Rectangular Large-Capacity 5-Leg Type MOLTRA to Meet the Needs of Energy Saving and Downsizing

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ABSTRACT

Electrical facilities are being required to improve energy efficiency to reduce greenhouse gas emissions and achieve carbon neutrality. Meanwhile, data centers and semiconductor factories have recently become using larger capacity cast resin transformers (MOLTRA) to respond to rising power demand, however, also requiring downsizing. To meet this need, Fuji Electric has developed the "V-ECO MOLTRA," rectangular large-capacity 5-leg type MOLTRA. It uses a 5-leg wound iron core whose core and coils are rectangular shaped. As a result, its height is 15% lower while maintaining the same energy-saving performance and footprint than that of the conventional product.

1. Introduction

With the aim of achieving carbon neutrality or a decarbonized society by 2050, there is a demand for the improvement of energy efficiency in electrical equipment to reduce greenhouse gas emissions.

In data centers and semiconductor factories, for which the market is expanding due to the advancement of digitalization in society, uninterruptible power systems (UPSs) are increasing in capacity(1) as the demand for electric power rises, and in turn, the capacity of transformers is also increasing. The number of cases where power distribution equipment is installed indoors is increasing, making it important to reduce the size of the equipment.

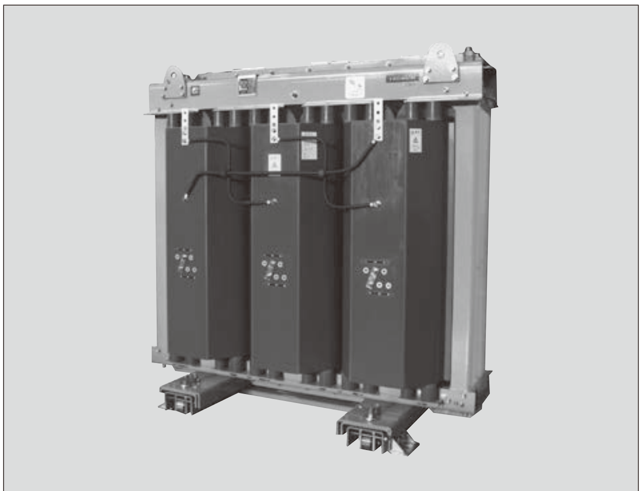

Fig.1 "V-ECO MOLTRA," rectangular large-capacity 5-leg type MOLTRA

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Fuji Electric's product MOLTRA*1 has been designated as specified equipment in the Act on the Rational Use of Energy (Energy Saving Act). It has also offered the "Top Runner MOLTRA 2014," which meets the second judgment standard that came into effect in April 2014 (Top Runner Transformer 2014*2).

In response to the need for large capacity, high efficiency and compact size (for indoor installation) described above, Fuji Electric has developed the "V-ECO MOLTRA," a rectangular, large-capacity 5-leg type MOLTRA with a reduced height (see Fig. 1) while maintaining the same energy-saving performance and footprint of the conventional product.

2. Large-Capacity MOLTRA

2.1 Overview

Fuji Electric has launched the "Top Runner MOLTRA 2014," which meets the requirements of the Top Runner Transformer 2014. In addition, it has released the "Amorphous MOLTRA" and "Super-Eco MOLTRA II" as ultra-high efficiency products mainly for small- and medium-capacity applications, respectively. Figure 2 shows the product line-up.

*1 MOLTRA: Fuji cast resin transformer (registered trademark of Fuji Electric Co., Ltd.)

*2 Top Runner Transformer 2014: Transformers that have achieved an efficiency higher than the standard energy consumption efficiency of the secondary judgment criteria prescribed in the "Criteria for manufacturers on improvement of performance of transformers" (Public Notice of Ministry of Economy, Trade and Industry No. 71 in 2012) for specified equipment under the Energy Saving Act

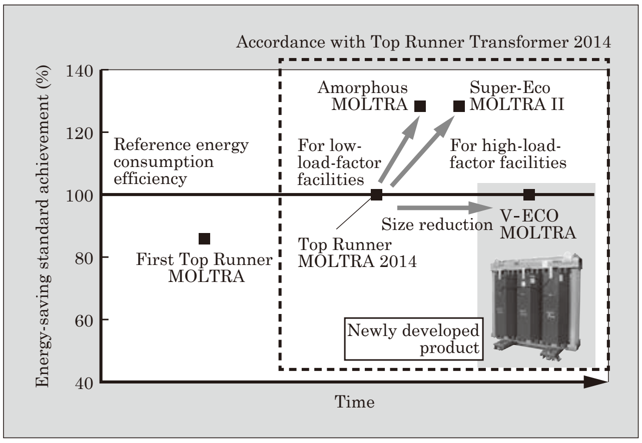

Fig.2 Product line-up

Fig.4 Switchboard

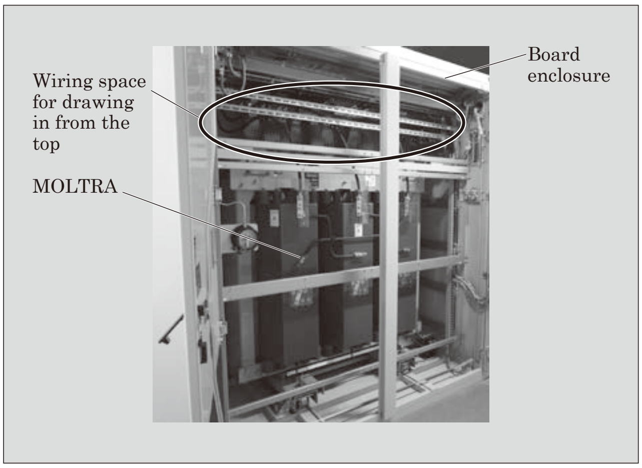

Fig.5 MOLTRA installed in a switchboard

2.2 Structure

Table 1 shows the coil shape and core structure for each capacity class of the Top Runner MOLTRA 2014. The models with capacities of 1,000 kVA or less use rectangular-shaped coils and three-leg wound cores as shown in Fig. 3(a). Meanwhile, the models with capacities greater than 1,000 kVA use round-shaped coils and three-leg stacked cores as shown in Fig. 3(b).

2.3 Challenges

Generally, the Top Runner MOLTRA 2014, which is used in data centers and factories, is housed in a switchboard as shown in Fig. 4. Figure 5 shows the MOLTRA installed in a switchboard. The switchboard transforms high-voltage electricity supplied from power stations or substations to low-voltage electricity. Switchboards should be designed to be standard 2,300 mm or less in height and reduce the footprint as much as possible in terms of dimensional constraints, such as the size of the electric room, ceiling height, overhead electric circuit space, and the loading and unloading route. The method of pulling in wiring cables into a switchboard varies depending on the installation, but when pulling in from the top, wiring space is required between the MOLTRA and the top of the switchboard, as shown in Fig. 5. For this reason, the MOLTRA must have dimensions that not only allow it to fit into a standard-height panel enclosure, but also allow the switchboard to have a space above it. Therefore, as capacities become larger, the size reduction of external dimensions has become a challenge. Such size reduction has become important because more and more power distribution equipment is being installed indoors.

Table 1 Coil shapes and core structures of the “Top Runner MOLTRA 2014”

Number of phases	Capacity	Coil shape	Core	
			Number of legs	Type
Three-phase	1,000 kVA or less	Rectangular	Three-leg type	Wound core
	More than 1,000 kVA	Round	Three-leg type	Stacked core

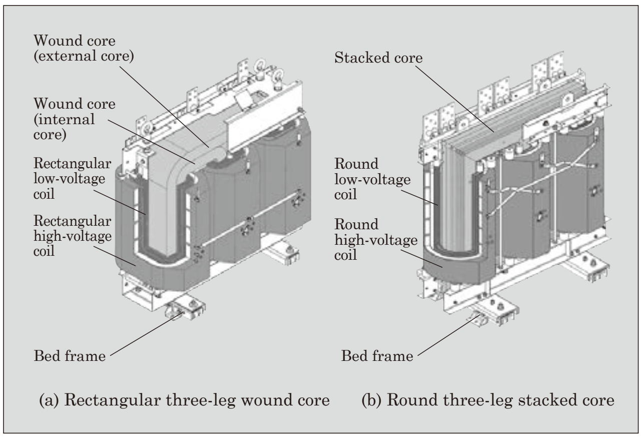

Fig.3 MOLTRA structures

3. Overview of the “V-ECO MOLTRA,” a Rectangular Large-Capacity 5-Leg Type MOLTRA

In response to the issues described in Section 2.3, we have developed the new V-ECO MOLTRA, which serve as a large-capacity MOLTRA of more than 1,000 kVA. It has an energy consumption efficiency equivalent to that of the Top Runner MOLTRA 2014 but with reduced height.

3.1 Size reduction

It has lower height than the Top Runner MOLTRA 2014s having a capacity of over 1,000 kVA by 15% to fit it into a standard height panel enclosure with 2,300 mm. Nevertheless, its footprint is the same size as the conventional product, achieving compactness. The following covers the specific means used to achieve this.

MOLTRAs with capacities exceeding 1,000 kVA generally employ a three-leg stacked iron core as shown in Fig. 6(a), but this time, we focused on a five-leg iron core to reduce the height dimension. Figure 6 shows the magnetic flux in the iron core represented by arrows and vector diagrams.

The five-leg stacked core has a structure in which the iron core (return leg) is also placed outside of the coils (U phase, W phase) as shown in Fig. 6(b). On the other hand, the five-leg wound core consists of four wound cores arranged in a row, with the cores insulated by a surface coating, as shown in Fig. 6(c). Although they have different structures, they share the same magnetic flux vector diagram and have the same magnetic flux distribution.

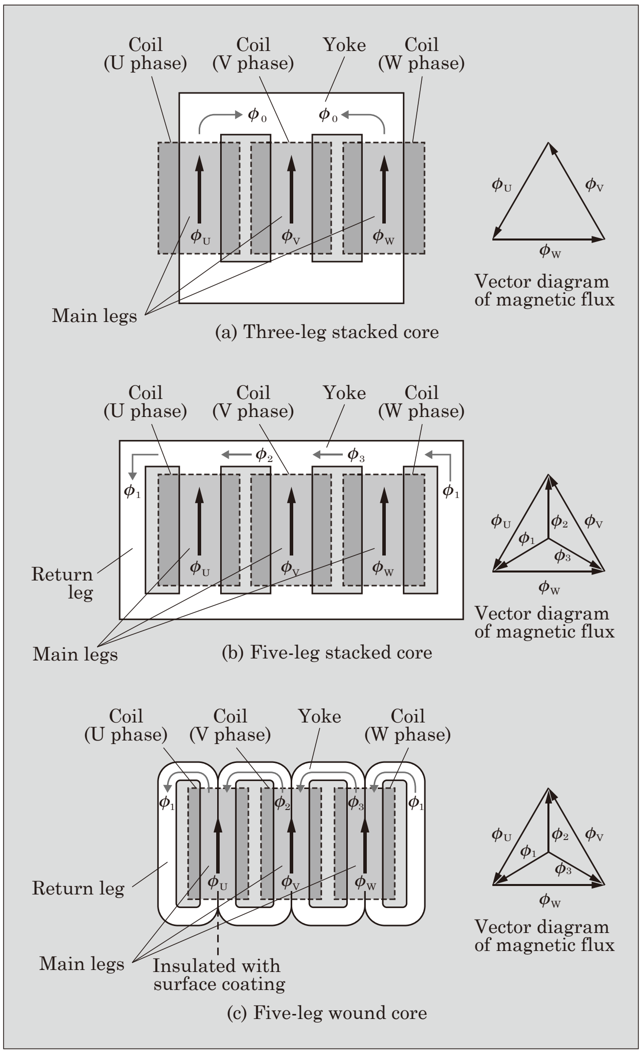

Fig.6 Structures of the three-leg iron core and the five-leg iron core

The amount of magnetic flux flowing in the main legs and yoke of a three-leg stacked iron core is all uniform, and the relationship between them is expressed by Equation (1).

$$|\overrightarrow{\phi_0}| = |\overrightarrow{\phi_U}| = |\overrightarrow{\phi_V}| = |\overrightarrow{\phi_W}| \cdots\cdots (1)$$

ϕ_U, ϕ_V, ϕ_W: Magnetic flux in the main legs (Wb)
ϕ_0: Magnetic flux in the yoke (Wb)

On the other hand, in the five-leg stacked core and the five-leg wound core, the magnetic flux flows into the return leg; therefore, as shown in the vector diagrams in Figs. 6(b) and 6(c), the magnetic flux flowing into the yoke and return leg is smaller than the main legs. The relationship of the magnetic flux between the main legs, yoke, and return leg varies depending on the differences in their magnetic resistance, but assuming that the levels of the magnetic resistance are the same, it is represented by Equation (2).

$$|\overrightarrow{\phi_1}| = |\overrightarrow{\phi_2}| = |\overrightarrow{\phi_3}| = \frac{1}{\sqrt{3}}|\overrightarrow{\phi_U}| = \frac{1}{\sqrt{3}}|\overrightarrow{\phi_V}| = \frac{1}{\sqrt{3}}|\overrightarrow{\phi_W}| \cdots\cdots (2)$$

ϕ_U, ϕ_V, ϕ_W: Magnetic flux in the main legs (Wb)
ϕ_1, ϕ_2, ϕ_3: Magnetic flux in the yoke and return leg (Wb)

Calculations for the magnetic flux density in the main legs B_1 (T) and the magnetic flux density in the yoke and return leg B_2 are represented by Equations (3) and (4). The space factors are assumed to be equal.

$$\overrightarrow{B_1} = \frac{\overrightarrow{\phi}}{S_1 \times \text{Space factor}} \cdots\cdots (3)$$

$$\overrightarrow{B_2} = \frac{\overrightarrow{\phi}}{S_2 \times \text{Space factor}} \cdots\cdots (4)$$

B_1: Magnetic flux density in the main legs (T)
B_2: Magnetic flux density in the yoke and return leg (T)
S_1: Core section area of the main leg (m^2)
S_2: Core section area of the yoke and return leg (m^2)

When uniformly designing magnetic flux density for the main legs and yoke, the cross-sectional area of the main legs and yoke should be the same for a three-leg stacked iron core. Meanwhile, to uniformly design the magnetic flux density in the main legs, yoke and return leg in the five-leg stacked iron core and five-leg wound iron core, the cross-sectional area of the yoke and return leg should be $1/\sqrt{3}$ times that of the main leg according to Equations (3) and (4), as the amount of magnetic flux in the yoke and return leg is $1/\sqrt{3}$ times that of the main leg according to Equation (2). Therefore, for the five-leg stacked iron core and the five-leg wound iron core, the height of the yoke can be reduced in comparison to the three-leg stacked iron core, enabling height reduction of the MOLTRA.

As described above, we found that it is possible to lower the height of the MOLTRA by applying these five-leg cores. On the other hand, because the core is also located outside of the coil, the five-leg stacked iron core in particular has the disadvantage of a larger width than the three-leg stacked iron core, as shown in Fig. 6(b).

Consequently, the V-ECO MOLTRA uses a five-leg wound iron core with four wound iron cores arranged side by side as shown in Fig. 6(c), as well as a rectangular coil shape. Compared to round coils, rectangular coils have a larger depth but smaller width as shown in Fig. 7(a). This is because a width increase seen in the five-leg stacked iron core in Fig. 6(b) can be suppressed to enable a compact design. In addition, there is the advantage of easier manufacturing than the five-leg stacked iron core.

However, rectangular-shaped low-voltage coils tend to have air gaps between conductors in the width direction, as shown in Fig. 8. Without solving this issue, the impact of reducing the width is small. Furthermore, these air gaps inhibit heat transfer by thermal conduction within the winding, thereby reducing the heat dissipation performance of the coil. We thus applied compressive force in the direction of the arrows using the dedicated jig to the width direction of the low-voltage coil as shown in Fig. 8 to suppress the generation of air gaps between conductors. As a result, we reduced the width of the low-voltage coil and achieved, as shown in Fig. 9(a), the five-leg wound iron core that has a width equivalent to that of the three-leg stacked iron core.

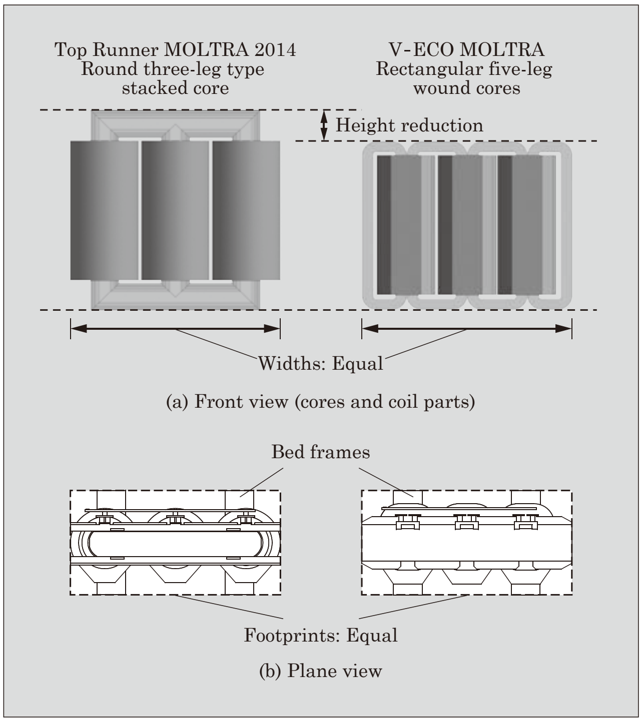

Fig.9 Comparison between MOLTRA external dimensions

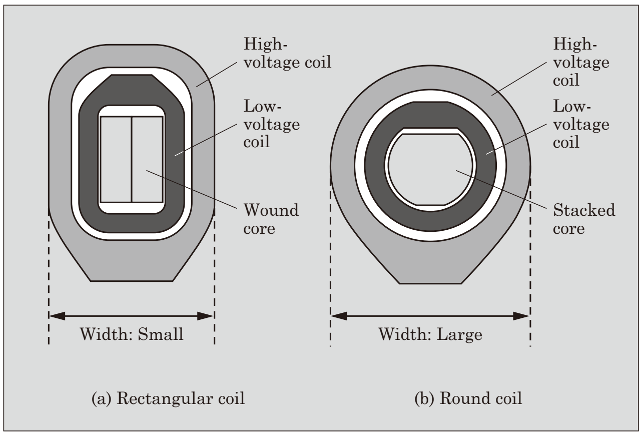

Fig.7 Cross-sectional views of coil parts

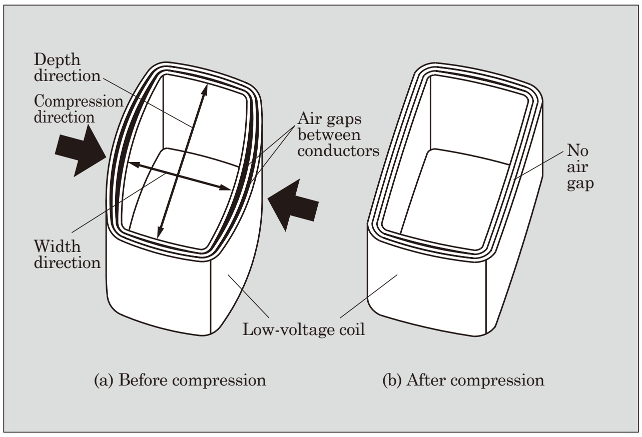

Fig.8 Compression of low-voltage coils (simple drawings)

As shown in Fig. 9(b), the depth of the MOLTRA is maximum at the bed frame. The bed frame is used to mount the MOLTRA to the switchboard and for fall prevention. Although the five-leg wound iron core structure has a greater mass than the three-leg stacked iron core structure because of the longer magnetic path length, its lower height of the center of gravity reduces the moment acting on the bed frame mounting bolts and other parts during vibrations, such as those caused by earthquakes. As a result, it can be stably installed with a bed frame of the same size as the conventional Top Runner MOLTRA 2014, which has a three-leg stacked iron core structure, maintaining same footprint as that of the existing product.

The outer side in the width direction of the five-leg wound iron core is the non-charging section (iron core), and the insulation distance (separation distance) from the side of the switchboard can be kept short compared with the conventional three-leg stacked iron core, of which the outer side is the charging section (high voltage coil). As a result, the footprint is equivalent to that of the conventional model, but the width of the board that houses the MOLTRA has been reduced.

3.2 Optimization of design

The newly developed V-ECO MOLTRA has comparable energy-saving performance to the Top Runner MOLTRA 2014 that exceeds 1,000 kVA. The following describes the optimization of the design and the energy-saving performance of the five-leg wound core.

In the five-leg stacked iron core, electromagnetic steel sheets stacked for each of the main leg, return leg, and yoke are integrated to form the core as shown in Fig. 6(b). Thus, the cross-sectional area of the main leg, return leg, and yoke can be adjusted by changing the width dimension of the electromagnetic steel sheet in the main leg and return leg and the height dimension of the electromagnetic steel plate in the yoke, respectively. Therefore, the cross-sectional area of the yoke and return leg can easily be made $1/\sqrt{3}$ that of the main leg.

On the other hand, the five-leg wound iron core uses four wound iron cores arranged in a row, with each core made of electromagnetic steel plates stacked in a spiral shape as shown in Fig. 6(c). The cross-sectional area of each wound core is the same at any portion, and therefore, the section area of the main leg is equivalent to that of two wound cores. As a result, the section area of the yoke and return leg is half that of the main leg, and the height can be further reduced compared with the five-leg stacked iron core. On the other hand, the yoke and return leg of the five-leg wound iron core have a magnetic flux of $1/\sqrt{3}$ times that of the main leg and a cross-sectional area that is half that of the main leg, and therefore the magnetic flux density is $2/\sqrt{3}$ times that of the main leg according to Equations (3) and (4). Thus, taking into account the fact that the magnetic flux density in the yoke and return leg is larger than that of the main legs, we designed the magnetic flux density in the main legs to be relatively low so that the iron core would not saturate and impair transformer function. In addition to the magnetic flux density reduction, we employed low-loss iron core because the five-leg wound iron core has higher power loss than that of the three-leg stacked iron core resulting from its larger mass.

These design optimization has enabled to maintain the same energy consumption efficiency as the Top Runner MOLTRA 2014 (40% higher energy consumption efficiency than the 1990 s model).

3.3 Other features

In addition to the increased energy performance and size reduction, the V-ECO MOLTRA has the following features.

(a) Significant noise reduction (−10 dB) compared with the 1990 s model
(b) High flame retardancy and type certified according to IEC 60076-11
(c) High insulation reliability due to suppression of partial discharge by applying molded windings cast in a vacuum environment

4. Postscript

This paper described the rectangular large-capacity 5-leg type MOLTRA, which was designed in response to the need for better energy performance and size reduction.

Going forward, we will continue to try to understand customer needs in order to develop the optimal MOLTRA products.

References

(1) Yasumoto, K. et al. “Common Backup Systems for Data Centers with Large-Capacity UPS. FUJI ELECTRIC REVIEW. 2020, vol.66, no.1, p.72-78.

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