Application of Power Amplifier OPA544 in Active Magnetic Bearing Control System

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Abstract: Adopt device power amplifier OPA544 to amplify the output load current in order to achieve the system's current increase. According to the completed mechanical analysis and the design of this specific active magnetic system, the controlling model was designed and a PID controlling strategy was selected to achieve a system simulation utilizing the whole module’s parameters. To control the suspension, a PID controlling circuit was designed to attain the full current necessary for maintaining lift. The use of two electronic OPA544 chips allows for push-pull power amplifier control, achieving the establishment of active magnetic plate dynamic equilibrium, as well as better system stability. Experimental data from the study supported the simulation. The system designed represents a practical model based on experimental data. These methods could be used as a reference for power amplifier component selection among similar systems.

Keywords: PID Control, Magnetic Bearing, Power Amplifier

Introduction

The relatively slow paced development of magnetic levitation systems in China illustrates the need for high technology practical solutions. Using a model capable of controlling multiple degrees of freedom applications make sense for the magnetic levitation manufacturing industry [1].

The typical model of magnetic suspension platform control systems uses the single degree of freedom as the principle application because of the lower precision requirements. The platform control model can be versatile, manipulating space control for single or multiple degrees of freedom mechanics. The experimental control system structure is simply sending the analog input signal through the PID circuit or other control conditioning circuit, then through the power amplifier which outputs the load current. Regardless of signal conditioning means, either analog control or digital control, power amplifier output signal remains analog current, which is necessary for the realization of complex control strategies.

In this paper, a power amplifier component OPA544 was used in the platform control system of a single degree of freedom. The power amplifier requires linearity distortion-free amplified signal, and low heat production component OPA544 meets these needs and provides fast response time for the platform system. According to the simulation and experimental data, the power amplifier OPA544 was able to achieve the single degree of freedom magnetic suspension control system. For verifying the OPA544 operational features, the control process had to be simplified, using the PID control strategy for testing purposes.

Suspension Platform System Model

Mathematical Suspension Platform System Model. Fig. 1 shows the shape of the solid plate model. In the center of the plate, a wedge-shaped beam supported the iron plate, and balanced the effect of gravity. Each side of the plate is a solenoid coil with the air gap between electromagnets and the plate. Output current ranges according to the electromagnetic force variation. The expectation upon achieving suspension was to make the platform's bottom surface parallel to the coil core.

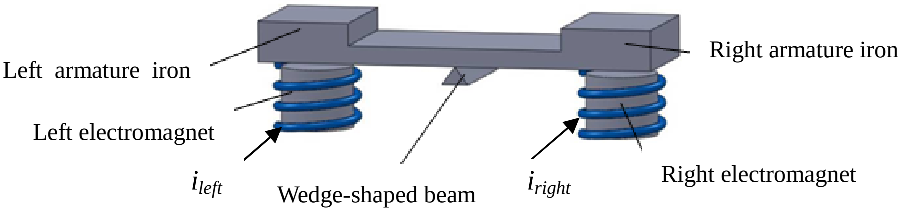


Fig. 1. Three-D outside view of the model

Force analysis on the plate model and mathematical reasoning has shown that the relationship between signal input and output corresponded with the air gap position △x and the sensor's voltage output △u for the model system in Eq.1:

$$\frac{\Delta x(s)}{\Delta u(s)} = \frac{\dfrac{k_i}{mL_0}}{S^3 + \dfrac{R}{L_0}S^2 - \dfrac{Rk_x}{mL_0}} \tag{1}$$

The system was simplified to a second-order system; its transfer function characteristic equation was a second-order system:

$$m\ddot{x} = k_x x(t) - k_i i(t) + f_d(t) \tag{2}$$

Physical parameters for the suspension platform system were below. The magnetic bias current was $1A$, air gap in equilibrium was $1.17 \times 10^{-3} m$, the cross-sectional area of the magnetic poles was $8 \times 10^{-4} m$, the number of turns in the coil was 480, and the moment of inertia was $0.232 kg \cdot m^2$ of the plate. As for the designed cut-off frequency for the PID control system, the power amplifier system should set up the minimum cut-off frequency with $5000 HZ$ .The static calibration sensitivity of current vortex sensor was $8000V/m$ and the linear working ranges from $-2V$ to $-12V$. Through measurement, it was known that the parameters of platform system's characteristic equation were the corresponding displacement stiffness coefficient $k_x = 3615 N/m$ and the current stiffness coefficient $k_x = 4230 A/m$ [4].

Controller Designing. When designing a controller based on the analysis above，the PID system can be designed to adjust the proportional gain control in series, with the shunt circuit of differential circuit and integral circuit, shown in Fig. 4. In the PID control circuit, the maximum integral time constant was $T_{i\max} = 25s$; minimum integral time constant was $T_{i\min} = 2.5 \times 10^{-3} s$;the differential inertia constant was $\varepsilon = 0.02$, the maximum leading phase angle of the differential circuit was $\phi_c = 74^\circ$;thus the differential part can make the system respond quickly. Differential time constant was 0.5 milliseconds, and could overcome integration time lag caused by the long recovery process, thus shortening the regulating time.

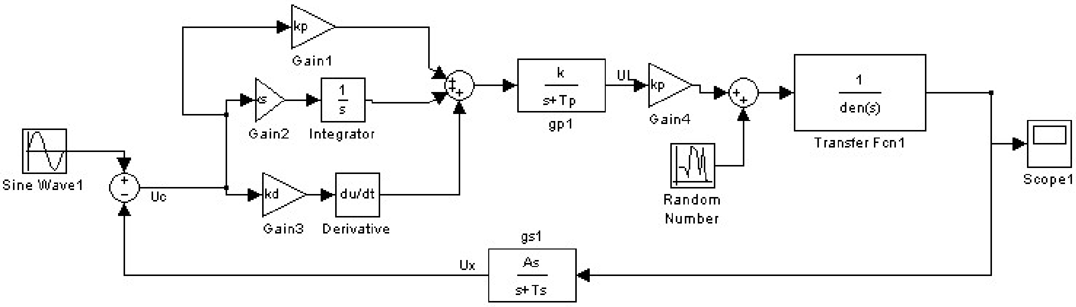


Fig.2. Closed-loop control block diagram

Simulation and Experimental Results

Both Simulation and actual experiments selected two OPA544 chips for the bipolar power amplifier circuit. As the system applied push-pull control mode to adjust the alternating current, the signal oscillated in the vicinity of the bias current. This control strategy forced the current in the controller to flow in the vicinity of the bias current so as to avoid inverse flow. This was demonstrated from the control principle that the current item varies strictly monotone with the electromagnetic force, despite the squared current in the mathematical equation relationship; in other words, the bias current limited current fluctuates in the local area, not across the zero current coordinate. Therefore, the design allowed for the magnetic field to be extremely stable with neither excessive force nor insufficient force resulting in system crashes [3].

Fig. 2 showed the closed-loop simulation module, and the analog circuit of the power amplifier was shown in Fig. 3. The prime amplifier circuit of PID outputted signals for this circuit, as well as additional control designing was according to the magnification coefficient 0.5 and bias current $I_0 = 1A$. It was simulated through well-known software-MULTISIM with amplitude of the AC voltage $0.5V$. Fig. 4 indicated the simulation results, and the AC input signal was a sine wave. It showed that waveforms featured distortion-free amplification.

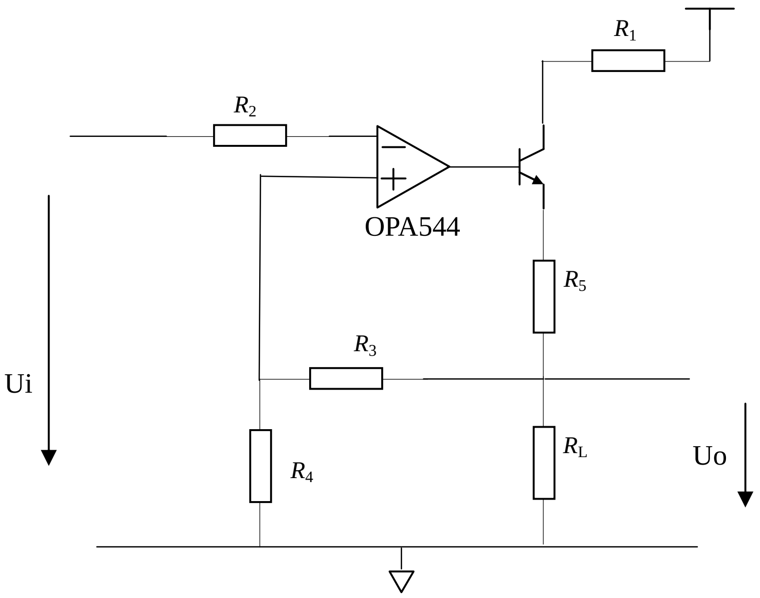


Fig.3. Power amplifier circuit

Circuit simulation verified the correctness of the system's model, and the structure shown in Fig. 2 was established following this. In terms of real platform, 4 paralleled solenoid was fixed around the magnetic iron core, equivalently quadruple the current generated by electromagnetic force; the supply voltage for OPA544 was $24V$. Resistance of winding was measured $R_{left} = 1.15\Omega$, $R_{right} = 0.98\Omega$ (Inductance is neglected due to the comparison with resistance $L_{left} = 10.82mH$, $L_{right} = 9.53mH$), the load voltage respectively was $v_{left} = 117.5mV$, $v_{right} = -121.5mV$,although the two parameters did not exactly equal each other, the error was tolerant, because they ranged within accuracy requirements. After observation of actual platform operation, serious oscillation occurred. Resistance values were then recalculated according to the stability of domain and facilitated fine adjustments. The appropriate value of resistance finally reduced the proportional gain coefficient and decreased plate vibration. Fine-turning can be done to gain a very stable and long-lasting suspension. There was a note that the center pivot of the fixed point should be adjusted to an appropriate location, so as to avoid the impact of mechanical friction in the flat-plate system. This adjustment would minimize such amplitude swing-effect and prevent cutting down

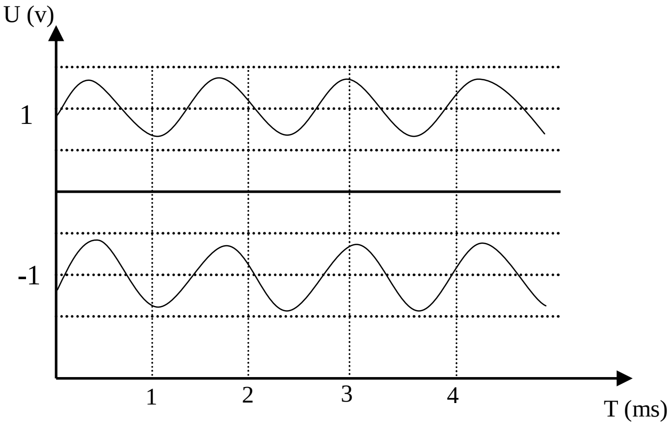


Fig.4.Simulation results

high-sensitivity of the plate mechanical respond. Owing to the physical parameter difference of the electromagnet system, the measured average load currents respectively were

$i_{leftt} = -0.65A$ and $i_{right} = -0.9A$.

The results above demonstrated OPA544 had the ability to complete system amplification, the response speed was within tolerance, and output current was about $1A$, satisfying the system. The following considerations were made based on further analysis of test results on the system:

Consider the one-way conductivity of diodes, the results were far from perfect.

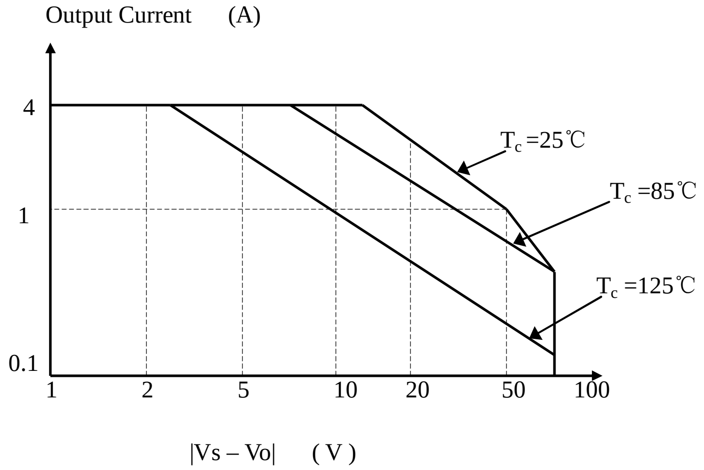


Fig.5. Safe operating area

The amplifier's working curve was taken into account, as shown in Fig. 5. Due to circuit design constraints, namely, the safe operation areas, tip41 device’s properties required that the transistor's base output voltage should not exceed $2V$, which was under the maximum output current of power amplifier OPA544. Otherwise the transistor would break down. Concerning OPA544 operation, based on the assumption that the lowest absolute value of the power supply input $15V$ would be taken and the output voltage requirement was not more than $2V$, the corresponding output load voltage was about $0.8V$ in the curve, when $T_C = 125℃$； When the heat distribution was quite good ($T_C = 85℃$), the output voltage was about $2A$, which nearly exceeded the output voltage limitation. If the heat distribution was extremely satisfactory ($T_C = 25℃$), then the output current was 4A, which was not an allowed output current.

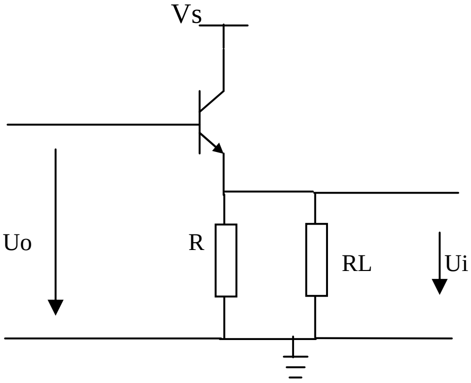


Fig.6. Grounded emitter amplification circuit

The analysis of the results indicated the design contradiction. In practice, therefore, the output can only be about $0.8V$. The requirements for high load current cannot be achieved, which limited the high load control of active magnetic bearing systems [2].

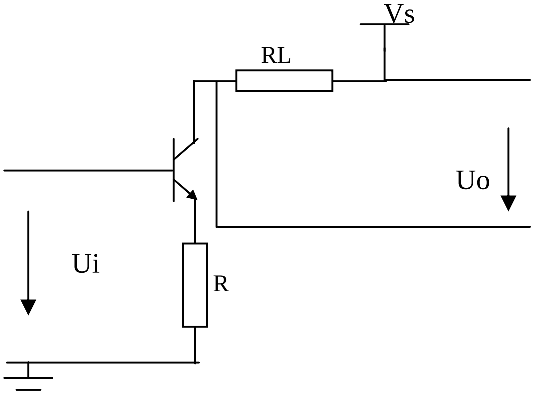


Fig.7. Emitter follower circuit

To view the output of the power amplifier directly linking to the transistor's base and the transistor's collector connected with the load, the connection in Fig. 6 was changed, as shown in Fig. 7. The compared grounded emitter amplification circuit is shown in Fig. 6. The emitter follower circuit can achieve the load current increases，but got an unsatisfactory load curve[5]. Simulation of the Emitter follower circuit in Fig. 8 showed that output distortion of channel 2, cannot realize the two direct controls on condition that the DC bias for the model ranged from $1.2V$ to $1.8V$. Peak to peak AC voltage varied between 0 ~ $0.7V$; the signal of channel 1 was input voltage, as shown in the Fig. 8.

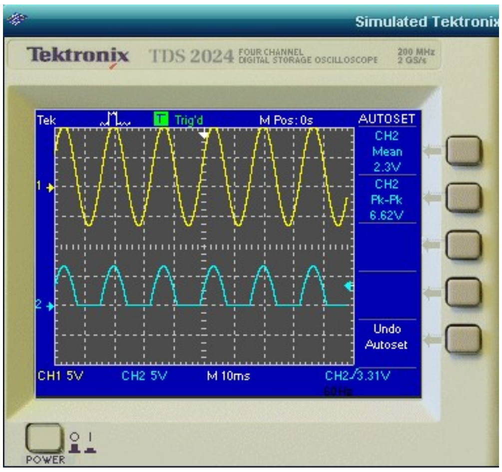
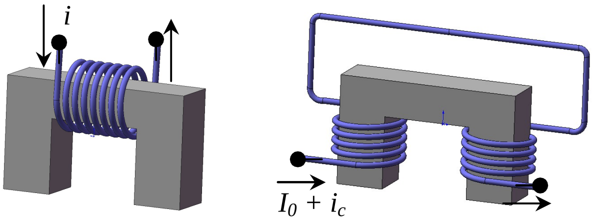


Fig.8. Simulation of emitter follower circuit

Conclusions

Based on the analysis, the power amplifier OPA544 in the suspension control system was suitable for models with small current and two-direction control [4].



(1) Prototype (2) Improved type

Fig.9. Superimposed current model

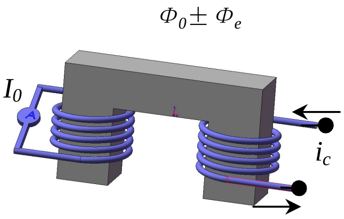


Fig.10. Superimposed magnetic field model

Generally speaking, there were three types of magnetic amplifier models. Two types were the prototype; type (1) was not frequently used. Type (2) was the improved type. See Fig. 9. The other one was the superimposed magnetic field type. See Fig. 10. The former two types featured the single-coil structure and the power amplifier output current needed a biased signal. Also there was zero tolerance for current inversion, which made the bias current necessary. However, the designed plate system was in accordance with type (2), where the slight variation near the set bias value weakened the operation of OPA544. Therefore, OPA544 was suitable for the superimposed magnetic field model, and large amplitude for load current output can be achieved [5].

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