Vibration Characteristics of Superconducting Magnets for the Yamanashi Maglev Test Line Vehicles

Masafumi OGATA

Engineer,

Tomohiro OKINO

Engineer,

Yamanashi Maglev Test Center,
Maglev Systems Development Dept.

Kazuya IKEDA

Engineer,

Toshiki HERAI

Chief Researcher,

Cryogenic Technology Lab.,
Maglev Systems Development Dept.

Motohiro IGARASHI

Senior Engineer,

Linear Express Development Div.,
Central Japan Railway Company

Takayuki FURUSAWA

Engineer,

On the Yamanashi Maglev Test Line, on-board superconducting magnets vibrate due to harmonic magnetic fields caused by ground coils while vehicles are running. Excessive vibration gives rise to a large heat load and makes it difficult to keep the superconducting state of the magnets. Therefore, the authors tested the superconducting magnets for vibration characteristics under these harmonic magnetic fields by an electro-magnetic vibration simulator. In this paper, the results of running tests are compared with those of simulations of the electro-magnetic vibration, and the analysis of vibration modes and components are introduced.

Keywords : Superconducting magnet, Yamanashi Maglev Test Line, vibration characteristics, electro-magnetic vibration

1. Introduction

On the Yamanashi Maglev Test Line, the driving force of vehicles is generated by a linear synchronous motor consisted of on-board superconducting magnets (SCMs) and propulsion coils on the guideway. While vehicles are running, SCMs vibrate due to harmonic magnetic fields caused by ground coils shown in Fig.1. Excessive vibration gives rise to large heat load and makes it difficult to keep the superconducting state of the magnets. So, the SCMs were tested for vibration characteristics under these harmonic magnetic fields by an electro-mag-

netic vibration simulator, and the test results have been applied to the design and manufacture of the SCMs for Yamanashi Maglev Test Line vehicles.

2. SCM for Yamanashi Maglev Test Line vehicles

Table 1 shows the major specification list of the SCM. The SCM is one of the most important components of the Maglev system to generate levitation, guidance and propulsion forces of vehicles. In consequence of the improvement to decrease the vibration and heat load under these harmonic magnetic fields¹⁾²⁾, the SCM with stable performance against vibration and closed refrigerating system have been realized.

Fig.2 shows the structure of the SCM. The SCM is composed of a tank section and coil section. In the tank section, a liquid helium tank, liquid nitrogen tank and on-board refrigerator, which liquefies gas helium evaporated in the SCM, are contained. In the coil section, a superconducting coil, inner vessel, radiation shield, outer vessel, persistent current switch and power lead are contained. The superconducting coil made of niobium-titanium alloy wire is refrigerated by the liquid helium in the inner vessel to keep the superconducting state. The radiation shield which is cooled by liquid nitrogen is placed around the inner vessel to prevent the intrusion of radiation heat. And these parts are covered with an

Fig. 1 Two types of ground coils on the guideway

Table 1 Characteristics of SCM for Yamanashi Maglev Test Line vehicles

• Composition	4 superconducting coils per SCM
• Pole pitch	1.35 m
• Magnetomotive force	700 kA
• Dimension	5.4 m (L) × 1.175 m (H)
• Weight	1,400 kg or less
• Levitation force per SCM	115.5 kN
• Static heat invasion	5 W or less
• Increase of heat load at running	3 W or less
• Capacity of on-board refrigerator	8 W or over at 4.5 K

Fig. 2 Structure of SCM

outer vessel in which a vacuum is contained. The SCM is energized by the exciting system at the train depot, and operated in a persistent current mode during vehicle running tests.

3. Cause of SCM vibration

Fig.3 shows the arrangement of the ground coils. Supposing that the pole pitch of the SCM is τ the coil pitch of the levitation-guidance coils is $\tau/3$ and that of the propulsion coils which are placed in a double layer is $4\tau/3$. Concerning the one layer of the propulsion coils which are at the connecting point of the guideway unit, half-length propulsion coils are used because the guideway consists of a number of units of finite length.

When the vehicle is running, the frequency of primary harmonic magnetic field on the SCM becomes sixth harmonic compared to that of the alternating current supplied to the propulsion coils. As this frequency depends on the vehicle speed, the SCM is influenced by the harmonic magnetic field of 309 Hz at the speed of 500 km/h.³⁾

Table 2 shows an example of the vibrating forces on the SCM induced by the sixth harmonic magnetic field from the ground coils. In this Table, these forces on the superconducting coil are divided between the translational force and moment by each ground coil.

Fig. 3 Arrangement of ground coils (top view)

Table 2 Vibration force induced on superconducting coil at running

	Propulsion coil (kN)	Levitation-guidance coil (kN)		Propulsion coil (kN)	Levitation-guidance coil (kN)
F _x	0.88	0.05	M _x	0.01	0.46
F _y	0.09	0.11	M _y	0.01	0.98
F _z	0.02	0.12	M _z	0.16	0.70

• Vehicle speed: 500 km/h
• Displacement: 0(y), balanced(z)
• Location: 2nd superconducting coil for running direction

4. Electro-magnetic vibration test

Electro-magnetic vibration tests can simulate the vibration state of the SCM when running. All the SCMs for the Yamanashi Maglev Test Line are tested for the characteristics of vibration and heat load by this simulation in the manufacturing process. Fig.4 shows an electro-magnetic vibration simulator. The SCM fitted to the bogie frame is exposed to the vibrating magnetic field which simulates the harmonic magnetic field from the ground coils when running.

The standard test condition of this simulation is to equalize the moment around the z-axis(M_z) shown in Table 2. From this Table, the SCM vibration is mostly influenced by the levitation-guidance coils but not by the propulsion coils. So, electro-magnetic vibration tests must be done with the harmonic magnetic field from the levitation-guidance coils simulating exactly the SCM vibration when running. If the pole pitch of the SCM is τ , the coil pitch of the vibration coil of the simulator is $2\tau/15$ for the simulation of the sixth harmonic magnetic field.³⁾

Fig. 4 Electro-magnetic vibration simulator

5. Results of SCM vibration

Two SCMs named sample_1 and sample_2 were tested. On each SCM, the acceleration of the superconducting coil, which is located on the right of the SCM on the ground coils side, was measured. Fig.5 shows the positions of vibration sensors on the superconducting coil. Sample_1 has four sensors of ①, ③, ④ and ⑥ and sample_2 has six sensors of ①, ②, ③, ④, ⑤ and ⑥. The direction of measurement by these sensors is the y-axis direction of Table 2.

Fig. 5 Vibration sensors on superconducting coil

5.1 Comparison between electro-magnetic vibration test and vehicle running test

Fig.6 shows the comparison between electro-magnetic vibration test and vehicle running test at the positions of ⑥ of sample_1 and ④ of sample_2. In Fig.6, the electro-magnetic vibration test means the result of the vibration simulation of sixth harmonic magnetic field from the levitation-guidance coils, and the vehicle running test means the vibration component of the sixth harmonic frequency of the alternating current supplied to the propulsion coils.

Fig.6 shows that the electro-magnetic vibration test almost exactly reproduces the vibration during the vehicle running test.

5.2 Vibration modes

These vibration sensors are placed around the super-

Fig. 6 Comparison of SCM vibration between electro-magnetic vibration and vehicle running tests

conducting coil, so the vibration modes of the superconducting coil should be estimated by the amplitudes and phases of each sensor.

Fig.7 shows the resonant vibration modes of sample_1 at 450 km/h and sample_2 at 410 km/h. Sample_1 shows a twisted mode and sample_2 shows a second bended mode at each speed. At the resonant condition, the superconducting coil shows particular vibration modes such as a twisted mode and bended mode.

5.3 Vibration components

Fig.8 shows the particular vibration components of ⑥ of sample_1 when running. In Fig.8, the component of the sixth harmonic means those caused by the propulsion coil and the levitation-guidance coil, and the component of the half-length propulsion coil means that by the half-length propulsion coil.

The component of the sixth harmonic is in good agreement with the full amplitude having some constant difference. It is known that the component of the sixth harmonic has the same behavior both in acceleration and deceleration, so the effect of the propulsion coil on the component of the sixth harmonic can be disregarded. Therefore, the component of the sixth harmonic is mostly influenced by the levitation-guidance coil. And the component of the half-length propulsion coil exist all over the entire range of vehicle speed, so this component must also be considered in analyzing the SCM vibration when running.

Fig. 7 Resonant vibration modes

Fig. 8 Particular vibration components at running

6. Conclusions

Concerning the vibration characteristics of the SCM for Yamanashi Maglev Test Line vehicles, the results of running tests were compared with those of the simulations of the electro-magnetic vibration, and the analysis of vibration modes and components were introduced.

Electro-magnetic vibration tests almost exactly reproduce the vibration during the vehicle running tests. At the resonant condition, the superconducting coil shows particular vibration modes such as a twisted mode and bended mode. The SCM vibration is mostly influenced by the levitation-guidance coil, but the effect of the half-length propulsion coil on SCM vibration must also be considered.

Acknowledgments

A further investigation of the SCM which has good vibration performance and heat load characteristics should be continued by these simulation and analysis methods.

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References

- 1) E.Suzuki, S.Saito, J.Ohmori, M.Oki and F.Suzuki: "Characteristics of Heating in a Superconducting Coil Mechanically Vibrated (in Japanese)", *Journal of the Cryogenic Society of Japan*, vol.29, No.10, pp.30-35, 1994
- 2) H.Tsuchishima, E.Suzuki and M.Terai: "Development of New Superconducting Magnet for Yamanashi Test Line (in Japanese)", *RTRI REPORT*, vol.8, No.10, pp.17-22, 1994
- 3) E.Suzuki: "Heating Phenomena in the Superconducting Magnet of Maglev Caused by Electro-Magnetic Vibration (in Japanese)", *Journal of the Cryogenic Society of Japan*, vol.29, No.10, pp.1-9, 1994