Design of magnetic flux detection test system for moving target

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Abstract. Magnetic detection based on the principle of magnetic flux induction is an important method for moving target detection and tracking. This paper designs and develops a test system based on a magnetic flux detection method in a laboratory environment. The article first introduces the overall design scheme and various components of the test system. Based on the target’s magnetic and motion characteristics, a motion simulation test platform is designed and developed. Based on the theoretical derivation and numerical simulation of the magnetic target, a sensor is designed and manufactured. The signal acquisition and analysis equipment acquires and analyzes the induced signals. According to different test purposes, the corresponding test methods are designed and various tests are carried out. The results show that the system design can meet the test requirements of the magnetic flux detection system, which is helpful for further research and optimization of the detection method.

1. Introduction

With the development and application of robots, drones, underwater submersibles and other technologies [1], the detection of these magnetic moving targets has increasingly become the focus of research [2]. Among them, as one of the important methods, the detection technology based on the principle of magnetic flux induction has been widely used in some fields, such as automobile monitoring [3]. For the magnetic detection of complex moving targets, the detection accuracy is required to be high, and qualitative analysis is not enough. A large number of quantitative experiments are also needed to provide research references.

In order to conduct in-depth research on the magnetic flux detection method for moving targets, a test system was designed and developed in a laboratory environment. The test system is mainly composed of a detection system and a target motion simulation system, which can simulate the situation where magnetic targets in different motion states pass through the magnetic flux detection sensors. By analyzing and researching the test results, the system design can be verified and optimized.

2. Overall design

2.1 Basic principle of magnetic flux detection

The basic principle of flux sensing is based on Faraday's law of electromagnetic induction: for a sized static closed coil, when a magnetic moving target passes through it, it will cause a change in magnetic flux, which in turn induces an electromotive force. And the induced electromotive force is linear with the negative value of the magnetic flux change rate of the coil circuit. Through quantitative calculation
and analysis of induced electromotive force, some magnetic characteristic parameters of the moving target can be inverted.

When the moving target is close to the detection coil, the magnetic field of the target can be simulated with multiple dipoles. When the distance is long, that is, when the distance is 5-6 times larger than the target size, it can be treated as a magnetic dipole [4]. This article is about long-distance situations, so the magnetic field of a moving target can be reduced to a magnetic dipole model. The test system is designed according to the basic principle of magnetic flux detection.

2.2 Test system overall plan
The test system consists of a magnetic flux detection system and a target motion simulation system. Among them, the magnetic flux detection system is composed of a sensor, a signal transmission line, and a signal acquisition and analysis device. The target motion simulation system uses a mobile platform to mount a magnetic block to simulate various motion states of magnetic targets. We set up a 4.5m long and 2m wide moving channel on the laboratory floor, lay the sensor under the channel, use a motion simulation system to simulate the situation of magnetic targets passing through the sensor in different motion states, and transmit the induction signal to the signal acquisition and analysis system for extraction and analysis.

3. Design of magnetic flux detection system
The magnetic flux detection system consists of three parts, including sensors, signal transmission lines, and signal acquisition and analysis equipment.

3.1 Design of the sensor
The sensor consists of an induction coil and a plug-in component, as shown in Figure 1. The thickness of the coil plywood is about 3cm, and the size of the coil skeleton is designed according to the measured magnetic and motion characteristics of the target. The sensor is laid at a given position on the laboratory floor. When the magnetic moving target enters the sensor's sensing range at a certain speed and height, the sensor will immediately generate an induction signal and pass it to the signal acquisition and analysis equipment. We can simulate different test conditions by changing the number, position, and series-parallel relationship of the coils.

Figure 1. Sensor schematic.

It can be known from theoretical analysis that when the coil size is the same order of magnitude as the target height, the larger the size, the larger the induced electromotive force, and the relationship is shown in Figure 2. Through further analysis, it can be concluded that the size of the coil will affect the power exponential relationship between the induced electromotive force and the height of the magnetic dipole [5].
Figure 2. Relationship between coil size and induction signal.

According to the magnetic and motion characteristics of the research target in this paper, the simulated target has a magnetic moment of about 180 A·m², a speed of 0.2 m/s to 1.2 m/s, and a height of 1.2 m to 2.4 m. The designed coil bobbin size is 20 cm * 80 cm, which is made of copper wire, the number of turns is 100 turns, and the length of the extended cable is about 15 m.

3.2 Design of signal transmission, acquisition and analysis equipment

In order to transmit the target signal induced by the sensor to the signal acquisition and analysis equipment with high fidelity, and further reduce the influence of electromagnetic interference in the external environment, the signal transmission line used in the test system is made by double-wire winding.

The signal acquisition and analysis equipment is used to extract the target induction signal and perform further analysis and processing. The test system uses a voltage collector with high precision and high sampling frequency. The noise level of the collector reaches 0.1 μV and the sampling rate reaches 3 KHz, which meets the requirements of the test system for signal acquisition instruments.

4. Design of Motion Simulation System

4.1 Introduction to motion simulation test platform

In order to accurately control the target’s motion state, a target motion simulation test platform is set up, as shown in Figure 3.

Figure 3. Target movement state simulation platform.

The mobile platform is controlled by a stepper motor. The axial movable distance is 4.5 m, the vertical adjustable range is 0.8 m to 3.0 m, and the adjustable speed range is 0.05 m/s to 1.2 m/s. There is a linear relationship between the speed and the pulse value. The platform accelerates and decelerates quickly and moves smoothly, which can meet the requirements of the test for the target speed.

4.2 Magnetic control of motion simulation test platform

The magnetic properties of the motion simulation test platform will cause great interference to the simulated target magnetic properties of the test. Therefore, during the processing of the mobile platform, the residual magnetism must be strictly controlled and low-magnetic or non-magnetic materials should be used as much as possible. However, due to various constraints, mobile platforms...
are inevitably partially magnetic. Therefore, it is necessary to find out the source and characteristics of its magnetism in order to separate it from the magnetic target of the test, thereby removing the background interference of the platform and improving the test accuracy.

In order to study the background magnetic characteristics of the mobile platform, a high-precision magnetic field vector meter was used to measure the magnetic size of the mobile platform near the induction coil. Figure 4 shows the magnetic field distribution of two selected measuring points near the induction coil when the mobile platform passes over the induction coil.

![Figure 4. Magnetic field distribution of mobile platform.](image)

It can be seen from the figure that the magnetic field disturbance generated by the mobile platform is around 1000nT. During the test, it was found that the vibration of the moving platform and the belt was the main source of magnetism of the moving mechanism. The fixing device between the moving platform and the drive belt is stainless steel. The device has remanence and is magnetized in the geomagnetic field or around magnetic targets. In order to improve the mechanical strength, a small amount of steel wire is embedded inside the driving belt. During the pulling of the platform, especially when braking, it will obviously tremble, which will cause the magnetic field fluctuation in the space around the belt.

The magnetic field disturbance of the mobile platform is more clearly displayed on the induced electromotive force detected by the induction coil, and has obvious reproducibility. The signal has obvious vibration characteristics accompanying the platform disturbance, the vibration amplitude is about 3μV, and the vibration frequency is about 10Hz, which is consistent with the intrinsic vibration frequency of the transmission belt, as shown in Figure 5.

![Figure 5. Magnetic field disturbance caused by belt.](image)

It can be seen from the magnetic analysis of the mobile platform that the induced signal caused by the platform itself has a certain effect on the target signal, which needs to be considered in the signal extraction process.
5. Test verification

5.1 Test plan
In order to verify the magnetic flux detection test system, a large number of tests were designed and carried out. The test protocol is as follows.

- To analyze the laboratory background environmental interference, lay the induction coil at a given location on the laboratory floor to collect laboratory background noise for about five minutes.
- In order to analyse the induction signals of targets in different motion states, the mobile platform is controlled to carry simulated targets and pass the induction coil back and forth multiple times at different heights and speeds.

5.2 Analysis of test results
The background magnetic field environment in the laboratory is relatively complicated. In addition to the disturbance of the geomagnetic field, various electronic instruments, electrical equipment and other nearby experiments will bring a certain degree of interference, which will cause some difficulties in the extraction of the target signal. Therefore, it is very important to analyze the characteristics and changes of background environmental interference.

At the beginning of the test, the ambient noise in the laboratory was measured multiple times with different numbers of induction coils, as shown in Figure 6. The source, intensity and characteristics of the noise are analyzed.

![Figure 6. Background interference measured with 4 coils in series.](image)

The frequency analysis of the collected noise signal found that there is a very strong power frequency component (50Hz) in the background interference. After that, the line of the acquisition instrument was modified to effectively remove the voltage interference caused by the power frequency. In addition, the rotation of the air-conditioning exhaust fan in the laboratory, the turning on and off of the large shaking table and some instantaneous interference will affect the signal extraction.

This test system is used to simulate the situation where magnetic targets in different motion states pass the sensor. The same target with a fixed magnetic moment size and direction was passed back and forth through the induction coil at different speeds and heights to compare and analyse the collected signals, as shown in Figure 7.
Figure 7. Signals generated by targets in different motion states.

The magnetic moment of the simulation target is about 180 A*m², and the N pole points in the moving direction. The platform moving speeds are low speed (0.24 m/s), medium speed (0.72 m/s), and high speed (1.2 m/s), and the platform heights are 2.4 m and 2.1 m, respectively. The figure shows the electromotive force signal induced by the target moving back and forth 10 times.

The wavelet threshold filtering method is used to process and analyse the target signal [6], and it can be obtained that, for magnetic targets with different motion states, the magnetic flux signals generated by them are different in amplitude and period. Significant differences in signal characteristics are consistent with the simulation results, verifying the validity of the test.

6. Conclusion

Based on theoretical research, this paper designs and develops a test system for magnetic flux detection methods for moving targets in the laboratory environment. According to the basic principle of magnetic flux detection, the overall scheme of the system was formulated, and the magnetic flux detection system and the motion simulation system were designed separately, and a large number of experiments were carried out. The results show that the test system can accurately simulate the situation of magnetic targets in different moving states passing through the detector, and can meet various test requirements, thereby verifying the effectiveness of the system and facilitating the further study of the magnetic flux detection method.

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