275 kV 117,000 kVA OSCILLATION-FREE TRANSFORMERS FOR NAGOYA SUBSTATION

By

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I. INTRODUCTION

These three 275 kV 117,000 kVA transformers, which we have now completed, will be installed in Nagoya Substation of Dengen Kaihatsu K. K. at the receiving end of the Sakuma-West transmission line and belong to three of the largest transformers in our country, both in voltage and in capacity. Fig. 1 and Fig. 2 illustrate their appearance, two having 147 kV winding as their secondary and the third 77 kV. Their test results were in every respect nothing but excellent.

The chief characteristics of these transformers are as follows.

1. The sum of iron loss and the copper loss has far less value than those transformers formerly manufactured. The efficiency at 90/90 MVA 275/147 or 77 kV load of the former is 99.50% while the same of the latter was below 99.38%.
2. The amount of auxiliary hps. necessary for oil pumps & ventilatings fans is only 15 kW amounting about half of those of the formerly manufactured ones.
3. The 275 kV H. T. side winding consists of cylindrical-layer coils by which the internal oscillations are perfectly eliminated. (Fig. 6)
4. The 147 kV or 77 kV medium tension side winding consists of disc coils with the single coil connection, having an initial voltage distribution far better than those of the double coil connection. (Fig. 3)
5. The tanks were manufactured as vacuum proof ones and the transformers were dried out under vacuum by heating with ultra red ray lamps from outside.

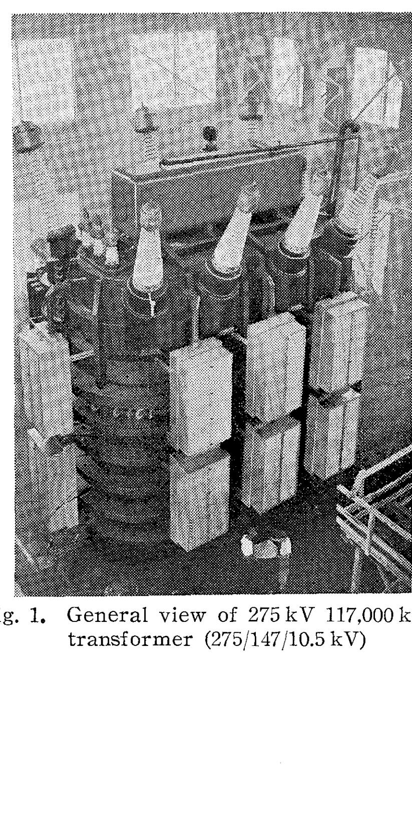


Fig. 1. General view of 275 kV 117,000 kVA transformer (275/147/10.5 kV)

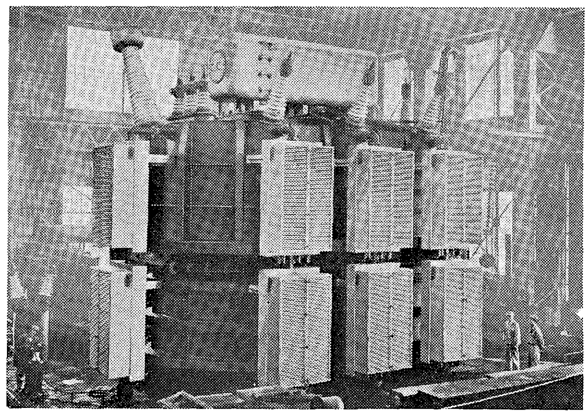


Fig. 2. General view of 275 kV 117,000 kVA transformer (275/77/10.5 kV)

II. RATING, WEIGHT and DIMENSIONS

Three transformers were manufactured, of which two sets with 147 kV M. T. winding and 1 set with 77 kV M. T. winding.

1. The Ratings for 2 Sets

Capacity :	3 phase, 3 windings, 60 c/s 90,000/99,000/45,000 kVA
Construction :	Forced oil fan cooled, with nitrogen sealed oil conservator

Voltages :	Primary side, 275–262.5–250 kV
	人 with earthed neutral
	Secondary side, 147 kV
	人 with neutral resistor
	Tertiary side, 10.5 kV
	△
Insulation level : (1×40 μs wave)	Primary side, Graded insulation
	Line terminal, 1,050 kV
	Neutral terminal, 400 kV
	Secondary side, Full insulation 750 kV
	Tertiary side, 150 kV
Weight :	Total 343 t.
	Oil 120 kl.
Dimensions :	10,000mm × 7,450mm × 10,700mm
	(width × depth × height)

2. The Ratings for 1 Set

Capacity :	Same as the above
Construction :	,, ,,
Voltages :	Primary side, 275–262.5–250 kV
	人 with earthed neutral
	Secondary side, 77 kV
	△
	Tertiary side, 10.5 kV △
Insulation level : (1×40 μs wave)	Primary side, Graded insulation
	Line terminal, 1,050 kV
	Neutral terminal, 400 kV
	Secondary side, Full insulation 400 kV
	Tertiary side, 150 kV
Weight :	Total 310 t.
	Oil 103 kl.
Dimensions :	9,800 mm × 6,900 mm × 9,840 mm
	(width × depth × height)

III. WINDING CONSTRUCTIONS AND IMPULSE VOLTAGE CHARACTERISTICS

The Constructions of three windings were determined as follows :

H. T. side ; cylindrical-layer winding

M. T. side ; disc winding with single coil connection

L. T. side ; cylindrical-block winding

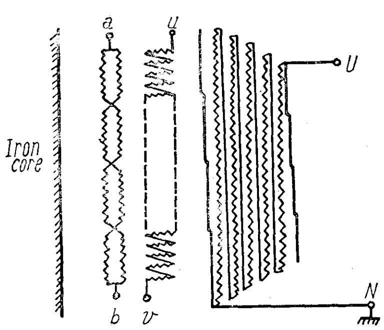


Fig. 3. Schematic diagram of windings

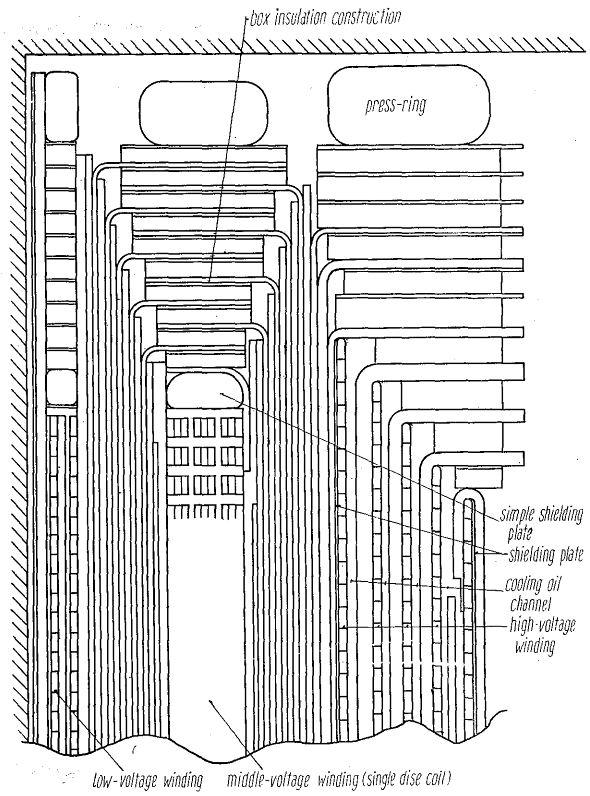


Fig. 4. Arrangements of windings and constructional features

Considering their impulse voltage characteristics, method of circulating oil circulation, construction of winding insulations, and economical use of raw materials. Fig. 3 and Fig. 4 illustrate the winding diagram and constructional features.

1. H. T. Winding

The cylindrical-layer-winding is our standard winding system for extra H.T. & special H.T. (>140 kV) transformers and it is an ideal winding system for 人 connection with solidly earthed neutral point. Its merits are :—

a. The winding being, quite free from internal oscillations, the voltage distributions corresponding to any incoming surge are possible to be calculated from turn ratios.
b. The insulations of the winding can be graded and reduced with the highest reliablity, which can by no means expected in the case of a winding with any oscillation.
c. The thickness of insulations between, H. T. & M. T. windings, determined by the insulating level of the M. T. in this case and not limitted by that of H. T. as in the case of disc winding, can be considerably reduced.

Fig. 5 is a side view of the transformer. The number of the layers of the winding are 5 for 2 transformers and 7 for the third one. The inside

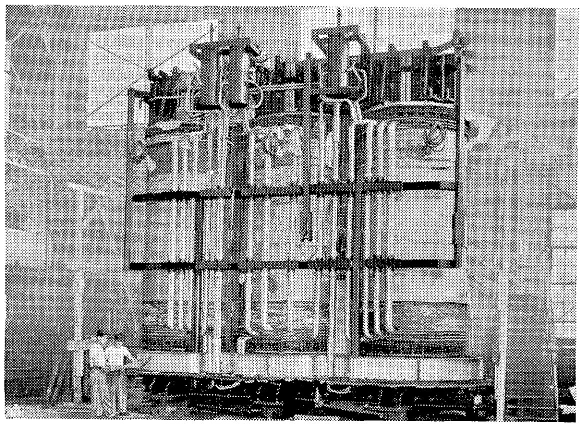
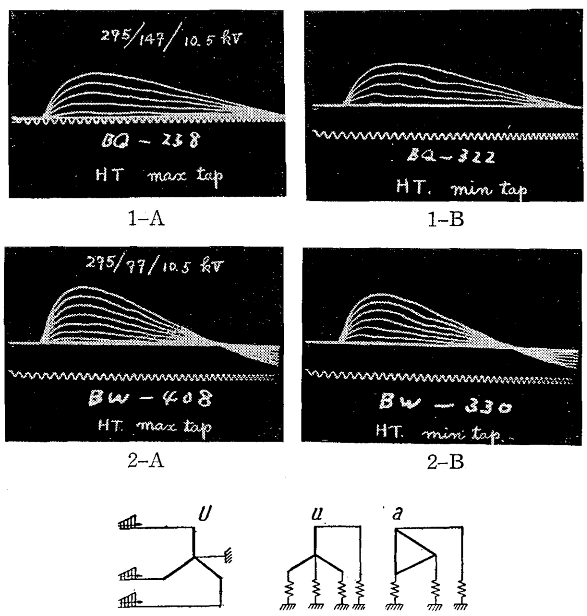


Fig. 5. Inside view



	max. tap	min. tap
147 kV. M.T. Units	1—A	1—B
77 kV. M T. Units	2—B	2—B

Fig. 6. Oscillograms of impulse voltage distribution within 275 kV cylindrical-layer-windings

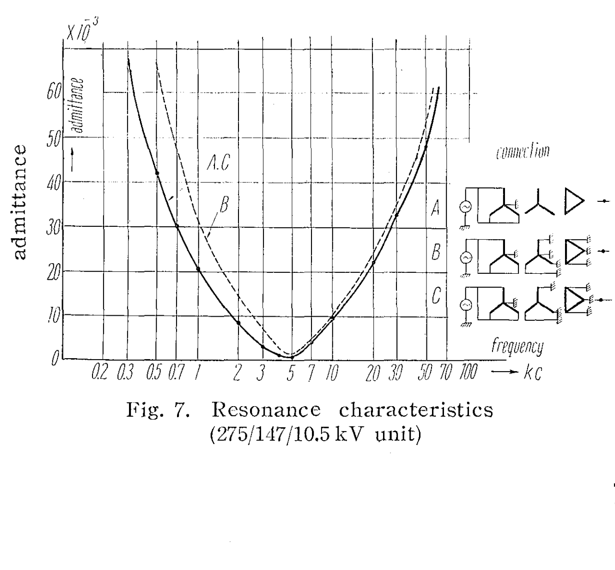


Fig. 7. Resonance characteristics (275/147/10.5 kV unit)

one layer at the transformer neutral is the tap winding layer in which 3 tap windings are wound parallel to eliminate the radial leakage flux and axial mechanical force due to the former.

Fig. 6 illustrates the oscillogram showing the distributions and changes of the internal voltage. The upper-most curve is the incoming impulse voltage applied to the 1st layer and the voltages of the other layers are proportional to the number of the layer. Fig. 7 is measured resonance characteristics. They are always free from any higher harmonics which indicates a perfectly balanced distribution of L and C without any local unbalance.

2. M. T. Winding

For M. T. winding, we adopted the disc coils which are easier to be constructed to the box type insulation and connected the coils in so-called single coil connection to reduce the voltage stresses between the coils.

The voltage rise of the neutral point is not noticed. This is due to the rather large capacity of the same point of the winding.

Fig. 8 is an oscillogram of M. T. neutral potential showing 100% applied voltage and neutral potential.

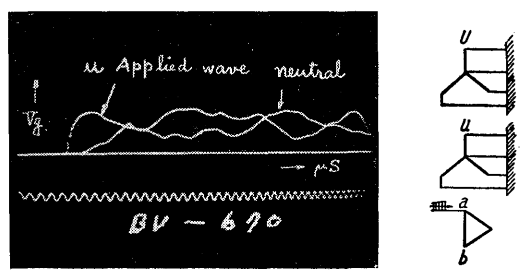


Fig. 8. Oscillogram of MT neutral Potential

3. L. T. Winding

Here we applied the so-called cylindical-block winding. The L. T. phase current reaches to $2{,}475/\sqrt{3}$ A and this winding method fairly suits the purpose. The impulse characteristics of the winding are also excellent. Fig. 9 is an example of the test results. Surge absorbers of each 0.1 F are provided at three line terminals which keep the transient impulse voltage delivered to L. T. winding below its B. I. L.

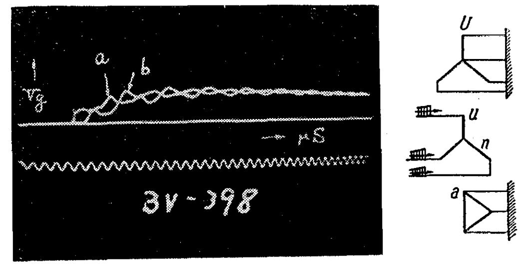


Fig. 9. Oscillogram of LT Potential

IV. MODEL TESTS

Following three model tests were made before we entered the manufacturing course.

(1) Magnetic model test.

Two magnetic models were completed one for the transformers with 147 kV M. T. winding, the other for that with 77 kV M. T. winding.

(2) Electrolytic bath test.

Two bathes in the similar way to the above, i.e. one with 147 kV M. T. winding and the other with 77 kV M. T. winding.

(3) Speed measurement test for circulating oil.

Using a wooden model corresponding to the section of windings, the speeds of oil were measured.

1. Magnetic Model Test

The data for the two models are

For 147 kV M. T. winding transformer

90/99/45 kVA 3-phase 60 c/s

2,750–2,625–2,500 V/1470 V/105 V

Connection : 人/人/△

Weight : Iron core 720 kg.

Copper 650 kg.

For 77 kV M. T. winding transformer.

770 V M. T. others same as above.

(a) (b) (c)

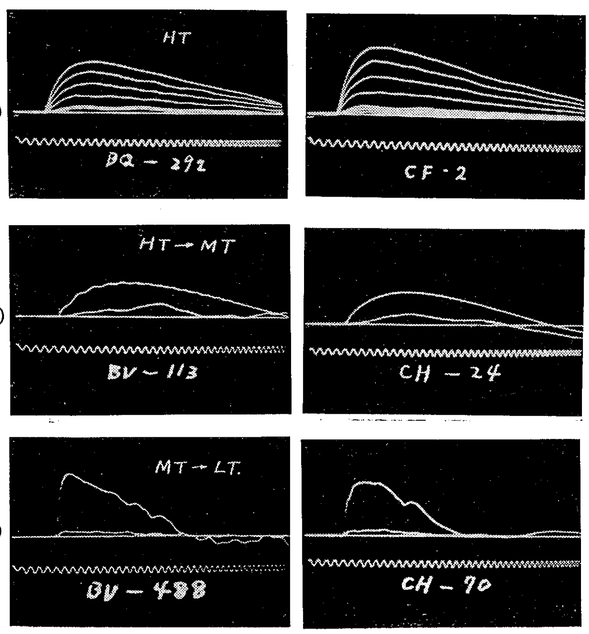


Fig. 10. Voltage oscillogram of 117,000 kVA transformer (right) and magnetic model (left)

(a) Voltage distribution within high voltage winding
(b) Transfered voltage from H.T. winding to M.T. winding
(c) Transfered Voltage from M.T. winding to L.T. winding

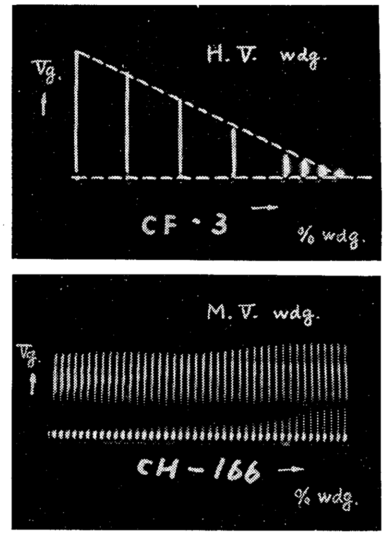
Oscillograms on the left hand side of Fig 10 are those of the main transformer and those on the right hand side are those of the magnetic model.

(a) is the potential change in the H. T. winding.

(b) is the voltage transfered from H. T. to M. T.

(c) is the voltage transfered from M. T. to L. T.

Fig. 11 indicates the maximum voltage distribution along the H. T. and M. T. winding.



(a) High voltage winding

(b) Middle voltage winding

Fig. 11. Maximum voltage distribution

2. Electrolytic Bath Test

The initial voltage distribution of transformer winding can be determined by a so-called resistance board by calculating the internal capacities of the windings in ohms but it is hardly possible to take account of static leakage flux. This difficulty is easily solved by using electrolytic bath and arranging a section of winding as shown in Fig. 12. The differences of dielectic constants of oil and insulating papers can be dealt with by changing the depth of the bath. The factor $\alpha = \sqrt{C/K}$ and equivalent capacity at incoming terminal C eq. in. can also be determined from this test.

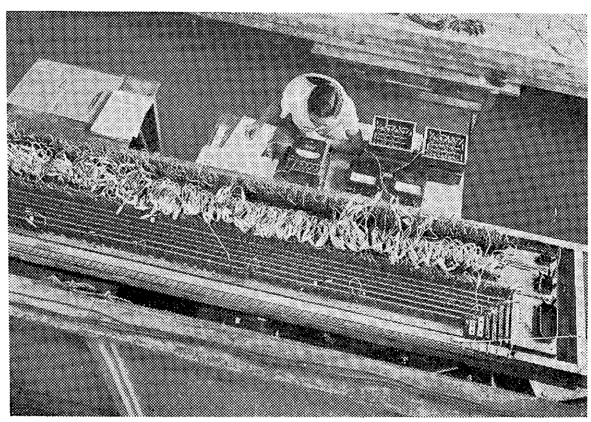


Fig. 12. The electrolytic tank for the determination of initial voltage distribution

Test results are given in Fig. 13, (a) is for H. T. winding and (b) for M. T. winding. In (a) the voltage drops at coil ends are clearly seen and in (b) $\alpha = \sqrt{C/K}$ is calculated to be ca. 26. Fig. 14 is the voltage distribution of M. T. winding arranged in single coil connection and in double connection.

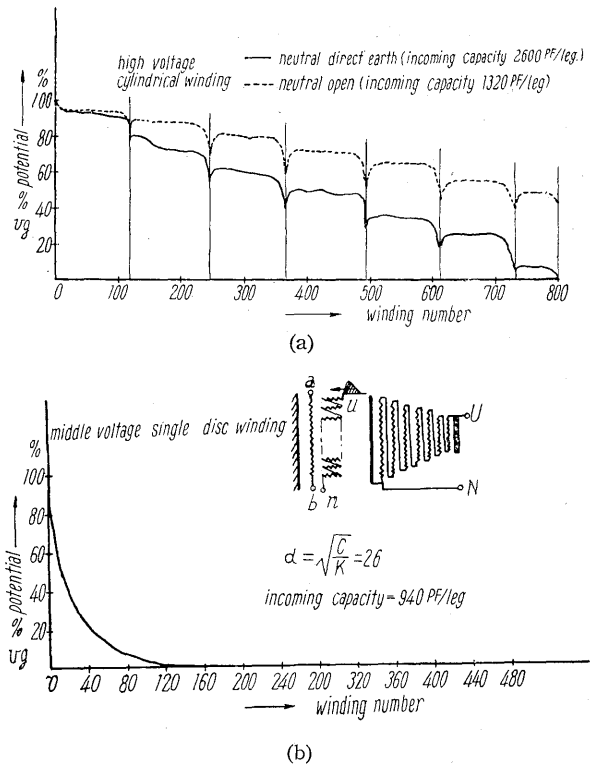


Fig. 13. Initial voltage distribution determined by electrolytic tank experiment

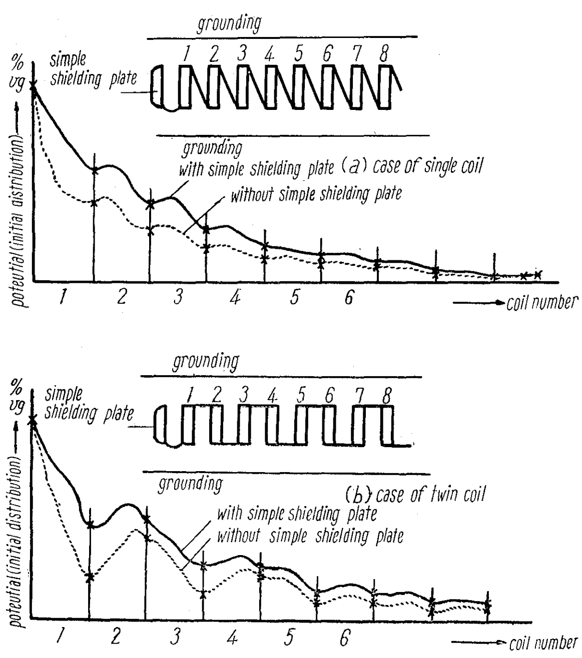


Fig. 14. Initial voltage distribution of
(a) single-disc winding
(b) double disc winding

The better distribution in the case of single coil connection can clearly be observed.

3. Speed Measurement Test for Circulating Oil

A bad oil circulation can cause a local heating of the winding, while a too much circulation means an energy loss. The aim of this test was to examine the oil flow inside the M. T. disc coil winding and to balance the necessary head in mm. of oil flow in H. T. cylinder coil, M. T. disc coil and L. T. cylinder coil windings.

Fig. 15 is a photo during the test. The size of oil ducts in the M. T. were properly adjusted and oil flows into the cylinder coil windings were in some extent thrattled.

A low temperature rise with a minimum cooling hps. were the results. The temperature rises of three windings after the heat run test were well balanced for H. T. 43.9 °C for M. T. 38.9 °C and for L. T. 42 °C and figures obtained as the sum of the auxiliary hps. for cooling the oil including the cooling fan were 15 kW, which became a minimum record for this capacity of large power transformers.

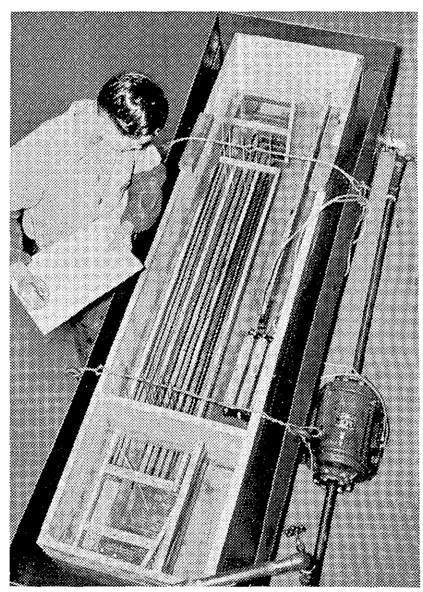


Fig.15. Model test for the determination of oil velocity within winding

V. CONSTRUCTIONAL DETAILS

1. Tank

The main transformer tank was splitted in 3 parts, i.e. base, lower body and upper body, to make easy the transportation by railway.

The three parts were welded to one body on site.

All parts were properly strengthened to make the tank vacuum proof.

As otherwise described, the drying out was made under 6～7 mm. Hg vacuum.

Six universal, wheels were provided, so as to make it possible to move the transformer both in lengthwise and in sidewise direction.

2. Cooling Equipment

The cooling elements consist of so-called U-fin type radiators. They are cooling pipes surrounded, by wire spirals. To improve the conductivity of heat from oil to the pipe, another spiral is provided inside of the pipe. The latter increases the head loss of oil in the pipe but instead of it we can reduce the speed of oil flow for the same given heat conduction. Fig. 16 shows the required auxiliary hps. against conducted heat quantities.

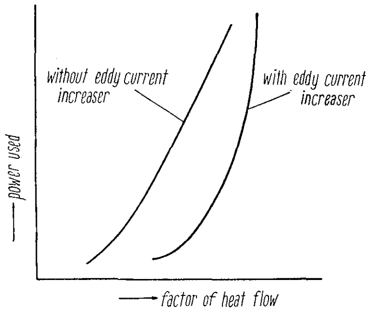
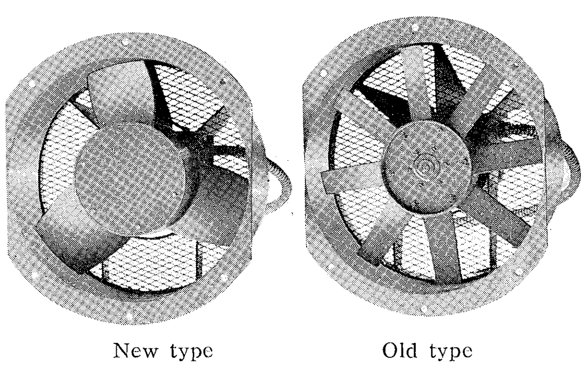


Fig. 16. Comparison of heat conduction

6 cooling units are attached on the tank wall, of which 1 unit is the spare, and each unit has 1 oil pump and 12 ventilating fans. The pump motors submerged in the oil flow, i.e. without packing. The fan with 3 blades and driven by 8-pole motor runs practically without noise. (Fig. 17)



New type Old type

Fig. 17. 117 MVA oscillation-free transformer

3. Nitrogen Sealing Device

To prevent the deterioration of oil a nitrogen sealing device of 3 chamber type was supplied. Chamber C, similar to the ordinary oil conservator was mounted on the transformer tank. Chamber B, expansion tank of nitrogen and chamber C, sealing oil tank are combined in on tank and installed separately from the main tank. Between chamber C and B is a small room filled with deoxidizing powder which absorbs the oxygen gas incoming into the nitrogen gas through chamber A during operation

VI. TRANSPORTATION and ERECTION on SITE

The specified efficiencies being too high to design the transformer portable in the limited dimensions of Japanese railway, the completed transformer was disassembled into parts after the necessary shop tests. The core was shipped leg by leg after disassembling the upper and lower yokes. The windings were packed also leg by leg but 3 windings of each leg together in one block and sealed in nitrogen gas. The tank was splitted in 3 parts.

On site, first 3 legs were erected on the lower yoke after assembling the latter sheet by sheet and then the winding of each leg was lowered into the leg. Last of all the parts of the tank were welded together. All these works were carried out using a 25 ton crane. After examining the leakage from the welded parts of the tank by a freon detector, the tank was filled under vacuum with necessary oil, treated in advance also under vacuum.

VII. THE DRYING OUT

1. Drying Out in the Workshop

The initial drying out of the transformer in our workshop was made by using the self tank and applying the ultra-red ray lamp heating from outside of the tank as shown in Fig. 18. By applying this heating method from side and bottom and watching the temperature by a lot of resistance temperature elements, every part of the transformer body was kept constant at 110 °C which is the most adequate

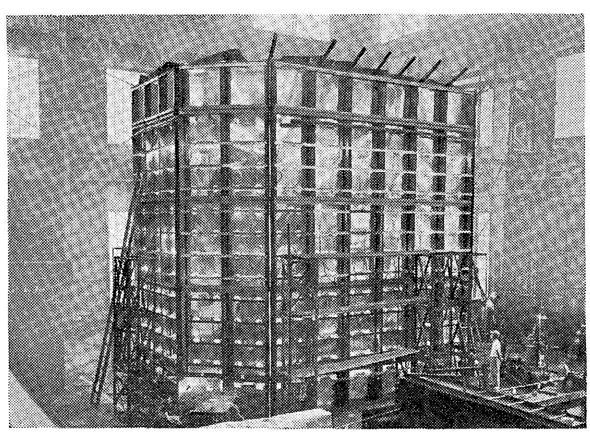


Fig. 18. Vacuum drying of transformer by ultra-red rays heating

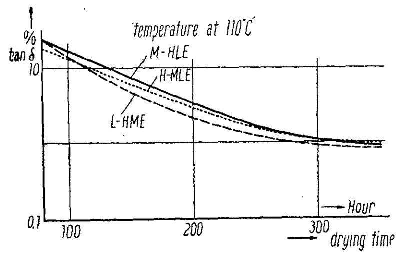


Fig. 19. Drying process of 117 MVA transformer

temperature for drying out. The vacuum during the process was 6 to 7 mm Hg. which also is enough for the purpose.

Fig. 18 is a record of the change of Tan-δ during the drying out process. The degree of drying out was also watched by quantity of regenerated water in the condenser of vacuum pump.

2. Drying Out on Site

Our improved oil heating set worked successfully for the drying out on site. This set is an improved oil boiler, the feature of which is a indirect heating of the main transformer oil by hot heating oil. By using this oil heating set and vacuum treated oil without air or oxygen gas the change of the colour and increase of acid value of the oil which were frequently experienced in former days, were thoroughly eliminated. The temperature of oil was kept 100 °C to 110 °C and the vacuum under 6 mm Hg. The acid value before and after the drying out were 0.007 and 0.009 respectively. The Tan-δ obtained were 0.21% for H-MLE 0.41% for M-HLE and 0.42% for L-HME at 25 °C.

VIII. TEST RESULTS

1. Iron Loss in kW

Voltage	147 kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
100 %	178	235	187	225
110 %	220	320	244	300

2. Copper Loss in kW at 75 °C

Windings	174kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
H-M (90MVA)	277.8	335.5	292	326
M-L (45MVA)	70.2	80.1	72.3	79.1

3. Efficiency in % at pf=1.0 75 °C

Based on 90,000 kVA between H-M

Load	147 kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
100 %	99.50	99.36	99.47	99.39
75 %	99.50	99.37	99.48	99.39
50 %	99.45	99.29	99.43	99.32
25 %	99.14	98.87	99.10	98.92

4. Auxiliary Loss in kW

Losses including	147 kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
Fans and pumps	15	20	15.5	20

5. No Load Current in %

Voltage	147 kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
100 %	0.99	2.2	0.91	2.1
110 %	1.92	3.8	1.68	3.7

6. Impedance in %

Between windings	147 kV. M.T. Units		77 kV. M.T. Unit	
	Test	Guarrantee	Test	Guarrantee
H-M (90 MVA)	10.90	10.0	10.60	10.0
M-L (45 MVA)	8.73	8.0	8.75	8.0
H-L (45 MVA)	3.04	3.0	2.97	3.0

7. Temperature Rise in °C

	147 kV. M.T. Units	77 kV. M.T. Unit
Top oil	30.4	30.9
H.T. Winding	43.9	48.9
M.T. Winding	38.9	46.6
L.T. Winding	42.4	45.4

8. Tan δ Measured in %

Between winding and earth (E)	147 kV. M.T. Units		77 kV. M.T. Unit	
	at 56 °C	at 30 °C	at 34.5 °C	at 25 °C
H-MLE	0.85	0.63	0.90	0.85
M-HLE	0.92	0.73	1.05	1.00
L-HME	0.95	0.80	1.05	0.95

9. Corona Test

This test was made by exciting from L. T. side with 130% voltage and inducing the corresponding over-voltages in the M. T. and H. T. windings. For detecting the presence of corona discharge, a microphone was submerged in the transformer tank. No sign of corona was observed. Further for the 3rd transformer with 77 kV M. T. winding, measurements were made with a Braun tube oscillograph as shown in Fig. 20. Oscillograms obtained are (a) and (b) of Fig. 21, both of which indicate that the transformer is corona-free. Fig. 21 c, for reference, is an oscillogram for a potential transformer with corona.

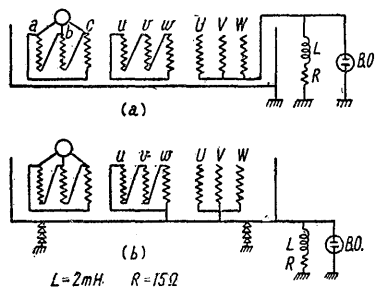


Fig. 20. Connection diagram of corona test

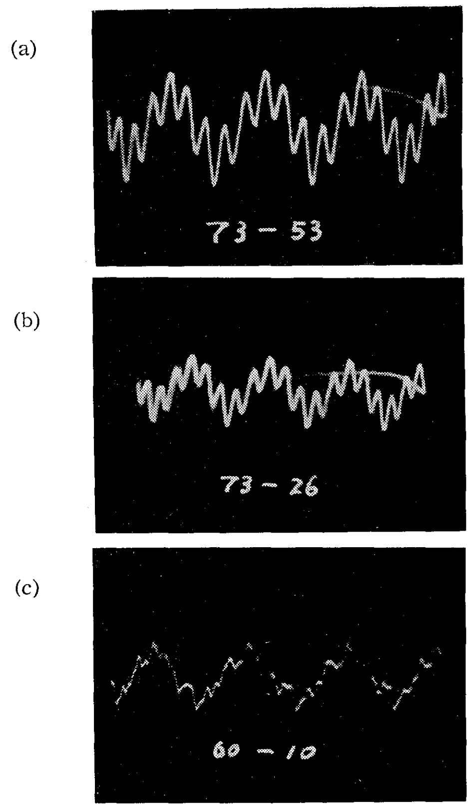


Fig. 21. Oscillograms obtained by corona test
(a): Test by (a) circuit (b): Test by (b) circuit
(c): Corona oscillograms obtained with corona for P.T.

10. High Voltage Test

The transformers were subjected to and withstood following high voltage tests.

a) A. C. test

H. T.	Induced test with 120 cy.	460 kV	1 min.
M. T.	For 147 kV winding	320 kV	1 min.
	,, 77 kV ,,	160 kV	1 min.
L. T.		50 kV	1 min.

b) Impulse tests (1×40 μs wave)

H. T.	Full wave 1,050 kV	Chopped wave 1,210 kV
M. T.	For 147 kV winding	
	Full wave 750 kV	Chopped wave 870 kV
	For 77 kV winding	
	Full wave 400 kV	Chopped wave 460 kV
L. T.	Full wave 150 kV	Chopped wave 170 kV