Recent for Mobile Transformer Technologies

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Abstract

After the two great earthquakes, the Great Hanshin-Awaji Earthquake (1995) and the Great East Japan Earthquake (2011), there has been a growing demand for mobile substation facilities in Japan. In addition, these facilities are required to have larger capacities and multiple functions. The mobile substation facilities are required to conform to various restrictions in terms of mass, dimensions, maximum inclination angle without tipping over, and other factors stipulated by Japanese Road Traffic Law. In order to meet these requirements, mobile transformers are designed and manufactured in consideration of the following factors:

(1) Making a proposal of reasonable specifications

(2) Adoption of a hybrid insulation system made of materials with high heat resisting property

(3) Active use of 3D CAD and mass control for highly accurate mass-related design

(4) Application of advanced strength analysis to structural modification

1 Preface

The interest on mobile substation facilities has increased after the Great Han-shin Awaji Earthquake disaster in 1995 and further heightened after the Great East Japan Earthquake in 2011. The same things can be said about mobile transformers. Presently, we are promoting public relations of these products focusing mainly on power utility companies in Japan. Apart from this, requirements for the operating environment and equipment performance are getting more rigorous year after year. In order to meet these requirements, it is necessary to use advanced technologies. This paper introduces the purpose of using mobile transformers and technologies for reducing overall equipment mass.

2 Purpose of Mobile Transformers

In regard to specifications for mobile transformers where applicable standards for distribution transformers are used, transformers with primary voltages of 66～110kV and capacities of 20MVA or below for distribution substations are mainly dealt with. Mobile transformers are used as an emergency power transformer when the existing power transformer in operation becomes inoperable. In this case, reasons for transformer stoppage are classified into two categories. One reason is for a scheduled shutdown for the purpose of replacement or repair servicing. The other reason is for taking a counteraction in the event of a sudden accident. The design concept for this transformer has to be examined according to which purpose the mobile transformer is being applied.

3 Operating Environment and Requirements

Mobile transformers are designed without designating a specific place of use or any specific substation. They are required to be compact, lightweight, and have a low-noise feature so that they can be moved to any substations.

If they are intended to work for any non-emergency scheduled long-term operation, they are expected to conform to specifications for ordinary distribution transformers. Mobile transformers have to be designed in accordance with large-capacity and low-noise specifications. In such a case, operating time and location are designated and prior clearance for vehicle pass can be applied. In this case, the adoption of a trailer loadable type makes sense because a large transportation load can be easily arranged to be large by prior application. If a mobile transformer is designed for emergency application, however, there is usually not enough time for statutory clearance in advance. In such a case, a compact truck type is generally adopted with an overall mass of 20 tons or lower because it is unnecessary to make prior clearance application arrangements for this size truck to pass. For a total mass of 20 tons or lower, it is difficult to manufacture an ordinary 20MVA distribution transformer. It is necessary to set up transformer mass and capacity and perform careful and well-balanced design, particularly in consideration of the maximum inclination angle without tipping over which is measured at the time of vehicle safety inspection in Japan.

Recently, vehicle tipping-over incident has increased. For special vehicles in particular, the maximum inclination angle without tipping over is measured at the time of vehicle safety inspection. This item inspection is carried out to confirm the performance of a vehicle under test such that it does not fall down even though it is actually tilted at an angle of 30 degrees. If a vehicle under test does not pass this inspection, some restrictions will be applied to this vehicle while it is on the road. In such a case, it becomes difficult to use in an emergency situation. Fig. 1 shows a view of measuring the maximum inclination angle without tipping over of a mobile transformer.

The mobile transformer comes in two types; an integral type where a mobile transformer and a vehicle are integrated and a separate type where a mobile transformer can be separated from a vehicle. An advantage of the separate type is that a trailer or truck can be used as a routine vehicle at the time of traveling,

Fig. 1 View of Measuring the Maximum Inclination Angle without Tipping over a Mobile Transformer

An Actual measured mobile transformer is tilted by 30 degrees together with a carrier truck to confirm whether it tips over or not.

and that no vehicle inspection is needed with the mobile transformer. It is then necessary, however, to remove a transformer from the vehicle at the time of vehicle inspection or storage. Consequently, it is necessary to provide for a large crane or a dedicated factory each time the transformer is unloaded.

4 Technologies for Mass Reduction

Mass reduction is an important factor for mobile transformers. Since many years ago, we have adopted a policy of using aluminum transformer tanks, with special explosion-proof construction where a tank and a conservator are joined together, low-noise aluminum coolers, polymer bushings, and others. For optimal design with high accuracy, we are recently focusing on three technologies for the mass reduction as described below.

4.1 Hybrid Insulation System

In the case of conventional mobile transformers, we used to adopt heat-resistant insulation paper (amine-added paper) that has thermal durability higher than that of ordinary craft paper. Such paper was applied to windings. This type of paper assures an average winding temperature rise of 70K that is 10K higher than the stipulation of Japanese Power Transformer Standard JEC-2200. Using this insulation paper, we have promoted the compact and light mass design for power transformer main bodies. The hybrid insulation technology introduced in this paper is based on the idea of the Hybrid Insulation System stipulated by the IEC60076-14. High-temperature insulation paper (aramid paper) is applied to windings, which belongs to a heat-resistant class higher than that of oil-immersed transformers, generally used in dry-type transformers and gas-insulated transformers. The effect of this paper is such that average winding temperature rise is raised to 95K. As a result, compact windings are realized by raising the current density much higher, and we also realized the compact and light mass design of the main body of the transformer. Table 1 shows the limits of temperature rise and Fig. 2 shows the parts where high-temperature insulation materials are used.

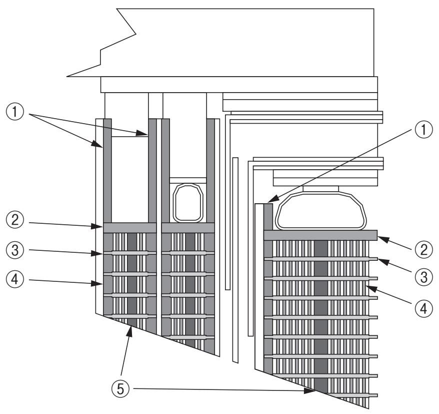
For mobile transformers, the effect of mass reduction depends on the specifications of each transformer unit. This effect, however, tends to increase for higher impedance machines where the amount of wires used is large. In this case, the expected effect of mass reduction amounts to 10%

Table 1 **Limits of Temperature Rise (IEC60076-14)**

Limits of temperature rise are shown for oil-immersed transformers where high-temperature insulation materials introduced in the IEC60076-14 are used.

		Ordinary equipment	Mixed insulation system	Semi-hybrid insulation system	Hybrid insulation system
Thermal durability class of high-temperature insulation materials		N/A	130	120	155
Maximum oil temperature (K)		60	60	60	60
Average winding temperature (K)		65	65	75	95
Limits of temperature rise around high-temperature insulation materials (K)		N/A	110	90	130
Situation of application of high-temperature insulation materials (See Fig.2 regarding the places used)	①	N/A	N/A	N/A	High-temperature insulation materials
	②	N/A	High-temperature insulation materials	N/A	High-temperature insulation materials
	③	N/A	High-temperature insulation materials are used only in highly heated places.	N/A	High-temperature insulation materials
	④	N/A	High-temperature insulation materials are used only in highly heated places.	High-temperature insulation materials	High-temperature insulation materials
	⑤	N/A	N/A	N/A	High-temperature insulation materials

Note: N/A: Not Applicable



① Vertical wedge
②③ Spacer for inter-winding horizontal duct
④ Wire sheath
⑤ Spacer for cooling duct in winding

Fig. 2 **Parts where High-Temperature Insulation Materials are Used**

Winding structural diagram is shown as introduced by IEC, where materials with different heat-resistant classes are used in windings.

to 20% for core-and-coil assembly mass. However, core-and-coil assembly mass is reduced, but heat generation is reciprocally increased. For this reason, large-capacity cooling equipment is required. It is therefore necessary to select a cooler unit that assures adequate cooling performance.

4.2 Mass Control by Effectively Using 3D CAD Design

In order to realize light mass and large capacities, a highly accurate mass control is needed. By raising the accuracy of the design mass, it is possible to design a machine as close as possible to the mass limitation. If accurate designing is achieved, it is then possible to increase the transformer capacity in proportion. Presently, a 3D CAD is being used for this design. For the light mass design, the shape of each mobile transformer tends to be complicated. This 3D CAD, is therefore being used for mass calculation of a mobile transformer.

In order to avoid an overweighing design of a mobile transformer, it is necessary to pursue a difference caused between design mass and actual measured mass in the middle of manufacturing for each component and process. Accuracy for design mass can be improved by data accumulation about actual measured mass of subdivided components and parts.

At each stage of manufacture, every worker measures in detail the mass of respective components and parts. It is difficult, however, to achieve accurate measurement without overlooking some weighing measurement. If subdivision of components is too excessive, measurement errors may occur. As such, some parts in a certain size of block have been weighed. In this practice, however, detailed mounting conditions of parts are unclear and oversight or duplication of weighing can occur. As a countermeasure, the mass summary tables have been produced in the unit of a part or blocks being weighed in each manufacturing process.

According to 3D CAD data, image diagram sheets are stuck to these tables so that the parts being weighed can be recognized at a glance. As a result, oversight or duplication of weighing can be avoided and accurate mass control became possible. In regard to a mobile transformer manufactured last year, for example, the aforementioned mass control table was used for the measurement and management of equipment mass. For a product of 25 tons in mass, the resultant error was less than 100kg between the finally measured mass and the summary mass in the mass control table. This result indicates that our product mass control is highly accurate. Table 2 shows the mass summary table.

4.3 Effective Structural Design by Strength Analysis

In order to meet the requirements of loading mass limitations and utmost expansion of capacities for mobile transformers, parts and components to be used have to have a mass as light as possible. Since this equipment is subject to frequent moving, its designing approach has to be focused on the securing sufficient reliability in the mechanical strength. For this purpose, the equipment exterior is made of aluminum alloys to reduce mass. Compared with ordinary ferrous materials, these materials have less strength which means it has a weakness against metallic fatigue, they, therefore, have to be carefully evaluated. At the start of each new design, strength is investigated by strength analysis based on the finite element method in order to realize reliability and light mass.

Strength of parts used in transformer exterior is evaluated together with vacuum withstand strength including the buckling strength against the vacuum oil filling to be conducted during production. Strength against fatigue due to vibration generated while equipment is in transport is also analyzed for strength evaluation.

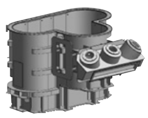
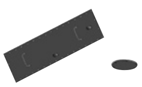
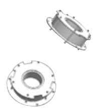
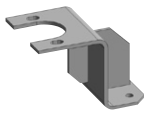
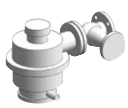
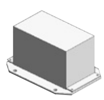
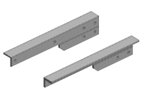
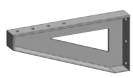
4.3.1 Vacuum Withstand Strength

Strength of an ordinary transformer tank can be evaluated by theoretical calculation unless the shape of the tank is complex. If the shape is complex, we conduct strength evaluation by CAE analysis through partial simulation of construction. This was a common practice before the advent of rapid progress of computers in 1980s. Nowadays, when the processing speed of computers has been extremely improved, even a tank in a complicated shape can be put into strength evaluation at the time of designing by analysis on an overall model consisting of detailed parts.

The shape of a mobile transformer tank is gen-

Table 2 Mass Summary Table

An example of “Mass Control Table” is shown, used for the reinforcement of mass control for mobile transformers.

	Mass of lower tank	Design value	Actually measured value	Difference		Mass of lower tank	Design value	Actually measured value	Difference
	Lower tank + Primary pocket	***.*	***.*	*.*		Valve set	6.0	6.0	0
	Hand hole + BCT cover	8.0	8.0	0		Primary BCT	26.0	26.0	0
	Dial thermometer support	6.0	5.5	−0.55		LCT bearing	3.0	3.5	0.5
	SPO set	12.0	10.0	−2.05		Acceleration meter	15.0	15.0	0
	SPO support	2.0	2.0	0		BUP support	10.0	9.5	−0.55

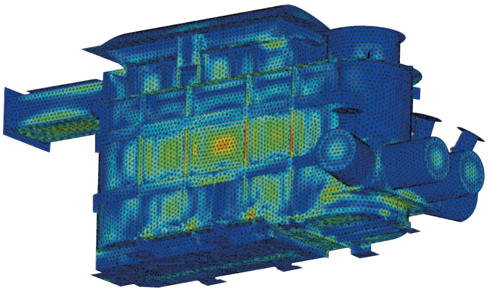


Fig. 3 Result of Vacuum Withstand Strength Analysis

A stress distribution diagram is shown. This diagram is obtained from a vacuum withstand strength analysis with the use of an overall model of mobile transformer.

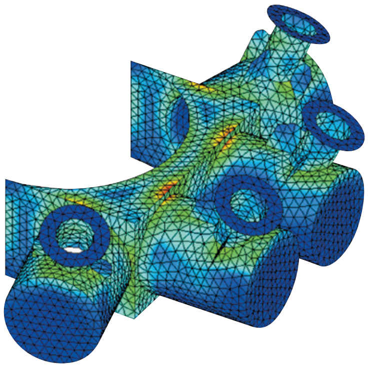


Fig. 4 Result of Dynamic Response Analysis Conducted during Transportation of a Bushing Pocket

A bushing pocket of mobile transformer is arranged into a model. The result of dynamic response analysis is shown, performed while the model is transported.

erally complex. However, an overall analytical model is used even for the evaluation of vacuum withstand strength. Fig. 3 shows the result of vacuum withstand strength analysis. In this analysis, reinforcement pitches, thickness, and shapes are changed within the range of minimum permissible design values for aluminum alloys so that optimal design can be accomplished toward the goal of minimum total mass for the transformer tank.

4.3.2 Strength for Transportation

Mobile transformers are frequently moved to places where they are needed for remedial activities in the case of a disaster or an emergency. While they are moved, dynamic loads are exerted on equipment; therefore, strength evaluation is indispensable in consideration of possible metallic fatigue during transport.

In regard to strength of aluminum alloy materials used, factory fatigue test is carried out. The testing items are a static load test for bending and tensile strength and a fatigue test in consideration of repeated loading. For strength against fatigue, a dynamic load is applied to the specimen about ten million times. According to the obtained test result, a permissible stress value is set up which defines an approximate load to withstand the loading of infinite repetitions.

For the analysis of transportation, evaluation of necessary parts is performed by dynamic response analysis by using a partial model. Fig. 4 shows the result of an analysis into a bushing pocket as an example of dynamic response analysis. Based on the results: (1) response analysis factoring a dynamic response element and (2) analysis result of fatigue strength measurement, we make a design to secure reliability of transportation strength. Strength for transportation is confirmed for its soundness not only by a desktop PC analysis study, but also by a final road running test.

4.3.3 Summary for Strength Analysis

Compared with ordinary power transformers, mobile transformers tend to be used under rigorous operating circumstances. Accordingly, an evaluation of strength is performed by analysis on the assumption of both static loading and dynamic loading during transportation. Reliability is secured based on the result of material evaluated and a road running test. In order to respond to the needs of our customers, we will continue to promote the adoption of new materials and effective design for larger capacity and lighter mass.

5 Postscript

We recognize that the requirements for lighter mass and larger capacity will continue in the future. To further simplify the fieldwork at the time of an emergency, there are another requests for mobile transformer to be integrated with circuit breaker units. Fortunately, we possess Vacuum Circuit-Breakers (VCBs). Together with our efforts to reduce total system mass, we will promote product development utilizing our technologies.

In addition, we will continue to develop high-quality and light mass mobile transformers using palm oil which is eco-friendly with high cooling efficiency and a low specific gravity.