“F-MELT100G Series” High-Efficiency, Medium-Frequency Induction Furnace

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ABSTRACT

The recent growth in automobile production has increased the demand for medium-frequency induction furnace used in production of casting parts. In addition, the increase in the stringency of energy saving regulations in various countries has created a greater need for high efficiencies and large capacities. Fuji Electric has developed the “F-MELT100G Series,” which comes with a high-voltage IGBT stack and high-efficiency furnace body that improves the melting consumption rate. These enhancements reduce electricity consumption, and a wide range of products are available with a power supply capacity of up to 20 MW. Moreover, this series is equipped with a direct digital control unit with self-check and RAS functions, enabling it to stabilize operations for systems and to quickly identify the cause of failures.

1. Introduction

Medium-frequency induction furnaces heat metals to one thousand and several hundred degrees Celsius to melt them by using electromagnetic induction produced by alternating current of several hundred Hertz. It is widely used as manufacturing equipment for casting parts used in automobiles or machines. In recent years, with the increase of automobile production in China, the demand for medium-frequency induction furnaces is increasing. In addition, the stringency of energy saving regulations in various countries has created greater needs for the functions such as improved maintainability and preventive maintenance as well as for higher efficiency and larger capacity. In order to satisfy such needs not only in Japan but also in overseas, especially China and Southeast Asia, Fuji Electric has developed the “F-MELT100G Series” high-efficiency, medium-frequency induction furnace. This paper describes the F-MELT100G Series, which offers furnace body capacity that has reduced equipment loss (conduction power loss caused by an induction furnace) and can melt metals of 3 to 30 t with a wide range of power supply capacities from 3 to 20 MW.

2. Reality of Power Consumption in a Cast Production Process

The pig iron and cast manufacturing industries are energy-consuming industries where the ratio of the power consumption charge required for production to the shipment value is 10 times or higher compared with general machinery manufacturing industry[1] (see Fig. 1). The melting process, in particular, accounts for approximately 60% of the amount of power consumption in cast manufacturing. Reducing the amount is one of the management challenges in the pig iron and cast manufacturing industries.

The amount of power consumption in the melting process is typically expressed by Expression (1).

Amount of power consumption =
Melting energy + Equipment loss +
Operation loss ······························ (1)

Melting energy: Energy required for melting metal
Equipment loss: Conduction power loss caused by an induction furnace (challenge to the manufacturer)
Operation loss: Power that does not contribute to metal melting, such as standby power and the power used for excessive heating of molten metal (challenge to the user)

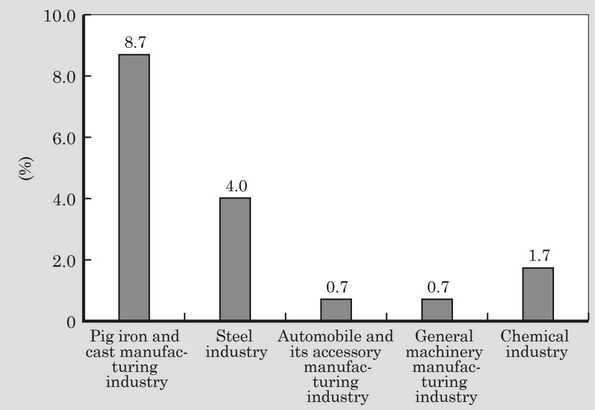

Fig.1 Ratio of power consumption charge to shipment value

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Consequently, reducing the amount of power consumption in the melting process requires the reduction of equipment loss and operation loss.

3. Features of the “F-MELT100G Series”

This chapter describes the features of the “furnace body,” which is the main component of the F-MELT100G Series and melts metal, the “medium-frequency power supply,” which supplies medium-frequency current of several hundred Hertz to the furnace body, and the “direct digital control unit,” which is a new instrument added to the medium-frequency power supply.

3.1 Features of the furnace body

(1) Structure of the furnace body

The power loss of the furnace body, which melts metals with electromagnetic induction effect, accounts for approximately 70% of the overall equipment loss. As shown in Fig. 2, the furnace body consists of a fire-resistant container (crucible) to contain iron or other materials to be melt, an induction coil positioned around it, and iron cores arranged along the outer periphery of the induction coil. The shapes and positional relationship of these components will greatly affect the power loss. Therefore, we used the furnace body structure shown in Fig. 2 and conducted electromagnetic field analysis by considering the amount of molten metal (volume) that changes from the start of the melting process through the heating process during which additional metal was fed until the specified temperature was achieved. To ensure the effective use of the power supplied to the induction coil, we modified items such as the diameter and height of the coil, the gap between the turns of the coil, and the shape of the iron core to create a unique induction coil structure.

The iron cores arranged along the outer periphery of the induction coil will help optimum distribution of magnetic flux and also serves as a supporting structure to suppress thermal expansion generated radially in the crucible as the temperature of molten metal rises.

As shown in Fig. 3, the iron cores had been fixed to the furnace frame with refractory cement in the conventional structure. There was a problem of increased loss when the crucible caused thermal expansion because the silicon steel plate that made up the iron core would deform. To prevent it, we changed the structure so that the iron cores are indirectly fixed to the furnace frame. This suppresses the internal stress generated in the iron core when the temperature rises compared with the conventional structure and prevents the increase of core loss.

(2) Furnace body supporting higher voltage

In view of the recent changes in the environment surrounding companies, the expansion of the large furnace market is expected due to the changeover to induction furnaces that can reduce CO_2 emission compared with coke ovens. As for the F-MELT100G Series, the range of power supply capacities has been expanded from conventional 8 MW to the maximum of 20 MW. The voltage applied to the induction coil has been increased to 6 kV, two times higher than the conventional models, to suppress the wiring loss caused by the main circuit current that increases with the increased capacity. However, when high voltage was applied to the conventional isolation structure, there was a problem of partial discharge between the end of the iron core and induction coil, as shown in Fig. 4.

To solve the problem, we changed the insulation to the one that not only can extend the insulation distance but also causes less change in relative permittivity and less decrease in volume resistivity even in the high-temperature, high-humidity and dusty use environment of induction furnaces. This insulation also has better flexibility and bending performance. We used the insulation to entirely wrap around the outside of the induction coil. With the conventional model, the partial discharge would start when the applied voltage becomes 6 kV as shown with ◎ in Fig. 5. It, however,

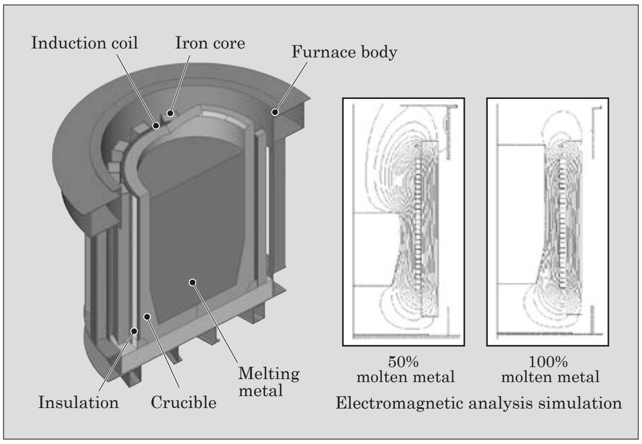

Fig.2 Furnace body structure and electromagnetic analysis simulation example

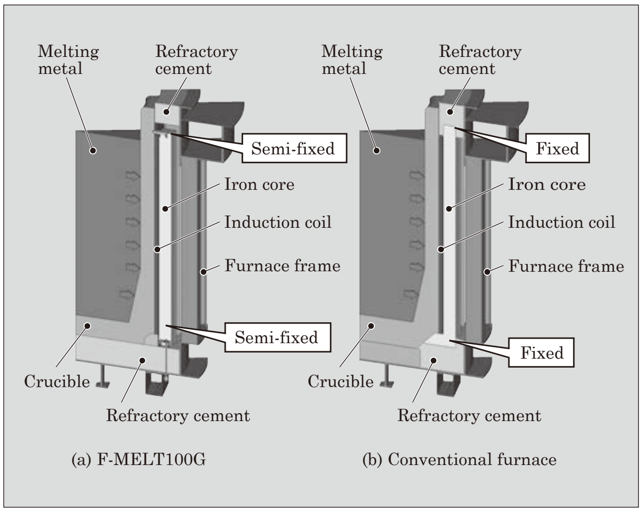

Fig.3 Comparison of iron core fixing structures

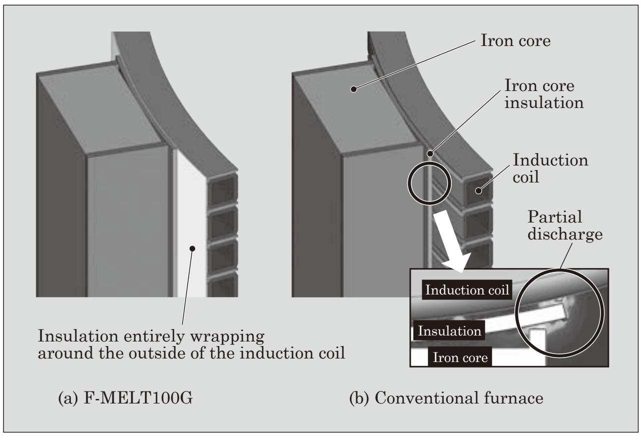

Fig.4 Location of partial discharge

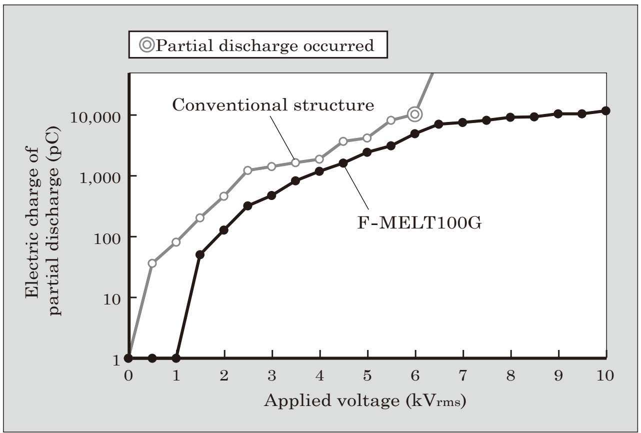

Fig.5 Comparison of occurrence and electric charge of partial discharge depending on the insulation method

has been improved to 10 kV or higher.

3.2 Features of the medium-frequency power supply

(1) New IGBT stack

In order to make the F-MELT100G Series have power supply capacities from 3 to 20 MW, we developed a high-voltage insulated gate bipolar transistor (IGBT) stack with a new structure. Figure 6 shows the high-voltage IGBT stack and its circuit configuration. To streamline the installation and replacement work, we developed a unit that integrate a high-voltage IGBT stack with an inverter equipped with IGBT modules, a capacitor for smoothing direct current, and busbar for connecting the main circuit. If the lengths of busbars connected to the modules are different, the wiring impedances will differ greatly during medium-frequency drive, resulting in significant current imbalance. In this high-voltage IGBT stack, we suppressed the difference in the wiring impedances by arranging the IGBT modules and smoothing capacitor so that the distances between them would be the same (see Fig. 7). As shown in Fig. 8, we also designed it to be easily stored in the panel and save space.

(2) Increased capacity resulted from high voltage design

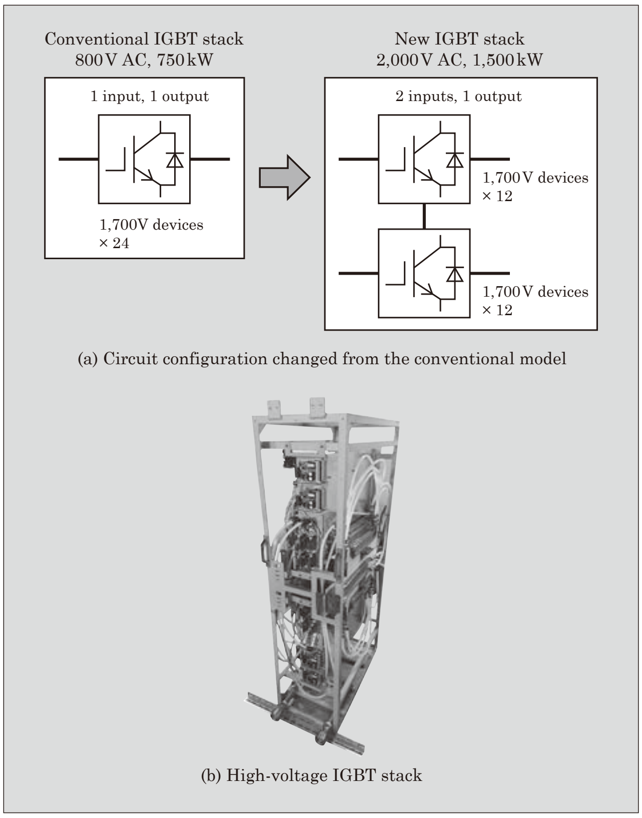

Fig.6 High-voltage IGBT stack and its circuit configuration

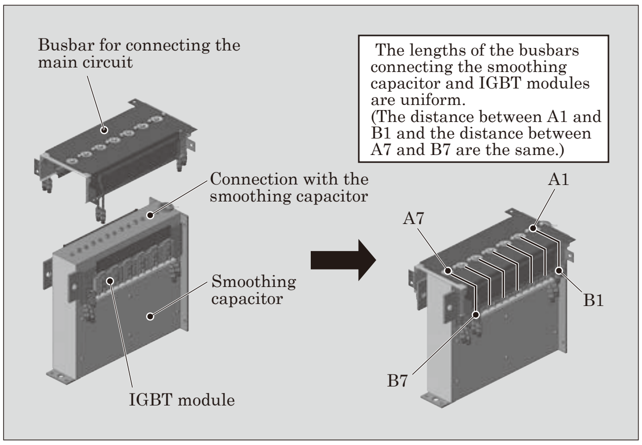

Fig.7 Locations of IGBT modules and smoothing capacitor

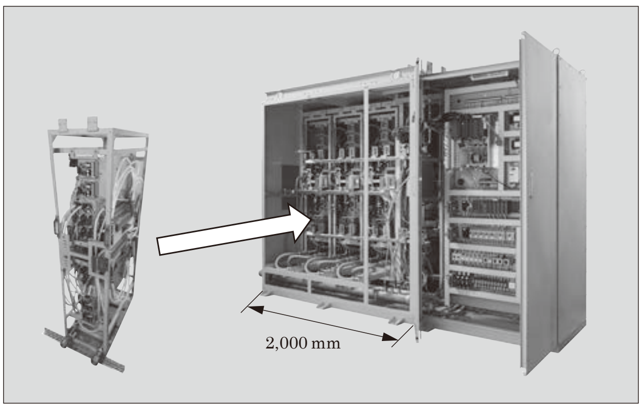

Fig.8 High-voltage IGBT stack and power supply panel

Two full-bridge circuits have been connected in series to support high voltage. This has doubled the power supply capacity of one stack with the same number of IGBT modules (750 kW → 1,500 kW).

(3) Miniaturization of the power supply panel

The high-voltage IGBT stack suppresses the current imbalance caused by the parallel connection of multiple stacks to small enough values by connecting them at the shortest distances. This has eliminated the need of a current balancing reactor. When compared with the stack of the same power supply capacity, the width of the power supply panel has been reduced from 2,670 mm of the conventional model to 2,000 mm as shown in Fig. 8.

(4) Improved maintainability

In terms of operating rate, it is important how to reduce downtime when equipment fails in the production site. If an induction furnace, which is in the upperstream process in a casting factory, should stop, it greatly affects the operation of the entire factory.

As a measure of reducing the work time before recovery, the heavy high-voltage IGBT stack weighing approximately 300 kg has been provided with casters so that it can be pulled out easily from the power supply panel. This has reduced the time for replacement work to half compared with the conventional model. The replacement can be done only from the front side of the panel. The maintenance space on the rear side of the panel, which was required for the conventional model, is no more necessary.

(5) Pre-start self-diagnostic function

Daily checks are critical to prevent recurrence of failures and to ensure stable operation of the equipment. The inspection of resistance or voltage of inverter's gate drive circuit or other components, in particular, had required special instruments and expertise. The F-MELT100G Series includes a new function to conduct self-diagnosis of equipment failure before starting operation. This function allows easy self-check of the gate drive circuit and driving power supply to reduce daily inspection work.

3.3 Direct digital control (DDC) unit

In order to avoid overcurrent and overvoltage, the medium-frequency power supply for induction furnaces should respond quickly to the abrupt fluctuation in the load impedance caused by the change in the thermal resistance of the materials being molten. Since the conventional products were controlled digitally with microcomputers, their response speed was slow and they could hardly handle abrupt load fluctuation. For the F-MELT100G Series, the direct digital control (DDC) using the combination of a field programmable gate array (FPGA) and a microcomputer is coupled with high-speed control software to digitize the inverter control for the induction furnace, resulting in improved responsiveness. Figure 9 shows the external appearance of the DDC unit.

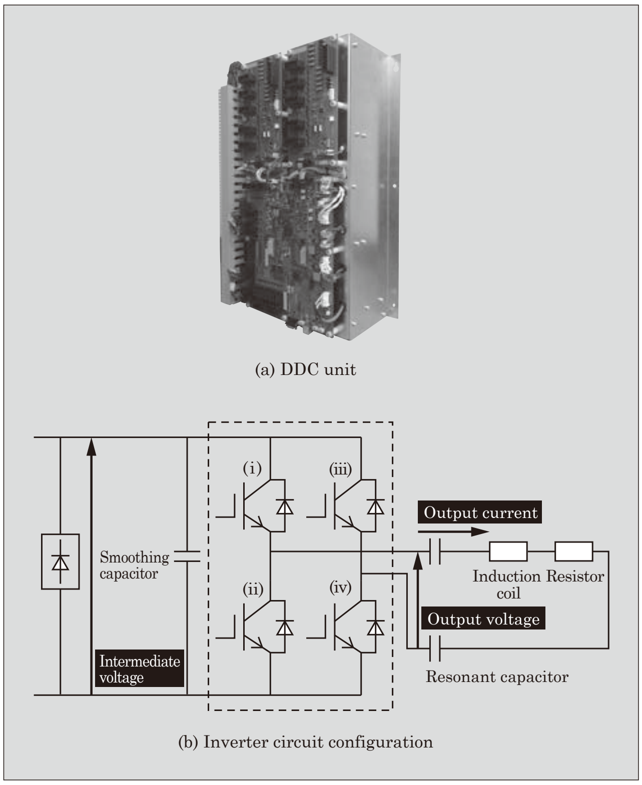

Fig.9 Features of the direct digital control (DDC) unit

(1) Faster active power calculation function

The method of active power calculation to make power control faster is as follows: When (i) and (iv) in Fig. 9(b) operate, the output voltage will be +2,000 V. When (ii) and (iii) operate, the output voltage will be −2,000 V. We then added up the instantaneous values of the output current and output voltage respectively every 3 μs as shown in Fig. 10 to obtain the power. Then we averaged the power value by using a 30-ms low-pass filter to calculate the average power. The calculated average power has been set as the PV (feedback) value for the constant power control. This calculation using FPGA has allowed active power calculation which took 1 s with a microcomputer to be completed within 30 ms. Furthermore, unlike conventional analog control that did not allow us to use control values as data, the DDC has allowed us to accumu-

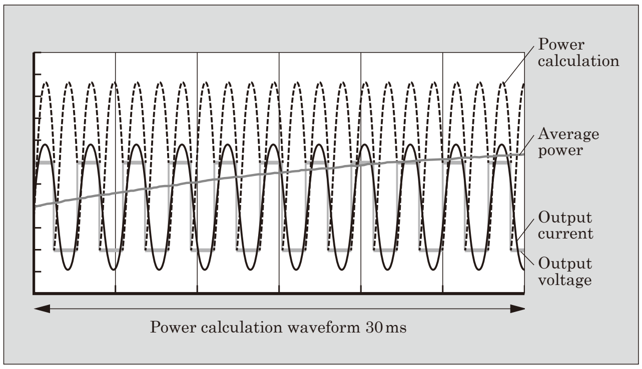

Fig.10 Waveform of high-speed power calculation

late control values as data through the communication with a programmable logic controller (PLC) and then use it for the analysis of the operating condition.

(2) RAS function

In order to reduce the equipment downtime required to investigate the cause when any failure occurs, the F-MELT100G Series has a reliability availability and serviceability (RAS) function on the DDC. This function continues recording of operation data such as the inverter output voltage and current values and gate signals on the RAM. When a failure such as short-circuiting or ground fault of the induction coil occurs, the operation data before and after the failure is automatically saved on the electrically erasable programmable read-only memory (EEPROM). By connecting a PC to the DDC unit, you can monitor the waveforms before and after the failure so that you can identify the cause of the failure easily. The DDC unit also has a communication function using MODBUS*-RTU. By connecting a PLC as shown in Fig. 11, you can check the status of occurred failure remotely. This function can reduce the number of site visits by service staff. Compared with the conventional model that could not provide sufficient failure data, the time required to determine the cause can be reduced significantly.

(3) Simultaneous control of multiple furnaces

The casting process using medium-frequency induction furnaces requires power distribution to prevent the total power of the furnaces from exceeding the upper limit specified in the power contract. The DDC of the F-MELT100G Series controls the power values of multiple furnaces in different stages such as one furnace has completed metal melting and keeps temperature during tapping and casting and the other furnace starts melting operation. Even when there is a need for changing the supplied power in accordance with the progress of the downstream casting process, the power distribution to respective furnaces can be controlled quickly, ensuring effective operation.

* MODBUS is a trademark or registered trademark of Schneider Automation, Inc.

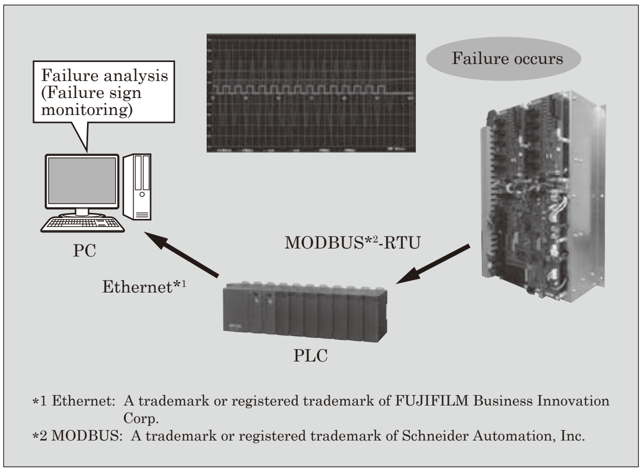

Fig.11 Remote monitoring function (connection of the DDC unit and a PLC)

4. Postscript

This paper described the details of the "F-MELT100G Series" high-efficiency, medium-frequency induction furnace. Fuji Electric will continue our efforts also in the future to solve the challenge to the user for the reduction of energy consumption in the melting process described at the beginning of the paper. We are determined to contribute to the productivity and stability improvement in the casting industry by developing and commercializing the functions to improve production efficiency in the entire casting factory through the use of IoT as well as the preventive maintenance functions to predict abnormalities from the operation conditions of the equipment.

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