

Design of the Displacement Detection System for Magnetic Bearing

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Abstract: A displacement detection system for magnetic bearing based on DSP (Digital Signal Processor) was designed. Target against some problems in measurement method of the rotor displacement, such as generating many displacement detection signals, occupying many A/D input ports and increasing the calculation load of DSP, a novel simple hardware circuit was designed, and an anti-aliasing filter circuit was equipped, which can solve the problem of signals aliasing, and improve the anti-interference capacity of the system. In addition, a temperature compensation method based on the software was put forward to eliminate the temperature drift of displacement sensors. Finally, the effectiveness and reliability of the displacement detection system were verified in the experiment.

Keywords: magnetic bearing; displacement detection; anti-aliasing filter circuit

1 Introduction

Magnetic Bearing (MB) is different from common mechanical bearing. High rotation speed can be achieved, because the magnetic field that stator windings provide can produce the radial force to suspend the rotor^{[1][2]}. The rotor of MB will deviate from the balance position, when suffered from an external interference. In order to achieve a stable suspension, the position of the rotor should be controlled in a closed-loop system. The rotor displacement signals are the basic foundation for such system. So a high precise detection system is much more significant for MB.

2 Structure of the detection system for MB

The structure principle diagram of detection system is shown as Figure.1 (QH8500 Eddy Current Displacement Sensors are adopted). The detection signals of sensors are sent into the judgment circuit of displacement direction, voltage adjustment circuit, filter circuit and DSP in sequence. Temperature sensors are also adopted to detect temperature near the displacement sensors, so to compensate the influence of temperature.



Figure.1 Structure diagram of displacement detection system

3 Hardware design

3.1 Judgment and adjustment circuits

A differential measurement method that can decrease radial displacement coupling is adopted here, so there are totally nine sensors (four in x direction, four in y direction and one in axial direction)^[3]. In order to save the I/O ports and improve the operating speed, a new simple hardware circuit is designed to calculate the variable displacement of the rotor, judge the moving direction, combine two displacement signals of differential measurement into one signal and process it.



Figure.2 shows the displacements of eccentric rotor.

When the rotor is in a balance state (as the dashed line in Figure.2), displacement sensors are just in the linear middle point of its measuring range. Under such a





Figure.3 Output voltages of displacement sensors

condition, the output voltage is presumed as U. Figure.3 shows the corresponding output voltage of displacement sensors.

When the rotor moves to the position of x' and x" along x-axis, the displacement of rotor along x-axis is $\Delta x'$ and $\Delta x''$, and the corresponding output voltage of displacement sensors is U'_x and U''_x .

According to the geometric relation in Fig.3, suppose R is the radius of the rotor, then:

$$\begin{cases} \Delta x = \Delta x' + R - \sqrt{R^2 - \Delta y^2} \\ \Delta x + R - \Delta x'' = \sqrt{R^2 - \Delta y^2} \end{cases}$$

The displacement variable value in the center of the rotor and the corresponding voltage are:

$$\Delta \mathbf{x} = \frac{1}{2} (\Delta \mathbf{x}' + \Delta \mathbf{x}'')$$
$$\Delta \mathbf{U} = \frac{1}{2} (\Delta \mathbf{U}'_{\mathbf{x}} + \Delta \mathbf{U}''_{\mathbf{x}}) = \frac{1}{2} (\mathbf{U}''_{\mathbf{x}} - \mathbf{U}'_{\mathbf{x}})$$
(1)

The output voltage range of displacement sensor QH8500 is from -2 to -18V, and assuming that the right direction of x-axis is the positive direction, then it can obtain ΔU <0 from Eq.(1), vice versa ΔU >0. In the same way, the rotor displacement direction along y-axis can also be judged.

Two differential signals on x-axis or on y-axis can be calculated by the circuit shown in Figure.4:



Figure.4 Displacement calculation Circuit

In Figure.4, if R_2/R_1 is equal to R_3/R_2 , U_3 can be expressed as:

$$U_{3} = \frac{R_{4}}{R_{3}} (U_{2} - U_{1})$$
 (2)

Where, U_1 and U_2 are output voltage values of the displacement sensors, and U_3 can be adjusted by changing the resistance values.

The allowable input voltage of DSP (TMS320L F2407) is from 0V to 3.3V, so a voltage adjusting circuit is needed, which is shown as Figure.5.



Figure.5 Voltage adjusting circuit

In Figure 5, U_0 can be derived as:

$$U_{0} = R_{11} \left(\frac{R_{7} U_{ref}}{R_{8} R_{5}} - \frac{U_{3}}{R_{10}} \right)$$
(3)

 U_0 can be directly sent to DSP, and the required voltage range (from 0V to 3.3V) can be obtained by choosing the proper resistance values according to Equation.(2) and Equation.(3). In the same way, the situation on y-axis can also be solved.

3.2 Anti-aliasing filter circuit

In order to avoid the signal spectrum aliasing, an anti-aliasing filter is added between the voltage adjusting circuit and DSP.

Rotational speed of the rotor for a MB in this paper is 20000r/min, and sampling frequency is ten times than the basic frequency of rotation speed. Sampling frequency is 3.3KHz, and cutoff frequency of passband is 1.65KHz.

In order to avoid the influence of the filter on the cutoff frequency signal, the filter performance indexes are as follows: cutoff frequency of passband is $f_c=1.65$ KHz, and attenuation is $\delta_c \leq 3$ dB, frequency of stopband initial point is $f_z=3.3$ KHz, and attenuation $\delta_z \geq 30$ dB. The ex-



ponent number n can be calculated by Equation. $(4)^{[4]}$:

$$n \ge lg \left[\left(10^{0.1\delta_{z}} - 1 \right) / \left(10^{0.1\delta_{c}} - 1 \right) \right] / \left(2 lg f_{z} / f_{c} \right)$$
(4)

Substituting f_c , δ_c , f_z and δ_z into Eq.(4), we can obtain: n = 5.

MAX7414 filter is used in this paper. When the external clock is adopted, the ratio of the external clock frequency (f_{clk}) to cutoff frequency (f_c) is 100:1. In order to obtain the needed clock frequency (f_{clk}), 40MHz clock signal of DSP is divided by 74HC4040 frequency divider, so the filter can work at the cutoff frequency $f_{clk}/100$.

The anti-aliasing filter circuit designed here is shown in Fig.6, and the amplitude-frequency characteristic of the filter is shown in Figure.7. According to Figure.7, the frequency over 1650Hz is obviously decreased.



Figure.6 Anti-aliasing filter circuit



Fig.7 Amplitude-frequency characteristic of the filter

3.3 Temperature compensation

MB will generate much heat when working, which will increase the temperature around displacement sensors. The high temperature may increase the coil resistance, and affect the detection accuracy ^[5]. Therefore, a temperature compensation algorithm based on DSP is

adopted here. The process of temperature compensation is as follows: The output voltages under different temperatures are confirmed in the experiments, and stored in DSP beforehand. When the output signal U_0 of displacement detection system at T[°]C is transferred into DSP, then DSP read the temperature measurement valve T from temperature sensors DS18B20, and look up the data stored, finally, amend the corresponding measurement values, thus the temperature compensation is achieved.

4 Experiments

The output voltage U_0 can be measured using high-precision digital voltmeters, each time when the rotor is moved by a self-designed device which can record the displacements moved. The theoretical values of U_0 can be calculated from such actual displacements using Equation.(3), and the experimental results of U_0 are shown in Figure.7.



Figure.8 Experimental result of U₀

It can be analyzed from Fig.8 that the maximum error of U_0 comparing with theoretical value is about 2.5%. Generally, the displacement range of the rotor is less than 0.01mm, so the higher accuracy can be obtained by choosing a measurement range of better linearity. For example, if a measurement range of 0.01mm near to the point of 1.25mm in Fig.8, the maximum error of U_0 can be reduced to about 0.2%.

5 Conclusion

The rotor displacement detection system for MB can save A/D input ports of DSP, eliminate the signal aliasing during sampling, and solve the temperature drift of displacement sensors. The effect is satisfactory in the experiments.



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