Improvement of the damping using the active damper coils system in the superconducting magnetically levitated bogie

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Abstract

Numerical simulation of the superconducting magnetically levitated bogie (JR Maglev) has been studied. This system, which is based on the side wall electrodynamic suspension (EDS), keeps the air-gap length at about 10 cm. Although the EDS system has the advantage of stable levitation without active control, the result of the numerical simulation shows that the damping factor of the levitation system is small. So the active damper coil system has been proposed. Copper coil is installed in front of the superconducting coil on the bogie as damper system. We have designed damper coils to increase the damping against vertical oscillation. Running simulation of the bogie considering the limitation of the power supply is undertaken. The active damper coil system decreases amplitude of the oscillation and damping factor becomes large, and its effect is confirmed by numerical analysis.

1 Introduction

A superconducting magnetically levitated (Maglev) transportation system has been developed in Japan, and the train with five cars has achieved 552 km/h in a manned vehicle run. Figs.1 show a cross section and an upper view of the system. The null flux eight figure levitation coils are set on the ground. And Superconducting coils that are used for both secondary of the linear synchronous motor and levitation magnet is installed on the side of the bogie. This system which is based on the side wall electrodynamic suspension (EDS), keeps the air-gap length at about 10 cm. When the bogie passes the center of the eight- figure levitation coil, its linkage flux becomes zero. Thus no current is induced on the levitation coil. When the bogie passes below the center of the levitation coil, current is induced on the levitation coils, and its value depends on vertical position and velocity of the SC coils. Interaction between this current and flux of the magnet, levitation force is generated. Although the EDS system has the advantage of stable levitation without active control, results of the numerical simulation show that the damping factor of the levitation system is small. So the active damper coil system has been proposed to increse damping of the system. In this paper, its effect against vertical oscillation of the bogie is shown.

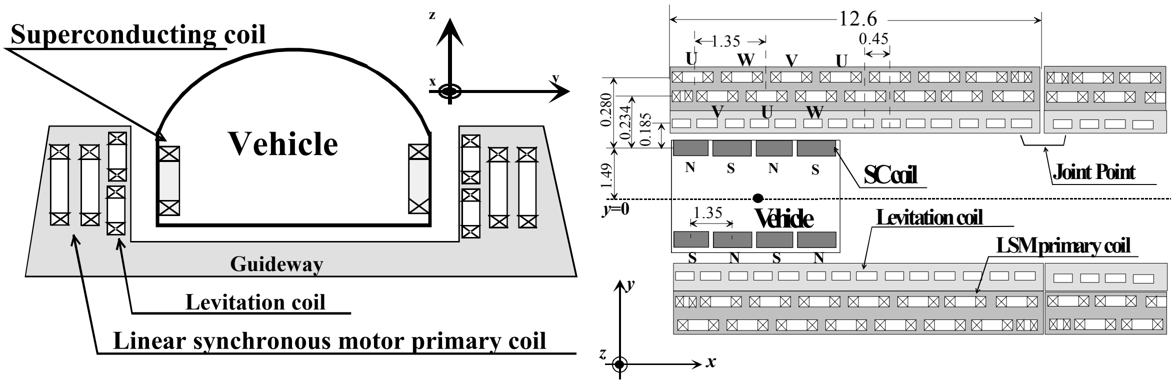

Figure 1. Superconducting magnetically levitated system

2 Analysis method

Levitation force is generated by passing the SC coils on the bogie [1][2]. Figure 2 shows principle of the levitation. The eight-figure null-flux connection is used for the levitation coil on the ground. If the bogie passes under the center of the eight-figure coils, levitation force is generated. We use virtual displacement method to calculate levitation force. Current induced in the levitation coils is calculated as follows [3]; the EDS system is given as an air-core coil system, and modeled as electric circuits. Mutual inductance between SC coils and levitation ones are calculted, and the electric circuit equations are given. Then solving the electric circuit equations, we can calculate the current of the levitation coils. The motion of the bogie is calculated by putting these electromagnetic forces. Iterating these procedures, the transient motion of the bogie is given. We use Eular method to solve differential equations. Figure 3 shows procedure for the calculation.

Figs 4 show the arrangement of the active damper coils. They are set in front of the SC coils. Two damper coils are installed for each SC coil. Same as the calculation for the levitation force, we regard the SC coils, the levitation coils and damper coils system as electric circuits. Then the current induced in the damper coils is given. As one bogie has eight SC coils, sixteen damper coils are set for one bogie. Their specifications are defined as follows; energy consumed in them is calculated when the bogie oscillates vertically for natural oscillation. The damper coils when the energy takes maximum value is defined as the optimal one. The specifications for EDS system (SC coil and levitation coil) are shown in Table 1, and that for damper coils in Table 2.

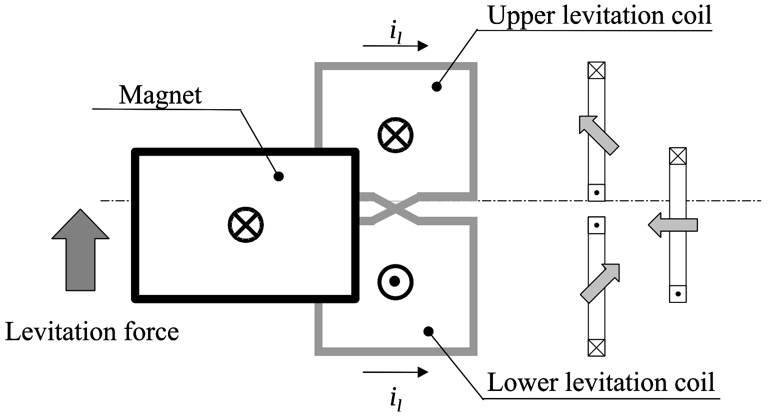

Figure 2 Principle for the levitation

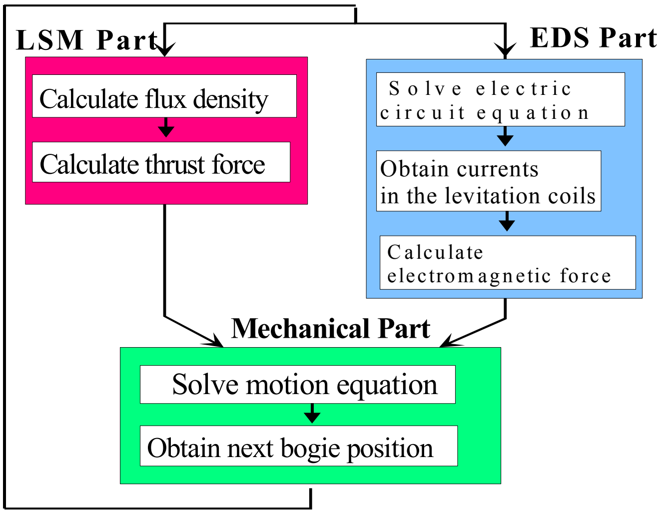

Figure 3. Procedure for the calculation

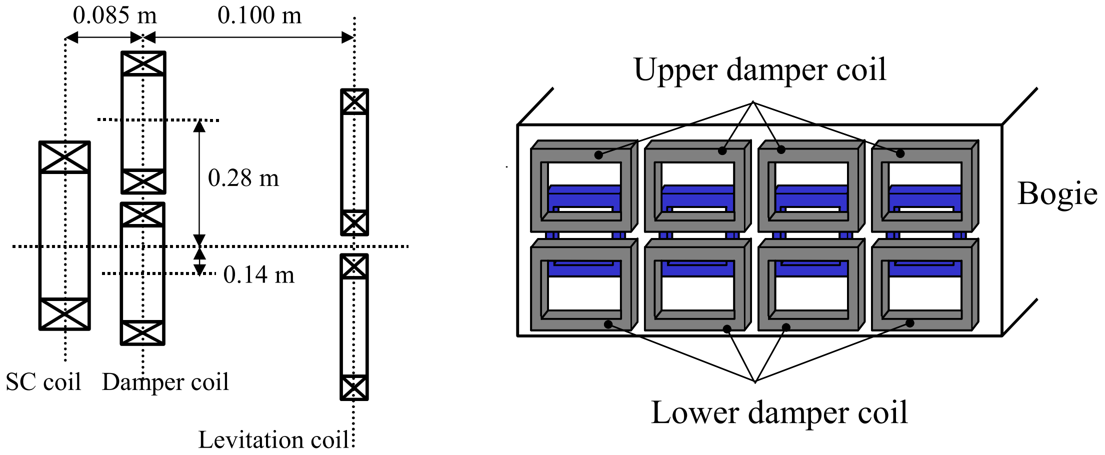

Figure 4. Arrangement of the damper coils

Table 1. Specifications for EDS system

SC coil	
Electromotive force	700 kAT
Width and Height	0.963m X 0.50m
Pitch	1.35 m
Levitation coil	
Width and Height	0.35m X 0.15m
Pitch	0.45m
Distance from SC coils	0.185m

Table 2. Specifications for the damper coils

Width and Height	1.06m X 0.40m
Turn	2
Resistivity	$1.724\mathrm{X}10^{-8}\ \Omega$ m
Self inductance	6.825 μ H
Diameter of the coil	0.05m
Distance from SC coils	0.085m
Distance from levitation coils	0.10m

3 Results

3.1 Method for the active damping

Voltage is applied on them to control oscillation of the bogie. Figs.5 show method for control against vertical oscillation. Because eight-figure connection is applied on the levitation coils, the polarity of the voltage applied on the upper damper coil is different from that of lower one. The calculated results show that the active damper coils works effectively when the voltage in proportion to the vertical acceleration of the bogie is applied [4].

$$V = -K_{az}\frac{d^2z}{dt^2} \qquad (1)$$

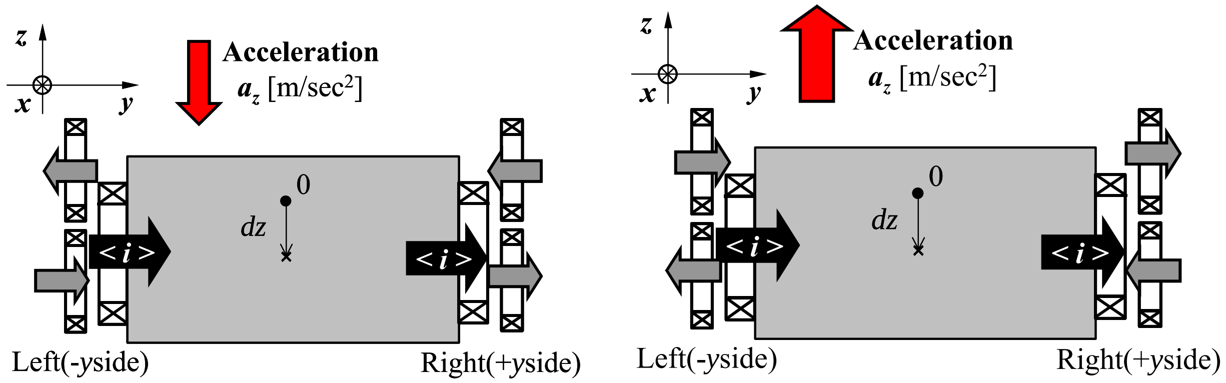

Figure 5. Method for control against the vertical oscillation

Where V is the applied voltage on the damper coils, z is the vertical position of the bogie and Kaz is coefficient.

Running simulation of the superconducting magnetically levitated bogie is undertaken. The bogie runs at constant velocity for running direction. The bogie moves freely only for vertical direction. Figure 6 shows vertical oscillation of the bogie. The results with passive damper coils and without it are shown. Interaction between weight of the bogie and levitation force causes the bogie oscillation, and center of the oscillation is about at $z = -0.04$ m where weight balances with levitation force of the EDS system. As shown in Fig.6, vertical oscillation of the bogie diffuses. So this EDS system has negative damping for vertical oscillation. Damping increases with passive damper coils and amplitude of the vertical oscillation becomes small. The damping factor c is calculated as shown in equation (2).

$$c = -\ln(A / A_0) / \Delta t \qquad (2)$$

Where A and A_0 are amplitude of the oscillation shown in Fig.7.

Polarity of the applied voltage is considered. Figure 8 shows the active damper model for vertical oscillation. The polarity of each damper coils is described $<j_{ru}>$, $<j_{rl}>$, $<j_{lu}>$ and $<j_{ll}>$ as shown in Fig. 8.

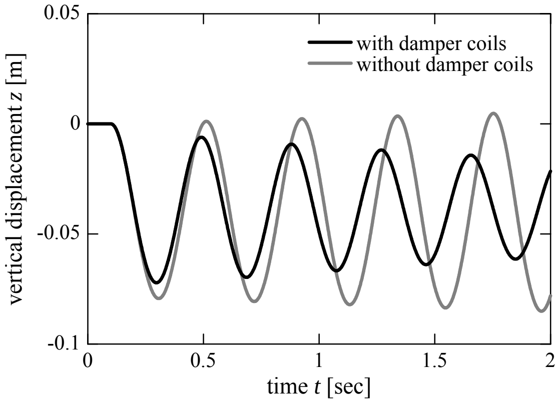

Figure 6. Vertical oscillation of the bogie

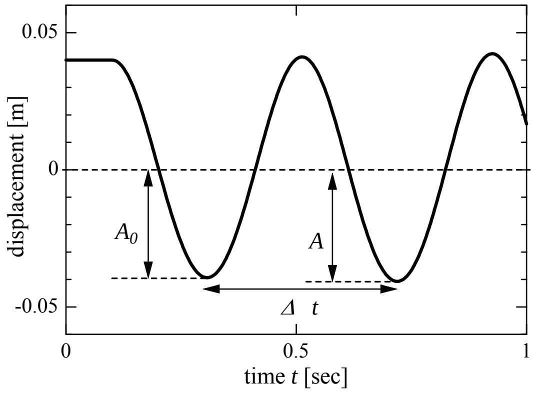

Figure 7. Calculation for damping factor

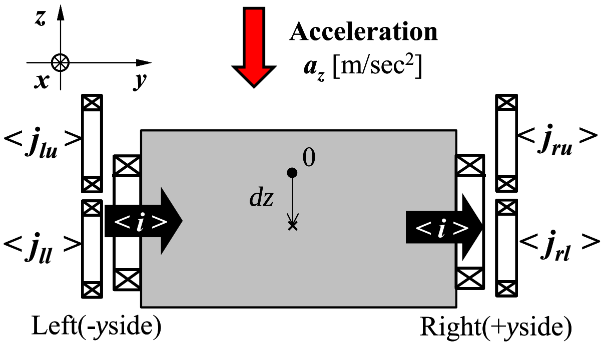

Figure 8. Model for active damper coils

Fig.9 shows dependence of coefficient Kaz on the vertical damping factor. Four polarity patterns are considered. Jz in Fig.9 means as;

$$Jz = <j_{ru}><j_{rl}><j_{lu}><j_{ll}> \qquad (3)$$

Jz=+-+- shows largest effect to increase the damping. In this pattern, polarity of the upper damper coil is different from that of lower one. Polarity of each damper coil corresponds to that of eight-figure levitation coil on the ground.

SC coil current changes its current to keep linkage flux value. As polarity of upper and lower damper coil is different, influence of the linkage flux by the active damper coils is small.

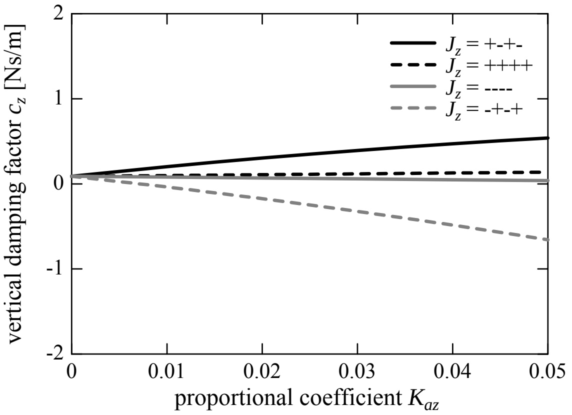

Figure 9. Dependence of the *Kaz* on the vertical damping factor

3.2 Effect of the damper coils on vertical oscillation

Figure 10 shows dependence of coefficient *Kaz* in eq.(1) on the maximum power *Wmax*. *Wmax* becomes larger at the larger *Kaz*. About 75 kW power is generated for one bogie, and 50 kW is needed for cabin facilities. Thus maximum power for the active damper coils is limited at 25 kW in this simulation. From Fig.10, *Kaz* should be less than 0.0288 to keep power capacity 25 kW for active damper coils.

Figure 11 shows dependence of *Kaz* on the vertical damping factor of the bogie. When *Kaz* becomes larger than 0.0288, the applied voltage needs more power than 25 kW.
In this simulation, if the applied voltage in eq.(1) becomes larger than 25 kW, it is set to keep 25 kW. As the power capacity is limited, optimal value of *Kaz* is confirmed. The damping takes maximum value at *Kaz*=0.271.

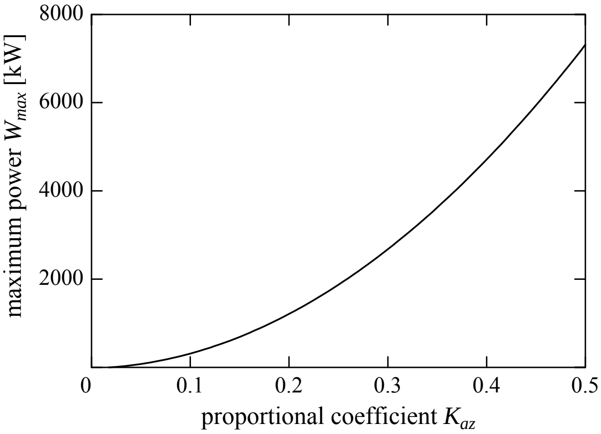

Figure 10. Dependence of the maximum power on the applied voltage

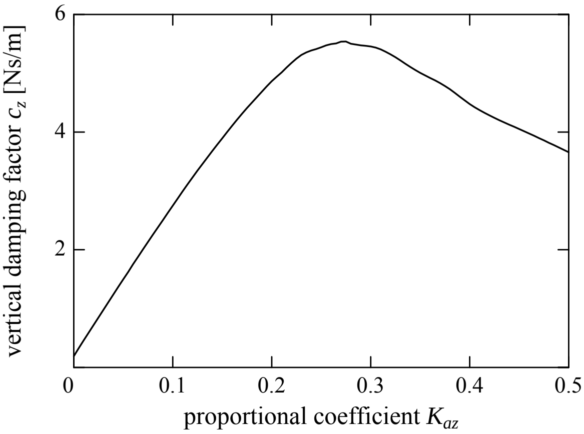

Figure 11. Dependence of the damping factor on the applied voltage

Figure 12 shows vertical oscillation of the bogie. The bogie runs for running direction x at constant velocity v=120 m/s. The initial position of the bogie is set at z=0, then moves freely. Results with *Kaz*=0.00288 which is limit for 25 kW power capacity, and 0.271 which is optimal value shown in Fig. 11, are shown. Result when *Kaz* is zero, is also shown. In this case, the damper coils are short circuited, and current is induced on the damper coils by levitation coil current on the ground. As a result, they work as passive damper coils. As damper coil has damping without applying voltage, oscillation of the bogie decreases even at *Kaz*=0. Large effect is observed at *Kaz*=0.271 where damping becomes largest in Fig.11. Figure 13 shows power for the active damper coils. Because of the limitation of the power for the active damper coils, maximum power is limited at 25 kW.

As current is induced in the damper coils, drag force against running direction becomes large. It causes engrgy loss for propulsion system. Although its influence is small, damper coil system should be separated when oscillation of the bogie does not happen.

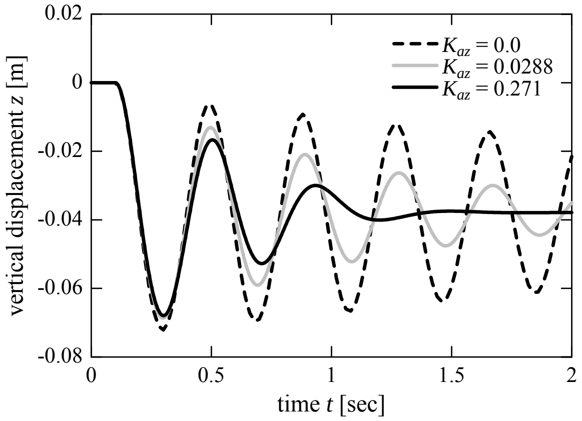

Figure 12. Vertical oscillation of the bogie with active damper coils

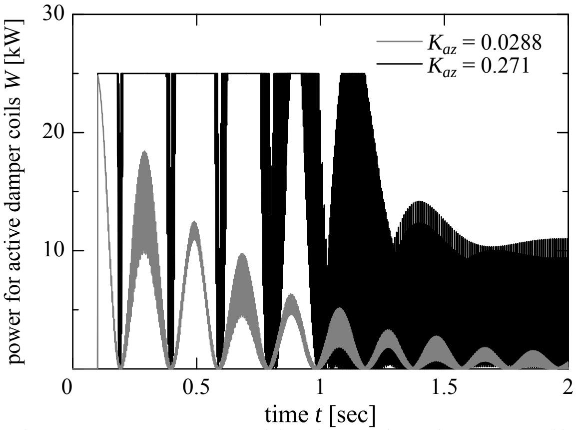

Figure 13. Power used in the active damper coils

4 Conclusion

Numerical analysis of the superconducting magnetically levitated bogie is undertaken. To increase the vertical damping of the system, active damper coil system is introduced. Effect of the active damper coil system on the vertical oscillation of the bogie is discussed. The limitation of the power for the active damper coils is considered, and optimal voltage applied on the active damper coils is given. The active damper coil system restrains vertical oscillation and damping factor becomes large. Effect of the active damper on the lateral oscillation and rotational oscillation will be studied for further research.

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6 References

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