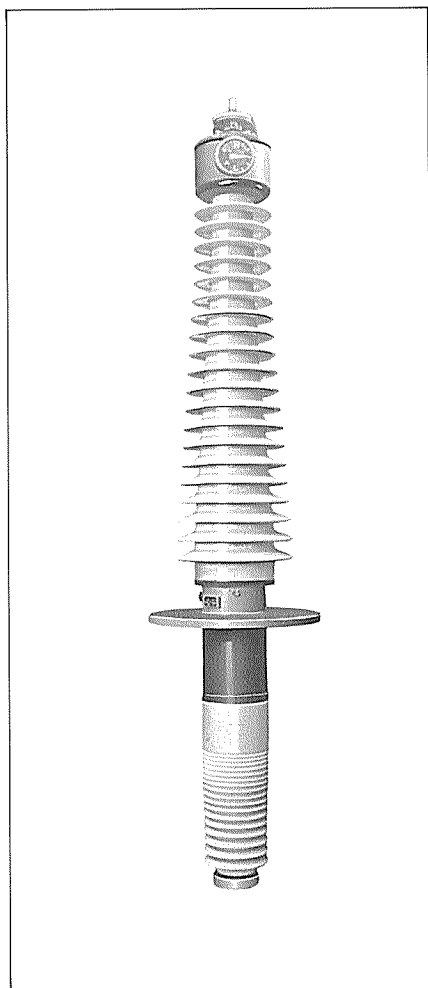


Fig. 38 Type OT condenser bushing

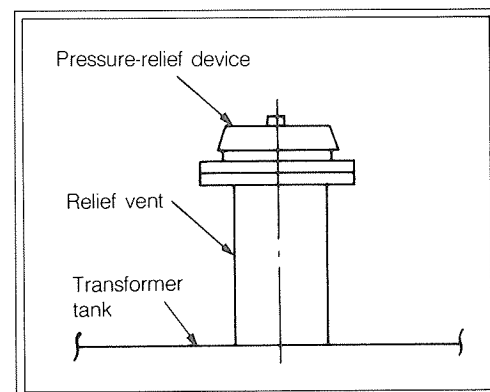


Fig. 39 Pressure Relief Device

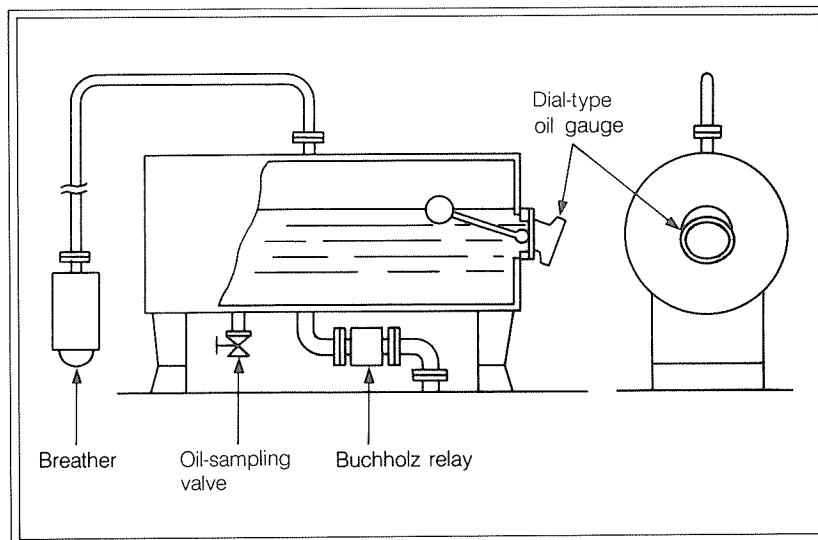


Fig. 40 Conservator

hot oil in the upper part of the tank from contacting the air directly, so that there will be less oil sludge produced as a result of oxidation. Any sludge formed settles in a sedimentation tank under the conservator and does not enter the transformer tank. The tank can thus be filled to the very top with oil, thereby applying pressure to the cover gasket, manholes, hand-holes and bushings to keep moisture out.

Should transformer fault occur, a pressure-relief device provides for the release of abnormally high gas pressure produced in the oil as a result of arcing, etc. As shown in Fig. 39, the pressure-relief device is provided as standard on the top of the transformer tank. The pressure-relief device, a mechanically closing type, detects abnormal pressure rises in the transformer tank. The operating pressure of the device is set to 0.083MPa. Furthermore, if desired, operation conditions can be signalled by an alarm or trip sounded by contacts provided.

8.3 Buchholz Relay

The Buchholz relay is another device well established for serving the same function as the sudden-pressure relay; it actuates an alarm in response to minor trouble, and interrupts power in the event of a major fault.

Both solid-insulating and fluid-insulating materials give off vapor when subjected to the high temperatures and pressures incidental to a fault condition; at the same time, a surge in oil flow occurs. The quality and color of the gas give an indication of the nature of the trouble, and the quantity gives an indication of the magnitude.

The Buchholz relay (Fig. 41) is connected in the pipe that

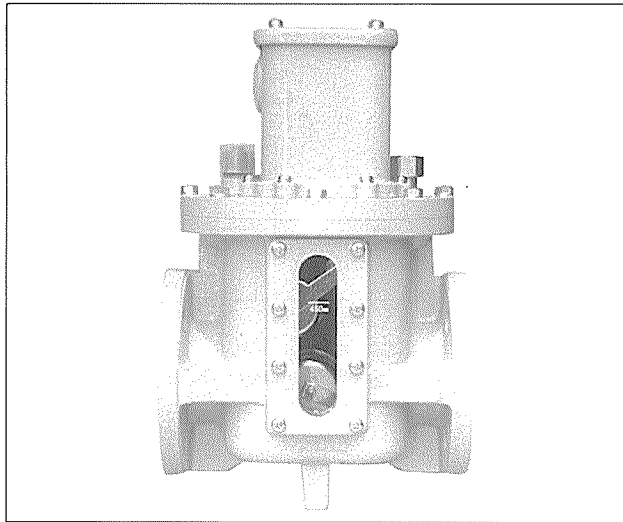


Fig. 41 Buchholz relay

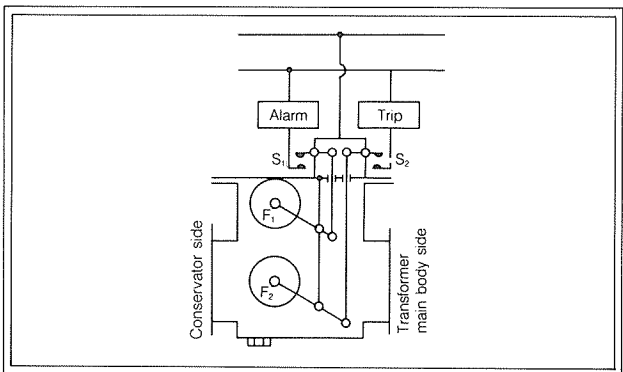


Fig. 42 Operational principle diagram

links the main tank and the conservator (Fig. 40). Gas, being buoyant, accumulates and lowers the level of float F_1 (Fig. 42) causing contact S_1 to close and actuate the alarm. If the fault is of major proportions, float F_2 is deflected by the surge in oil flow, causing contact S_2 to close, thus effecting an interruption of the main power circuit.

A glass window is provided for inspection of the accumulated gas.

8.4 Base

A skid plate or skid base is provided as standard.

8.5 Valves

The transformer is provided with three valves to facilitate oil filtering, draining and sampling.

8.6 Thermometer

A dial-type thermometer is provided to measure the maximum oil temperature in the upper part of the tank.

Alarm contacts on the thermometer are connected to an alarm device on the switchboard that will sound whenever the oil temperature exceeds the specified level. The thermometer itself is usually mounted near the nameplate where it is clearly visible.

The dial-type thermometer (Fig. 43) has a double-walled sensing element with a protective tube gasketed to the transformer tank. Thus there is absolutely no oil leakage at the thermometer, which can even be detached for servicing and remounted without lowering the oil level of the tank.

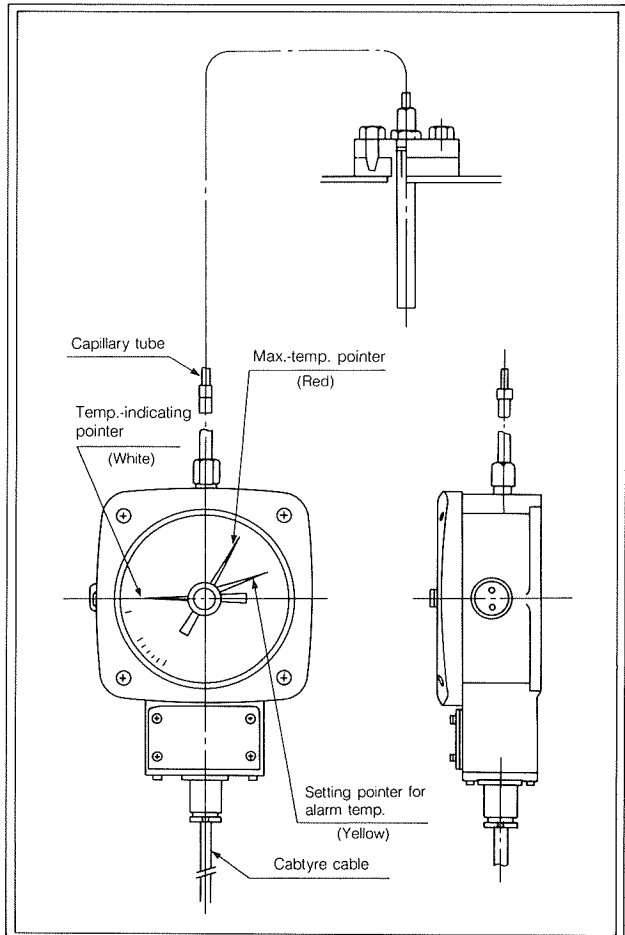


Fig. 43 Dial-type oil thermometer

8.7 Oil Gauge

A dial-type oil gauge uses a pointer to indicate the oil level. This has the advantage of being visible from a distance and, unlike with a dip-stick, contamination of the oil is not a problem in checking the oil level.

As shown in Fig. 44, this oil gauge has a float which rises or falls with the oil level. This vertical movement is converted by gears into a rotating motion, which is then transmitted to the pointer via a pair of permanent magnets inside and outside the conservator. The rotating axis does not pass through the conservator wall and no oil leakage can occur.

The gauge also has an alarm contact for indicating that the minimum oil level has been reached by sounding an alarm on the switchboard.

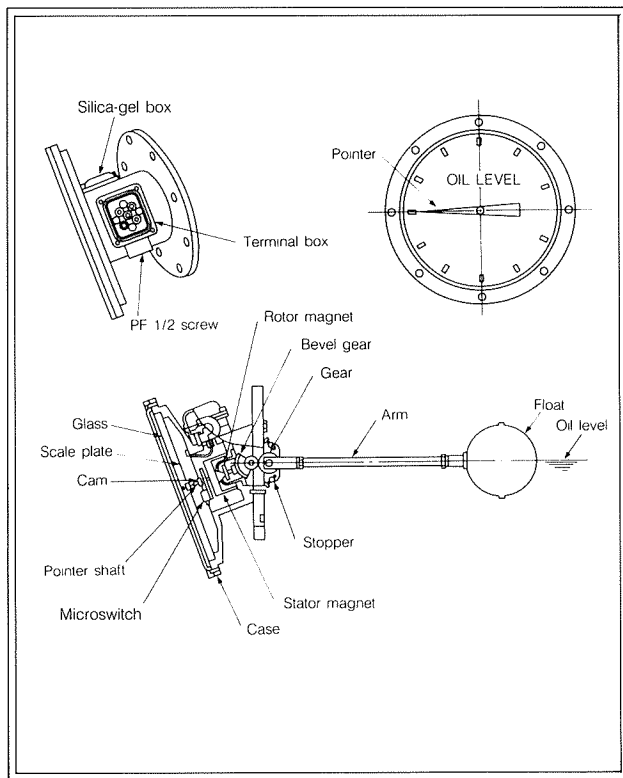


Fig. 44 Dial-type oil gauge

8.8 Dehydrating Breather

The transformer is always breathing as the oil level of the conservator rises or falls with temperature changes, and if atmospheric moisture is thereby drawn into the tank, oil deterioration is accelerated. To prevent this, a dehydrating breather is placed in the breathing path. The breather is not necessary when nitrogen gas is sealed in the tank.

To extend the life of the dessicating agent in the breather, a polyester sponge filter (see Fig. 48) is used together with oil. This keeps the dessicant out of direct contact with the outside atmosphere but permits it to absorb moisture from the air as it comes in, as well as helping to keep dust out.

The standard dessicant is blue silica-gel, which changes color as it absorbs moisture. The color can be checked easily through a glass inspection window. Silica gel can be dried and re-used, but it must be checked periodically, and replaced at least once a year.

8.9 Other Items

Lifting lugs and manholes or hand holes are provided.

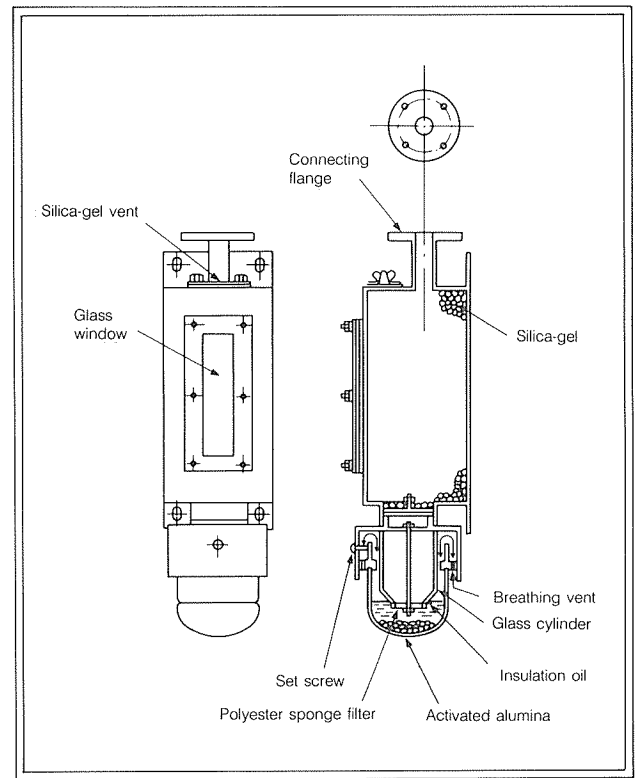


Fig. 45 Dehydrating breather

9 OPTIONAL ACCESSORIES

9.1 Oil-Preservation Equipment

The chief cause of deterioration of transformer insulating oil is oxidization and water contamination from contact with air, with the result that it is necessary to filter and regenerate the oil once every few years. However, if the oil is completely isolated from the air by means of a rubber bag-type conservator or by nitrogen sealing, deterioration of the oil will be considerably slowed, so that the transformer will operate with the same dependability as when new.

This is the reason why the oil-preservation system has come to be used increasingly, even for small-capacity transformers.

9.1.1 Rubber-Bag Type Conservator

In the rubber bag-type oil-preservation system, an oil-resistant synthetic rubber bag is provided in the conservator to prevent the air from coming into contact with the oil, providing the same function as nitrogen sealing.

The construction is shown in Fig. 46. Compensation for variations in oil volume due to expansion and contraction is made by the variation of the shape of the bag, which is therefore designed to withstand repeated expansion and contraction.

Any variation in the oil level in the main conservator is transmitted to the oil gauge by the rubber bag, which is connected to the outside via the breather, to prevent the entry of moisture.

9.1.2 Nitrogen Sealed-off Transformer

Nitrogen sealed-off transformers have gaseous nitrogen sealed in the space above the oil level in the conservator or the tank. This space is made especially large in order to keep nitrogen pressure variation, due to the expansion or contraction of the insulating oil, within the permissible range. A separate nitrogen chamber may be provided if the conservator capacity is insufficient.

The advantages of this system are high reliability, and easy inspection and maintenance due to the simplicity of construction.

9.2 Type SPO Sudden-Oil-Pressure Relay

A ratio differential relay is often used to detect transformer-insulation breakdown, but in a transformer with a wide tapping range or a rectifier transformer (for which a differential relay fails to function properly), or when an effective mechanical protector is needed to assure complete protection, a Type SPO sudden-oil-pressure relay is used.

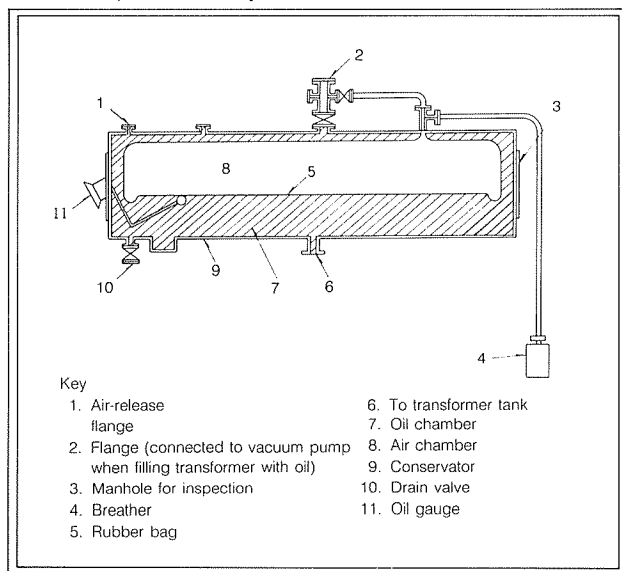


Fig. 46 Rubber bag-type oil-preservation system

When an internal fault occurs in an oil-immersed transformer, the internal pressure rises suddenly due to the arc in the oil. The internal fault can be detected by a sudden-oil-pressure relay operating by the pressure rise. The sudden-oil-pressure relay functions depending on the rate of change of pressure, and does not respond to the normal pressure variations in the tank. Figs. 47 and 48 show the appearance and construction of the relay.

The relay is attached to the transformer tank; the equalizer provides the pressure bleed for neutralizing the effect of slow pressure changes in the tank, and the microswitch-action bellows provides for detection of a sudden pressure change indicating a fault, in which case the bellows will expand and operate the microswitch. This type of relay is superior to other types in sensitivity and reliability.

The sudden-oil-pressure relay is normally adjusted to a minimum working-pressure difference of 31.4kPa/s and a minimum working-pressure rise rate of 58.8kPa/s. Thus, if gas pressure rises at a rate of 98kPa/s, the relay is actuated in 0.31~0.54 seconds. The relay stays inoperative if the rate of rise is 58.8kPa/s or below.

An externally accessible test plug is provided, allowing easy field-testing of the working characteristics of the relay.

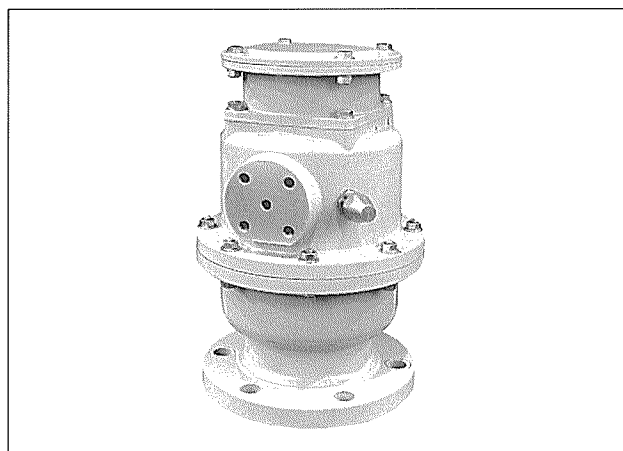


Fig. 47 SPO sudden-oil-pressure relay

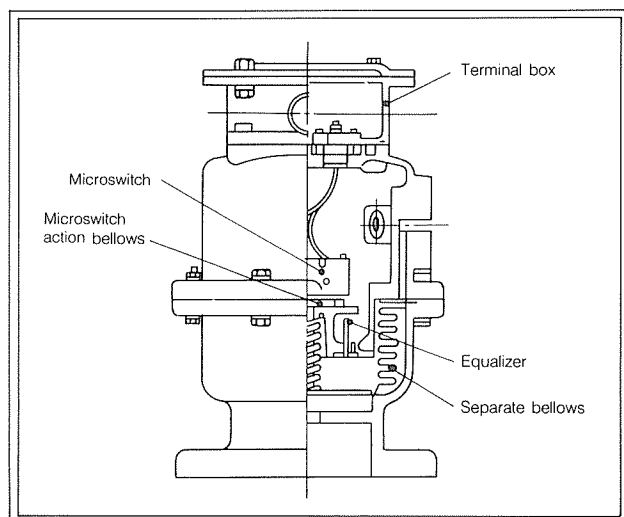


Fig. 48 Inner construction of the SPO sudden-oil-pressure relay

9.3 Off-Circuit Tap Changer

An off-circuit tap changer is used when changing tap voltages in the de-energized condition. The standard model is operated on the tank cover, but other models that can be operated on the floor by hand or motor are also available.

The off-circuit tap changer varies in construction, depending on voltage, current and the number of taps. A typical unit, shown in Fig. 49, consists of fixed and movable contacts arranged on an insulation board. The movable contact has two pairs of parallel wipers, which are firmly pressed onto the fixed points by springs.

These contacts have a self-cleaning action and even during short-circuiting stay in perfect contact by virtue of self-attraction between the parallel contacts.

The operating rod has ample mechanical and dielectric strength. It is connected to the operating handle on the cover via upper and lower universal joints, which allow the rod a certain amount of freedom of movement where it is connected and thus keeps it free from mechanical strain.

Secure seal construction is employed where the rod passes through the tank cover, to prevent oil leakage. The operating handle on the tank cover has a tap-position indicating dial and a locking device.

9.4 On-Load Tap-Changer

Transformer voltage is conventionally adjusted by means of an off-circuit tap changer on the primary or secondary winding. However, this method has considerable disadvantages in that the transformer must be separated from the line before operating the tap changer, necessitating a power outage. Also, depending on the load characteristics, transformer voltage may need frequent adjustment, and it is often extremely inconvenient to cut off the power supply each time.

The on-load tap changer solves this type of problem, and is being used increasingly as a means of offering better power-supply service.

Type MR high-voltage, on-load tap changers are manufactured under license from Maschinenfabrik Reinhausen of West Germany (Fig. 50).

Type MR tap changers are available in insulation classes ranging from 30~220kV and for currents ranging from 200~1,600A. Three-phase, Y-connection, neutral tap changing is standard. A short-duty resistor is employed as an impedance to limit the circulating current developed when bridging the taps. Tap changing is accomplished by means of a quick-action diverter switch and a tap-selector switch. The diverter switch uses four resistors to reduce contact erosion, and both the diverter and tap-selector switch are of the built-in flush type so that no live part is exposed, thus facilitating transportation and installation. The oil in the diverter switch is, of course, completely separated from that in the transformer tank, and the diverter switch can be easily lifted up independently of the main tank. These features combine to provide easy maintenance and inspection of the contacts.

The motor-driven mechanism is compactly built and can be mounted directly on the transformer tank.

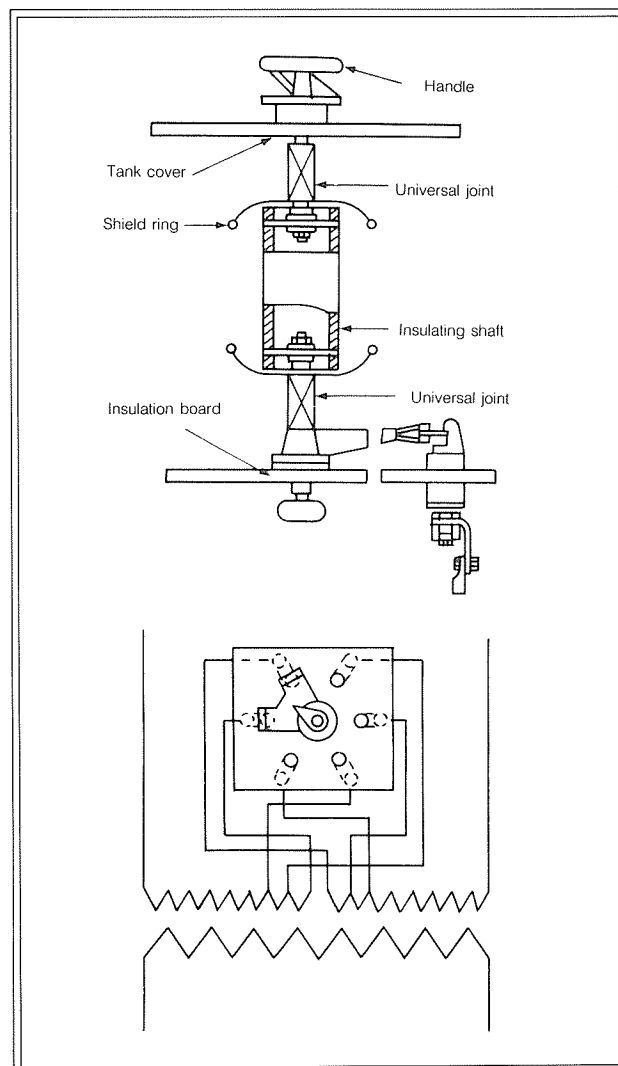


Fig. 49 Off-circuit tap changer

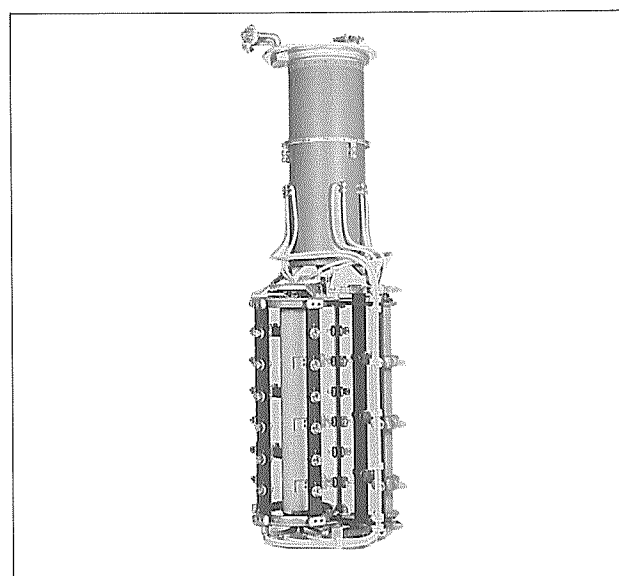


Fig. 50 Type MR on-load tap changer

9.5 Wheels

Wheels—either flanged or flat—can be fixed to a transformer base according to the customer's specification. In later models, the wheels can be turned at right angles, eliminating the need for a traverser for turning the transformer. As shown in Fig. 51, each wheel frame is fixed by means of 4 bolts, so that by raising the tank a little on 2 jacks, the wheels can be rotated and repositioned at right angles.

9.6 Anti-Earthquake Clamping Devices

To keep the transformer from moving during earthquakes, clamping devices are fixed to the foundation. The bolts for this clamp (Fig. 52) should be embedded in the concrete foundation so that the transformer, when positioned properly, may be fixed securely. The transformer can be fixed to, or unfastened from, these bolts as desired.

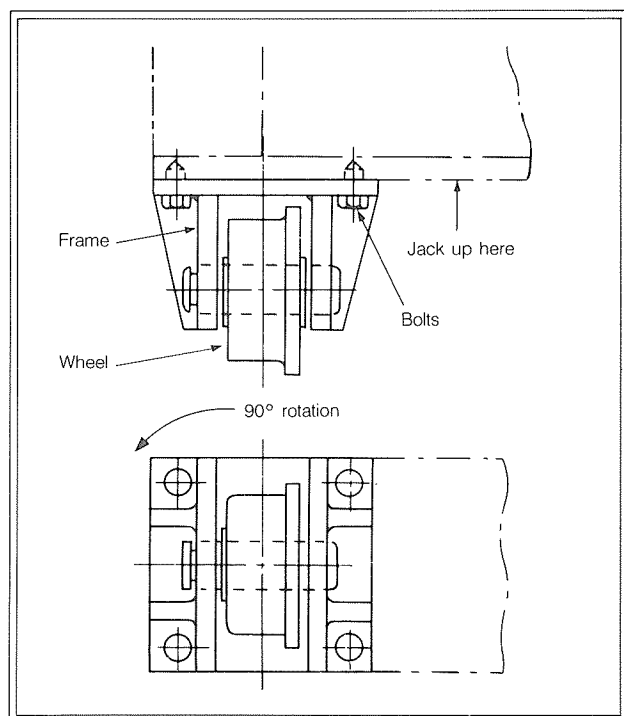


Fig. 51 Bi-directional flanged wheel

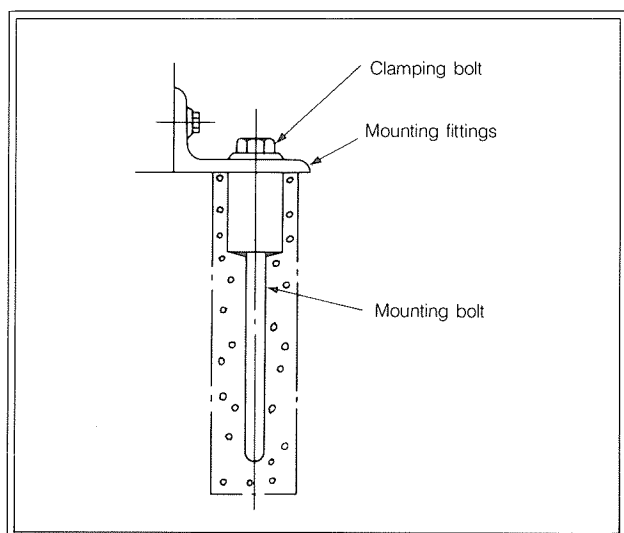


Fig. 52 Foundation bolt

9.7 Resistance Element for Temperature Detection

This provides remote indication at the switchboard of the oil and winding (coil) temperature. This temperature-sensing element is placed where the oil temperature is highest.

In measuring the winding temperature, the transformer secondary current is applied to the heat coil (Fig. 53) heating the temperature-sensing element in proportion to the load current. Then, the highest oil temperature, which now corresponds to the winding temperature, is measured.

This method of measuring is adopted because it is dangerous to insert a temperature-sensing element directly into the high-voltage coil of the transformer; on the other hand, covering the element with a thick insulator would affect its sensitivity.

The standard temperature-sensing element is the resistance type, which measures temperature by detecting changes in resistance via a bridge circuit.

The switchboard is fitted with a thermometer, a control resistor, switch, etc., and can be used for measuring the temperature of a group of several transformers. Lead-wire resistance must be 0.4 ohms or less, for accurate indication.

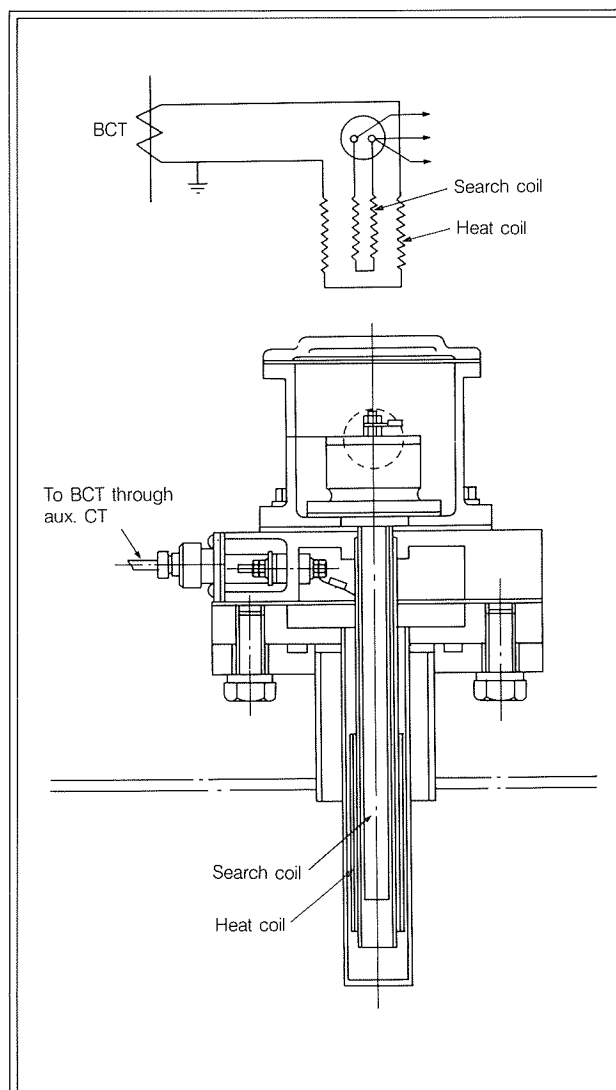


Fig. 53 Resistance element for temperature detection

10 CONSTRUCTION OF SPECIAL TRANSFORMERS

10.1 Cable-Connected (Elephant) Transformers

Even in indoor substations in built-up areas and in underground power stations it has been standard practice to connect power-cable heads to the transformer bushings in the air. This method, however, requires large air-gap insulation, which means a larger installation area and a larger building to house the transformer. To overcome this disadvantage, a new method has been developed whereby power cables are connected directly to the transformer in the oil. This so-called cable-connected system is now employed at a number of installations around the world. Because no live parts are exposed, greater protection is assured, both for personnel, and for the equipment itself against damage from salt-laden air or dust. In cable-connected transformers, the transformer bushings and cable heads are connected in a separate connection box. Fig. 54 shows a cable-connected transformer.

Transformers under 20kV are normally connected to the cables in the air-filled connection box.

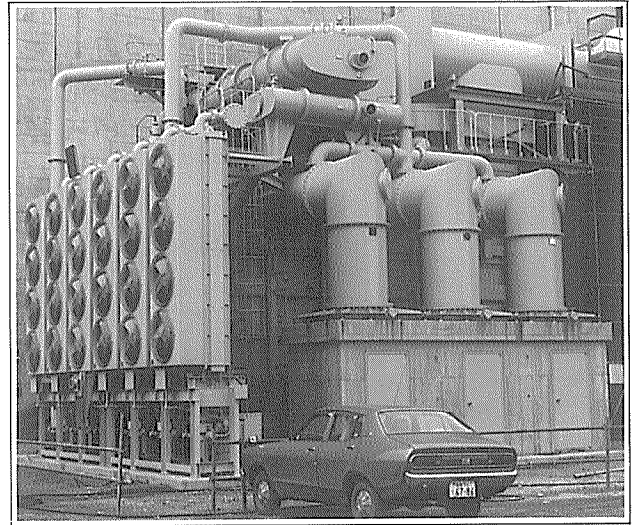


Fig. 54 870MVA 281.25/16.575kV cable-connected transformer

10.2 Autotransformers

Autotransformers are used to connect two solidly grounded systems. With one portion of the high-voltage and low-voltage windings in common, the mass and dimensions can be reduced, and efficiency improved. The construction of the Mitsubishi shell-form transformer is also suited to the autotransformer, as it gives a large degree of design freedom and easy drawing out of the tap leads. A number of large-capacity autotransformers have been built, including many 500MVA 500/275kV single-phase units for Japanese EHV systems. Hundreds of this type have also been exported to many countries as over the world.

10.3 Low-Noise-Level Transformers

Increasing industrial noise has aroused concern, leading to the formulation of antinoise regulations in many big cities. On the other hand, the growing demand for power has resulted in a steady increase in substation facilities in these areas. This situation has boosted the demand for low-noise-level transformers.

To lower the noise level of transformers, the flux density of the core may be lowered, and more care can be taken in core construction, but these steps cannot effect a decrease of more than 10dB. If further reduction is required, transformers must be soundproofed as shown in Fig. 55.

Self-cooling is used as far as possible, but where this is insufficient, a water-cooled system or a forced-air-cooled system using low-noise-level fans is employed. Mitsubishi transformers show extremely low noise levels; in fact, they are considerably below the levels specified in NEMA standards. However, when it is desired to reduce noise levels even further, a soundproof barrier can be provided.

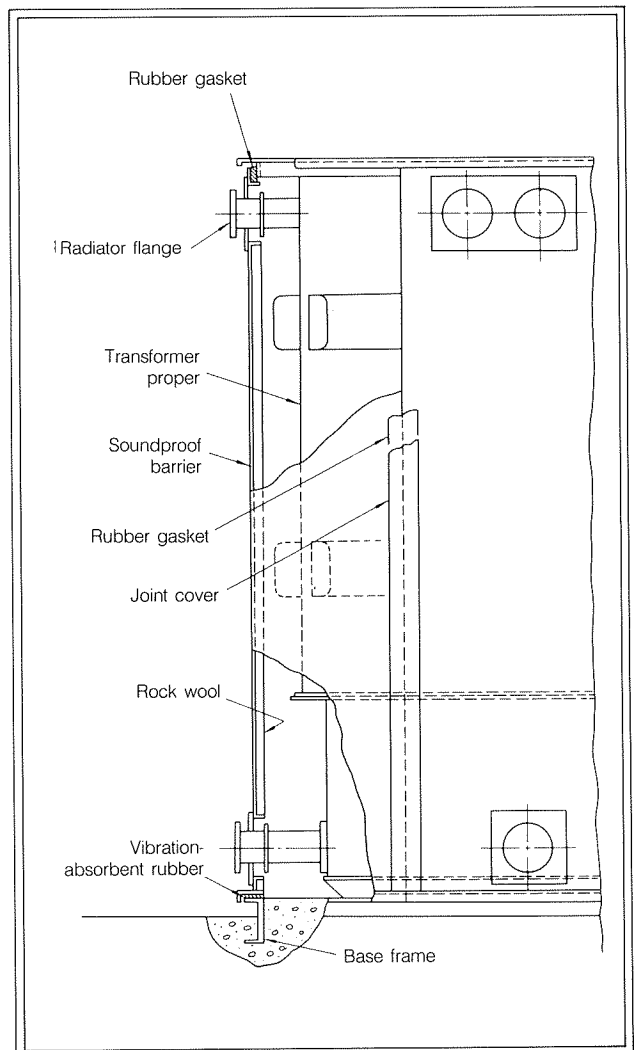


Fig. 55 An example of soundproof-barrier construction

