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Control System Designed for Electromagnetic Suspension of High-Speed Vacuum Transportation

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Abstract

The given article presents the control system designed for electromagnetic suspension of the high-speed vacuum transportation. The simulation results have proved that the proposed control system allows us to achieve the stable levitation of the vehicle in the entire speed range under the minimal power consumption to ensure the levitation for the high-speed vehicle.

Keywords: high-speed vacuum transportation, magnetic levitation, control system, electromagnetic levitation, computer model, Matlab/Simulink

INTRODUCTION

With magnetic suspension, the gap clearance varies in a wide range and with high frequency [1] which requires the high-speed control to regulate the air-gap. The article [2] considers three types of the control system: PI-controller, hybrid controller and a controller based on the fuzzy logic. The hybrid controller and fuzzy logic controller show quite good efficiency. At the same time, the hybrid controller is based on the logic which, in case of the high gap error signals, uses a P- controller having different amplification factor; for its activation the threshold value of 2 mm is set. Therefore, the higher the air-gap error signals, the higher the factors in the controller.

The present article considers the controller design based on the quadratic dependence on the gap change, it means that, the control value will be generated based on the squared value of the gap error signal.

The electromagnetic suspension system is unstable and so it requires the constant operation of the control system. It should be taken into account that the greater the deviation from the set value, the faster the corrective action is to be taken.

Thus, it seems effective to develop a controller based on the squared value of the gap error signal.

The parabola equation (fig.1, curve 1) is the following:

$$\mathrm{y} = \mathrm{k}(\Delta \mathrm{z})^2 \tag{1}$$

where k – coefficient; Δz – air gap error signal.

In the system under consideration, it is necessary to take into account the sign of the signal error, and then the equation for the system will have the following form:

$$\mathrm{y} = \mathrm{k}(\Delta \mathrm{z})^2 \cdot \mathrm{zign}(\Delta \mathrm{z}) \tag{2}$$

The result is shown in figure 1, curve 2.

The disadvantage of this equation from the control point of view is the fact that when the deviation is little (near zero), the error amplification factor will drop almost to zero. In this case, the system is not able to process little deviations in a proper way.

To eliminate the above disadvantage, it needs to shift the parabola equation relatively to Δz and y to the value dz. Thus, we can get the graph shown in figure 1, curve 3 and the equation will be:

$$\mathrm{y} = \mathrm{k}(\Delta \mathrm{z} + \mathrm{dz})^2 \cdot \mathrm{zign}(\Delta \mathrm{z} + \mathrm{dz}) - \mathrm{kdz}^2 \tag{3}$$

Applying the above equation at the input of the PID – controller, it is possible to obtain the stable lifting and levitation of the vehicle. However, in this case there is an unequal control at the positive and negative error value. In some cases, this property can be used, but to regulate the levitation the control should be equal.

For this purpose, we change the equation to get the curve 4 shown in figure 1.

The equation will be the following:

$$\mathrm{y} = |\mathrm{k}(\Delta \mathrm{z} + \mathrm{dz} \cdot \mathrm{zign}(\Delta \mathrm{z}))^2 - \mathrm{kdz}^2| \cdot \mathrm{zign}(\Delta \mathrm{z}) \tag{4}$$

Thus, we have managed to realize the nonlinear dependence of the control action magnitude on the error magnitude, which is especially important for unstable systems.

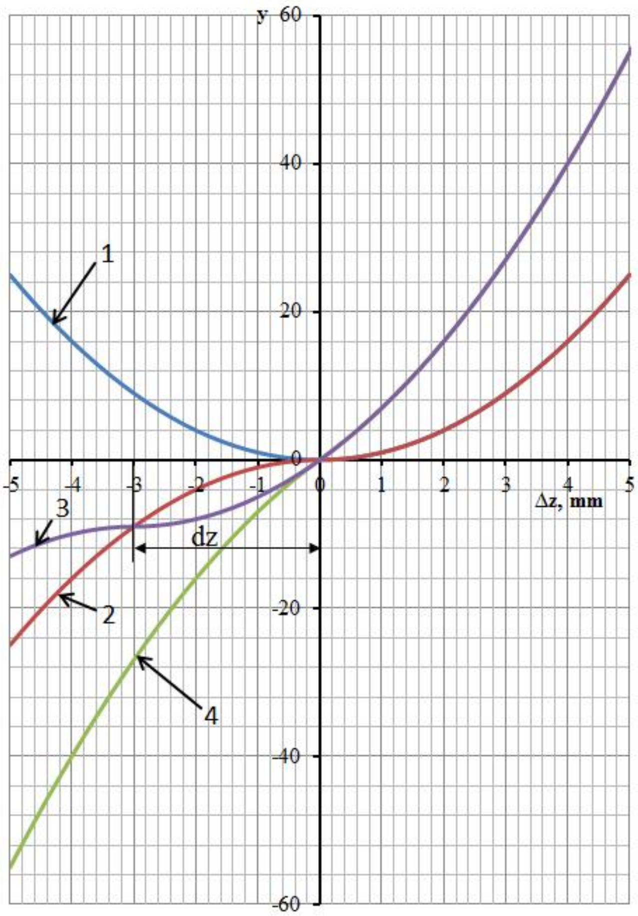

Figure 1. Generation of the gap error quadratic dependence

The control system functional diagram, developed on the basis of the above equation, is presented in figure 2.

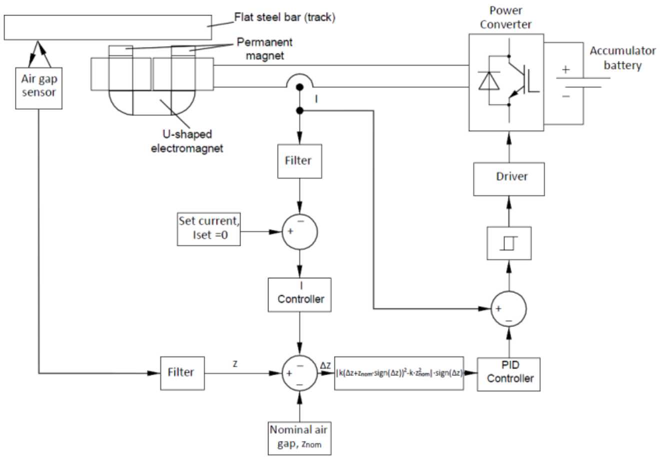

Figure 2. The control system functional diagram

The control system operation algorithm is described as follows. The signal from the air gap sensor goes through the filter to the comparison unit with a nominal gap value; Δz error value goes to the unit generating the quadratic dependence of the error signal, then the dependence obtained goes to the PID-controller. The PID-controller generates the current set value that is subtracted from the magnitude of the current flowing through the coils of the U-shaped electromagnet. The obtained value is fed to the hysteresis unit to form a current corridor. The driver provides communication between the control system and the power converter. To reduce the power consumption, there is a current controller that is designed to maintain an average current value equal to zero. To do this, the current value flowing through the coils of the U-shaped electromagnet goes to the filter, and then to the comparison unit with a set current value equal to zero; the received signal is fed to the integrated controller, which generates the value of the air gap shift, which is also fed to the comparison unit with a nominal gap value.

RESULTS

In order to check the decisions taken, the control system computer model has been developed in MATLAB/Simulink software. The description of the computer model of the electromagnetic suspension is given in [4].

The present work considers the «Control System» unit which structure is demonstrated in figure 3.

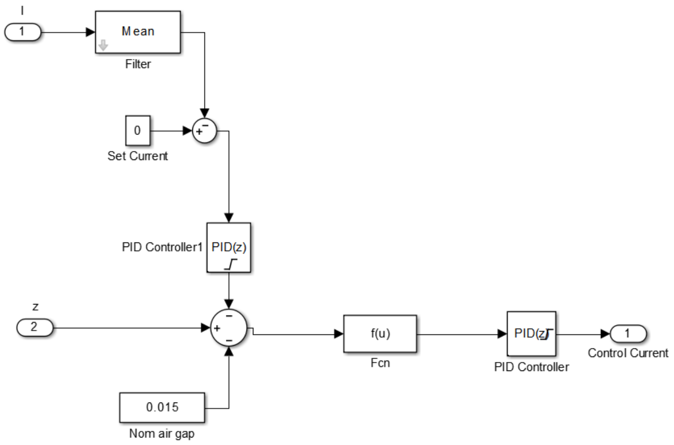

Figure 3. «Control System» Unit

The Control System unit has been designed in accordance with the control system functional diagram, shown in figure 2. The standard units were used as PID-controllers. The generation of the gap error quadratic dependency was performed with Fcn unit, where the equation given in formula 4 is indicated.

The simulation was performed for the vehicle weighing 600 kg. Figure 4 demonstrates oscillograms for a single electromagnetic module of the suspension.

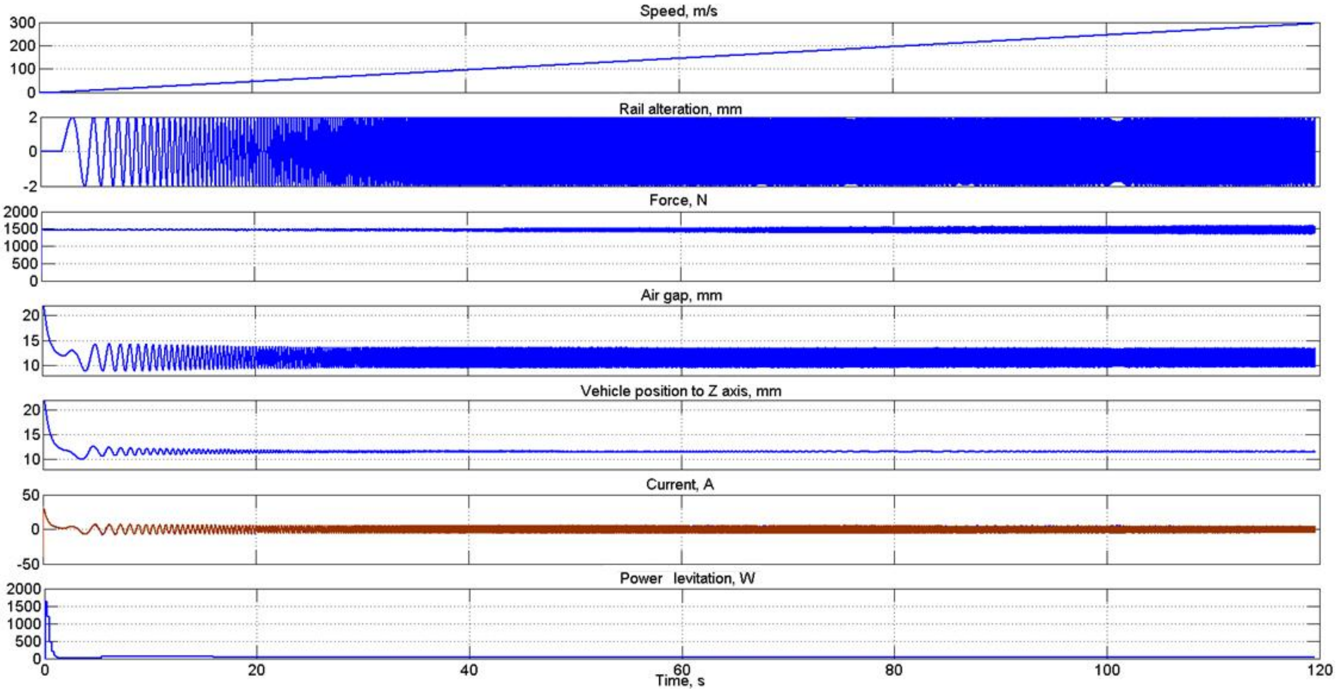

Figure 4. Simulation results

The initial air-gap is 22 mm. During the first two seconds, the vehicle is lifted and a nominal working gap of 12 mm is set. At the time point of 2 sec, the vehicle starts to accelerate.

To simulate the electromagnetic suspension, acceleration of 2.5 m/s^2 is accepted. It is assumed that the suspension rails of 30 meters long are sagged by 4 mm, which is represented by a sinusoidal signal (Rail alteration) with amplitude of 2 mm. The frequency of the air gap change increases in proportion to the speed. Figure 4 shows that the size of the air gap changes in the same way as the rails deviation. In this case, the position of the vehicle in the space along Z axis is practically unchanged, due to the system inertness. The amplitude value of the electromagnet current of the suspension was 5 A. When lifting the vehicle, the power consumption of a single electromagnet was 1600 W per one electromagnet, and when driving the power was about 50 W per one electromagnet.

CONCLUSION

Therefore, the control system proposed in this work, which was developed on the basis of the air-gap error quadratic dependence of the electromagnetic suspension for the PID-controller, has shown the stable operation of the suspension in the entire speed range, with account of rails unevenness. The power, required to suspend a vehicle weighing 600 kg when traveling at a speed of 278 m/s (1000 km/h), was slightly more than 200 W, which fully meets with the requirements for a vacuum high-speed vehicle.

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