

The Research of a Differential Magnetoresistive Linear Displacement Sensor Measurement System

Jianhui ZHU, Siqin CHANG, Jianguo DAI

School of Mechanical Engineering, Nanjing University of Science and Technology,
Nanjing 210094, China

Tel./fax: +86-25-84315451

E-mail: changsq@njjust.edu.cn

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Abstract: For a single magnetic resistance displacement sensor is used for detecting the linear displacement of electromagnetic linear actuator (ELA), and the decline of detection precision caused by strong electromagnetic interference, and the problem of low control accuracy etc., a scheme of the dual differential magnetoresistive is proposed. The sensors with respect to the basis magnet about layout electromagnetic interference signal makes the output signal have a pair of opposite signal at initial position. The two signals of magnetoresistive sensor are added so as to improve the signal amplitude, and at the same time interference quantity could decrease after the two reverse signal summation of output interference magnetic field on the sensor. The feasibility of scheme is tested and verified by simulation with the use of Ansoft software to simulate the change of environmental magnetic field. The test results show that the disturb is effectively inhibited with the use of differential scheme in this paper, the signal amplitude is increased by two times, the accuracy and resolution is improved.
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Keywords: Displacement sensor, Magnetic resistance, Electromagnetic interference, Linear displacement.

1. Introduction

The perception of location and measurement is an indispensable course for linear actuator motion control process [1–3]. Displacement feedback to the control system is the key factor to achieve the precise control of movement [4, 5]. Therefore it put forward higher requirements on the displacement sensor. While as a non-contact magnetoresistive sensor, because of its unique advantages, small size, high precision, non-contact, long service life, wide measuring range, it is widely used in various industries [6, 7], such as, gear speed [8], compass technology [9, 10], permanent-magnet synchronism motor (PMSM) [11], pneumatic drive [12] and microfabricated spin-valve [13]. Magnetic resistance

displacement sensor transforms the variation of the magnetic field angle into linear displacement. It can be used for angle displacement measurement and detection of linear displacement [14–16]. But when applied to complex industrial environment and because of the interference by external stray magnetic fields, especially the electromagnetic interference. It results in precision decrease, and the output instability [17–19]. In the actual detection of electromagnetic linear actuator displacement (As shown in Fig. 1), and at the initial moment of actuator loading current. The interference of external magnetic field causes a big error to the output of the sensor output. So how to eliminate the error generated at this time has become a problem to be solved in the application of magnetoresistive sensor.

In this paper, it is based on a magnetoresistive sensor chip, and on the analysis of the magnetoresistive principle, with the use of Ansoft software to simulate and calculate for the best layout area of magnetic steel, a differential scheme is presented for the elimination of electromagnetic interference on measurement results. It achieves the precise control of linear displacement, and increases signal amplitude and resolution ratio while restrain interference.

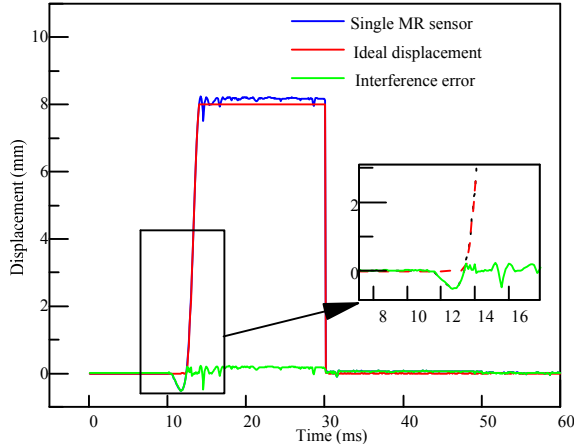


Fig. 1. Interference in displacement detecting.

2. Principle of Reluctance Type Displacement Sensor

2.1. Magnetoresistance and Differential Reluctance Principle

Magnetoresistive effect refers to the phenomena of anisotropic magnetoresistance (AMR) in ferromagnetic material changes with the external magnetic field. Using magnetoresistance effect to make up Wheatstone bridge (As shown in Fig. 2), When applying a bias magnetic field on a bridge, it makes the magnetization of all resistance and electric current have the change of the included angle of about 45° . The change of orthogonal magnetic field direction makes the two resistors in the two diagonal increase ΔR , while the two reverse placed resistors decreases ΔR , so bridge loses balance, and generates a voltage signal output. Thus it can calculate the corresponding linear displacement.

According to magnetoresistive principle in case of the magnetic field without interference, the sensor output is:

$$V_{out} = K \times V_s \times S \times \sin 2\theta \quad (1)$$

In the equation above, V_s is the sensor supply voltage, θ is the angle between the direction of the external magnetic field and current in the sensor, K is the internal amplifiers' gain of sensor, S is the material parameter.

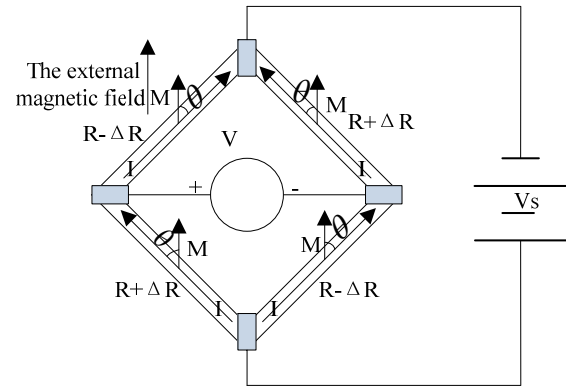


Fig. 2. Diagram of magnetoresistive sensor.

The structure of differential inductance sensor designed in this paper is represented in Fig. 3. The presence of magnetic field interference makes the magnetic field generate a deflection angle at the initial position. The relative sensor A is $+\omega$, and the relative sensor B is $-\omega$. So the output of sensor A & B is separated for:

$$V_A = V_{out} + K \times V_s \times S \times \sin 2\omega \quad (2)$$

$$V_B = V_{out} + K \times V_s \times S \times \sin (-2\omega) \quad (3)$$

For left and right arrangement of the two sensors in the initial position, the bias magnetic field with respect to the four resistance bridge reluctance is a fixed output, that is, V_{out} output is a steady state value, meanwhile the two sensor distance is fixed relative to the magnetic steel, and output is equivalent. It is obtained by adding the Equation 2 and the Equation 3:

$$\begin{aligned} V_{add} &= V_A + V_B \\ &= 2V_{out} + K \times V_s \times S (\sin(2\omega) - \sin(2\omega)) \\ &= 2V_{out} \end{aligned} \quad (1)$$

It can be obtained from the Equation 4, the two symmetrically arranged sensors by signal phase can eliminate the interference signal generated by magnetic field, and can expand two times the amplitude of the output signal, and improves the signal resolution. In this paper, based on the principle, it presents a new design model of differential reluctance linear displacement sensor.

2.2. Analysis of the Interference Magnetic Field

In the actual process of using magnetic displacement sensor, magnetic interfering field is spurious and unknown. In the designed differential reluctance scheme, relative position between sensor A and B is smaller, so magnetic field interference in

this small range relative to the A and B is considered as a parallel magnetic field. Suppose a field as shown in Fig. 4, D is magnetic interfering field, and the angle between the direction of magnetic interfering field and axis is 0° - 180° . In order to facilitate the analysis, the marked angle between axes on map is 90° . In the initial position, the included angle between axis M and electric current I is 45° . When there is the presence of a magnetic interfering field, the magnetic field along the axis M direction and magnetic interfering field D can be combined.

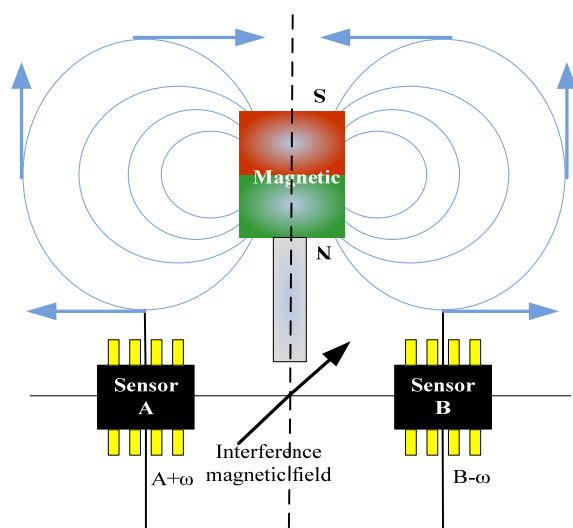


Fig. 3. The structure of differential magnetoresistive displacement sensor.

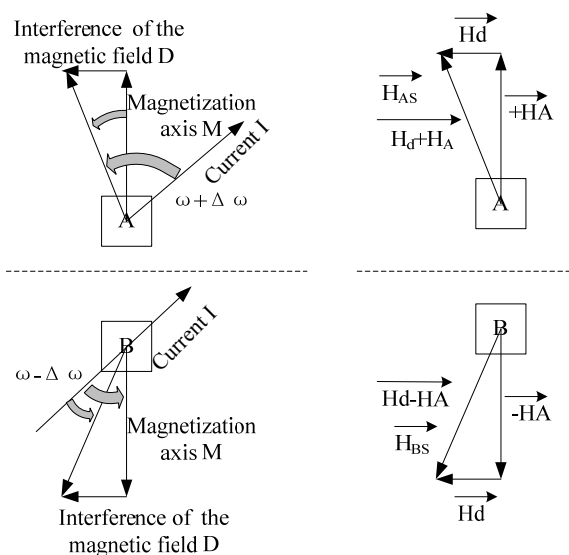


Fig. 4. Distribution of magnetic field interference and vector combining.

Relative to the sensor A:

$$\vec{H}_A + \vec{H}_d = \vec{H}_A + \vec{H}_d = \vec{H}_{As} \quad (5)$$

Relative to the sensor B:

$$-\vec{H}_A + \vec{H}_d = -\vec{H}_A + \vec{H}_d = \vec{H}_{BS} \quad (6)$$

In the equation above, $\vec{H}_A$ and $-\vec{H}_A$ are internal magnetic field vector of sensor, $\vec{H}_d$ interfere with the magnetic field vector, $\vec{H}_{As}$ and $\vec{H}_{BS}$ are synthetic magnetic field respectively A and B. Through the synthesis of magnetic field vector, the original angle between axis and current is changed. It is $\omega + \Delta\omega$ on A, while $\omega - \Delta\omega$ on B. Thus an output voltage comes. By means of Equation 2, 3, 4, the disturbances- generated voltage is eliminated through the summation method. On a special occasion, when the included angle between magnetic interfering field D and axis M is 0° and 180° , The strength of the magnetic field along the axis M direction can only increase or weaken. It can not cause the angle change between the axis M and current I, therefore it has no effect on the output voltage. But because A and B are symmetric arrangement, when the included angle between magnetic interfering field D and axis M is 180° - 360° , it is the same with the above analysis.

3. Magnetic Field Simulation

3.1. The Simulation and Test for Magnetic Field of Magnetic Steel from Different Positions

In order to select the appropriate sensor layout area, a 3D simulation model of the magnet is set up with the help of Ansoft software, to simulate the direction variation of the magnetic field around magnet steel. The distance of simulation magnetic center in the X axis direction is respectively 6 mm, 8 mm and 10 mm, and ± 8 mm in the Y axis direction. The simulation results are shown in Fig. 5.

As can be seen from Fig. 5, the closer away from the magnetic steel position, the more gentle the variation of the magnetic field angle. It means that the output voltage is lower resolution, and in the nearer distance position, the angle of the magnetic field is failure to maintain consistent, because the angle change is directly reflected in the output voltage. Through the test to check the sensor output under the three positions, the tested motion range is 8 mm as shown in Fig. 6(b). As can be seen from Fig. 6(b), it can ensure the whole range of linear line if sensor output at the 10 mm position. With the position approach of sensor and magnetic steel, the output is not in its linear range. And compared with the simulation results, it also verified the further between sensor and magnetic steel, the higher the output resolution. The experimental results show that the greater voltage changes, the smaller the slope of the curve becomes.

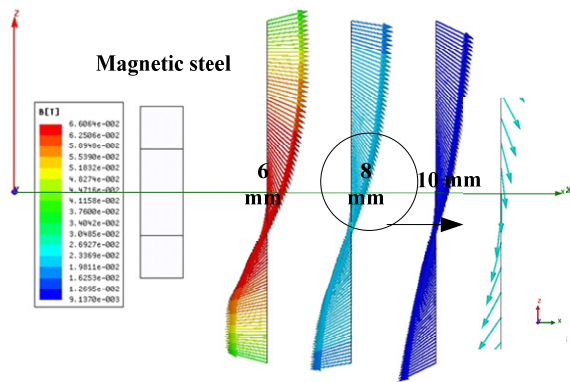


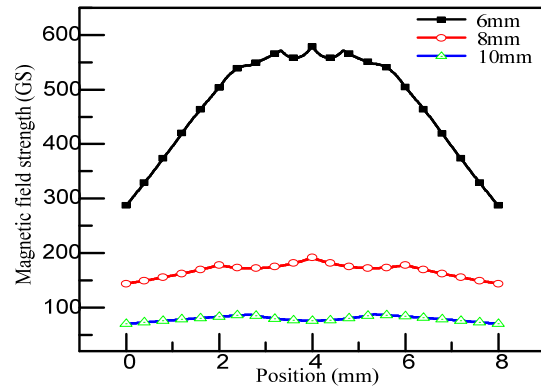
Fig. 5. The angle of magnetic field in motion region.

Table 1. Bias magnet parameters.

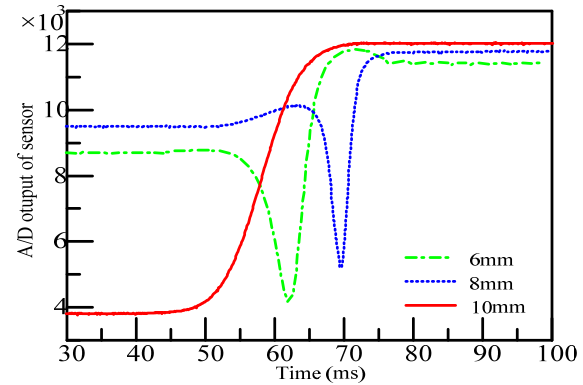
Name	Parameter
Magnet types	Cylindrical shape and axial magnetization
Dimension	5 mm × 6 mm
Mass	0.2 g
Magnetic strength	4000-4500 GS
Material	NdFeB45

3.2. The Strength of the Magnetic Field at Different Positions

The bias magnetic field required for sensor has location requirements between the above magnets and sensor, but also consideration should be given to the saturation problem for the bias magnetic field strength of sensor. In the Ansoft software, it simulates and calculates magnetic field strength in the whole range of motion and region. According to the performance of magnetoresistive sensor, magnetic field intensity is required to reach more than 80 GS. In the premise of magnetic saturation, try to use small size magnetic steel as far as possible, on one hand small magnetic steel is helpful for the use of sensor placement space limit, on the other hand magnetic steel with small surface volume means small quality, so the control system dynamic quality reduces, which is more conducive to improve the dynamic performance of actuators. Therefore, based on considerations of the above two conditions, simulation is made to the change of magnetic field strength in the motion area. The selected magnetic steel specifications are shown in Table 1. The results of simulation and test are shown in Fig. 6. With change of the distance between magnet and sensor, magnetic field intensity can decay continuously, but does not meet the requirements of the linear region. And if the distance is too far away, it cannot realize the saturation of the magnetic field strength. Therefore, after combination for the saturability of magnetic field intensity and the consistency of magnetic field angle change, the magnetic steel is determined to be arranged in 10 mm location area.



(a)



(b)

Fig. 6. The magnetic field strength in motion region and experimental test.

4. Scheme of the Dual Magnetostrictive Layout

4.1. Achievement of Differential Scheme

In order to ensure the accuracy of test results, reluctance type of displacement sensor in the actual use of the process, must have a better anti-disturbance performance. The resistance value of magnetoresistive bridge is easily influenced by external environmental temperature changes on the one hand, and on the other hand reluctance is easily interfered by external stray magnetic fields, especially when applied to electromagnetic interference, Such as electromagnetic linear actuator, at the moment of the actuator loading initial current, it causes the change of the magnetic field around, thus bring the fluctuations of sensor output.

In the non-contact displacement sensor, another sensor using differential method is linear variable differential transformer (LVDT) whose working principle is that transform the change of measured displacement into the variation of transformer coil inductance by means of electromagnetic induction. The magnetic field generated by the primary coil through the core to the secondary coil, the secondary coil induces voltage according to Lenz theorem; the induction voltage by two secondary coils has differential motion, then output voltage signal. In

conditions of the primary coil voltage fluctuation interference, and after subtraction of voltage through the two secondary coil transformers, it is still able to maintain a constant output.

Use the principle of differential transformer to eliminate the interference or error of measuring system. Compensation method of software or hardware can generally be used to eliminate the influence of temperature. Differential method can also be used to weaken test bias caused by temperature. And as for electromagnetic interference, in addition to the necessary shielding measures, the differential method is proposed to implement in this paper, the specific scheme is shown in Fig. 7.

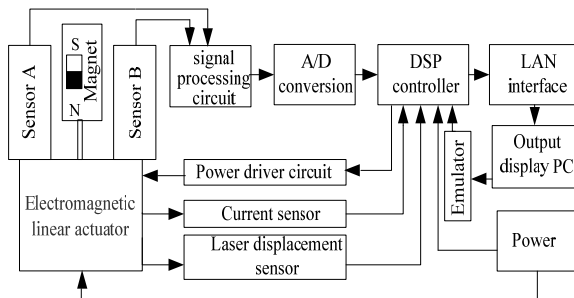


Fig. 7. Dual magnetoresistance differential scheme.

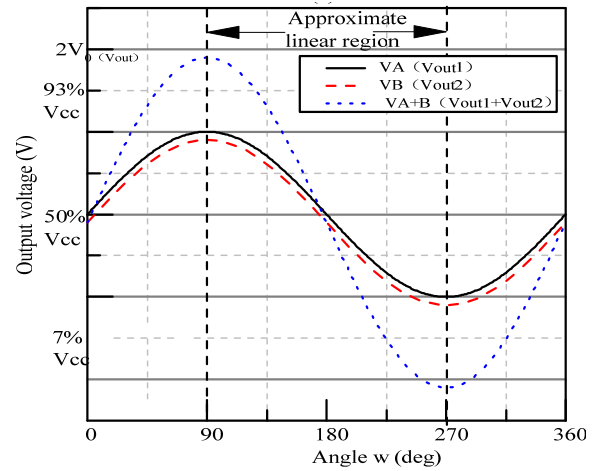
The designed differential scheme mainly uses double reluctance in both sides of the moving magnetic steel to generate symmetrical arrangement, installed on the upper end of the electromagnetic linear actuator. The output signal after process conducts conversion of A/D, and then is sent to digital signal processing (DSP) control unit, is given to the control system as the feedback signal, and use laser displacement sensor to do calibration at the same time. Finally the signal is transmitted to the host computer to output display through Ethernet port.

4.2. The Output Signal Processing

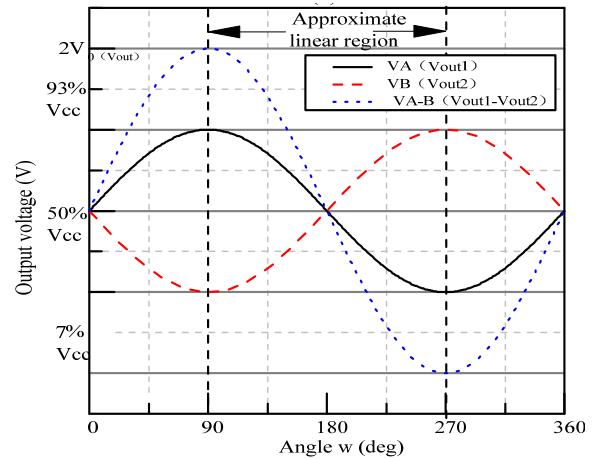
Take advantage of magnetoresistive sensor can output signal of sine and cosine at the same time, then through signal processing circuit, that is addition and subtraction circuit. If the electromagnetic interference is in the same direction, 180° phase shift is made on the signal of a sensor output, then subtracts sine signal from another sensor; if in the opposite direction, then pluses the output sine signal. Results are shown in Fig. 8.

As can be seen from Fig. 8, neither addition nor subtraction will change the original sensor linear zone. And after plus or subtraction, the amplitude of the output signal has increased nearly 2 times, thus increases the output signal of the sensor resolution. The output difference of sensor A and B in the Fig. 8(a) is because the error of two sensors in the

initial installation, which causes the amplitude of output voltage is not the same, but through differential method, it can also eliminate the influence of error.



(a)



(b)

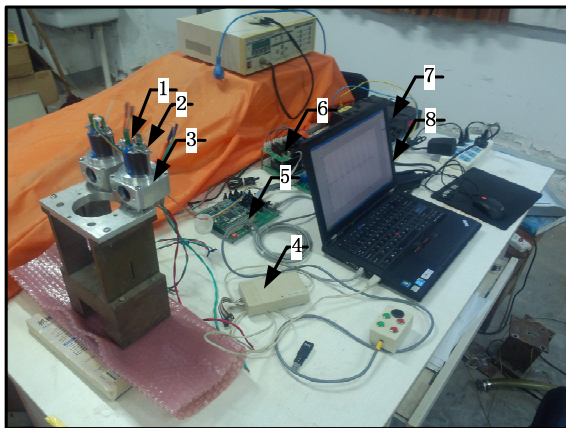
Fig. 8. The processing of output signal.

5. Experiment Analysis

5.1. The Static Test of Single Reluctance

According to the above analysis, the designed differential inductance sensor is used to control system of electromagnetic linear actuator. The test platform of differential magnetoresistive sensor is established as shown in Fig. 9. The bias magnet and electromagnetic linear actuator coil is connected together to have movement in order to verify the linear region of designed sensor, and to verify the magnetic field simulation. It can not only satisfy the magnetic saturation region, and consistency of magnetic field angle variation, but also ensure that the output of the sensor is linear in the whole movement. The first test is sensors work in static condition, and let the electromagnetic linear actuator move under a very small current, while the magnetic

field around basically keeps unchanged, the output of sensor at this moment is tested and carries on the contrast with the laser displacement sensor. Results are shown in Fig. 10. As can be seen from Fig. 10, the designed sensor can guarantee its linearity of the motion region in static condition. It is further proved the feasibility of simulation region around the bias magnetic field in Ansoft software, which provides theoretical support and guidance for the design of sensor static condition. It is further proved the feasibility of simulation region around the bias magnetic field in Ansoft software, which provides theoretical support and guidance for the design of sensor.



1.sensor A 2.Sensor B 3.ELA 4.Emulator
5.DSP controller 6.Power driver circuit 7.Power 8.PC

Fig. 9. Sensor experimental test platform

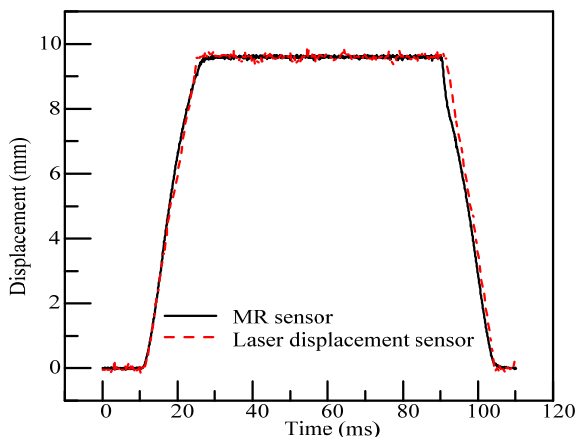


Fig. 10. The results of sensors static test.

5.2. Double Reluctance to Eliminate Magnetic Interference under Dynamic Conditions

In the established test platform of a double reluctance, let the electromagnetic linear actuator stay in high speed linear motion, and the sensor output signal feedback to control system. In the condition of actuator loading large current (bigger than 10 A), a larger interference magnetic field exists around the

sensor, especially at the initial moment of actuator motion, due to a larger current is need to start, so magnetic field interference at this moment is also strong. Also during the actuator has reverse movement, a large reverse current is needed to load. Due to the interference signal on the designed dual magnetoresistive sensor is reverse, through the aforementioned additive method of signal processing, it can eliminate the interference of externally applied magnetic field caused by the actuator motion. Results are shown in Fig. 11.

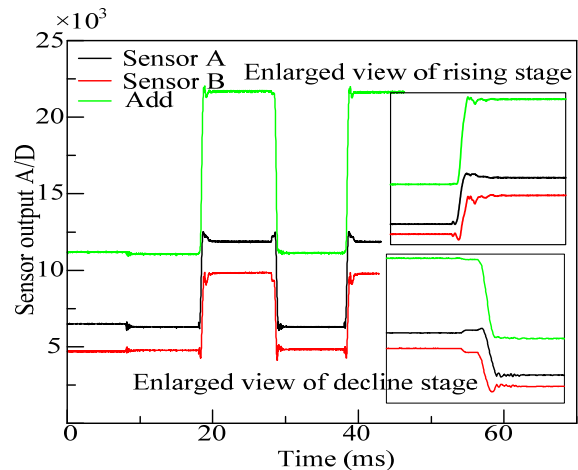


Fig. 11. The results of sensors dynamic test.

As can be seen from Fig. 11, in the actuators motion process, the interference is maximum at the initial time. The interference is maximum in the initial startup when reverse motion, and after through differential double reluctance, the interference can effectively eliminate whether in the actuator rise or decline stage. In order to further verify the anti-jamming ability of double reluctance to other external magnetic field, magnet steel is applied in around sensor to simulate the other magnetic field effect on test results. Results are shown in Fig. 12.

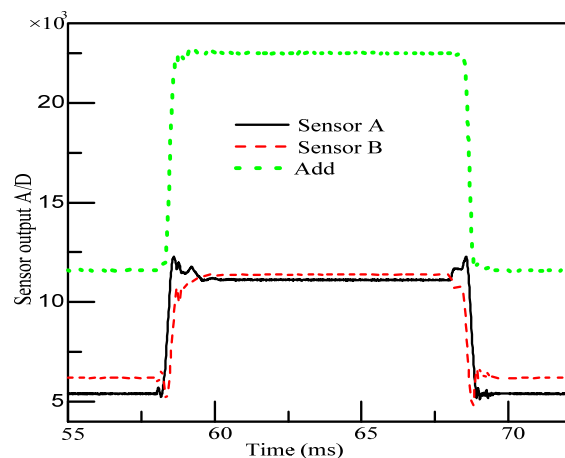


Fig. 12. The results of sensors dynamic test with suppression of magnetic fields.

As seen from Figure, after an interference magnetic field is externally added, the sensor output is capable of ensuring the stable operation. After calculation, the designed differential inductance sensor in contrast with a single reluctance, A/D of disturbance variable is: sensor A -138-1269 and sensor B -314-(-1227), the added signal is reduced to 0-(-10). It can be seen that the differential scheme by double reluctance can effectively suppress the interference, and can meet the precision control of linear displacement.

6. Conclusions

In this paper, it presents a design scheme based on differential reluctance linear displacement sensor magnetoresistive principle, and sets up a 3D simulation model of sensor bias magnetic steel, and tests the variation of magnetic field intensity and angle by simulations, and determines that the sensor layout area is 10 mm position. The designed sensor is to have static and dynamic test, and the test results under static state and laser displacement sensor are compared to prove its good linearity; the comparison of dynamic test results and individual magnetoresistive sensor verifies the differential scheme can suppress electromagnetic interference good, and can satisfy the high precision of linear displacement detection.

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