Characteristics of Electromagnetic Force of Ground Coil for Levitation and Guidance at the Yamanashi Maglev Test Line

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At the Yamanashi maglev test line, two types of ground coils are used. One is for propulsion and the other for levitation and guidance. To confirm the characteristics of electromagnetic force of the ground coil for levitation and guidance, we measured the electromagnetic force directly with a measurement coil. The measurements of electromagnetic force, magnetic spring and current corresponded with the computed values to prove that the characteristics of electromagnetic force satisfy the design requirements.

Keywords: Maglev, ground coil, electromagnetic force, magnetic spring

1. Introduction

At the Yamanashi maglev test line, two types of ground coils are used. One is for propulsion and the other for levitation and guidance. The electromagnetic force is generated between the ground coils for levitation and guidance and the on-board superconducting magnets (SCMs) of test vehicles. To confirm the characteristics of electromagnetic force, we measured it directly with a measurement coil temporarily installed at the Yamanashi Maglev Test Line. Characteristics of electromagnetic force are those of levitation force, guidance force, current and magnetic spring. This paper reports the measurement results and characteristics of electromagnetic force.

2. Measurement method

2.1 Measurement coil

Table 1 shows the specification of the measurement coil. Fig. 1 shows the outside shape of a measurement coil. There are two types of measurement coils. One is a coil for measuring levitation force and the other for measuring levitation and guidance force. In the basic specification, they are the same as the ground coil for levitation and guidance used at the Yamanashi Maglev Test Line. But they are different in the structure of winding. The winding of the measurement coil for measuring levitation and guidance force forms the same levitation and guidance current circuit as those of the ground coil at the Yamanashi Test Line, and winding of the measurement coil for measuring levitation force forms only a levitation current circuit. Fig. 2 shows the layout of the measurement coils for measuring levitation force and for measuring levitation and guidance force. They were installed temporarily in succession and also installed on the opposite side of a guideway sidewall. Therefore, four coils were installed in total.

2.2 Load converter

As each measurement coil was set at the guideway sidewall on the load converters (four converters per coil), we can measure the force in three directions (longitudinal, lateral and vertical) at the same time. All electromagnetic force generated in the measurement coil is supported by the load converters. The tip area of a load converter has bolts to be set with nuts. To ensure the sensitivity of measurement, the load converter is made of an aluminum hybrid metal though it causes eddy current loss.

Table 1  Technical details of measurement coils

<table>
<thead>
<tr>
<th></th>
<th>Measurement coil for measuring levitation force</th>
<th>measurement coil for measuring levitation and guidance force</th>
</tr>
</thead>
<tbody>
<tr>
<td>coil shape</td>
<td>&quot;8&quot; shape coil</td>
<td>same as left</td>
</tr>
<tr>
<td>size between center of coil to center</td>
<td>350 mm × 340 mm</td>
<td>same as left</td>
</tr>
<tr>
<td>corner winding radius</td>
<td>100 mm</td>
<td>same as left</td>
</tr>
<tr>
<td>size between upper coil to lower</td>
<td>420 mm</td>
<td>same as left</td>
</tr>
<tr>
<td>number of winding</td>
<td>24 (12 layers × 2)</td>
<td>same as left</td>
</tr>
<tr>
<td>terminal for guidance current circuit</td>
<td>no terminal</td>
<td>with terminal</td>
</tr>
</tbody>
</table>
2.3 Dealing by impulses

The electromagnetic force acting on the test vehicles is obtained as a reaction of the sum of the electromagnetic force acting on ground coils for levitation and guidance. We can obtain the value from mean force acting on a ground coil for levitation and guidance for a certain time length multiplied by the number of the coils where force acts at the same time. When we define $F(t)$ as a half (one side of right or left) force acting on a bogie of the test vehicles, $F(t)$ is expressed by Eq (1).

$$F(t) = -\sum_{n=-\infty}^{\infty} f(t + n\Delta t) \quad \cdots \cdots \cdots \cdots \quad (1)$$

$f(t)$: Force acting on the ground coil for levitation and guidance at time $t$

$\Delta t$: Time length for the test vehicles to move between two ground coils for levitation and guidance.

When we define the mean force acting on the test vehicles when they move between two ground coils for levitation and guidance as $F$, Eq (1) is expressed by Eq (2).

$$F = \frac{1}{\Delta t} \int_{-\infty}^{+\infty} F(t)dt = -\frac{1}{\Delta t} \int_{-\infty}^{+\infty} f(t)dt \quad \cdots \cdots \cdots \cdots \quad (2)$$

Eq (2) means $F$ is the impulses acting on a ground coil for levitation and guidance divided by $\Delta t$.

Merits of this method of dealing by impulses are as follows.

1. Noise is easily removed because the noise influence is slight and measured values do not change if they pass a filter.
2. We can get measured values accurately both at low and high speed tests because the impulses are not influenced by the resonance of measurement apparatuses.
3. It is easy to read the impulses of measured waveforms.

It was necessary to use load converters that had good sensitivity in this measurement. Therefore it becomes difficult to read part of the electromagnetic force of measured waveforms directly because part of the natural frequency overlaps the measured waveforms in proportion to the speed. Then we decided to adopt a method to obtain the impulses by integrating the measured waveforms and calculated the electromagnetic force.

2.4 Measurement system

Fig. 3 shows the measurement system. We measured the levitation current, guidance current, displacement of the test vehicles, and so on at the same time as the electromagnetic force. We set sensors in the guideway of the test line and set amplifiers and recorders under the guideway. We used a digital memory recorder and analyzer (EDX) to record data and we input measured data into a personal computer in the measurement room under the elevated track of the test line through an optical local area network after inputting the data into the EDX.

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**Fig. 1** Outside shape of the measurement coils

**Fig. 2** Layout of the measurement coils in the guideway

LN (LS) coil: measurement coil for measuring Levitation force that were set at the Northern (Southern) side of the guideway sidewall

LS (GS) coil: measurement coil for measuring levitation and Guidance force that were set at the Northern (Southern) side of the guideway sidewall
3. Measurement results

3.1 Measurement conditions

In this measurement, we changed the positions of the measurement coils into the vertical direction or lateral direction as shown in Fig. 4.

3.2 Measurement results

3.2.1 Waveforms of electromagnetic force

Fig. 5 and Fig. 6 show measured waveforms and impulses of vertical electromagnetic force acting on the measurement coil for measuring levitation and guidance force that were set at the southern side of the guideway sidewall (GS coil) when one bogie of the levitating test vehicles passed at a constant speed of 151 or 298 km/h. We set the measurement coil to measure levitation and guidance force that were set at the northern side of the guideway sidewall (GN coil) at a position of $\Delta z = 0$ millimeter and $\Delta y = 20$ millimeters, and set other measurement coils at a position of $\Delta z = 0$ millimeter and $\Delta y = 0$ millimeter (standard position). Though part of natural frequency overlaps the measured waveforms at a speed of 298 km/h, we can understand that their impulses are not affected by the natural frequency.

3.2.2 Characteristics of the relation between electromagnetic force and velocity

Fig. 7 shows the characteristics of the relation between the longitudinal, lateral or vertical force and velocity at one side of the bogie with those calculated by a computer. We calculated the longitudinal, lateral or vertical force by Eq (2) from the electromagnetic force acting on the measurement coil for measuring levitation force that were set at the southern side of the guideway sidewall (LS coil) when one bogie of the levitating test vehicles passed at a constant speed. We set all the measurement...
coils at a place of the standard position. Because the measured longitudinal force included electromagnetic force acting on the load converters, the longitudinal force shown in Fig. 7 was calculated from the Joule loss by the levitation current measured at the same time. The measured force corresponds with those calculated by a computer.

### 3.2.3 Characteristics of levitation force

Fig. 8 shows the characteristics of the relation between vertical displacement and levitation force per bogie. We calculated the vertical force by adding the vertical (levitation) force at one side of a bogie that we calculated by Eq (2) from the electromagnetic force acting on the measurement coils for measuring levitation force that were set at the southern and northern side of the guideway sidewall. The calculated levitation force shown in Fig. 8 which was calculated by a computer from measured vertical displacement of a bogie correspond with the measured values.

### 3.2.4 Characteristics of magnetic springs

Fig. 9 shows the characteristics of magnetic springs at the bogie with those calculated by a computer. We calculated the magnetic springs from the impulses acting on the measurement coils for measuring levitation and guidance force and displacement of the measurement coils that were set at the southern and northern side of the guideway sidewall. We denote vertical spring constant as $k_{zz}$, rolling spring constant as $k_{\phi\phi}$, lateral spring constant as $k_{yy}$, lateral spring constant coupled with rolling displacement as $k_{y\phi}$, and rolling spring constant coupled with lateral displacement as $k_{\phi y}$. The measured spring constants correspond with those calculated by a computer.
3.2.5 Characteristics of currents

Fig. 10 shows the root mean square values that we calculated from the waveforms of levitation current and guidance current with those calculated by a computer. The calculated currents shown in Fig. 10 that we calculated by a computer when vertical displacement is balanced and lateral displacement is zero correspond with the measured values.

4. Conclusion

The characteristics of electromagnetic force of ground coil had previously been obtained from the displacement and load measured on the test vehicles, but we measured electromagnetic force acting on a ground coil for levitation and guidance directly at the side of ground and calculated the characteristics of its electromagnetic force. The measurements of electromagnetic force, magnetic spring and current calculated from the impulses at the bogie of the test vehicles corresponded with the computed values to prove that the characteristics of electromagnetic force satisfy the design requirements.

Acknowledgment

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References