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LARGEST CAPACITY IN THE WORLD, 30kV 7.5MVA FUJI MOLDED TRANSFORMER FOR SENDAI STATION, JAPANESE NATIONAL RAILWAYS

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I. FOREWORD

Safety measures for electrical facilities installed in densely populated urban areas are becoming stricter year by year.

In the past, when non-inflammability was required of a transformer, which is the main apparatus of these electrical facilities, for safety, non-inflammable oil immersed transformers or "H" class dry varnish type transformers were employed. However, maintenance and inspection of the "H" class dry varnish type transformer adopted on a full scale after the manufacture of non-inflammable oil immersed transformers was prohibited were more trouble some than those of the oil immersed transformer. Therefore, a non-inflammable dry transformer as easy to maintenance and inspect as the oil immersed transformer, but without the insulating oil was strongly demanded.

In 1974 we introduced the Fuji molded transformer, the first transformer in Japan to be both non-inflammable and easy to maintenance and inspect, to meet this demand.

The winding section of the Fuji molded transformer is molded in epoxy-resin, and since the winding is covered with non-inflammable epoxy-resin, the transformer is non-inflammable. In addition, since a rational insulation construction was achieved through the use of high dielectric strength epoxy-resin, substantially smaller dimensions and lower weight than those of the conventional dry transformer have been achieved and noise reduction and other characteristics have been improved.

The Fuji molded transformer has received high praise from all user's ever since its introduction in 1974, and the more than 1,500 units delivered up to now are continuing to operate favorably.

One such unit is the 3-phase, 7.5 MVA, 31.5/6.6 kV "B" class air forced cooling dry type molded transformer, the largest capacity in the world, manufactured and delivered as the power supply transformer for the Sendai Station of the Japanese National Railways.

The manufacture of this record making transformer called on our highest technologies from functions and construction design to selection of suitable materials, epoxy-molded system, and other manufacturing technologies and was performed under complete quality control.

In factory test upon completion of manufacture, excellent results were obtained not only for the test items prescribed in Japanese National Railways Standards (JRS 32102) and transformer standards (JEC-168), but also in heat cycle test, partial discharge test, and other special tests for performances verification, and its reliability was confirmed.

The specifications, construction, and performance verification results of the large capacity 3-phase, 7.5 MVA 31.5/6.6 kV Fuji molded transformer will be outlined in this article.

II. SPECIFICATIONS

The specifications of the Fuji molded transformer conform with Japanese National Railways Standard JRS 32108 (Dry Transformer for Special High Voltage Use) and are as follows:

Cooling system, application: "B" class air forced cooling dry type molded transformer, power transformer
Number of phases, frequency: 3-phase, 50 Hz
Capacity, rating: 7.5 MVA, continous
Primary, secondary rated voltage: (Primary) 31.5/ (secondary tape voltage: F34.5-F33-R31.5-F30.0 kV [4 taps])
Connection: (Primary) Delta/(secondary) delta (Ddo)

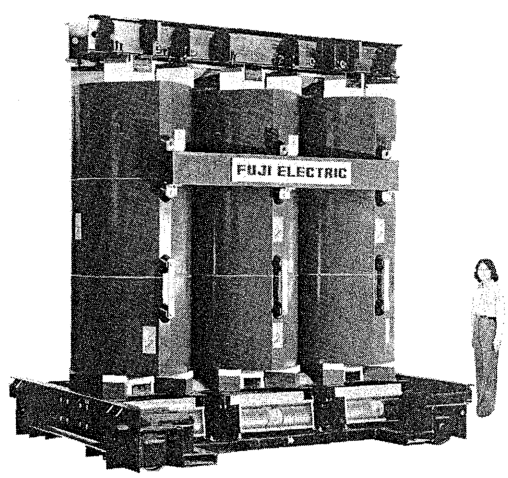


Fig. 1 Fuji molded transformer (3ϕ, 50 Hz, 7.5 MVA, 31.5/6.6 kV)

Insulation test voltage:

Potential test: (Primary) 70/(secondary) 16 kV, for one minute

Impulse voltage test: (Primary) 130/(secondary) 35 kV, full wave (1 x 40) μs standard waveform

Dimensions: Width 3,500 Depth 3,200 Height 3,470 (mm)

Weight: 20.5 t

An exterior view of this transformer is shown in *Fig. 1*.

III. CONSTRUCTION

The construction of the 3-phase 7.5 MVA Fuji molded transformer is outlined in *Fig. 2*.

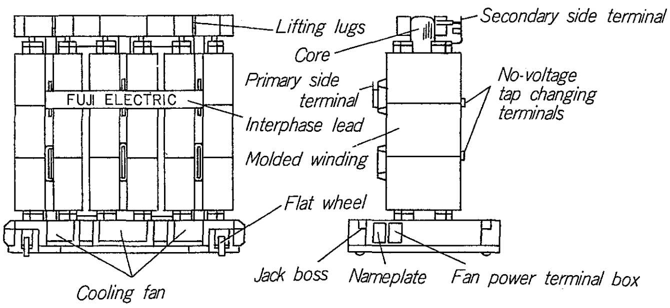


Fig. 2 Construction of 3ϕ 7.5 MVA Fuji molded transformer

1. Core

The core employs cold rolled oriented silicon steel sheet having the highest class characteristics. The core legs employ a braced up with tape system, thus making tightening bolt holes unnecessary. The joint section was made 45° joint to improve the no-load characteristics. Since high quality silicon steel is more sensitive to mechanical stress during machining, assembly, and transportation, extra special care was taken during manufacture to maintain the high performance no-load characteristics. One specific example of such care was the prevention of a drop in the characteristics by bending and other external force at the core by using equipment for core stand-up when standing up the core.

2. Winding

The basic winding construction employed in series design of 5,000 kVA and smaller units, which have an abundant record of achievements, and backed by an electronic computer, was employed in the design of the molded winding, the heart of a molded transformer.

1) Adoption of partition-molded winding

The molded winding of molded transformers is partitioned to cope with for the larger external dimensions which accompany larger capacity.

This is done for economical reasons, mainly in manufacture, and also for higher reliability from the standpoint of technology.

The winding of this transformer has an overlapped series connection in which the primary molded winding is partitioned into top, middle and bottom sections and the secondary molded winding is partitioned into top and bottom sections.

Controlling the stress of the resin of molding parts by means of the size and shape of the molding itself, size and shape of the insert, amount of resin used, etc. is complex. Furthermore, since the equipment for epoxy-molding and equipment for heat hardening are large and uneconomical, a highly reliable molded winding has been made by alleviating the resin stress distribution by partitioning the winding molding parts without making them infinitely large.

The winding partitioning part was decided by giving special consideration to making the electromagnetic mechanical force generated at short circuiting small.

2) Insulation

The dimensions of the epoxy resin layer and atmospheric parts, and the arrangement of the interphase leads, etc. were decided on the results of electric field calculation by computer mapping and dilectric strength tests by actual model.

As a result, no problems were encountered in the dielectric strength test during completion testing of this transformer. Moreover, there was no corona generated at the normal usage voltage and excellent results were obtained.

3) Alleviation reduction of stress in epoxy-resin parts

Since the especially high current capacity winding, terminal fixtures, lead plates, etc. of this transformer are molded, special countermeasures were taken to alleviate the epoxy stresses. Since the low voltage winding leads carry a high current and the cross sectional area of the conductors is large, a new construction (Patent Pending) having a simultaneous flexible effect and buffering effect was adopted, and excellent results were displayed in alleviating the resin stresses.

4) High voltage winding

The thickness of the resin was decided from electric field calculation by computer mapping, electromagnetic force at short circuits, etc. Special consideration was also given to the coupling construction of the part between the winding blocks to improve the strength against the heat cycle during operation. The winding was partitioned into three parts in the axial direction and the partitions were bonded together as a construction and a winding strong against vibration and short circuiting was realized.

5) Low voltage winding

The low voltage winding is basically the same as the high voltage winding. However, since it is a lead conductor for large current unique concepts were employed to alleviate resin stress and from the standpoint of cooling related to heat dissipation. In addition, the winding was partitioned into two parts in the axial direction and the partitions were bonded together as a stick construction, the same as the high voltage winding.

3. Interphase leads

1) Primary interphase leads

Since the three parts of the 30 kV interphase voltage conductor corresponding to the U, V, and W phases are a single resin molding, special emphasis was given to insulation design. The insulation was designed by calculating the electric field by computer mapping. A construction with a corona shield installed was employed so that corona is not generated at the terminal fixtures and windings. Since the molded parts are fairly long, as an assembly, a construction having a resin stress alleviation and flexible effect was employed at the internal conductors.

2) Secondary interphase lead

Since the interphase lead of a molded 6 kV high current conductor, conscientious measures were taken to alleviate stress so that the thermal strain of the resin is small.

4. Winding support

Ample consideration was given to the temperature rise of the molded winding during operation and the electromagnetic force of the winding at short circuiting when deciding the support structure of the winding top and bottom terminals. This construction is a flexible construction, and measures were taken so that mechanical force is not applied to the molded winding during operation and the transmission of noise to the winding surface by vibration by core magnetic distortion is prevented.

5. Cooling

A cooling fan is installed at the bottom of the winding and a forced air cooling system is employed to cool the molded winding and core, which are the main heat sources.

Since a cooling fan is installed at the bottom of the winding at the front and rear of the molded transformer and the transformer is constructed so that an effective cooling effect is obtained by passing the forced cooling air from the fan over the surface of the core and molded winding, even a small cooling fan displays an adequate cooling effect. Moreover, since this transformer is installed in a special high-voltage cubicle, consideration has been given so that it is ventilated by a ventilation fan installed at the ceiling of the power receiving panel to ventilate the air inside the panel.

6. Protection system

When this transformer is to be used at an overload, a sequence case which operates a dial thermometer with alarm contacts installed at each phase of the molded winding is incorporated as a protection system. Consideration has also been given so that perfect operation as a system which issues an alarm even when trouble has occurred at the cooling fan can be expected.

IV. QUALITY CONTROL

In the manufacture of the largest capacity in the world 3-phase 7.5 MVA Fuji molded transformer, the total quality control (TQC) system, which is the basis of our product

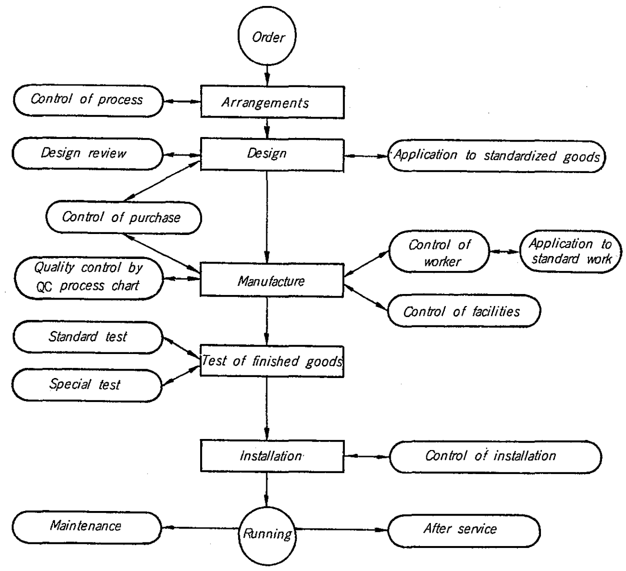


Fig. 3 Flow chart of quality control system

quality control, was faithfully followed to improve the product quality. This system assures product quality by complete performance of the responsibilities of each department at all stages of the production process from management to research, development, design, manufacture, inspection, installation, and after-sales service. The quality control system is outlined in the flow chart of *Fig. 3*.

1. Quality control at the design stage

In the design stage, the materials and parts prescribed by our company standards, etc. are applied and these materials and parts machined and manufactured under ample quality control according to the quality control process chart, etc. Upon completion of the product, the design is studied by factory and central research laboratory specialists and then by the pertinent personnel of the business department to assure better product quality and reliability.

2. Quality control at the production department

1) Application of quality control progress chart

In the manufacture of Fuji molded transformers, a quality control progress chart in which the control item, control level standard and measurement method, record of quality confirmation, etc. are entered for each work process is prepared for all the work, including casting work, and measures to secure quality are faithfully formed by the related departments, including the quality assurance department. Then effective measures are formed and applied by study and consulatation at the relevant departments even for intermediate processes, as required.

2) Control of skills, facilities and environment

The manufacture of the Fuji molded transformer involves casting, lead connection, bolting of structural parts, and many other manual operations. Management of the skills of the workers employs a "Important basic work control" for important work and the workers are given technical training and approval and only those which have passed are specified. The actual work is performed at a dust-free work site using the newest equipment for epoxy-casting in a vacuum condition, winding machine, etc.

3. Quality control of purchased parts and materials

Regarding the use of purchased parts, materials, etc., stable quality purchased parts are applied by means of vendor technical guidance and periodic inspection, etc. Then a purchased parts stocking control system is established for their effective application.

4. Product completion test

At the product completion test not only is satisfaction of the required specifications prescribed by Japanese National Railways Standards confirmed, but a heat cycle test, partial discharge test, and other special tests are conducted to prove that performances are adequate.

V. TEST RESULTS

At the performance verification tests in the complete state, good measured results were obtained and this record making product was proved to be a high reliability product having the ample performances set at the design study stage.

Each item conforming with Japanese National Railways Standards (JRS 32108) and transformer standard (JEC-168) was tested and it proved to be a low loss, high efficiency transformer as shown in *Table 1*.

Table 1. Characteristics of 3ϕ 7.5 MVA Fuji molded transformer

Efficiency (100% load)	99.43% at cosρ = 1.0 99.29% at cosρ = 0.8
No-load current (100% voltage)	0.38%
Voltage regulation	0.86% at cosρ = 1.0 7.6% at cosρ = 0.8
% impedance voltage	9.55%

The main contents of the test results will be described below.

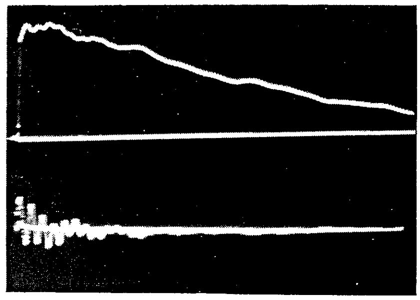
1. Impulse test

At the impulse test, a (1 x 40 μs) full-wave standard waveform impulse voltage was impressed and it was proved that this voltage could be withstood without any abnormalities. The test voltage was the following value based on Japanese National Railways Standards (JRS 32108).

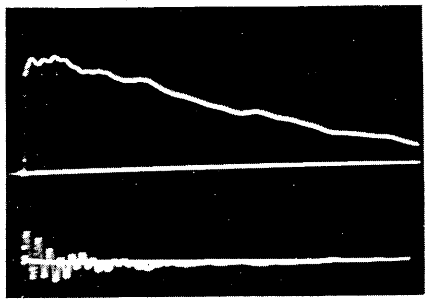
Primary 31.5 kV side: 130 kV

Secondary 6.6 kV side: 35 kV

The oscillograph waveforms when a 50 % reduced value impulse voltage and a 100 % rated impulse voltage were applied at the primary 31.5 kV side ungrounded test are given in *Fig. 4* for reference purposes.



(a) Waveform when 50% reduced voltage impressed (full wave 65 kV)



(b) Waveform when 100% rated voltage impressed

Fig. 4 Impulse test voltage waveform

2. Temperature rise test

A loading back temperature rise test method in which loss are supplied by opening part of the primary 31.5 kV side delta connection, passing a zero phase current corresponding to the rated current, and exciting by impressing the rated voltage at the secondary 6.6 kV side with the test circuit shown in *Fig. 5*, was performed.

The cooling fan installed at the bottom of the transformer was operated normally at the temperature rise test, and it was proved that the forced cooling air from this cooling fan effectively cooled the core and molded winding surfaces.

The temperature rise test results are given in *Table 2*.

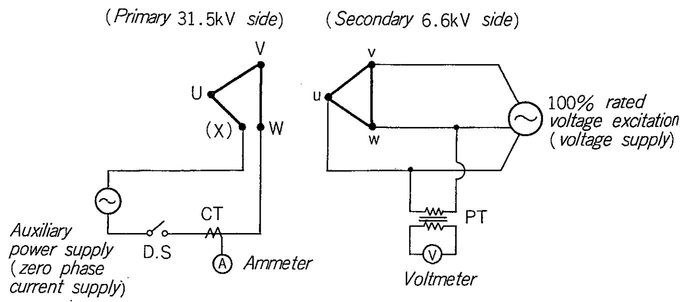


Fig. 5 Temperature rise test circuit

Table 2. Results of temperature rise test

100% voltage excitation, core temperature rise	62 deg
100% rated voltage powering, winding temperature rise	Primary: 60 deg Secondary: 59 deg

3. Noise measurement

Noise measurements were made by no-load excitation at the rated frequency and rated voltage from the transformer secondary 6.6 kV side and with the cooling fan operating normally.

Noise measurements were made according to JEM 1117 and JEM 1118. Whereas the noise level of the conventional "H" Class dry varnish type transformer is approximately 68 phons, the result of measurement of the Fuji molded transformer was 69.1 phons and an extremely low noise measurement value was obtained and the effectiveness of the various measures adopted for noise reduction in the Fuji mold transformer construction was proved.

Fuji molded transformer noise measurement value: 69.1 phons (mean value) [A scale]

4. Partial discharge test

If there are any insulation defects at the molded part of a molded transformer, partial discharge at that part will often be initially large. Therefore, the aprtial discharge test is an effective method of electrically testing a molded transformer for performance verification.

A partial discharge test was also performed on the largest capacity in the world 3-phase 7.5 MVA Fuji molded transformer. The good results shown below were obtained and, together with the results of the dielectric strength test according to the standards, it was proved that its insulation characteristics were perfect.

Partial discharge test: No corona at the normal usage voltage was proved.

5. Heat cycle test

At the heat cycle test a partial model winding having the same specifications of the high direction part of the actual 3-phase 7.5 MVA transformer was manufactured as a test product, a (room temperature → −20°C → room temperature → +100°C → room teperature) heat cycle was repeated 5 times on this test product and no cracking, peeling, etc. was confirmed by visual inspection and no change in the partial discharge test and other electrical characteristics before and after the heat cycle was confirmed.

VI. SHIPMENT AND CARRYING IN

Damage to a performances verified product manufactured under adequat quality control and changes in its performances by vibration and shock during shipment makes the stringent quality control performed up to that point meaningless.

Although this transformer is large, it was transported from the factory to the installation site on a flat trailer for perfect shipment.

To prevent displacement of the dimensions and the application of unreasonable stress to the molded winding by vibration and shock during shipment, the transformer body was packed by amply supporting and fixing it for shipment.

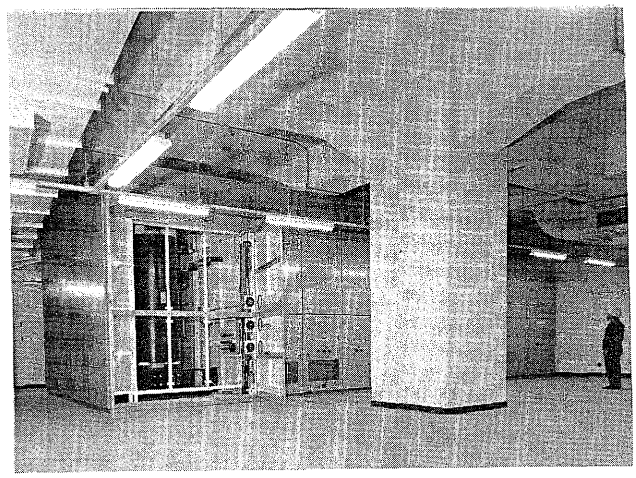


Fig. 6 Installation of Fuji molded transformer

Then monitoring was performed by installing a vibration acceleration meter and the trailer speed was limited to an average 20 km/h. The results of measuring the vibration generated during shipment confirmed that the transformer could be transported at a vibration acceleration of 0.2 G or less without any adverse effect on the transformer body.

The transformer was carried into the underground electric room at the installation site from the hatch of the building and moved on the floor of the building by means of the accessory cart of the transformer body and carefully transported to the special high voltage power receiving panel inside the transformer room and installed.

At the installation site, the molded transformer is operated inside a cubicle. The installed transformer is shown in *Fig. 6*.

VII. CONCLUSION

Today's electrical facilities demand improvements from the standpoints of non-inflammability, simple maintenance and inspection, safety, and operating rationalization.

The Fuji molded transformer with numerous special features that meet these various demands is acclaimed by all users and has a record of numerous applications. Its applications are expected to expand further in the future.

The manufacture of the largest capacity in the world 3-phase 7.5 MVA Fuji molded transformer and its proven excellent quality and performances and continued good operation have proved that the manufacture of similar high capacity molded transformers in the future by securing ample product reliability through the use of our high level molded transformer manufacturing technology is possible.

The trend in future electrical facilities will be toward an increase in transformer unit capacity from the standpoint of economy. The high capacity Fuji molded transformer manufactured at this time can be effectively applied. The authors will be happy if this paper serves as reference in this case.