STRESS EVALUATION OF THE PLG GROUND COIL WITH GFRP FASTENING DEVICES

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ABSTRACT

The GFRP fastening devices are presumably effective to prevent from not only abrasion of resin but also relaxing axial tension of fastening bolts. Ground coils are applied a certain type of stress, for example electromagnetic stress, thermal stress, fastening stress, residual stress and foreign substances impact stress. We describe about the strength evaluation test results for the PLG ground coil with GFRP fastening devices on the point of the stress which caused by the electromagnetic force, thermal expansion and fastening deformation.

1. INTRODUCTION

Ground coils provided along the entire length of the guideway are essential for outdoor use over a long period of time in the superconducting magnetically levitated transportation system. Therefore, high reliability is inevitable for the ground coils. It is important to evaluate the stress around the fastening devices on the point of the mechanical strength of the ground coil, because the stress in generally concentrates there. We describe about the characteristics of this new fastening device which is made of GFRP and the measurement results of the stress on the PLG ground coil (combined Propulsion, Levitation and Guidance ground coil), in which GFRP fastening devices are experimentally inserted.

2. FASTENING DEVICE FOR GROUND COIL

2.1 Style of the fixing coil to the guideway

Some methods for fixing the coil to the guideway have been examined. For example, a direct bolt fixing, an indirect fixing by the FRP auxiliary parts and a burying into the concrete on the guideway. As the result of the comparison, we consider the direct bolt fixing is more preferable than others because it is simple and easy to install the coil to the guideway.

2.2 Development of the direct bolt fixing method

It is necessary for the bolt fixing method to prevent from loosening axial tension of fixing bolts, because the loosening

axial tension causes to increase the time for maintenance. Furthermore it can affect the safety of the system.

The fastening devices made of stainless steel, which are expected to have the least creep, have previously been used in PLG ground coil, because a main cause of the decrease in axial tension is considered to be the creep of the mold resin. Figure 1 shows the stainless steel fastening device. Although this could prevent from loosening axial tension, another problem was occurred. The interface between the fastening device and molded resin make the loose and abrasion of the interface under the alternative electromagnetic load condition, because the interface does not adhere to relax the concentration of the stress around the fastening device and to allow the relative displacement on the interface.

Accordingly we are now under developing the fastening device made of GFRP, whose property is nearer to molded resin than stainless steel. Figure 2 shows the GFRP fastening device. This is the thick pipe made by winding of the impregnated GFRP sheets and heating and cutting to suitable length. The inner area of the GFRP fastening device is anisotropic and strongly reinforced in a direction parallel to the axis. And in the outer area of it the glass fiber is orthogonally oriented to make its elastic modulus similar to that of the molded resin. The GFRP fastening device is expected to have some following advantages.

- (1) The anisotropic property of the inner area prevent from loosening the axial tension of the fastening bolt.
- (2) It is possible to adhere the interface between fastening device and molded resin, because the material property of the outer area of GFRP fastening device is close to that of molded resin and it prevents from the abrasion.
- (3) Eddy current loss does not occur in it.
- (4) A variety cylindrical shape can be easily made by a machinery cutting.
- (5) It has the potential to lower the cost of the ground coil.
- (6) It is lighter than stainless steel fastening device.

Fig.1 Stainless steel fastening device

Fig.2 GFRP fastening device

3. STRESS MEASUREMENT

3.1 Specimen

The PLG ground coil has three functions of propulsion, levitation and guidance. Accordingly the number of the coils installed on the guideway can be reduced and expected to be reduce the construction cost of the system. We experimentally made the PLG ground coil in which GFRP fastening devices inserted. In addition, we measured the stress on it by the bench test equivalent to the practical use. Figure 3 shows the coil used as a specimen.

Fig.3 PLG ground coil in which GFRP fastening devices are inserted

3.2 The stress from the electromagnetic force

We used an electromagnetic vibration test apparatus for a ground coil to measure the stress from the

electromagnetic force. Figure 4 shows the foregoing test apparatus. The PLG ground coil was set in front of the superconducting magnet as showed in Fig.4.

In case the current, which applies onto the equivalent force on the coil, is flow, the heat generation makes it difficult to separate the electromagnetic stress from thermal stress.

That is a reason why we applied one-tenth of the Electromagnetic force of the practical running condition on the specimen and considered 10 times of the measured stress value are almost equivalent as practical value.

Fig.4 Electromagnetic vibration test apparatus for a ground coil

3.3 The stress from the thermal rise of conductor

The PLG ground coil was set on the stainless plate which is the model of the guideway to which the coil is fixed (The plate will hereinafter be abbreviated "guideway model"). After that the direct current was applied to the PLG ground coil so that the thermal rise of the upside coil conductor will be saturated at 30 degrees. The thermal rise was estimated by the resistivity of the conductor. Figure 5 shows this measurement.

3.4 The stress from the deformation by fixing the coil on the guideway

The PLG ground coil was set on the guideway model with the condition in which the space between the GFRP fastening device and guideway model was adjusted to $\pm 1.5\text{mm}$ by using the stainless steel shim plates.

Fig.5 Measurement of the stress from thermal rise of conductor

4. STRESS EVALUATION

4.1 The results of stress measurement

Figure 6 shows the points of the stress measurement. Figure 7 shows the measurement results of the stress on the PLG ground coil.

4.2. The mean stress and the stress amplitude

The stress on the PLG ground coil is the resultant stress of the static stress and the dynamic stress. The stress from the electromagnetic force is the zero-to-peak amplitude stress. We considered the stress from the thermal rise of conductor to the static stress, because the cycle of the thermal rise is sufficiently less than that of the electromagnetic force. Moreover we considered that the residual stress is constant at all point. Therefore we calculated the mean stress and the stress amplitude in the manner given by Equation 1 and 2.

Fig.6 Measurement point of the stress

Fig.7 Measurement results of stress on PLG ground coil

$$\sigma_{mean} = \frac{1}{2} \sigma_e + \sigma_t + \sigma_f + \sigma_r \quad (1)$$

$$\sigma_{amp} = \frac{1}{2} |\sigma_e| \quad (2)$$

σ_{mean} : mean stress, σ_{amp} : stress amplitude, σ_e : the stress from electromagnetic force, σ_t : the stress from the thermal rise of the conductor, σ_f : the stress from the deformation by fixing the coil on the guideway, σ_r : the residual stress

4.3. The stress limit diagram of molded resin

Figure 8 is the stress limit diagram of molded resin, which contains three presumptions as follows.

- (1) The fatigue strength of 10^8 cycles was extrapolated from the fatigue test result of 10^7 cycles.
- (2) The environmental factor such as ultraviolet rays and moisture will deteriorate the strength of the molded resin to 81%.
- (3) The shape of the stress limit line is resembled to that of another epoxy resin.

As a result, the stress value of the representative point on the PLG ground coil is plotted under the stress limit line.

Fig.8 PLG ground coil in which GFRP fastening devices are inserted

5. CONCLUSION

GFRP fastening device is expected to improve the reliability of the PLG ground coil for the superconducting maglev system. The PLG ground coil in which the fastening devices were inserted was experimentally made and we measured the stress on them. The stress of the

representative point on the PLG ground coil was under the extrapolated stress limit line.

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