UDC 621.314.2+621.318.4

800KV 2000MVA TRANSFOMER AND 400MVAR SHUNT REACTOR

Tadaaki Fujimoto
Ichiro Tanaka
Hiroshi Takahashi
Kenji Ohkubo

1 INTRODUCTION

Fuji Electric, for interlinking among its series of equipment, has developed and manufactured 14 units of singlephase $800/\sqrt{3}$ kV, 2,000/3 MVA autotransformers which are of the highest voltage and the largest capacity class in the world, as well as 10 units of $800/\sqrt{3}$ kV, 400/3 Mvar shunt reactors of the same category. For this class of 800 kV transformers, Fuji Electric has a rich experience: our record shows production of 80 transformers, 110 shunt reactors and 4 ultra-high voltage (UHV) transformers of $1{,}550/\sqrt{3}$ kV. The transformers and reactors, objects of this report have been produced as equipment of extra-high reliability, on basis of our rich experience as constructors of this type of equipment, utilizing to full the results of the latest analytical technology for their designing and for their manufacture, full consideration was taken for their quality control.

The following describption introduces the outline of the transformers and reactors.

2 SPECIFICATIONS AND OUTER VIEWS

Table 1 and *Table 2* show specifications of transformer and reactor, respectively. Bank capacity of the transformer are 2,000 MVA and that of shunt reactor, 400 Mvar, this is the world record class. Specifications for insulation level prescribe the value of 1,950 kV for impulse test voltage, 800 kV for induced test voltage and $1.5\ \mathrm{Um}/\sqrt{3}$ for 30 minutes for long-period partial discharge test.

3 TRANSFORMER COMPOSITION

3.1 Iron core

Four-leg iron core construction is adopted. For silicone steel plate, the highest-class Hi-B steel plates are used. For tightening the iron-core, a band tightening system using reinforced glass tape is adopted for both main and return legs. The section of the yoke and return leg is elliptic. By adopting this form, the magnetic flux flow becomes even and tightening torque also becomes uniform, so that better

Table 1 Specifications for transformers

Type	Outdoors, single-phase autotransformer forced oil ventilation cooling system
Rated capacity	Primary winding 2,000/3MVA; Secondary winding 2,000/3MVA; Tertiary winding 2/3MVA
Rated capacity	$765/\sqrt{3}$kV $400/\sqrt{3}$kV 33kV
Tap voltage	$806{,}4/\sqrt{3}$-$765/\sqrt{3}$-$726.3/\sqrt{3}$kV
Test voltage	Lightening impulse test, full wave 1,950kV chopped wave 1,950kV Switching impulse test 1,425kV Partial discharge test voltage (to ground) 693kV (30 min.)
Frequency	50Hz
Impedance	14%

Table 2 Specifications for shunt reactors

Type	Outdoors, single-phase, oil filled self-cooling system
Rated capacity	400/3 Mvar (Max. 438/3 Mvar)
Rated voltage	$765/\sqrt{3}$kV (Max. $800/\sqrt{3}$kV)
Test voltage	Lightning impulse test, full-wave 1,950kV chopped wave 1,950kV Switching impulse test 1,425kV Partial discharge test (to ground) 693kV (30 min.)
Frequency	50Hz

Fig. 1 Outer view during the test (transformer)

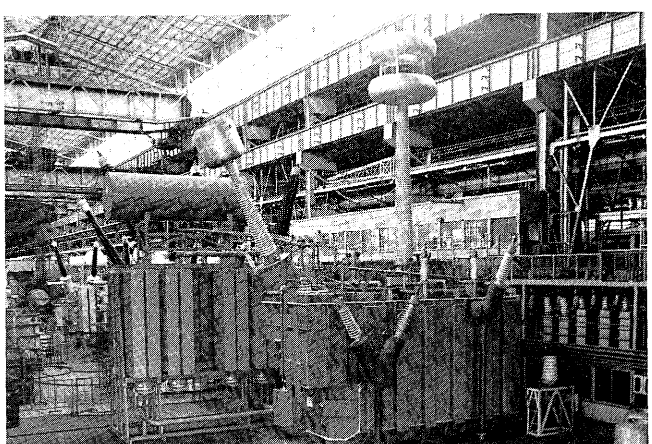


Fig. 2 Outer drawing (transformer)

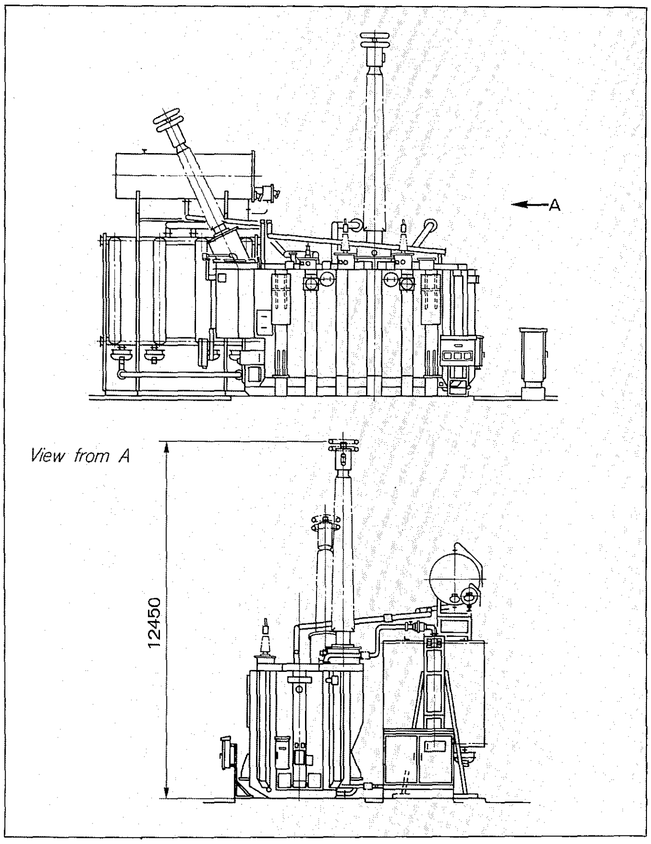
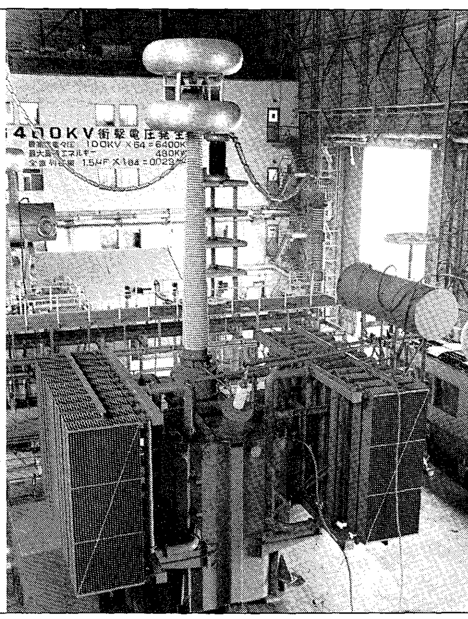


Fig. 3 Outer view during the test (shunt reactor)



characteristics can be obtained and, at the same time, vibration and noise characteristics is also improved. Cooling ducts are located in parallel with blocked layer in the section of the iron core to improve the cooling characteristics. As the transformer is of large capacity, for the iron core end where the magnetic flux leaking from the winding comes to contact at right angle, an iron core slit is provided to prevent local overheating.

Fig. 4 Outer drawing (shunt reactor)

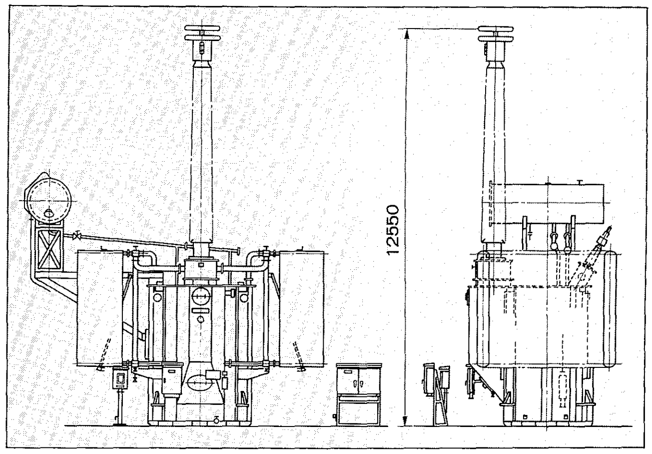
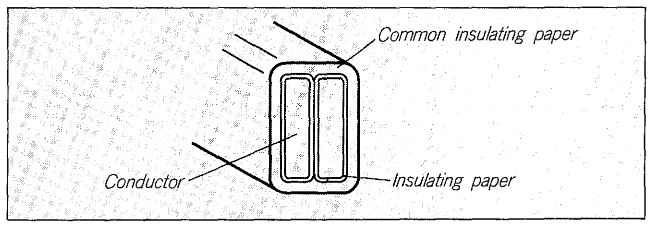


Fig. 5 Composite wire



3.2 Winding

The main leg is composed of two legs and the windings are coaxially arranged by order of exciting winding, parallel winding and series winding from inner side to outer side. And for antoher return leg, tertiary winding and tap winding are coaxially arranged. Tertiary capacity makes a striking contrast for it is 2/3 MVA, 1/100 only of the primary capacity. It is by this reason why tertiary winding is provided in the return leg in order to decrease the short-circuit current at the time of tertiary short-circuiting and to make impedance larger.

For both series winding and parallel winding, Hiser cap disc winding that is excellent in cooling and mechanical characteristics is adopted. This Hiser cap disc winding is made suitable for winding of the UHV-class transformer by changing series capacitance in the midway of the winding thus making potential distribution to be more or less linear.

By locating the line end in the center of the series winding, voltage of upper and lower winding ends are lowered, thus insulation is made simpler.

For winding, as seen in *Fig. 5*, composite conductor is used to minimize the stray flux loss and to make compact. floaeting load loss and to compactize the size.

3.3 Insulation

Oil gap multiple division system by the insulating barriers is adopted for both inside and outside of the coil. Usually the relationship between the gap length and the breakdown voltage is, as shown in *Fig. 6*, that the longer the gap length is, the breakdown-voltage will come down, and on the contrary, when it is smaller, the breakdown field

Fig. 6 Gap length-breakdown stress

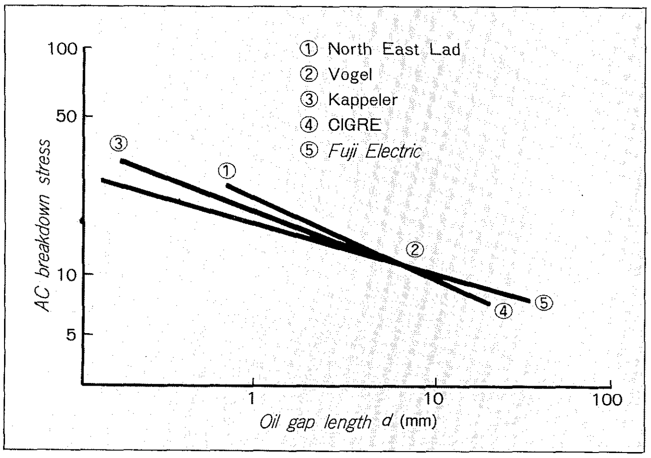
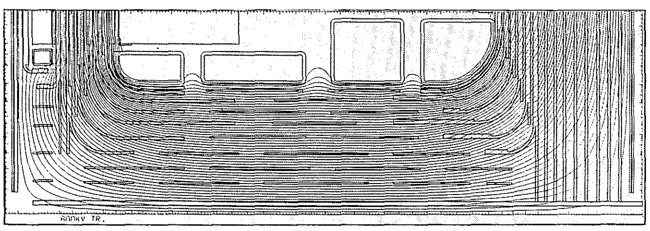


Fig. 7 Winding lower part and to tank field mapping



tends to be higher. Consequently, for the shapes and arrangement of the insulation barrier, mapping has been made using a computer for calculating the electric field of each gap in detail, so that it will never be less than the permitted value. In order to avoid that no creeping breakdown along the insulation barrier should take place, the barriers are devised to be arranged along the equipotential surface as much as possible.

3.4 Countermeasures for leaking magnetic flux and winding vibrations

Magnetic leakage flux generated by the winding becomes larger in function of increase in capacity per leg. For constructing transformers this time, as they are of largest capacity in the world, in fact as large as 2,000 MVA, local overheat due to magnetic flux leak and loss due to floating load are duely taken into consideration and as the optimum structure, that of two-leg structure for main winding has been adopted. As for individual countermeasures, for reducing the loss due to eddy-current within the winding, selection of the optimum dimension of the conductor according to distribution of leak magnetic flux was made. Also, for the inner wall of the tank, silicone steel plate shield which absorbs the leakage magnetic flux has been provided. Furthermore, this shield is further fractioned in its width as compared with that of conventional ones, so that generation of loss due to tank shield could be suppressed to the minimum.

On the other hand, another problem caused by the leakage magnetic flux is how to take up measures against vibrations and noise generated from the vibration of winding in large-capacity equipment. In order to analyze the

Fig. 8 Multivalent point vibration model

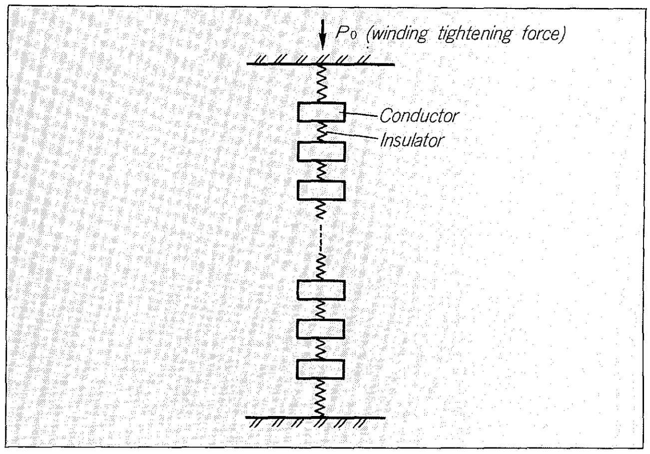
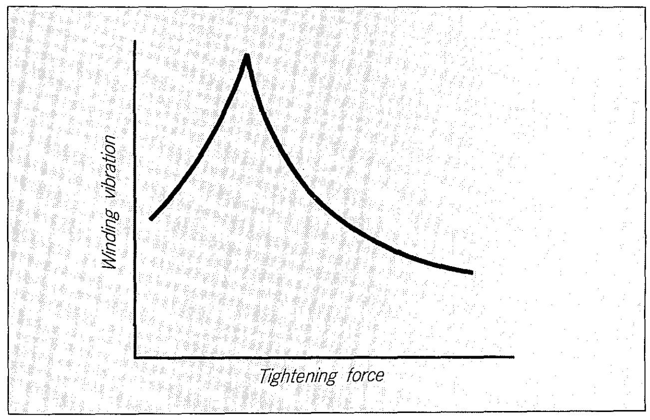


Fig. 9 Relationship between tightening force and winding vibration



vibratory phenomena in the state of operation, dynamic analysis has been conducted using computer by putting the winding into the series of multivalent-point vibration as shown in *Fig. 8*. The relationship between the tightening force of winding and vibrations is, as shown in *Fig. 9*, the distribution having resonance points. For that, the tightening torque of the winding has been determined taking into consideration of electromagnetic mechanical force at the time of short-circuit and vibratory characteristics at the normal operating time.

3.5 Lead and bushing-end insulation

For 800 kV side, by using thick insulating paper on the lead surface to restrict surface field, then by arranging multiple coaxial barriers on outer side, to divide the oil gap, thus dielectric characteristics will be improved. Further, the jointing part between lead and bushing is covered by forming insulation barrier in a special shape to enhance dielectric strength. This forming insulation barrier is moulded directly from craft pulp, whose degree of freedom of the shape for producing the mould is high and the precision of the dimension also is high, so that it is very suitable for insulating UHV transformers.

For 800 kV bushing, those of draw rod type have been adopted. Connection to lead is made by this rod so that operation outside the tank can be effectuated and connection works can be made easily. As for insulation of bushing end, in due consideration of each potential of metallic foil within bushing conderser cone, field mapping has been made to determine the position and shape of the forming insulation barrier.

3.6 Cooling system

For cooling system, a panel type radiator is used. The transformer has a self cooling capacity of 60%. In case 100% cooling is required, forced oil cooling system will be functioning by using cooling fan and oil feed pump. In this equipment, oil piping is so arranged that no erroneous operation should take place in Buchholtz relay at the time of oil feed pump starting.

Furthermore, a meticulous care has been taken for the distribution of fluid velocity at the time of self cooling, since the dimensions of the winding are large.

Shunt reactors are of completely self-cooling type and special measures have been taken for securing the cooling oil passage in the winding and iron core, thus enhancing the cooling efficiency.

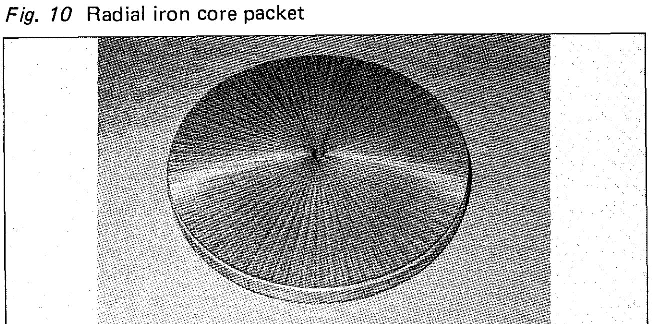
A special waveform type is adopted for panel radiator in order to obtain larger cooling surface, thus improving the cooling performance.

4 CONSTRUCTION OF SHUNT REACTOR

4.1 Radial iron core

Iron core consists of center leg made of oriented silicone steel plate with gap core type. For iron core, radial iron core for which Fuji Electric has a vaste experience is adopted. *Figure 10* shows the outer view of the radial iron core packet. Since the iron core for the shunt reactor of this time is much larger than those of conventional equipment, Fuji Electric has conducted compression test on iron core packet manufactured in trial, and confirmation has been made as to a good adherence life in comparison with those of conventional type.

Fig. 10 Radial iron core packet



4.2 Improvement of iron core packet space factor

In order to reduce size and weight of gap iron core type reactor using radial iron core, improving the space factor of the iron core packet is an important problem.

For piling up the silicone steel plate iron core packets, a method as shown in *Fig. 13* is available. Here, taking up an example of piling method shown in *Fig. 11*(b), we like to show the relationship between 1-block angle a and space factor in *Fig. 12*, and in *Fig. 13*, iron core packet outer diameter change in function of 1-block angle a when iron core packet effective sectional area is kept constant. From

Fig. 12 Relationship between 1-block angle a and space factor

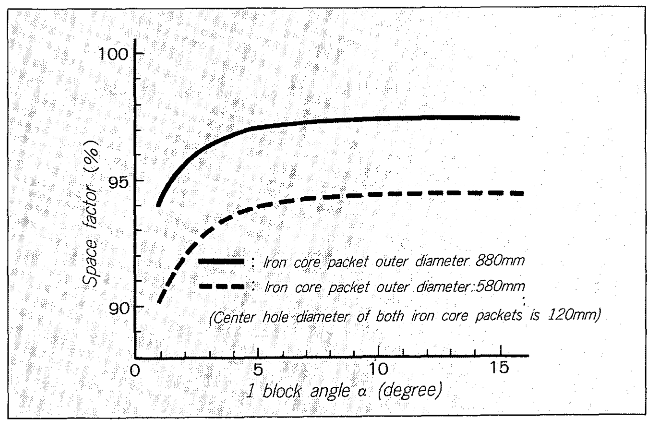


Fig. 13 Relationship between 1 block angle a and Iron core packet outer diameter when the effective sectional area of the iron core packet is kept constant.

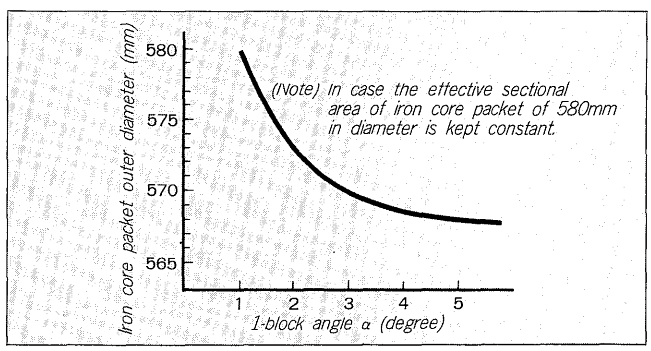


Fig. 11 How to pile up radial iron cores

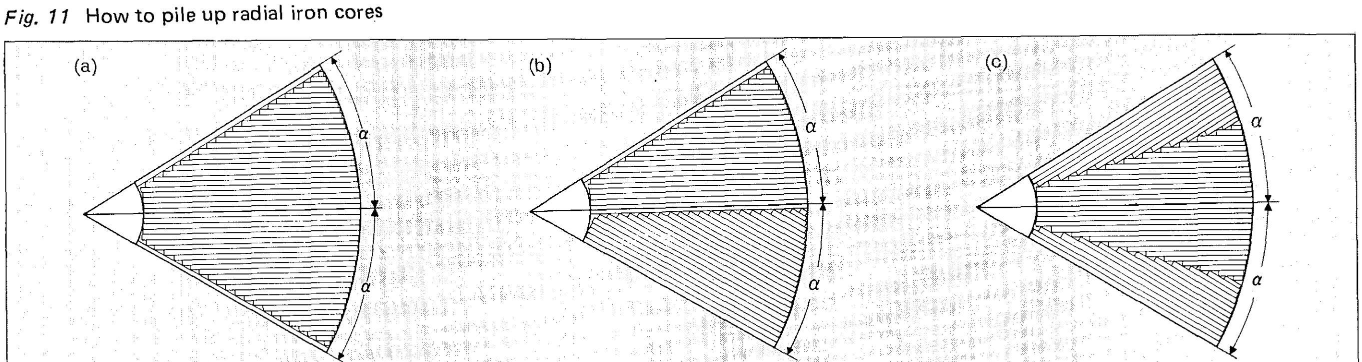


Fig. 14 Magnetic field mapping

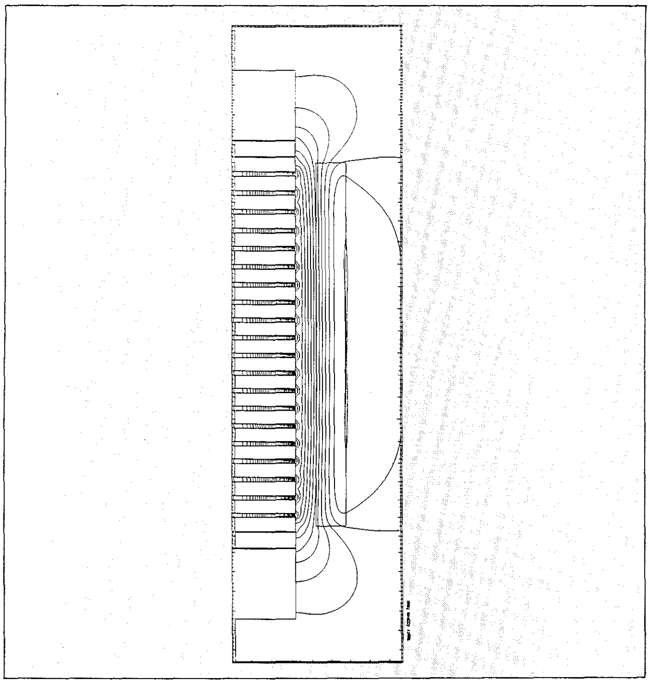
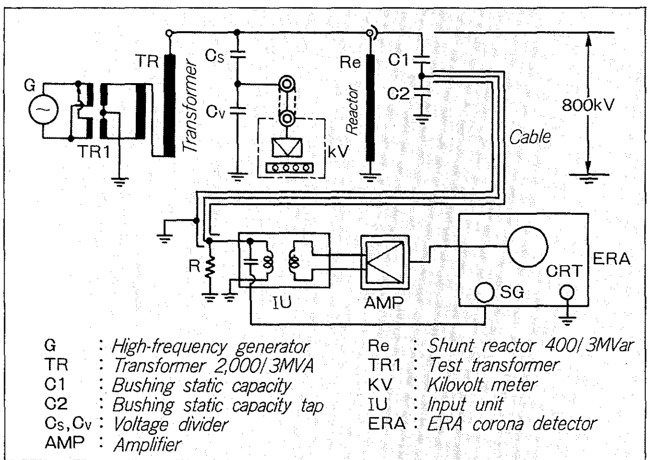


Fig. 15 Inductive dielectric strength test circuit



this example, we can be sure of the fact that it is possible to reduce the diameter and improve the space factor of the iron core packet by suitably choosing the 1-block angle a.

4.3 Vibration and noise characteristics

As the cause of vibrations of shunt reactors, we can cite magnetic attraction of the iron core gap part and electromagnetic force of the winding.

As for countermeasures for those due to iron core:

(1) To make magnetic flux distribution uniform at each gap. That is, by changing gap dimension of the center of the main leg and the gap dimension at the main leg end, the magnetic flux density at each gap is made uniform.

(2) The gap material has the same or better modulus of direct elasticity than that of iron core packet and spacer material used is made of alumina porcelain that presents no secular change.

(3) Iron core itself is strongly tightened in the axial direction and this tightening torque is of a value with sufficient margin against the magnetic attraction empirically.

On the other hand, as for the vibrations due to winding, we have carried out dynamic analysis using computer just as the case of transfromers, for determining the optimum tightening torque.

By taking up the above-mentioned countermeasures, both vibrations and noise have been within the bound prescribed by the specifications.

4.4 Loss

Among losses produced in the equipment, except for those due to winding resistance, all losses are due to magnetic flux. In particular, since the equipment in question has a large capacity, it is important to grasp exactly the magnetic field distribution and losses produced. For this, we have carried out magnetic field mapping by finite differential method to determine the quality of material and position of each structural materials. *Fig. 14* shows the result of calculation of the magnetic field mapping.

5 TEST

Fig. 15 shows the inductive dielectric strength test circuit for transformers and shunt reactor. This test circuit is set up by combining transformer and shunt reactor just as in case of actual system and this is a highly reliable and rational test circuit. Also, as for the shunt reactor, the test can be substituted by the impulse test as per indications of the standard specification, however our test has been conducted through above indicated test circuit. With all that, it has been confirmed that there produced no corona by applying 800 kV for 1 minut by Fuji Electric Large-Power Test Installation, and by applying the maximum circuit voltage $(800/\sqrt{3}\text{ kV}) \times 1.5$ times more of voltage (that is, 693 kV) for 30 minutes.

For the above fact, the reliability for a long term of the equipment as UHV equipment has been proved.

6 CONCLUSION

The equipment we have introduced by this report are the transformers and shunt reactors of the largest-capacity-in-the-world class. For securing their good performance, we have designed and manufactured under a severe quality control. The results of shop test obtained have been excellent satisfying the designed value.

The accumulation of designing technology and manufacturing techniques obtained from designing and manufacturing of these transformers and shunt reactors has been great, and the applicable equipment are not limited only to 800 kV transformers but to all large capacity equipment destined both domestic and overseas markets. And we are positive that the experience we have earned will accelerate greatly making of equipment in the future higher in reliability, fewer the loss and more compact for future designing and manufacture of Fuji Electric's transformers and shunt reactors.