# Development of Non-Linear Resistive Tape for Voltage Stress Grading

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Keywords High-voltage rotary machine, Motor, Voltage stress grading, Electric field analysis, Non-linear resistive material, Micro-varistor

**Abstract**

**In recent years, with the advancement of power electronics technology, the demand for higher performance in various electrical devices is increasing. Therefore, the importance of voltage stress grading technology that relieves stress on electrical insulation is also increasing.**

**Nonlinear resistance materials are essential materials for voltage stress grading technology with varistor characteristics. For example, they are used in surge arresters, Gas-Insulated Switchgears (GIS), rotating machines, and power semiconductors.**

**We have applied our Zinc Oxide (ZnO) material technology to research and develop a new nonlinear resistance material by combining ZnO varistors with resin.**

## 1 Preface

In recent years, the demand for higher performance in various electrical devices has been increasing. The importance of voltage stress grading technology that relieves stress on electrical insulation has also increased.

In fluid machinery, there is also a demand for inverter-driven motors with higher capacity and higher speeds, aiming to reduce environmental load through resource saving and high efficiency. As a result, higher voltages and higher frequencies are being used, and the importance of voltage stress grading technology is increasing. In particular, discharge and heat caused by electric field concentration at the end of the stator winding is a problem.

For many years, we have manufactured Zinc Oxide (ZnO) elements, which are nonlinear resistance materials, and sold them for use in surge arresters. Nonlinear resistance materials are essential for voltage stress grading with varistor characteristics. These are used in surge arresters, Gas-Insulated Switchgears (GIS), rotating machines, and power semiconductors. We have applied our ZnO material technology to meet the needs of higher voltages and higher frequencies in electric motors. We have developed a new voltage stress grading tape by combining micro-filled ZnO varistors with resin. We also used this to verify the solution of problems at the ends of the stator coil windings of rotating machine. In this paper, we introduce the prototype and evaluation of the voltage stress grading tape.

## 2 Issues and Solutions Related to Voltage Stress Grading

Fig. 1 shows the voltage stress grading structure at the ends of the stator coil windings of rotating machine. At the ends of the stator coil windings of rotating machine, the electric field concentrates due to a sudden change in potential between the end of the corona prevention layer and the main insulation outside the iron core. Here, corona discharge and heat occur, which can cause short-term insulation breakdown. Conventionally, a field relaxation layer using silicon carbide, a nonlinear resistance materi-

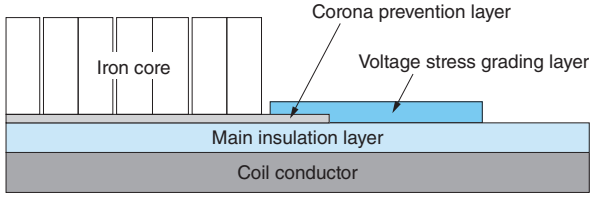


**Fig. 1 Voltage Stress Grading Structure**

A voltage stress grading structure is shown around the winding edge part of the rotating machine stator coils.

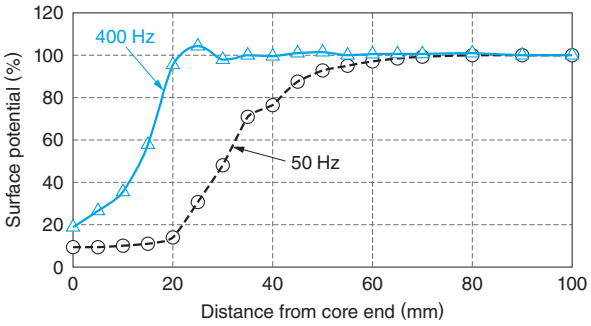


**Fig. 2** **Result of Layer Surface Potential Measurement (Comparison between Frequencies)**

The result of surface potential measurement is shown for conventional voltage stress grading layers when 1500 V is applied at power frequency (50 Hz) and high frequency (400 Hz). Based on the result of comparison between 50 Hz and 400 Hz, it is recognized that the surface potential rapidly rises at a high frequency.

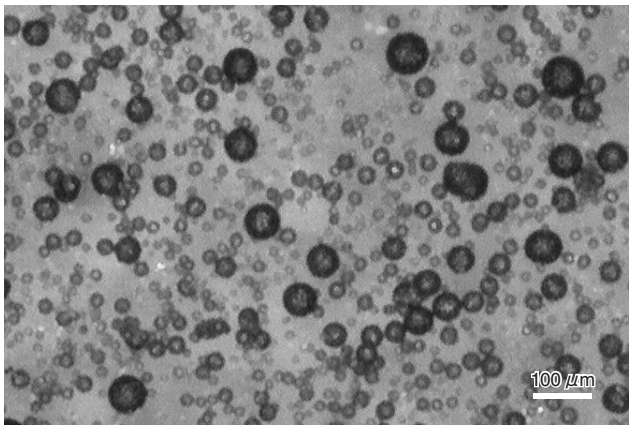


**Fig. 3** **ZnO Microvaristor Filler**

A microscopic photo of the ZnO microvaristor filler is shown, which was produced through the application of techniques for surge arrester ZnO element.

al, was used to prevent the sudden change in potential. This suppresses discharge and prevents short-term insulation breakdown.

In recent years, large-capacity, high-speed electric motors are required to be driven at high voltages and frequencies of several hundred Hz. However, conventional electric field buffer layers cannot suppress sudden changes in potential as frequencies increase. As a result, corona discharge and heat generation due to the concentration of voltage stress occur, leading to short-term insulation breakdown.

Fig. 2 shows the surface potential comparison results of a conventional volage stress grading layer when 1500 V is applied at commercial frequency (50 Hz) and high frequency (400 Hz). At high frequency, the surface potential rises suddenly compared to commercial frequency. The field relieving effect is smaller. We speculated that our ZnO element for surge arresters, which has excellent nonlinear characteristics, is also effective in voltage stress grading at high frequencies. As a result of prototype production, evaluation, and electric field analysis, we found that it may be effective. We applied ZnO material technology to create a ZnO microvaristor filler. Current conductive materials and resins were mixed to make up a paint and this material was painted on the glass cloth. A voltage stress grading tape was produced in such a prototype-making process. The prototype tape was evaluated as a voltage stress grading tape applicable to a high frequency and a high voltage.

## 3 Basic Characteristics of Voltage Stress Grading Tape for High Frequency Application

### 3.1 Specifications of Voltage Stress Grading Tape for High Frequency Application

Fig. 3 shows the ZnO microvaristor filler produced by applying our ZnO element technology. The prototype tape has a ZnO microvaristor filler layer kneaded with resin on both sides of the glass cloth substrate.

### 3.2 Electrical Characteristics

To confirm the voltage stress grading effect, a sample coil was produced using the voltage stress grading tape, and the surface potential was measured. Fig. 4 shows a view of the measurement. Three types of sample coils were prepared using carbon, silicon carbide (conventional material), and ZnO as the voltage stress grading material. A sinusoidal voltage was applied to the coil. The potential was measured via a potential probe from an aluminum wire wrapped around the surface of the voltage stress grading material. The aluminum wire was shifted in 5 mm increments along the length of the coil, with the end of the voltage stress grading material set as 0 potential, and the potential at each position was read. Fig. 5 shows the surface potential measurement results for each material. Compared with the conventional material, the potential was lower at all positions. This fact suggests that ZnO material is effective. However, the electric field has a large potential gradient at the 15 to 20 mm

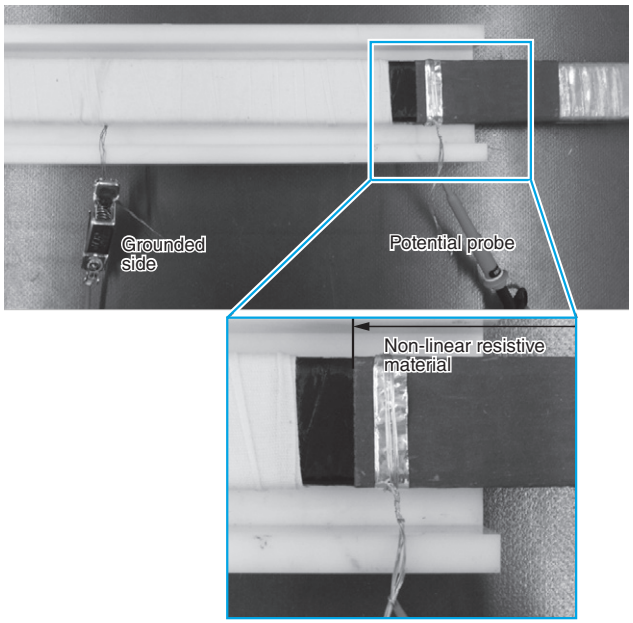


**Fig. 4** View of Surface Potential Measurement

A view of surface potential measurement on a sample coil is shown.

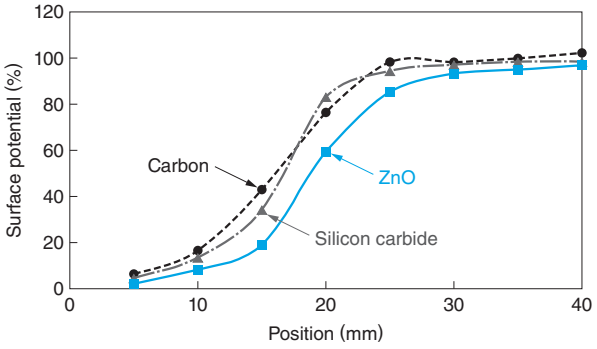


**Fig. 5** Surface Potential Measurement Results

When compared with conventional materials, the potential is lower in all positions and it was recognized that the ZnO material is effective. It is, however, necessary to note that some improvement is needed around the section of 15 to 20 mm.

position. There are some points that need to be improved, such as the material blending and the way the tape is wrapped.

### 3.3 Verification of Voltage Stress Grading Effect Using Analytical Model

The voltage stress grading effect was confirmed by electric field heat transfer coupled analysis based on the characteristics of each material. The analysis was performed using the general-purpose multiphysics software called “COMSOL Multiphysics”. A 3D model simulating the end of the stator coil was created. Various material parameters, inputs, and boundary conditions were set. A strong interaction frequency steady state analysis of the electric field and heat transfer was performed. **Fig. 6** shows a 3D model of the stator coil. A feature of this analysis is that the current-voltage characteristics of the high resistance layer are converted to volume resistivity electric field characteristics. This reflects the nonlinear material characteristics of the high resistance layer. **Fig. 7** shows the maximum electric field values for various materials as an example of the coupled analysis results. All of the locations where the electric field was concentrated were the overlapping areas of the low resistance layer and the high resistance layer. The results confirmed that the maximum electric field of ZnO was about 50% lower than that of silicon carbide. On the other hand, it was confirmed that the electric field

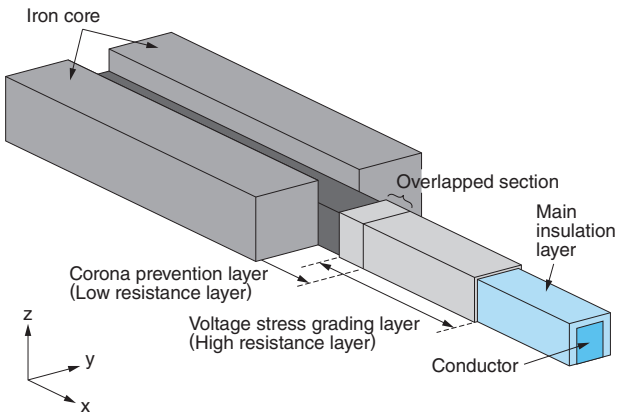


**Fig. 6** 3D Model of Stator Coil

A 3D model of stator coil used for the coupled analysis is shown.

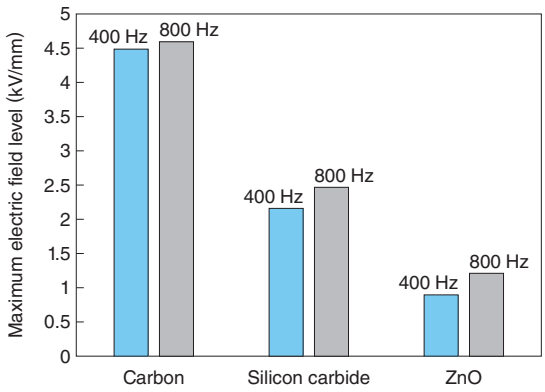


**Fig. 7** Coupled Analysis Results

For an example of analytical result, maximum field levels are shown for the respective materials. When compared with the case of silicon carbide, the ZnO material resulted in a fact that the maximum electric field level can be lowered by approximately 50%.

relaxation effect in the overlapping areas was small. This was confirmed by comparing the electric field measurements and analysis results performed in **Section 3.2**. The next step is to improve the accuracy of the analysis.

## 4 Postscript

We have developed and evaluated a voltage stress grading tape for high frequency application. Our ZnO element technology for surge arresters was applied. We could confirm that by effectively utilizing the nonlinear characteristics of ZnO, abnormal electric field concentration can be prevented even in the high power frequency range. This shows that a high frequency insulation system can be realized.

Going forward, we will continue to study materials to increase the speed and capacity of electric motors and meet market expectations.


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