Development of the Ground Coil for Practical Use by the Combined Propulsion, Levitation and Guidance System

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Abstract

It is required to reduce the cost of ground coils used in the superconducting maglev system given their large quantity in use. They should also have high reliability and improved workability at installation. Therefore, we developed a ground coil for practical use by the combined Propulsion, Levitation and Guidance system (PLG coil) to reduce the construction cost of the superconducting maglev line. After repeating calculation and examination, we made some PLG coils on trial, and examined them to confirm their initial performance. As a result, we confirmed that their initial insulation strength was satisfactory and they were able to be put into practical use.

1 Introduction

Ground coils are required to reduce their cost. On the other hand, since they are used outdoors for a long period of time, they should also have high reliability. Therefore, we developed a ground coil for practical use by the PLG system [1] to reduce the construction cost of the superconducting maglev line. First, we calculated the characteristics of the PLG coil system whose upper and lower unit coils were asymmetric and arranged at pitches of 120 degrees. Next, we performed conceptual designing. After that, we made some connections between ground coils on trial to be applied to PLG coils, and examined their performance. Then, we made some PLG coils on trial, and examined their initial performance. This paper reports the results of calculations and examinations.

2 Characteristics of PLG coil

2.1 Discussions on specifications

At the development of the superconducting magnet to respond to 120-degree-pitch levitation coils, PLG coils were required to reduce lateral vibration of on-board superconducting magnets in the high speed operation of maglev vehicles. Therefore, we decided to discuss a PLG coil whose upper and lower unit coils were asymmetric. In discussing its specifications, we noted the following.

(1) Regarding the propulsion characteristics, the PLG coil shall have characteristics equivalent to those of an existing propulsion coil.

(2) The temperature rise characteristics of the PLG shall be improved as far as possible, while maintaining necessary levitation and propulsion characteristics.

2.2 Conditions of the discussions

We discussed the optimum specifications of the PLG coil by applying the optimization method, in consideration of geometrically constraining condition (coil arrangement, conductor volume and other conditions), performance constraining condition (electromagnetic characteristics and other conditions) and objective function (maximization of lift-to-drag ratio, minimization of coil heat generation and other functions). Table 1 shows the conditions considered in discussing the specifications for the PLG coil.

Table 1 Conditions considered in discussing the specifications

Coil pitch	0.9 m (120-degree-pitch)
Conductor volume	Equivalent to the existing levitation coil
Lamination factor	80 %

2.3 Characteristics of the PLG coil by the specifications

2.3.1 Optimum specifications of the PLG coil

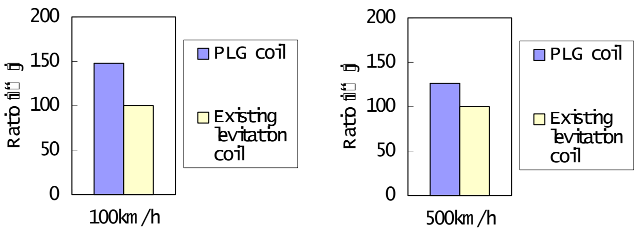
We calculated the characteristics of the PLG coil optimally designed as discussed in the preceding section for the high speed operating section of maglev line. Table 2 shows the basic specifications for the PLG coil.

Table 2 Basic specifications

Length×height (Upper coil)	0.755 m×0.23 m
Length×height (Lower coil)	0.755 m×0.37 m
Cross section of coil conductor	0.1 m×0.04 m

2.3.2 Levitation performance

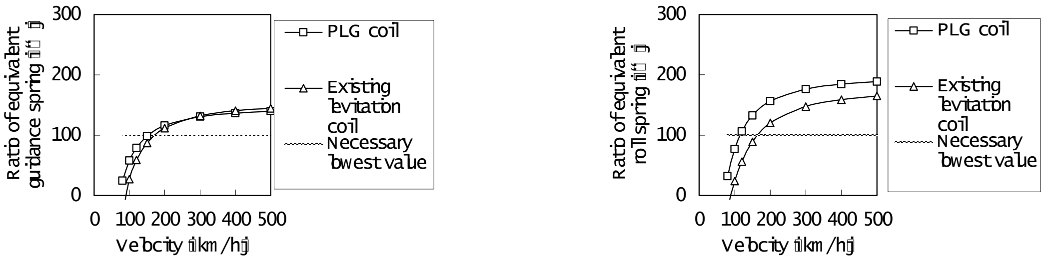
Figure 1 shows the lift-to-drag ratios of a PLG coil and an existing levitation coil. In these Figures, the lift-to-drag ratios of the existing levitation coil is indicated as a standard. The lift-to-drag ratios of the PLG coil increases to a large extent in comparison with that of the existing levitation coil.



(a) At 100km/h (b) At 500km/h

Fig. 1 Lift-to-drag ratio

Figure 2 shows the characteristics of the equivalent magnetic spring constant per maglev vehicle bogie by the PLG coils and the existing levitation coils. In these Figures, the lowest value necessary to levitate a maglev vehicle is indicated as a standard. Maglev vehicles can start a levitated run at lower speed by the PLG coils than by the existing levitation coils.



(a) Equivalent guidance spring constant (b) Equivalent roll spring constant

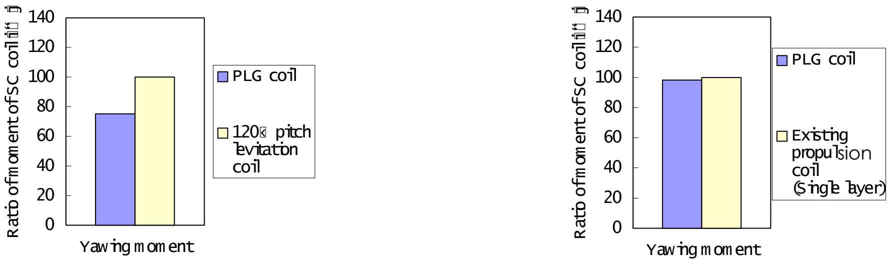
Fig. 2 Equivalent magnetic spring constant

2.3.3 Propulsion performance

The efficiency by the PLG coils increases by about 2 % more than by the existing propulsion coils. The capacity of power supply by the PLG coils is just about equal to that by the existing propulsion coils.

2.3.4 Repression of the vibration force acting on superconducting coil

Figure 3 shows the vibration force (yawing moment) acting on the maglev vehicle onboard superconducting coil by the PLG coils and 120-degree-pitch levitation coils or the existing propulsion coils. In these Figures, the yawing moment by the 120-degree-pitch levitation coils or the existing propulsion coils are indicated as a standard. The yawing moment by the PLG coils decreases to a large extent in comparison with that of the 120-degree-pitch levitation coils.



(a) By levitation coils (b) By propulsion coils

Fig. 3 Vibration force acting on the superconducting coil

3 Conceptual design

3.1 Stress analysis

We performed thermal stress analysis of the PLG coil and stress analyses of the PLG coil by electromagnetic force and uneven installation under actual conditions based on the specifications discussed in the preceding section. Figure 4 shows the shape and size of the analysis model. Based on the results of the analyses, we estimated the stress by a Goodman-line graph, and confirmed that there were no problems in the mechanical strength of the PLG coil.

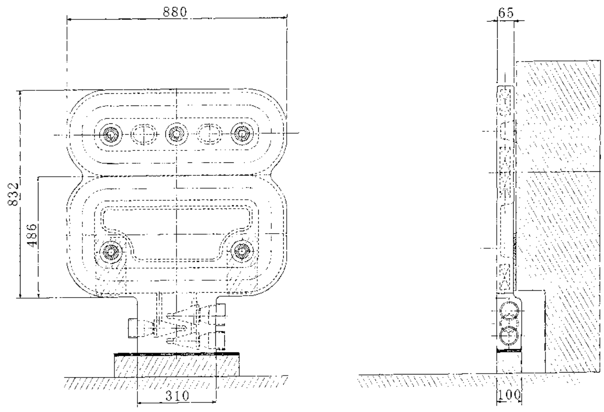


Fig. 4 Analysis model (Vertical force supported on the lower side)

3.2 Electric field analysis

We performed electric field analysis of the cross section of the PLG coil and the connection between coils. As a result, we obtained an optimum corner radius of coil wire and insulation dimension to the ground, and confirmed that there were no problems in the insulation strength of the connection between coils.

4 Examination of trial connections between coils

4.1 Aim of development of connection between coils

Because the PLG coils need wiring for guidance in addition to wiring for propulsion, we need to think of workability enough. Therefore, we decided to develop a connection between coils, while aiming at the following.

(1) To improve vibration resistance, the shape of the connection shall be of the straight type.

(2) To improve insulation reliability, the structure of the connection shall be of the inner corn type and to keep contact pressure with springs.

(3) In view of the workability in the field, the length and outer diameter of the connection shall be miniaturized as far as possible.

4.2 Specifications

Table 3 shows the conditions of connection for use, and Fig. 5 the outer shape of trial connections.

Table 3 Conditions for use

Environmental condition	Environmental temperature Environmental moisture Water immersion	-30～50℃ Max. 100% (Dew condensation) Temporarily water immersion
Voltage condition	Nominal voltage Cumulative hours of voltage charged	33 kV About 10,000 hours (Equivalent to use for 30 years)

4.3 Examination results

We made some trial connections between coils and examined them to confirm the initial performance. Consequently, we confirmed that there were no problems in the insulation strength or airtightness. Furthermore, to confirm their durability for long term use, we performed a voltage charging and vibrating test, and an outdoor voltage charging and energization test. Consequently, we confirmed that there were no problems in the insulation performance or the appearance of the insulator. As a result, we confirmed that the connection satisfied electrical, mechanical and thermal durability.

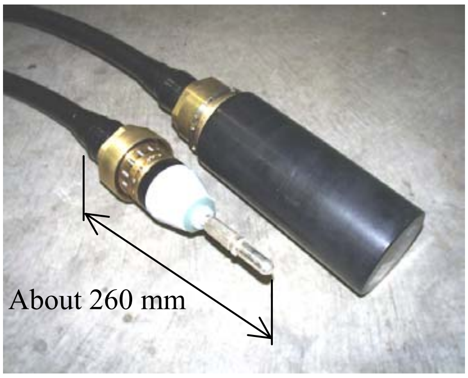


Fig. 5 Outer shape of trial connections

5 Examination of trial coils

5.1 Specifications

Table 4 shows the conditions of a PLG coil for use, and Fig. 6 the outer shape of a trial PLG coil.

Table 4 Conditions for use

Environmental condition	Environmental temperature Environmental moisture Antiweatherability	-30～50 degrees C Max. 100% (Dew condensation) All weather
External force condition	Maximum electromagnetic force Cyclic number	Longitudinal : 17 kN Lateral : 32 kN Vertical : 62 kN About 1.4×10^8

Voltage condition	Nominal voltage Cumulative hours of voltage charged	33 kV about 10,000 hours (Equivalent to use for 30 years)
Energization condition	Propulsion current Time of turning on electricity Maximum temperature for use	390 A About 20 seconds out of 300 seconds (At 250km/h) 80 degrees C

5.2 Examination results

We made some trial PLG coils and performed examinations such as partial discharge test, dielectric breakdown test and impulse dielectric breakdown test as shown in Fig. 7. Consequently, we confirmed that their insulation performance at nominal 33 kV were normal. Therefore, they had satisfied the initial insulation strength. Their dielectric breakdown voltage and impulse dielectric breakdown voltage were 1.5 times or over the test voltage at the withstand voltage test. Therefore, they were at a satisfactory level as nominal 33 kV equipment.

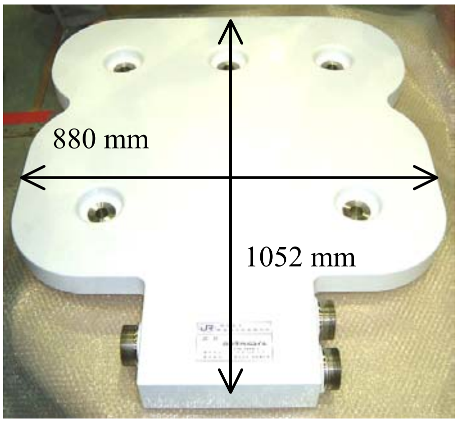


Fig. 6 Outer shape of trial PLG coil

Fig. 7 Impulse dielectric breakdown test

6 Measurement of electromagnetic force at the Yamanashi test line

6.1 Measurement method

To confirm the characteristics of the PLG coils, we measured their electromagnetic force by the measurement PLG coils temporarily installed at the Yamanashi maglev test line as shown in Fig. 8. As each coil was set at the guideway sidewall on the load converters, we were able to measure the force in three directions (longitudinal, lateral and vertical) at the same time. All electromagnetic force generated in the coil is supported by the load converters. [2]

Fig. 8 PLG coils at the Yamanashi maglev test line

6.2 Measurement results

Figure 9 shows the characteristics of the relation between the propulsion force and the current, Fig. 10 between the lift-to-drag ratio and velocity, and Fig. 11 between the guidance spring constant and velocity. Every characteristic is that of the maglev vehicle bogie, and every Figure shows the characteristics calculated by a computer. As a result, we confirmed that the measurements correspond basically with those calculated by a computer.

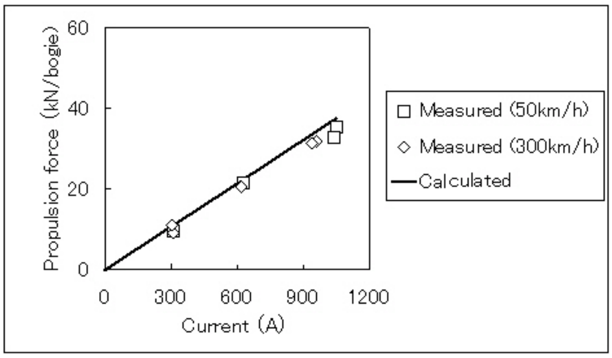
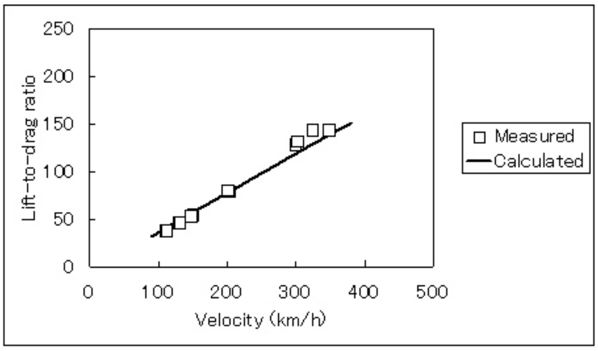


Fig. 9 Current characteristic



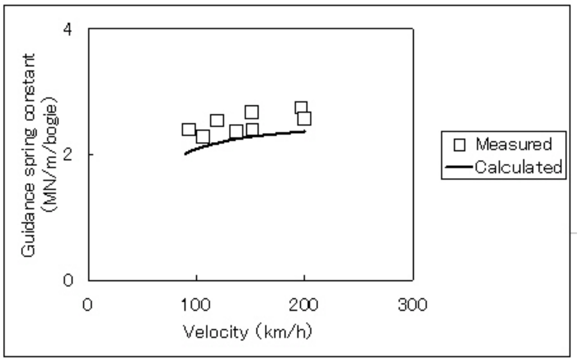


Fig. 10 Lift-to-drag ratio characteristic

Fig.11 Guidance spring constant characteristic

7 Summary

Discussions in this paper are summarized as follows.

(1) We discussed specifications of a PLG coil whose upper and lower unit coils were asymmetric for the high speed operation section, and calculated its characteristics. In the result, we confirmed that it was able to repress the vibration force acting on the superconducting coil.

(2) We performed conceptual designing of the PLG coil, and obtained useful knowledge about designing and manufacturing an actual PLG coil.

(3) We made connections between coils on trial on the assumption that they were applied to PLG coils, and confirmed that they had good performance through examinations.

(4) Based on the above result, we made some PLG coils on trial, and examined them to confirm the initial performance. As a result, we confirmed that their initial insulation strength was satisfactory.

(5) We measured electromagnetic force of the PLG coils at the Yamanashi test line, and confirmed that the measurements corresponded with the calculated values.

8 Conclusion

We introduced the development of the ground coil for practical use by the PLG system. We confirmed that PLG coils made after calculations and examinations satisfied the initial insulation strength and characteristics of electromagnetic force as we had expected. We obtained their possibilities for practical use. At present, we are performing a long term outdoor voltage charging and energization test and a cyclic loading test of the PLG coils to confirm their durability for 30 years.

9 Acknowledgments

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