State of levitation of linimo (HSST system) during EXPO2005

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ABSTRACT: Temperature affects precision of gap sensor. Carrying weight affects magnet gain due to saturation of magnetic field. Both temperature and carrying weight affects stiffness of levitation control. Though such condition changed very much, stiffness of levitation control of Linimo was not changed so much during EXPO2005.

1 INTRODUCTION

Linimo, or Tobu-Kyuryo-Line, which is the first perpetual commercial application of HSST system, has been operated since March 6 2005. Though we did not have enough period for test run, Linimo played an important role as a railway transportation for EXPO2005 without serious trouble. It carried nearly 20 million passengers during EXPO.

While it snowed on the opening day of EXPO, the temperature became more then 35 degrees centigrade in summer. While empty weight of a Linimo car is 17,000 kg, many of the trains during EXPO were full of passengers and carrying weight was 11,000 kg a car during EXPO. Despite such variation of environment, the levitation control of Linimo was stable and stiff enough.

This paper shows the actual state of levitation during EXPO.

Figure 1: Linimo train

2 ENVIRONMENTAL INFLUENCE ON LEVITATION CONTROL

2.1 *Siffness of levitation*

Figure 2 is the block diagram of levitation control of Linimo.

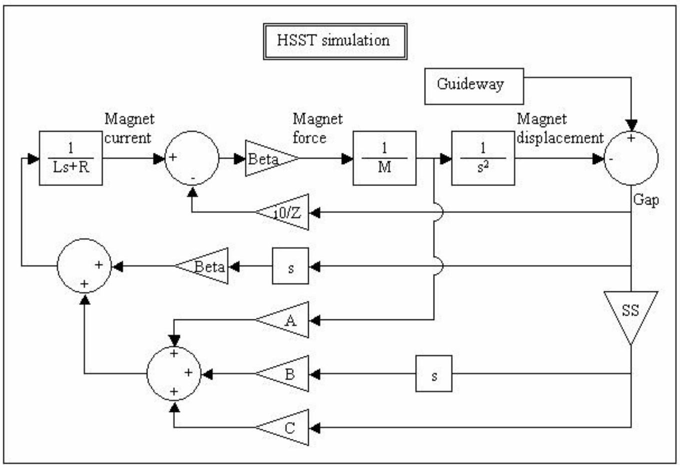

Figure 2: Block diagram of the levitation control of Linimo

Where R = electric resistance of magnet coil; L = total inductance of coil; Z = target air gap of magnet; $i0$ = typical current of magnet coil; $Beta$ = magnet gain; M = mass of bogie; SS = sensor sensitivity; C = proportional feedback gain of gap; B = differential feedback gain; A = acceleration feedback gain.

According to (Yamamura et al.1976), power spectral density of gap and root mean square of gap can be calculated as Equation 1 and Equation 2 respectively

$$\Phi_x(\omega) = \left|T(j\omega)\right|^2 \Phi_z(\omega) \qquad (1)$$

where Φ_x = PSD of magnet gap; ω = angular velocity of disturbance; T = transfer function from guideway to gap; Φ_z = PSD of guideway irregularity.

$$\sigma = \sqrt{\int_{\omega_1}^{\omega_2} \Phi_x(\omega)d\omega} \qquad (2)$$

where σ = root mean square of gap; ω_1 = lower end of angular velocity bandwidth; ω_2 = higher end of angular velocity bandwidth; Φ_x = PSD of gap.

Using Equation 1 and Equation 2, we can calculate spectrum of gap and root mean square of gap. In this paper we use random irregularity and bending of guideway as guideway irregularity like (Morita et al. 2004). Standard calculated root mean square of gap is 0.74mm. Figure 3 shows standard calculated spectrum of gap.

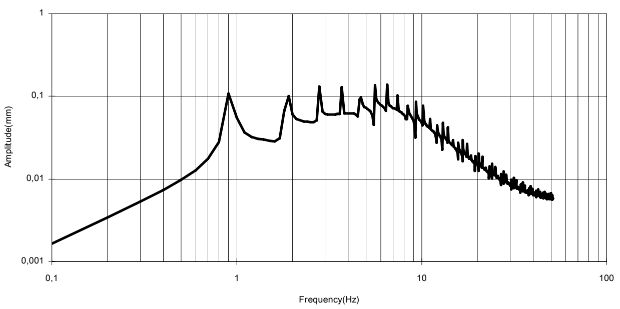

Figure 3: Standard calculated spectrum of gap

2.2 Temperature

It snowed on the opening day of EXPO2005, but it became more than 35 degrees centigrade in summer. Difference between maximum and minimum temperature during EXPO is more than 30 degrees. Temperature affects sensitivity of gap sensor and consequently levitation control. Figure 4 shows the spectrum of gap when sensitivity is reduced 2%.

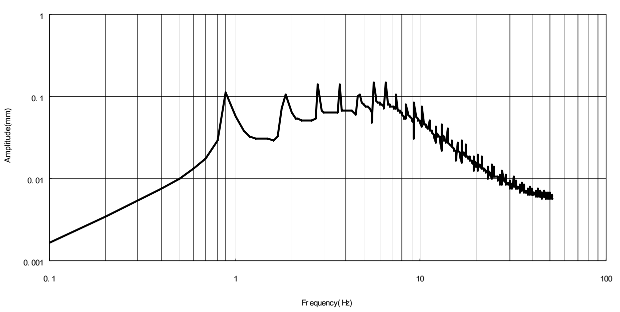

Figure 4: Calculated spectrum of gap with less sensitive sensor

While amplitudes of 10 Hz or higher become smaller, amplitudes of less than 10 Hz, which is relatively larger, become larger than standard ones. Calculated root mean square of gap is 0.77 mm.

2.3 Carrying weight

Linimo is a kind of urban maglev. Its empty vehicle weight is 17,000 kg, but carrying capacity is 11,000 kg. Levitation control has to work properly in a wide range between 17 kN and 28 kN per module.

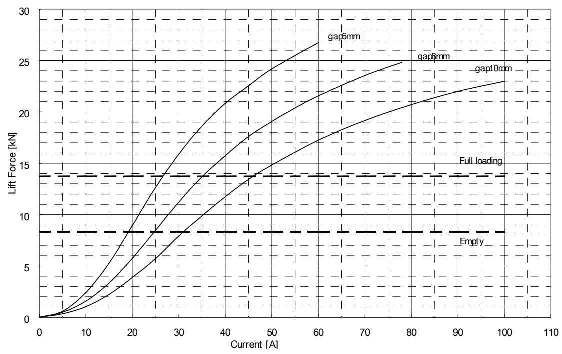

Figure 5: Magnet force against current

Figure 5 shows magnetic attractive force of half module against current. Horizontal axis is current and vertical axis is magnetic force. The upper curve shows magnetic force against current when the gap is 6 mm. The center curve shows that when the gap is 8 mm and the lower curve shows that when the gap is 10mm. The upper horizontal line shows the magnetic force when the vehicle is fully loaded and the lower line shows the force when the vehicle is empty. The slope of tangent of 8 mm curve at the intersection point with upper horizontal line is nearly 20% less steep than that with lower horizontal line. That means magnet gain when the vehicle is fully loaded is nearly 20% smaller than that when it is empty.

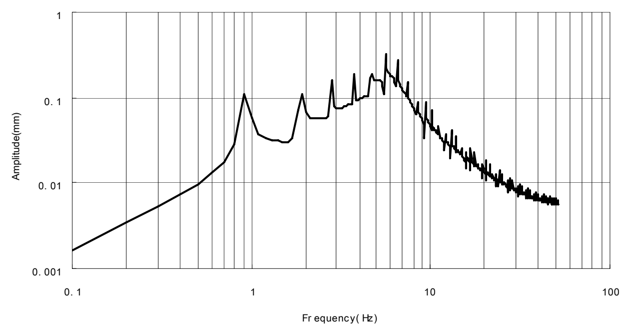

Figure 6: Calculated spectrum of gap with smaller magnet gain

Figure 6 shows spectrum of gap when magnet gain is 20% smaller than standard gain. Amplitudes between 2 Hz and 10 Hz become larger and calculated root mean square of gap is 1.10 mm. In our experience we know gap fluctuation can be as large as

4 times root mean square. In this case gap fluctuation can be 4.40 mm. Allowable gap fluctuation of Linimo is designed as 4 mm. We had to take steps to reduction of magnet gain

3 ACTUAL STATE OF LEVITATION DURING EXPO

In spite of environmental change, levitation control of Linimo had kept stable and stiff enough during EXPO thanks to some arrangement.

Some examples of measured gap are shown in secondary chapters. Horizontal axis is time and one division corresponds 4 seconds. Bottom curve shows speed. Bottom of the chart corresponds 0 km/h and one vertical division corresponds 50 km/h. The curve is near the second graduation line from bottom and that means train ran at the speed of about 95 km/h.

Upper 4 lines show gaps of front pair module of front car. Following 4 lines show gaps of center pair module of center car. Following 4 lines show gaps of rear pair module of rear car. One vertical division corresponds 4 mm. Allowable fluctuation of gap is designed to 4 mm and these lines may not cross upper or lower graduation line. At some several places, lines radically move downward across the lower graduation line and soon come back. There, gaps do not actually grow wide. Gaps of rail make sensor output larger than correct one. We have taken steps for gaps of rail not to disturb levitation control. Upward movement of lines means upward movement of magnets. All these gaps are measured with car number 111-112-113. They are measured on upward track between Koen-nishi station and Geidai-dori station.

Some examples of measured spectrum of gap are also shown in secondary chapters. These were calculated as average amplitude of measured gaps of center pair module of car number 112.

3.1 Cold and many passengers

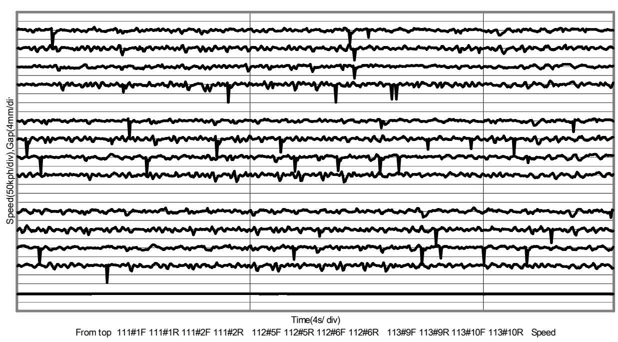

Figure 7: Measured gap on March 31

Figure 7 shows gap fluctuation at about 7 o'clock in the evening on March 31. Maximum temperature of the day was 17 degrees centigrade and minimum temperature was 3 degrees. Cars were full of passengers who were going home from EXPO site.

Figure 8 shows spectrum of gap calculated by gap fluctuation of Figure 7. Root mean square of gap is 0.79 mm.

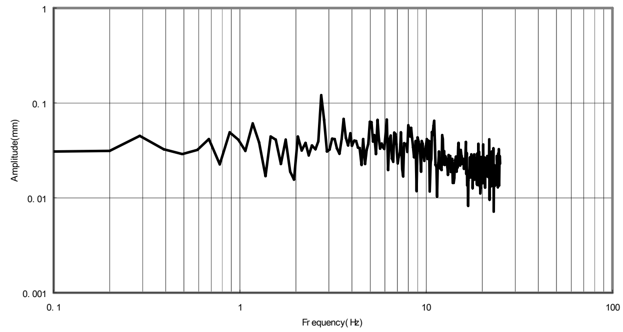

Figure 8: Measured spectrum of gap on March 31

3.2 Hot and few passengers

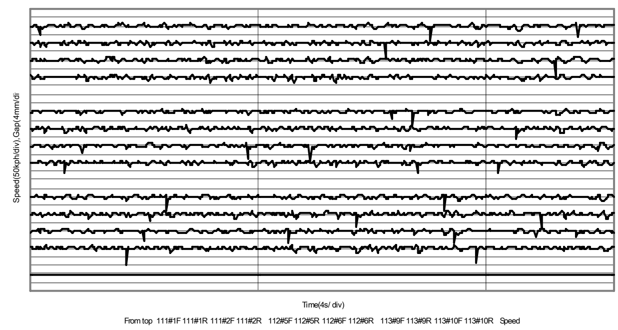

Figure 9: Measured gap on August 12

Figure 9 shows gap fluctuation at about 8 o'clock in the morning on August 12. Maximum temperature of the day was 31 degrees centigrade and minimum temperature was 26 degrees. A few passengers were on board because this train was leaving EXPO site in the morning.

Figure 10 shows spectrum of gap calculated by gap fluctuation of Figure 9. Root mean square of gap is 0.63 mm.

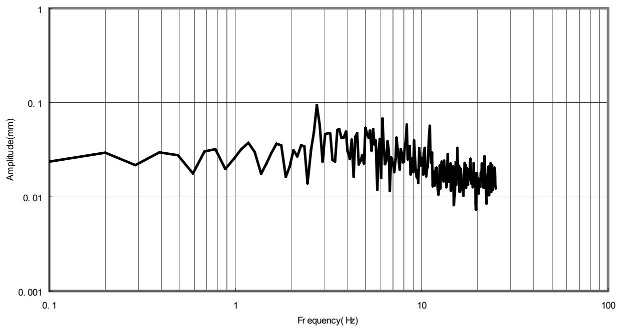

Figure 10: Measured spectrum of gap on August 12

3.3 *Hot and many passengers*

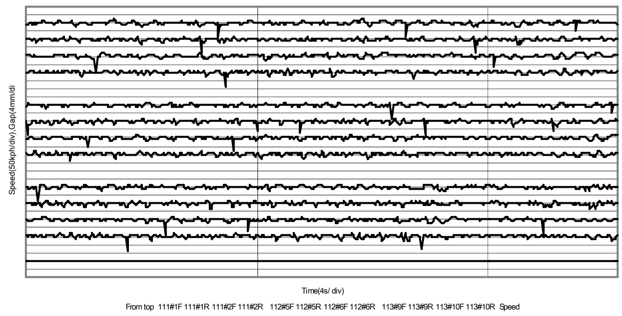

Figure 11: Measured gap on August 12

Figure 11 shows gap fluctuation at about 5 o'clock in the evening on August 12. Maximum temperature of the day was 31 degrees centigrade and minimum temperature was 26 degrees. Cars were full of passengers who were going home from EXPO site.

Figure 12 shows spectrum of gap calculated by gap fluctuation of Figure 11. Root mean square of gap is 0.67 mm.

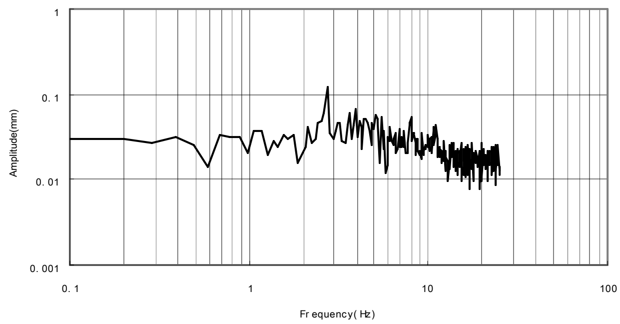

Figure 12: Measured spectrum of gap on August 12

Compared Figure 12 with Figure 8, amplitudes between 5 Hz and 10Hz are smaller and consequently root mean square of gap is smaller. This result is opposite to simulated result as it was hotter on August 12 than on March 31. We think that transformation of guideway due to temperature and regular guideway maintenance affected the result.

Compared Figure 12 with Figure 10, amplitudes are a little larger and consequently root mean square of gap is a little larger. Simulated results have much difference due to carrying weight, but measured results have little difference thanks to some arrangement.

4 CONCLUSION

As stated above, levitation control of Linimo had kept stiff enough during EXPO2005 despite environmental change. We have successfully restrained influence of environmental change on levitation control. Linimo's achievement during EXPO has proved that HSST system has been very mature as urban transportation system.

5 REFERENCE

Morita, M. & Iwaya, M. & Fujino, M. 2004. The characteristics of the levitation system of Linimo(HSST system), *The 18th international conference on magnetically levitated systems and linear drives, Shanghai, China, 26-28 October 2004.*

Yamamura, S. & Abe, S. 1976. Control and speed – Characteristics of magnetially levitated vehicles of attracting magnet type. *The institute of electrical engineers of Japan* 96(5): 17-24.