Magnet Wire with Enhanced Tolerance for High Frequency Voltage

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Overvoltage, resulting from the application of a high frequency voltage, and its subsequent steep surge on an inverter-fed motor can significantly damage insulated systems due to partial discharge. Therefore, magnet wire with a high tolerance for surges and low dielectric permittivity is needed. This paper describes our new magnet wire coated with a porous insulator for enhanced surge resistance.

Keywords: magnet wire, motor, partial discharge, low permittivity, withstand voltage life

1. Introduction

Today, inverter drive systems are widely used for industrial motors to reduce their size and enhance efficiency. At the same time, motor drive frequency and voltage continue to increase. The problem associated with such advances in motor design is that partial discharge resulting from overvoltage/inverter surge erodes the insulated coating film of the magnet wires, thus shortening the withstand voltage life of the motors.(1) To extend the service life of an inverter-driven motor, it is necessary to control partial discharge from magnet wires. As a promising discharge control technique, the development of a magnet wire made of a low permittivity material is underway. Sumitomo Electric Industries, Ltd. has developed coaxial and many other types of cables using a technique that can reduce the relative permittivity*1 of an insulator by forming microscopic air bubbles in the insulation film, and has placed these cables on the market. Recently, this paper's authors have successfully developed an innovative low permittivity magnet wire by applying this technique to the magnet wire's thin insulation film. The withstand voltage life tests, which were carried out by applying a high-frequency AC voltage to the test samples, have verified that the new wire has superior withstand voltage life compared to conventional magnet wires. This paper discusses the features of the newly developed magnet wire.

2. Partial Discharge from Magnet Wire

2-1 Inverter surge voltage generated in the magnet wire

Inverter surge voltage is a steep voltage that appears at the terminal of an inverter-driven motor when the inverter is switched on/off (Fig. 1). Inverter surge voltage increases in proportion to the length of the cable between the inverter and the motor, and the peak value of the surge voltage often reaches approximately two times the DC voltage inside the inverter.(2)

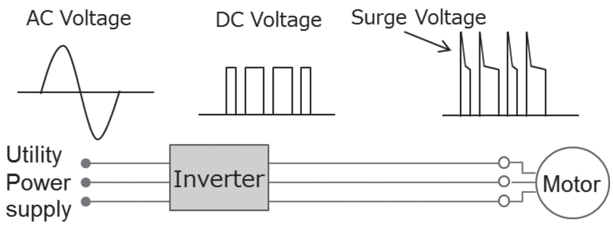

Fig. 1. Schematic Illustration of Inverter Surge Voltage

2-2 Deterioration of magnet wire coating film due to partial discharge

When the voltage applied between magnet wires exceeds the partial discharge inception voltage (PDIV), micro discharge (partial discharge) occurs on the surfaces of the magnet wire coating films. Long duration partial discharges begin to erode the insulation films, resulting in dielectric breakdown (Fig. 2). To extend the withstand voltage life of a motor, its magnet wire must prevent the generation of partial charge even when high-frequency, high voltage power is applied. It is known that PDIV generally correlates with relative permittivity and insulation film thickness, as reported by Dakin et al. (Eq. 1). However, increasing the thickness of the insulation film reduces the ratio of the conductor area to the motor slot area (space factor) and decreases motor efficiency. Therefore, reducing the relative permittivity of the insulation film is essential to enhance the PDIV without reducing the space factor.

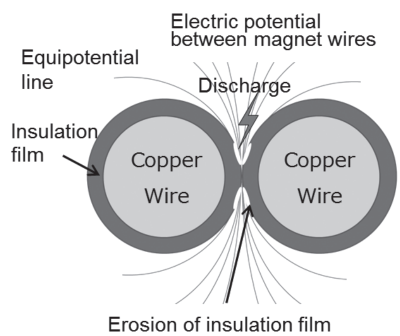

Fig. 2. Partial Discharge from Magnet Wire and Erosion of Insulation Film

[Dakin's solution]

$$V = \sqrt{2} \times 163 \times (t/\varepsilon_r)^{0.46} \quad \cdots\cdots (1)$$

V : Partial discharge inception voltage*2 [Vp]
ε_r : Relative permittivity of insulation film
t : Thickness of insulation film [μm]

3. Magnet Wire Coated with Low Permittivity Foamed Insulation Film

The introduction of air bubbles having a relative permittivity of 1.0 into an insulation film is a known technique for reducing a film's relative permittivity.(3),(4)

Sumitomo Electric has commercialized coaxial and many other types of cables for which the relative permittivity of the insulation films has been reduced by forming a number of microscopic air bubbles in the films. In this research study, the effects of introducing air bubbles into a magnet wire's thin insulation film were investigated (Fig. 3). As a result, the relative permittivity of a polyimide (PI) insulation film was significantly reduced by introducing air bubbles into the film. Hereafter, a magnet wire coated with an insulation film containing air bubbles is referred to as a "foamed magnet wire" and the volume ratio of the air bubbles in the insulation film is referred to as the "foaming rate."

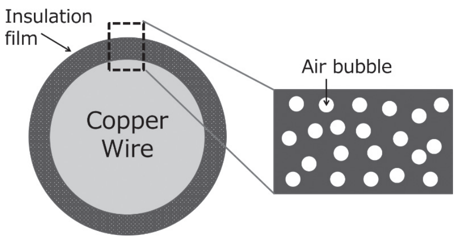

Fig. 3. Schematic Illustration of Foamed Magnet Wire

The relationship between the foaming rate and relative permittivity of a foamed magnet wire is shown in Fig. 4. The relative permittivity decreased when the foaming rate increased, as calculated theoretically. A PI insulation film having a relative permittivity of 3.0 reduced its relative permittivity to 2.2 and 1.7 when air bubbles of approximately 30 vol% and 50 vol% were introduced, respectively.

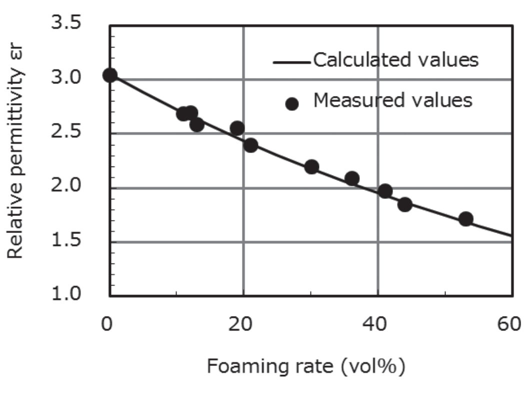

Fig. 4. Relative Permittivity of Foamed Magnet Wire

4. Measurement of PDIV

For the PDIV measurement samples, both foamed and unfoamed magnet wires with a conductor diameter of 1.0 mm and a PI insulation film thickness of 30 μm were used. The foamed magnet wires had PI foaming rates of 10, 20, and 30 vol%. Twisted wire pairs were prepared for the measurement test, as specified in JISC3216-5. An example of a twisted wire pair is schematically shown in Fig. 5.

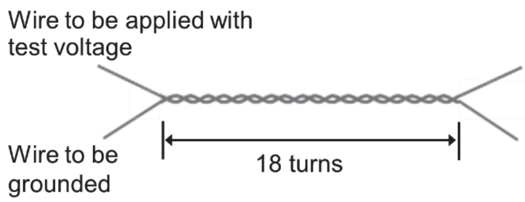

Fig. 5. Schematic Illustration of Twisted Wire Pair

The PDIV of each measurement sample was measured consecutively for 10 times at a temperature of 25°C and humidity of 50%, and the 10 measured values were averaged. To check the high-temperature partial discharge characteristics of the magnet wires, the PDIVs of a magnet wire sample coated with a PI film and a wire sample coated with a foamed PI film at a foaming rate of 30 vol% were measured at 100°C and 200°C, respectively. The circuit used for the PDIV measurement test is shown in Fig. 6. In this circuit, a current sensing resistor was connected to the measurement sample in series to measure the partial discharge current pulse through a bypass filter that was installed to isolate the frequency components of the power supply.

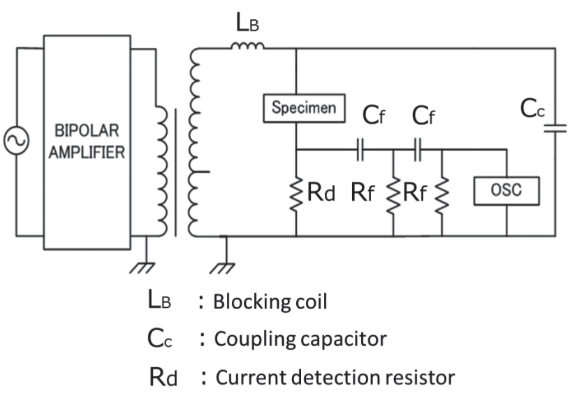

Fig. 6. PDIV Measuring Circuit

To measure PDIV, a 60 Hz AC voltage was applied to each measurement sample while raising the voltage at a rate of 1.0 kV/min, and the instantaneous voltage was measured at the moment a discharge current was detected.

At 25°C, the PDIV of the magnet wire sample coated with a foamed PI film was remarkably higher than that of the wire sample coated with a PI film, as shown in Fig. 7. The PDIV increased in proportion to the foaming rate. In particular, the PDIV of the magnet wire sample coated with a foamed PI film at a foaming rate of 30 vol% was measured to be 985 Vp, which was more than 200 Vp higher than that of the magnet wire sample coated with a PI film (770 Vp).

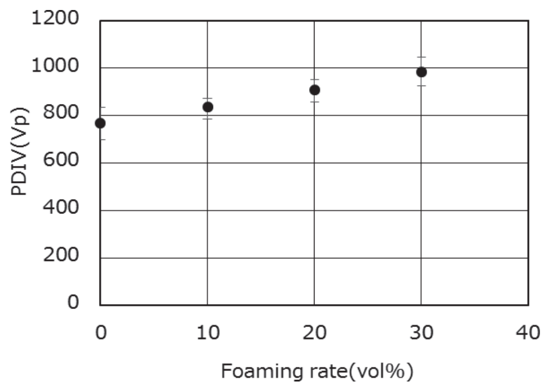

Fig. 7. PDIV Measurement Result for Magnet Wire Coated with Foamed PI Film (at 25°C)

At high temperatures of 100°C and 200°C, it was confirmed that the PDIV decreased for both the magnet wire samples coated with a PI film and those coated with a foamed PI film, as shown in Fig. 8. A possible reason is that the density of air existing between neighboring magnet wires decreases as the temperature increases, improving the conditions required for discharge. Additionally, it was confirmed that the PDIV decrease ratio of the values measured at room and high temperatures between a magnet wire coated with a foamed PI film differed little from that of a magnet wire coated with a PI film. In other words, the PDIV decrease ratios of both types of magnet wires are almost independent of temperature change.

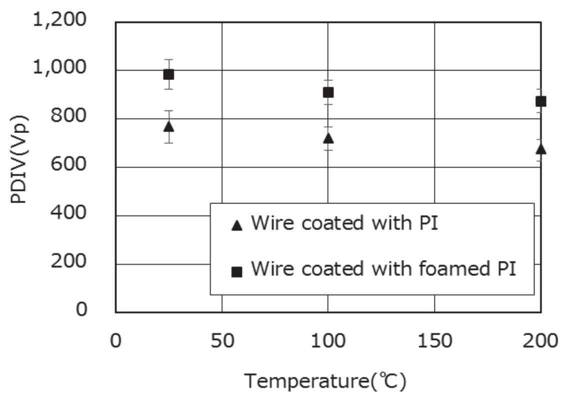

Fig. 8. High-temperature PDIV Measurement Result for Magnet Wire Coated with Foamed PI

5. Withstand Voltage Life Measurement

When a voltage equal to or higher than the PDIV is applied to a motor, partial discharge occurs between the magnet wires and gradually erodes the insulation films until the wires are broken down dielectrically. The amount of time it takes for a magnet wire to sustain dielectric breakdown at each applied voltage is called the withstand voltage life. This study measured the withstand voltage lives of magnet wires. The measurement samples comprised of the twisted wire pairs of the magnet wire coated with a PI film and the magnet wire coated with a foamed PI film with a foaming rate of 30 vol% were used for the PDIV measurement test. With the test temperature and relative humidity set at 25°C and 50%, respectively, a 10 kHz sinusoidal AC voltage was applied to the measurement samples to measure the time required to reach dielectric breakdown. To determine the withstand voltage lives of the sample magnet wires at a high temperature, the test temperature was raised to 200°C. The test equipment used for the withstand voltage life measurement is schematically illustrated in Fig. 9.

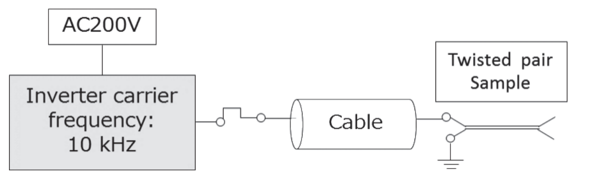

Fig. 9. Schematic Illustration of Withstand Voltage Life Measuring Equipment

The relationship between the measured voltage and the time the magnet wire took to reach dielectric breakdown at this voltage is shown in Fig. 10. The white plots in the above figure indicate the test termination time for the

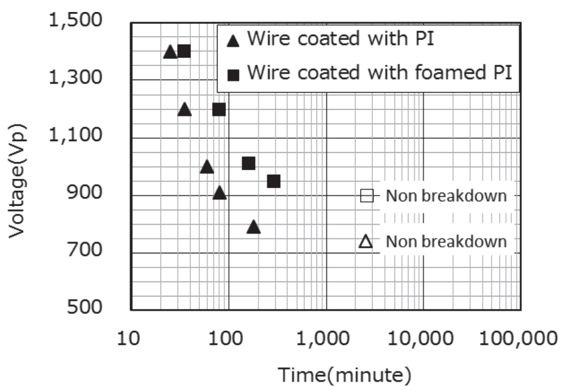

Fig. 10. Withstand Voltage Measurement Result (at 25°C)

measurement samples that did not suffer dielectric breakdown. The surface conditions of the dielectrically broken down samples were examined after test completion. As a result, any trace of discharge was detected in the insulation films. When a test voltage of 1,200 Vp was applied to both the magnet wire coated with a PI film and the magnet wire coated with a foamed PI film at a test temperature of 25°C, dielectric breakdown occurred after 36 and 80 min, respectively. At a measurement voltage of 900 Vp, the magnet wire coated with a PI film was dielectrically broken down after 78 min, while the magnet wire coated with a foamed PI film did not suffer dielectric breakdown even after 2,500 min. It was confirmed from the above results that the magnet wire coated with a PI film foamed by introducing air bubbles provided better protection against dielectric breakdown than a magnet wire coated with a non-foamed PI film, and therefore has a longer withstand voltage life.

The results of the withstand voltage life test carried out at 200°C are shown in Fig. 11. When a test voltage of 1,200 Vp was applied, the magnet wires coated with a PI film and those with a foamed PI film suffered dielectric breakdown after 25 and 43 min, respectively. When a test voltage of 900 Vp was applied, the magnet wires coated with a PI film and those with a foamed PI film reached dielectric breakdown after 42 and 205 min, respectively. At a test temperature of 25°C, the magnet wire coated with a foamed PI film withstood the test voltage of 900 Vp without causing dielectric breakdown. However, at high temperatures, the magnet wire coated with a foamed PI film was estimated to have a reduced PDIV and the insulation film was eroded owing to partial discharge. In addition, when a test voltage of 800 Vp was applied to the magnet wire coated with a foamed PI film and a test voltage of 650 Vp was applied to the magnet wire coated with a PI film, both wires resisted dielectric breakdown for more than 2,500 min. It was confirmed from the above test results that a magnet wire coated with a foamed PI film has a superior withstand voltage life compared to a wire coated with a PI film at a room temperature of 25°C, as well as at a high temperature of 200°C.

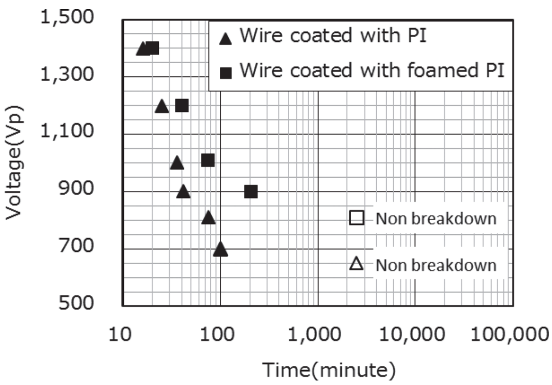

Fig. 11. Withstand Voltage Measurement Result (at 200°C)

7. Conclusion

An innovative low permittivity magnet wire has been successfully developed by applying a technique for forming microscopic air bubbles in insulating materials to the thin insulation film of a magnet wire (Table 1). The new magnet wire, which was coated with an insulation film into which air bubbles were introduced, demonstrated a withstand voltage life remarkably longer than that of conventional magnet wires. The frequency and voltage of the power supplied to industrial motors will be further increased to reduce size and improve operating efficiency. The newly developed magnet wire, which is superior to conventional magnet wires used in industrial motors in terms of withstand voltage life, is expected to expand the service life and potential applications of industrial motors.

Table 1. Evaluation Result

			Conventional wire (PI)	Developed wire (Foamed PI)
Insulator Material			Polyimide	Polyimide
Foaming rate (vol%)			0	30
Relative permittivity			3.0	2.2
PDIV (Vp)			770	985
Withstand voltage life (min)	25°C	1,200 Vp	35	80
		900 Vp	80	Non breakdown
	200°C	1,200 Vp	25	40
		800 Vp	75	Non breakdown

Technical Terms

*1 Relative permittivity: A measure for the ease of the polarization of an insulator. The partial discharge inception voltage (PDIV) of an insulator increases as its relative permittivity decreases.

*2 Partial discharge inception voltage (PDIV): Voltage that triggers discharge between magnet wires. Discharge in a motor often deteriorates the magnet wire insulation films and shortens the motor’s service life.

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