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50 MVA CARBIDE FURNACE TRANSFORMER

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I. INTRODUCTION

In 1967, Fuji Electric delivered a 50 Mva electric furnace transformer, the largest unit ever built in Japan, for the Omi plant of the Electro Chemical Industrial Co., Ltd, where a similar unit rated at 45 Mva, the largest unit at that time, has already been installed in 1963.

The transformers should preferably be transported to the installation site, the so called " assembled transportation type ", as a unit to insure high quality. However, in general transformers used in electric furnaces, the secondary side has a low voltage with a wide range of on-load voltage adjustment since it supplies a large current, a main transformer and series transformer, arranged in the same tank, are necessary. Therefore, it is often difficult to transport as an " assembled transportation type ". This transport problem was overcome by introducing many new concepts concerning the interior design. Therefore, this 50 Mva transformer was transported on a " Dropped center car " as shown in *Fig. 2,* although the 45 Mva unit was transported on a " Fahrbar type car " shown in *Fig. 4,* in which, the total track width was utilized to the maximum limit and the transformer was transported by placing it on railway

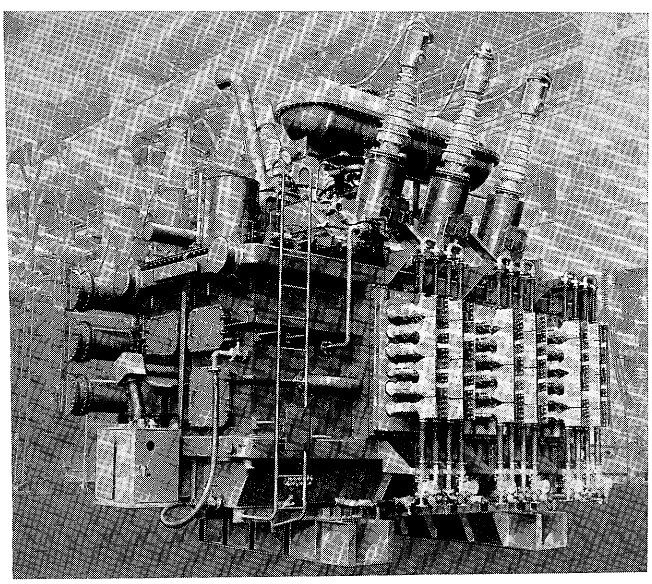


Fig. 1 50 Mva furnace transformer

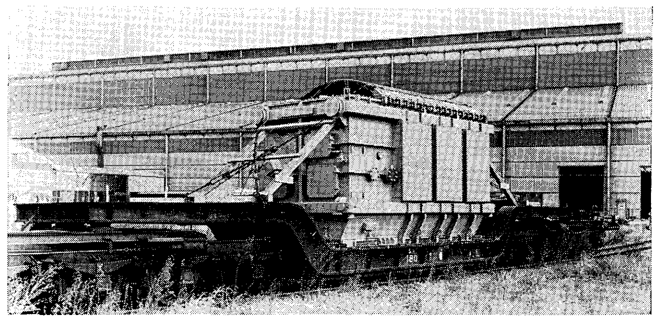


Fig. 2 Transportation of 50 Mva transformer

***Table 1* Comparison of 50 Mva Trasformer and 45 Mva Transformer (alreadly installed)**

	50 Mva Transformer	45 Mva Transformer
Type	Indoor use, oil immersed, forced-oil-cooled with forced-water-cooler, core type, on-load tap changing	Same as left
No. of Phase	3	Same as left
Frequency	50/60 Hz	Same as left
Capacity	50,000 kva	45,000 kva
Overload Capacity	For each 1 deg. drop from a maximum cooling water temperature of 25°C, 0.8% overload against the rated capacity is possible. However, the overload limit is 120% against the rated capacity.	
Voltage	63,000/300～258^R～144 v (6 v step, 27 taps)	Same as left but secondary rated voltage is 234 v
Secondary Current	112,000 amp	111,000 amp
Connections	△ or 人/△ (Delta or Wys/ open Delta)	Same as left
Total Weight	120 t (88.2%)	136 t
Weight of Core & Windidgs	64 t (94.8%)	67.5 t
Weight at Transportation	74 t (79.5%)	93 t
Oil Quantity	29,500 *l* (84.8%)	34,800 *l*
Overall Dimensions	6485×4900×6030 (Hight) (mm)	4950×4700×6610

Note: Figures in brackets ( ) for the 50 Mva transformer are percentage values in relation to 45 Mva unit

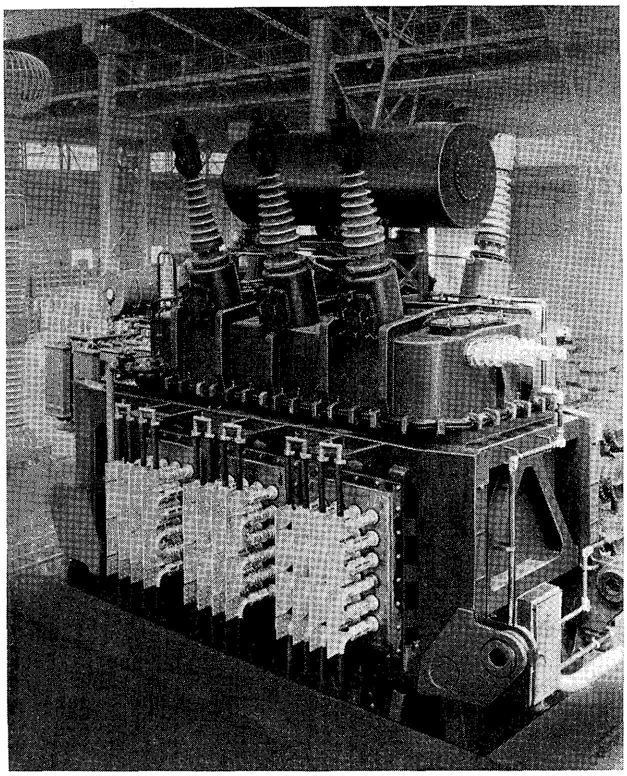


Fig. 3 45 Mva furnace transformer (already installed)

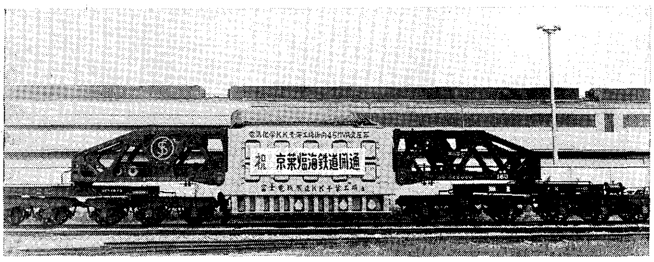


Fig. 4 Transportation of 45 Mva transformer

wheels.

Table 1 shows a comparison of ratings, weight and dimensions between the 50 Mva and 45 Mva transformers. Although this 50 Mva transformer set new records in capacity, the newest internal construction (as described below) was employed, so that the dropped center car method of transport could be used. It was possible to reduce the total weight of the 50 Mva unit to 88.2% of the 45 Mva unit and the transport weight to 79.5%. The characteristics of the new unit were higher than those of the 45 Mva unit.

Fig. 1 shows the exterior of the 50 Mva transformer and *Fig. 2* shows the transportation method. The 45 Mva transformer's exterior view and transportation method are shown in *Fig. 3* and *Fig. 4* respectively.

II. CONNECTIONS

Transformer connection diagrams are shown in *Fig. 5* and *Fig. 6*. The latter shows single line connection. As can be seen from the diagrams, the transformer employs a direct step down system in which 63 kv of the primary side is lowered to 300～144 v on the secondary side. Like in the 45 Mva transformer, voltage regulation is by means of an indirect system using the main and series transformer. When the ratio of the maximum and minimum secondary voltages is over 2, the indirect system is more economical. The reason for this is that, in secondary voltage regulation by tap changing from the primary side, the voltage of which is kept constant, the flux density in the core differs considerably at maximum and minimum secondary voltage, which leads to lower utilization of core cross-section and difficulties in secondary voltage regulation at equal intervals.

The tertiary winding of the main transformer serves as an intermediate circuit for on-load tap changing regulation of the secondary voltage. A condensor for phase advancing is connected in the tertiary winding to improve the load power factor.

Secondary current can be measured by the current transformer connected in the primary side of the series transformer.

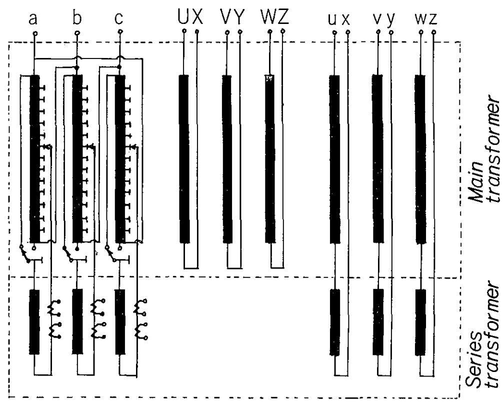


Fig. 5 Connection diagram

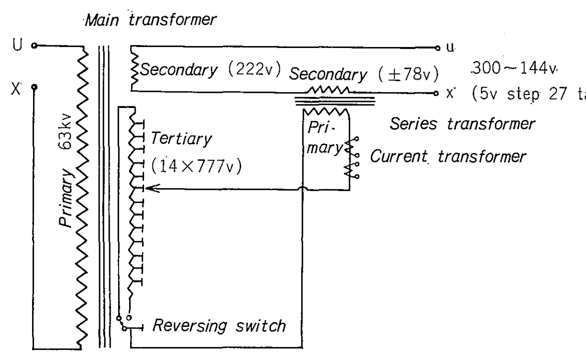


Fig. 6 Single line connection diagram

III. CORE AND WINDINGS

The 45 Mva transformer used the "Fahrbar" type car system for transport. Although the capacity of this transformer has been raised to 50 Mva, it can be transported on a dropped center car. The main reasons for this are that impedance voltages were made almost equal by rationalization of the core and windings and the winding height could be decreased. The factors which allow for decreasing winding height are as follows.

1) By using a band clamping core, the core weight as well as the average length of the winding can be decreased.

2) The secondary side copper sheet coil was specially developed for decreasing the winding height. Eddy current loss is less than in the 45 Mva unit.

3) Insulation constructions were rationalized.

1. Iron Core

The iron core is made from grain orientated silicon steel sheets (G_{11}). It is a 3-phase, core type consisting of three legs. The steel sheets are fastened together by the most up-to-date band clamping system. In this system, the cross-section is about 20% and the diameter about 10% less than in the 45 Mva unit; the winding diameter is therefore smaller. If the leakage flux is made the same as in the 45 Mva unit, the winding height can be decreased by about 10%. It is mainly because of this decrease in height that the dropped center car transportation system can be used.

The band clamping core is superior to the bolt clamped core in the following points:

1) Clamping bolts are never used in this core. The steel plates are clamped together with hot-hardened resin impregnated fiberglass bands and it is not necessary to make holes in the steel.

2) There is no disturbance in magnetic flux flow due to bolt holes and no-load loss also becomes small to allow uniform flow to the steel rolling direction.

3) In bolt clamped cores, it is very difficult to achieve equal clamping pressure, but almost uniform clamping is possible with the band clamping system.

4) In the band clamping core, the effective area of the core cross-section is improved by an extent corresponding to the area of bolt holes in bolt clamped cores, so that in the band clamping core, iron core diameter and weight is substantially reduced.

As was mentioned above, the use of the band clamping core allows for a considerable decrease in the weight, no-load loss and no-load current. This type of core is shown in *Fig. 7*.

2. Windings

The arrangement of the primary, secondary and tertiary windings in the main transformer is shown in *Fig. 8*. The winding arrangement of the series transformer is not shown in the figure, but from the core side, the primary and secondary windings are arranged coaxially. The primary winding uses disc coils, while the secondary winding is wound continuously with the main transformer secondary winding using the "figure-8 type" copper sheet coil construction developed by Fuji Electric.

1) Main transformer primary winding

As shown in *Fig. 8,* the main transformer primary winding is arranged between the secondary and primary windings. The winding's capacitance to earth becomes about twice in comparision with the usual case when the higher voltage windings arranged outermost. Therefore, the voltage distribution for impulse surge gets worse. To eliminate this fault, a special interleaved disc-type coil (also known as a high series capacitance winding) interleaving effectively 2 parallel conductors was employed as the primary high voltage winding. In this winding α ($=\sqrt{C/K}$, where C is the capacitance to earth and K is series capacitance) is about 1/3 of that in the case of the disc winding, and the impressed voltage between coils becomes about 50% less than that in the disc winding type. In this way, insulation construction can be simplified.

Since the capacity of the primary winding is increased and the winding height is decreased, the radial dimension, i.e. the winding width, is increased. As was mentioned above, the insulations between turns

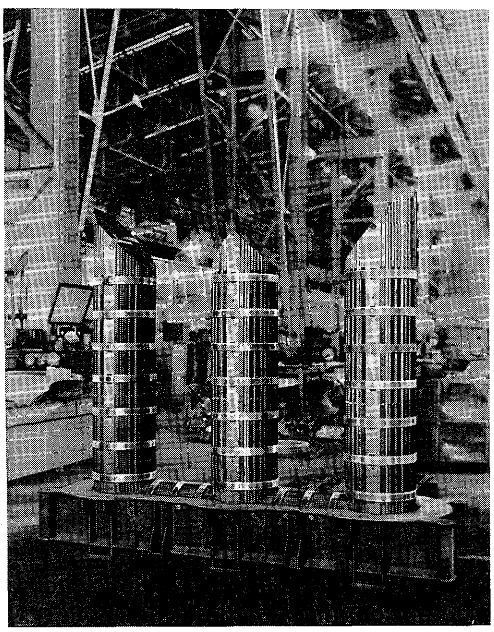


Fig. 7 Band clampling core

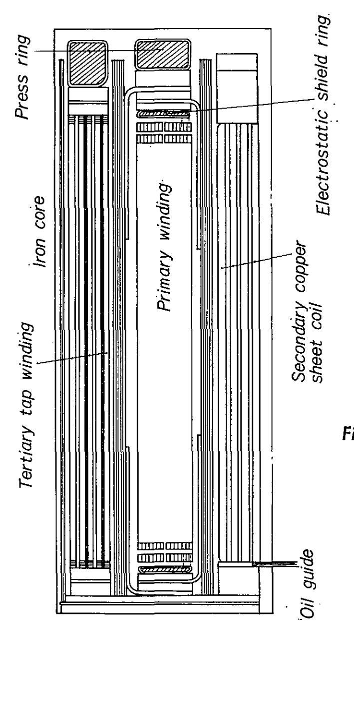


Fig. 8 Arrangement of windings

and between the coils are rationalized and furthermore the thickness of conductors at right angle to leakage flux is decreased to keep the stray loss low, so that the overall winding widths increase only slightly.

2) Secondary winding

This winding consists of the previously mentioned "figure-8" type copper sheet coil which combines the main and series transformer into a single unit. This winding is specially constructed so that the end and beginning of the winding are directly connected, by means of flexible leads, water cooled terminals which pass through the tank wall and collected together in one place. Therefore, the construction is relatively simple in spite of the large current. The copper plates at the beginning and end of the winding face each other, so that the increase of the resistance and impedance due to the leads as well as stray loss is kept lower. The copper plate (with a specially treated surface) is in direct contact with cooling oil. By making the winding cylindrical, the cooling oil flows easily and very effective cooling of the winding is provided by the forced oil system. Mechanical strength is also high, because of the copper plate construction which is most suitable for windings of transformers such as those used in electric furnaces where short circuits are likely to occur from time to time.

In this transformer, the winding height is lower than in the 45 Mva unit and, in order to keep the current approximately equal, the thickness of the copper plate is increased. However, since the stray loss which usually arises in the copper plate is proportional to the square of the thickness of the plate which crosses the leakage flux at right angles and product of the number of conductors arranged in the radial direction, increasing the plate thickness is not recommended. For this reason, the two-parallel system copper sheet coil was recently developed to keep the plate thickness small and the stray loss lower than in the 45 Mva unit. Because of this specially developed copper sheet coil, it has become possible to design and manufacture furnace transformers with current capacities of about 200,000 amp $/ \sqrt{3} =$ 115,000 amp. *Fig. 9* shows an external view of this special copper sheet coil.

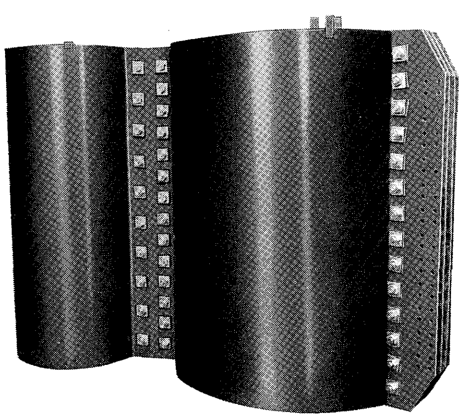


Fig. 9 Secondary copper sheet coil

3) Tertiary tap winding

The tertiary tap winding consists of a 5 layer parallel wound cylindrical tap winding. Since the advantages of this winding have been given in previous issues of the Fuji Electric Review, details will not be repeated here. In this type of construction, the magnetic center does not change in respect to each tap and leakage flux in the radial direction is small. Therefore, even in electric furnace transformer where there is a danger of short circuits, almost no axial electromagnetic force is generated.

4) Pre-press treatment and drying

Except for the secondary copper sheet coil, all other parts must undergo pre-press treatment and drying. In this way, almost all contraction of insulation materials can be eliminated, even after many years of use, and slight contraction in the windings can be compensated for by previous pre-press treatment. In other words, the insulation material shows an elastic action and the pre-press force, which is determined by the electromagnetic force generated during a short circuit, is set within the elastic limit. Therefore, there is no danger of any slackness occurring in the winding.

IV. TANK AND ACCESSORIES

Special points concerning the tank and accessories are as follows:

1) The tank is designed to withstand vacuum. In spite of the larger capacity, it is not necessary to consider tank construction such as in the "Fahrbar" type car, because the dropped center car type transportation is used. Therefore, the weight of the tank can be made lighter.

2) The oil conservator is Fuji Electric's standard diaphragm type, in which both surfaces of the nylon film are covered with a thin menbrane of nitrile rubber which completely seals the oil. Therefore, there is no maintenance difficulties like in the nitrogen gas seal type.

3) Cleaning of the primary side 63 kV bushings is facilitated by the platform placed on the tank cover. The accessories have been arranged by stressing maintenance. Pipings for the cooling water of the 6 set coolers have been collected in one place for convenience in supplying and draining water. Thus, as above, the most careful consideration has been given to ensure easy maintenance.

V. ON-LOAD TAP CHANGER

The on-load tap changer is of the tank type, with a rated voltage of 20 kv and a rated current of 600 amp and is meant to be used with 27 taps. The oil chamber is divied into an upper and lower section. The upper section contains a diverter switch and the lower section contains a tap selector with a reversing switch.

The diverter switch employs a new-type Jansen switch with a 1-resistor system. Since 1955, Fuji Electric has produced more than 530 of these switches. The special characteristics of this switch are as follows:

1) Since a revolving type arcing contact with parallel division is used, the electrical life of the contact is over 300,000 operations.

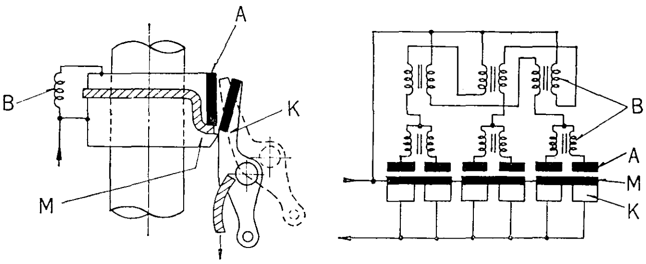
2) The change-over springs are divided in parallel and operation reliability is high.

Fig. 10 shows this type of contact. On the on-load tap changer shown in *Fig. 11*, the upper diverter switch and the lower tap selector are 3-phase devices.

Since the oil in the diverter switch chamber is contaminated by the switching arc, it is kept separate from the oil in the main body and a hot-line oil filtering apparatus is provided to clean the oil without cutting the power. This oil cleaning system operates for about 2 hours every day so that the diverter switch oil is always kept clean.

The tap selector operates without carrying current and although the insulation oil is not contaminated, it is in a chamber separate from the main body. This is provided so that, for frequent tap changing, the oil can be drained independently of the main body oil at inspections.

The required overload capacity is as shown in *Table 1* and the step voltage and the current through



M: Main contact A: Arcing contact
K: Moving contact B: Current balancing reactor

Fig. 10 New-type diverter switch contacts

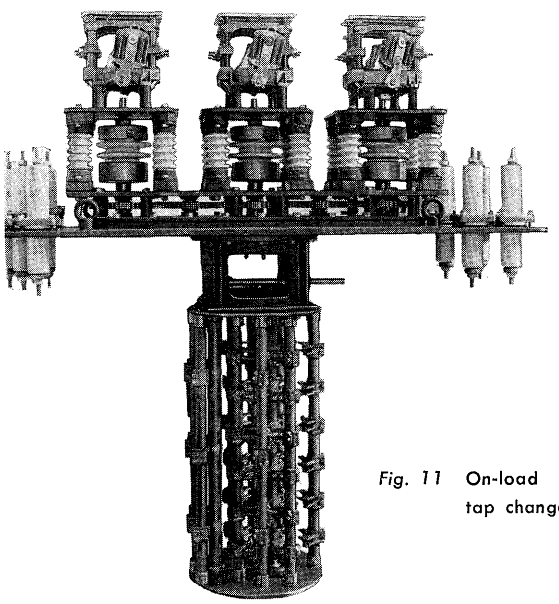


Fig. 11 On-load tap changer

the on-load tap changer is shown in *Fig. 12*. Sufficient margin is available for a maximum overload current of 600 amp and for a step voltage of 777 v.

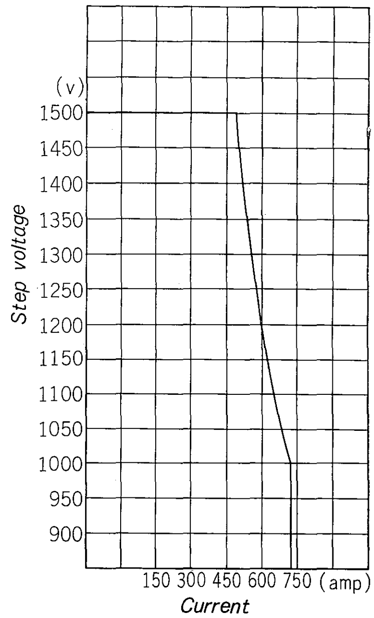


Fig. 12 Application curve for diverter switch

VI. CONCLUSION

An outline is given above of the first 50 Mva electric furnace transformer produced in Japan which was delivered to the Omi plant of the Electro Chemical Industrial Co., Ltd. The latest techniques were applied in the band clamping core, special interleaved disc-type coil, special copper sheet coil and so forth in this furnace transformer. Unlike the " Fahrbar " type car transport system used in the 45 Mva unit, it was possible to use a dropped center car transport system in this 50 Mva unit.

The transformer easily passed the tests specified in JEC168 and the characteristic values were all within the guaranteed values. Although the capacity was greater than the 45 Mva unit and the weight became lighter, total loss was about the same, i.e., the absolute value of efficiency at 100% load is 0.1 to 0.15% higher than that of the 45 Mva unit.

In this transformer, there is a direct step down system from the 63 kv, but a direct step down of the 100 to 140 kv class is also possible. Actually, in the rectifier transformer similar to this furnace transformer construction, the direct step down system from 132 kv voltage was already applied. Since it is possible to produce a copper sheet coil with a current capacity of about $200{,}000/\sqrt{3}$ amp$=115{,}000$ amp, an electric furnace transformer with a capacity of about 90 Mva for a direct step down system from voltage class of 140 kv can also be manufactured on request.

Since the contract to manufacture a 50 Mva electric furnace transformer has been completed, Fuji Electric will continue to further the development of high capacity, high voltage electric furnace transformers.