Development of Insulation Resin Impregnation Analysis Technology

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Abstract

One technical issue with high-voltage rotating machines is the ability to impregnate the stator coil with resin. In high-voltage rotating machine stator coil insulation constructed by wrapping insulating tapes, poor impregnation due to poor resin permeability has a significant impact on the electrical performance. Establishing a method to confirm impregnation has become a major challenge.

To solve this impregnability problem, we conducted an impregnation analysis using coil modeling. As a result, impregnability was determined by analysis.

By applying this analysis method, even when changing various impregnation conditions, the degree of impact can be known in advance, and development time can be expected to be shortened.

1 Preface

Currently, resin impregnation of stator coils is a technical challenge for high-voltage rotating machines. The standard method for determining the quality of resin impregnation is to measure capacitance during impregnation, but the method for determining impregnation failure is still not sufficient.

In this paper, we introduce a resin impregnation analysis method using coil modeling that we are considering to solve this problem.

2 Analysis Method

2.1 Analysis Software (Composite Simulation Software)

The analysis software used for the resin impregnation analysis was PAM-COMPOSITES (PAM-RTM), a molding process simulation software for composite material manufacturing by ESI Japan, Ltd. This software is used for the analysis of molding like Resin Transfer Molding (RTM).

2.2 Analysis Method

Fig. 1 shows the analysis model. Modeling an insulated bar coil implemented in a 3D mesh. For this model, resin impregnation conditions and various physical property values are input into PAM-RTM and analyzed. In the analysis, the permeability of the insulating layer is a particularly important physical property value, which is determined as follows.

We first find a value called the flow front position, which represents the penetrating tip of the resin. This is used in injection molding and other processes. Fig. 2 shows a resin-impregnated bar

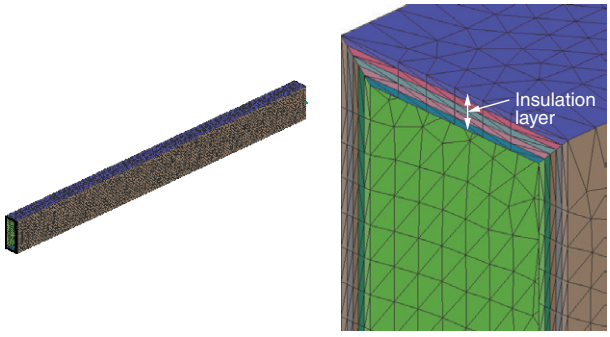

Fig. 1 Analysis Model

An analysis model is shown. This modeling is implemented for a bar coil in 3D-mesh mode.

Fig. 2 Resin-Impregnated Bar Coil Cut Model

This shows a resin-impregnated bar coil cut model. It is visualized to obtain the flow front.

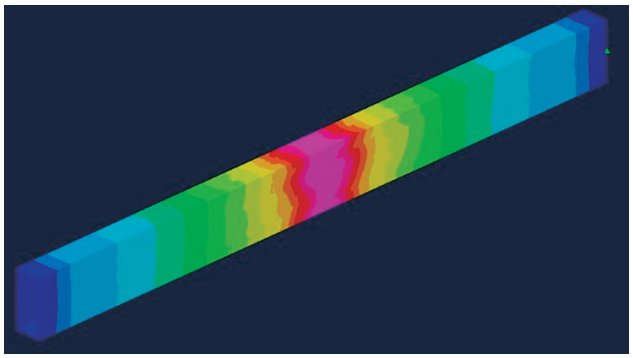

Fig. 3 Contour Diagram for Analysis of Resin Penetration (Impregnation)

This shows a contour diagram for the analysis. It shows resin impregnability. This data was obtained through analysis.

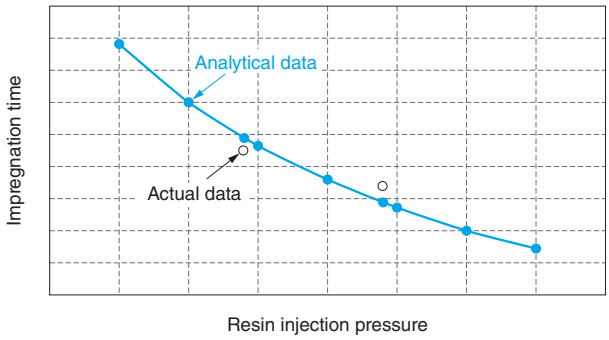

Fig. 4 Graphs of Resin Injection Pressure – Impregnation Time Characteristics

Graphs of resin injection pressure – impregnation time characteristics obtained through analysis is shown.

coil cut model. We created a cut model of a coil impregnated with colored resin, visualized the degree of resin penetration (impregnation), measured the flow front position, and then, calculated the permeability coefficient from equation (1) based on Darcy's law.

$$K = \frac{X^2 \mu}{2Pt} \quad \cdots\cdots (1)$$

Where, K = Impregnability coefficient, X = Flow front position, μ = Viscosity, P = Resin injection pressure, and t = Time.

This is then analyzed using PAM-RTM to obtain contours that show the resin permeability for each impregnation time. **Fig. 3** shows a contour diagram for analysis of resin penetration (impregnation).

By using this method to understand the permeability coefficient of the insulating layer, the degree of impregnation can be determined analytically even if the composition of the insulating layer changes. If the insulation configuration of the coil, such as the insulation tape, number of turns, is changed, analysis using PAM-RTM can help determine ideal conditions such as impregnation time and pressure.

2.3 Application of Analysis Results

By further performing this analysis, it is possible to investigate the degree of influence on impregnability under the following two conditions which are important parameters of resin impregnation.

The ideal resin injection pressure is first studied. By using the model shown in **Fig. 1** and applying the analysis results, it is possible to understand the relationship between resin injection pressure and impregnation time. **Fig. 4** shows the relationship between resin injection pressure and impregnation time. It is also possible to know the resin injection pressure at a certain point inside the coil insulation layer.

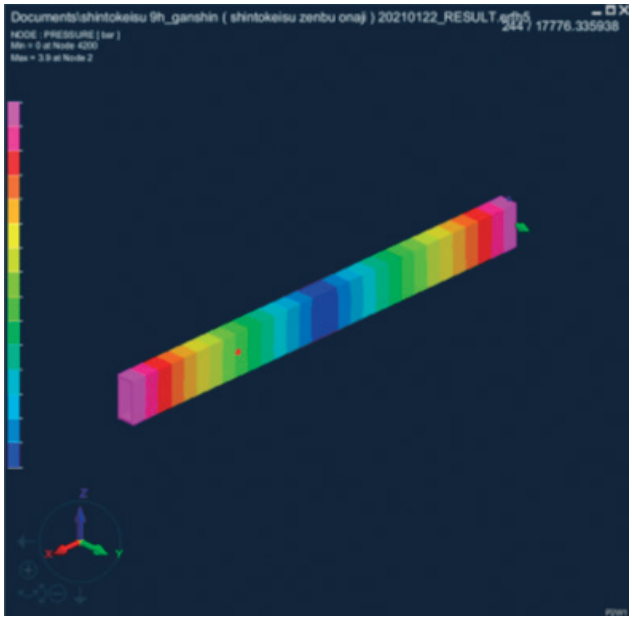

Fig. 5 Contour Diagram for Analysis of Changes in Resin Injection Pressure inside Coil

This shows a contour diagram of resin injection pressure changes inside the bar coil. This data was obtained through analysis.

Fig. 5 shows a contour diagram for analysis of changes in resin injection pressure inside the coil, and **Fig. 6** shows a graph of changes in resin injection pressure over time at various points within the coil insulation layer. This makes it possible to know in advance how the resin injection pressure will decrease due to the lengthening of the coil.

The second issue is resin viscosity. **Fig. 7** shows the relationship between resin temperature (viscosity) and impregnation time obtained through

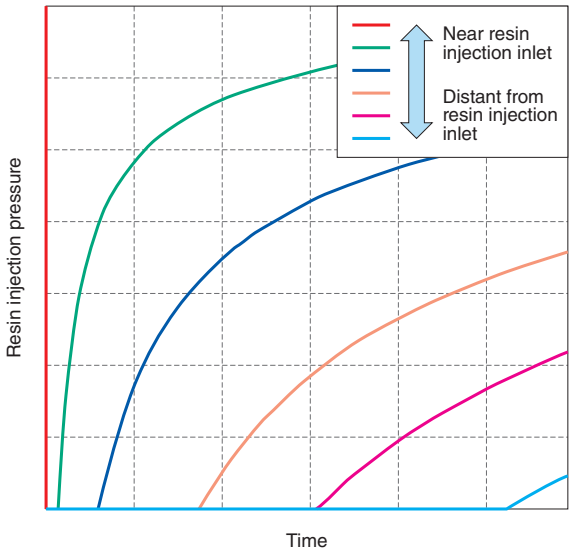

Fig. 6 **Graphs of Resin Injection Pressure Changes Inside the Coil**

This graph shows resin injection pressure changes inside the bar coil. This data was obtained through analysis.

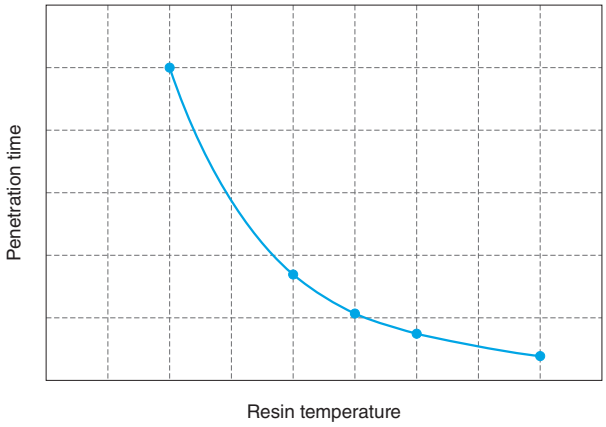

Fig. 7 **Graph Showing Relation Between Resin Temperature and Penetration Time Characteristics**

This shows the penetration time characteristics at the respective resin temperatures. The data was obtained through analysis.

analysis. Even if the resin viscosity changes due to the resin type or some environmental change, the resulting change in impregnation time can be known in advance, making it easy to identify the ideal impregnation time.

As described above, the analysis method using PAM-RTM can be used as a tool to consider ideal conditions (such as impregnation time). This is the case (1) when impregnation conditions are changed due to equipment renewal or (2) when coils become longer.

3 Postscript

We introduced an impregnation analysis method using coil modeling using the molding process simulation software PAM-COMPOSITES (PAM-RTM) developed by ESI Japan, Ltd. Impregnation analysis using this coil modeling is considered a useful tool for eliminating impregnation defects.

Furthermore, when considering newly developed insulating layers and impregnation conditions, ideal impregnation conditions can be known in advance, which can be expected to shorten development time.

As described above, we believe that this software is useful as a method for resolving all issues and problems related to resin impregnation. We will continue to strive to improve the accuracy of impregnation analysis using coil modeling and contribute to improving the reliability of rotating machine products.

Lastly, we would like to express our deepest gratitude to the related people in the sales and technical divisions of ESI Japan, Ltd. for their extraordinary guidance and efforts during this resin impregnation analysis.