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Manyetik Anomali ile Ferromanyetik Malzemenin Hareket Yönlerinin Uzaktan Belirlenmesi

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ÖZET

Manyetik anomali kullanılarak uzaktan algılama yöntemleri savunma teknolojileri ve endüstriyel amaçlı uygulamalarda günümüzde giderek önem kazanmaktadır. Bu çalışmada demir, nikel, kobalt gibi ferromanyetik malzemelerden imal edilmiş cisimler hareket ettirilmiş ve manyetik anomali gözlemi neticesinde bu cisimlerin uzaktan algılanması ve hareket yönlerinin belirlenmesi hedeflenmiştir. Çalışma kapsamında geliştirilen bilgisayar kontrollü tarayıcı sistem ile hareket hâlindeki cisimler prototip olarak modellenmiş ve değişik sensörlerle manyetik ölçümler yapılmıştır. Geliştirilen sistem ve elde edilen bulgular makale kapsamında tartışılmıştır.

Anahtar Kelimeler: Manyetik Anomali, Uzaktan Algılama, Tarayıcı Sistem

Remote Detection of the Movement Direction of Ferromagnetic Materials by Magnetic Anomaly

ABSTRACT

Presently, the methods of remote detection through magnetic anomaly have been gradually gaining importance in applications for industrial purposes and defense technologies. The aim of this paper is, by means of magnetic anomaly observation, to remotely sense and determine the direction of motion of moving objects produced from ferromagnetic materials such as iron, nickel, and cobalt. With a computer controlled scanner system devised for the research, objects in motion have been modeled as prototypes and magnetic measurements implemented by a variety of sensors. In this paper are also discussed the system developed and the findings.

Key words: Magnetic Anomaly, Remote Detection, Scanner System

1. INTRODUCTION

Remote detection of the positional changes of the magnetic materials on the surface of the world can be used in applications for both industrial and military purposes. As is known submarine targets within the continental shelf of a country are detected today by sound waves through the sonar system. After the sound waves are sent and reflections gathered, detection is made if there is or not a moving target in the area. However, since sound sensors in the moving targets can identify the sound waves, both moving targets and human beings can understand that they are detected. Targets of ferromagnetic components such as planes and submarines can also be detected by magnetic method in addition to sonar and radar techniques [1-7]. Targets of this type distort the magnetic grids of the Earth when they are in motion. If the distortion in the magnetic field grids of the earth (magnetic anomaly) can be sensed, this type of targets can be detected without their awareness of the detection. But since magnetic effect sensitivity of the sensor used here is crucial, its employability in sensing magnetic effects must be tested prior to the use [8-15]. For the purposes set out in our study, first a field (2×10^{-5} T) identical with the field between the magnetic poles of the earth is produced, and then is devised a computer controlled scanner system which can change the position of representative target, planned to move in this field, on the x-y axes. The sensor voltage changes, due to the change in the position of the object, occurring in the magnetic sensor remaining fixed in the field are determined. Setting out from these changes, determining the employability of the sensor in sensing magnetic effects, and direction of the moving object have been our concern. The system developed and results of the experiments based on this system are also discussed in this study.

2. MAGNETIC ANOMALY MEASUREMENT SYSTEM

2.1 Water Tank

In line with the aim of our study, a 1m × 1m × 1m wooden water tank, in which a work piece with metal components will move, is manufactured (Figure 1). Then, inner surface of the tank is insulated against water. Thus, a suitable condition for metal work piece to be used in the experiment is created so as to let it move in the air when the tank is empty and in the water when full.

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Figure 1. Appearance of the Water Tank.

2.2 Magnetic Field Source

In our study, as a source of magnetic field, we have used a solenoid of 600 coils, 1m in length, and 20 cm diameter. An oscillator produced sine-like AC signal with 200 Hz frequency and 1 V amplitude is given through amplifier to the solenoid to create a magnetic field. The magnetic field in the solenoid is, by the help of an iron core fastening like the one in Figure 2, inserted between the iron plates beneath the solenoid. That the magnitude of magnetic flux between the plates is 10^{-5} T and that it is homogeneous is determined with teslameter. Thus, a magnetic field identical with that of the Earth is created inside the water tank.

Figuer 2. Two different aspects of the magnetic field source.

2.3 Two Dimensional (2D) Scanner System and Its Control

In the next phase of our study, 2D scanner system to ensure the iron-containing workpiece moving in the tank is developed (Figure 3). Materials like aluminum plate, brass rod, brass screw, and Castamid, which do not bear magnetic characteristics, are used in the manufacturing of 2D scanner system. Two-dimension mobility in the 2D scanner system is achieved by the stepper motors placed on each axis. Iron workpiece is connected to the scanner system with a castamid rod as seen in Figure 3.

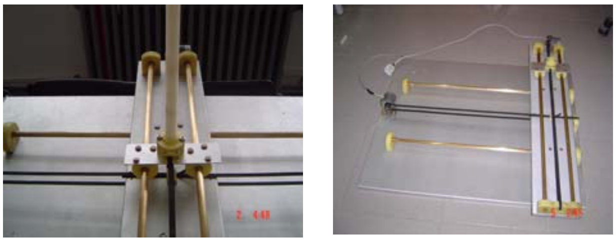


Figure 3. Two different aspects of the 2D scanner system.

Once the mechanics of the scanner system is complete, it is due now for computerized control of the stepper motors prompting the system. To this end, is developed an electronic unit, which processes and gives the suitable signals coming from the parallel port of the computer to the terminals of the stepper motor. Within the electronic unit the followings are available: Stepper motor control circuit, the amplifier, amplifying the voltage value coming from the sensor, a one-to-one AC to DC converter, and an ADC (Analog Digital Converter) circuit. The structure and connection scheme of these circuits are presented in figure 4.

As seen in Figure 4, control of the stepper motors is performed by the data port of the parallel port, and that of ADC is by data input control port and status port. It should be noted that during the control of the stepper motors any possible harm on the computer is averted through optical isolation of the parallel port of the computer and control circuit of the stepper motors. As for the voltage coming from the sensor, it first enters the amplifier so that necessary amplifications can be done. Then, this AC voltage is transferred to computer via ADC after a DC conversion of the same value by an AC-DC converter. In our study, the parallel port is programmed so that voltage value can be transferred to computer via ADC and the scanner system be brought to the desired position by stepper motors working in coordination.

2.4 Control Program of the System

The flow chart of the program written to transfer the voltage value to the computer via ADC and bring the scanner system to the desired position by stepper motors working in coordination is shown in Figure 5.

When the control program is run, first comes the main menu. Seven different subprograms with access from the main menu are seen in Figure 5. Of these, “experiment information” and “program exit” subprograms, not being related to the motion of the system, determine where to transfer in order the data coming from the sensor and exit the program. It is not possible to run the other subprograms in the flow chart unless the “experiment information” subprogram is run.

Therefore, the first thing to do, when the main program is run, is to enter the “experiment information” subprogram and determine which file to look for the voltage values coming from the sensor during the experiment, and in which folder to save them. Later on, the subprogram “ intermittent motion of the sensor for field control” is run to test whether the magnetic field created in the water tank, which is the sphere of motion of the scanner system, is homogeneous or not. For the test the sensor is fixed at the rod-like castamid seen in Figure 3, and once the system runs, data coming from the sensor is read at the intervals determined. Furthermore, as a precaution against the cases like power outage, the subprogram can be interrupted with the “sudden stop “ command, and resume later.

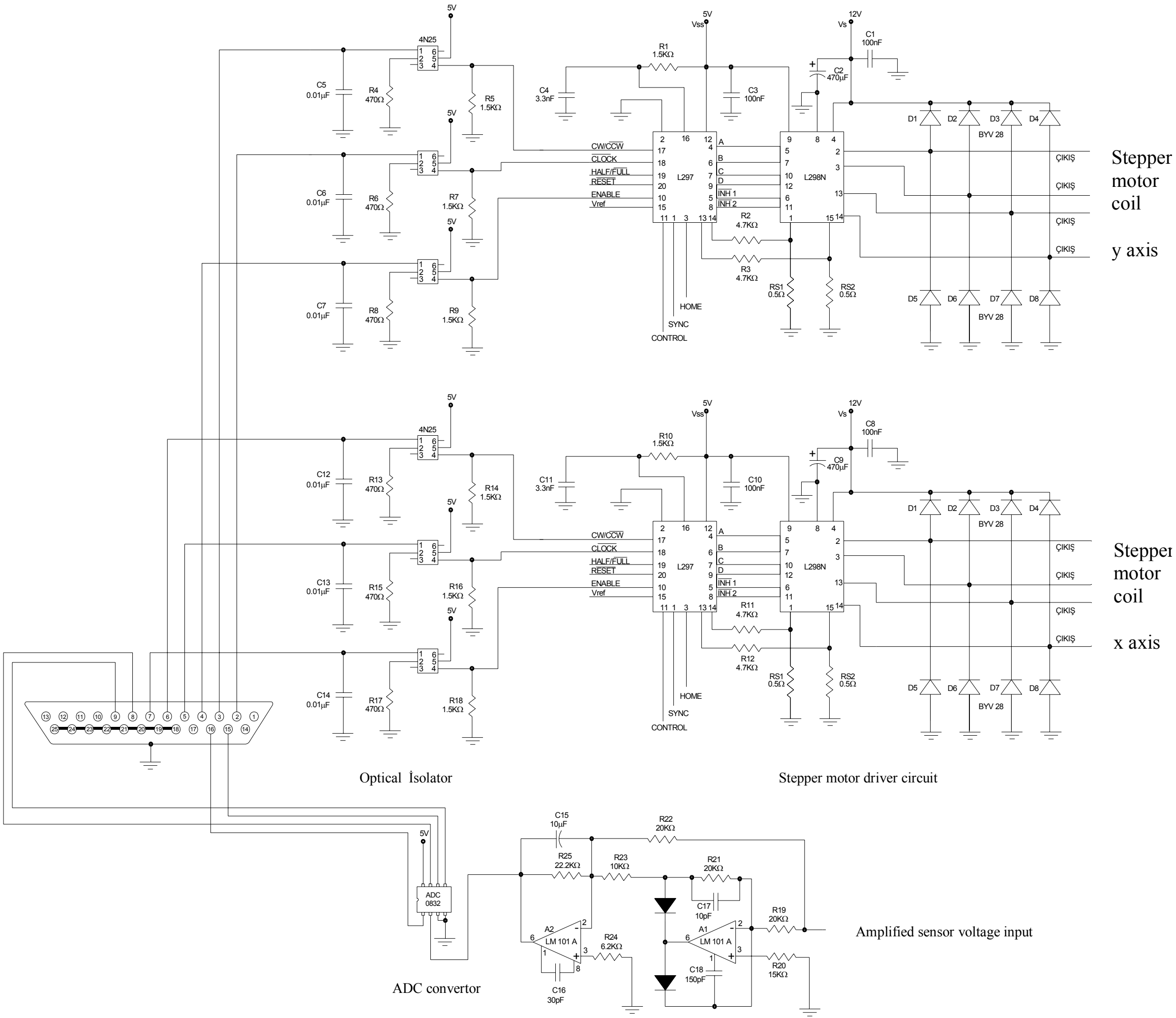
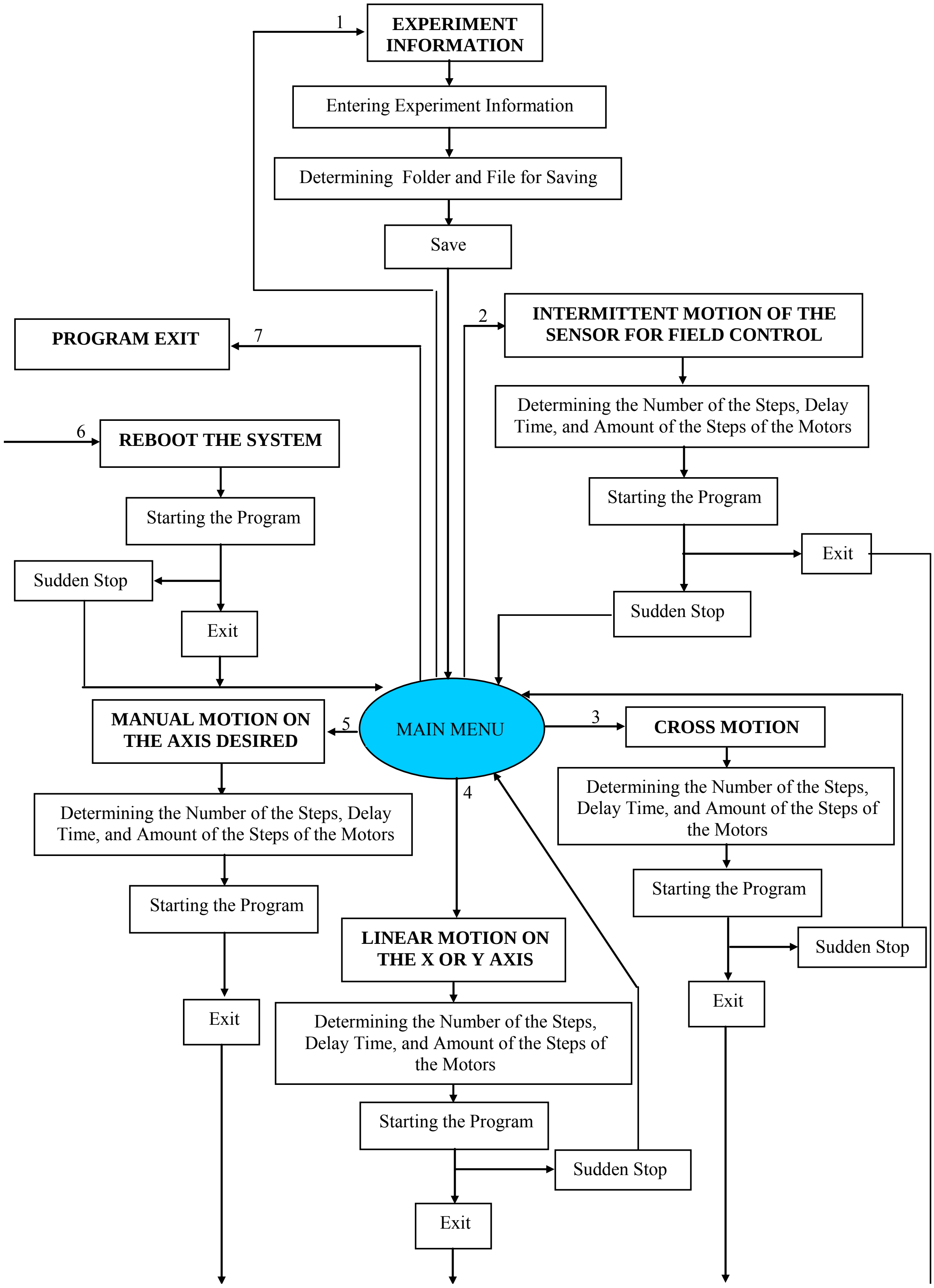


Figure 4. The structure and connection scheme of the electronic unit.

After the homogeneity check of the field, sensor is placed to a fixed point within the scanning field, and the metal piece is fixed at the castamid rod on the scanner. In this scanning field, the metal piece can be arranged for two different motions through the subprograms, “cross motion” or “linear motion on x or y axis”.

At the end of each subprogram, the last coordinates of the system are saved and automatically transferred to reboot the subprogram. Once “reboot” subprogram is activated, rebooting of the system is achieved. “Reboot” subprogram can also be interrupted by “sudden stop “ command and program can be quitted before the system reboots. If the program is not interrupted, the system reboots, and the scanner system is now ready for the next experiment.

After the rebooting process is over, by running from the main menu, the subprogram “exit the program”, triggering given to the parallel port is nullified and the currents given to the Stepper motors on the scanner are cut. Moreover, as seen on the flow chart, “manual motion” subprogram is added to the main program in order to obtain one or more data at any point within the scanning field of the scanner. Thus, it is possible with this subprogram to realize the small scannings we want for any reason to recur in the experiment.


1
EXPERIMENT INFORMATION
Entering Experiment Information
Determining Folder and File for Saving
Save
2
INTERMITTENT MOTION OF THE SENSOR FOR FIELD CONTROL
Determining the Number of the Steps, Delay Time, and Amount of the Steps of the Motors
Starting the Program
Exit
Sudden Stop
7
PROGRAM EXIT
6
REBOOT THE SYSTEM
Starting the Program
Sudden Stop
Exit
MAIN MENU
5
MANUAL MOTION ON THE AXIS DESIRED
Determining the Number of the Steps, Delay Time, and Amount of the Steps of the Motors
Starting the Program
Exit
4
LINEAR MOTION ON THE X OR Y AXIS
Determining the Number of the Steps, Delay Time, and Amount of the Steps of the Motors
Starting the Program
Sudden Stop
Exit
3
CROSS MOTION
Determining the Number of the Steps, Delay Time, and Amount of the Steps of the Motors
Starting the Program
Sudden Stop
Exit

2.5. Producing the Magnetic Anomaly Measurement System

After the completion of the program, the scanner system is placed on the water tank, and connection between all the units is established. Connection scheme of the system and a picture is shown in Figures 6 and 7 respectively.

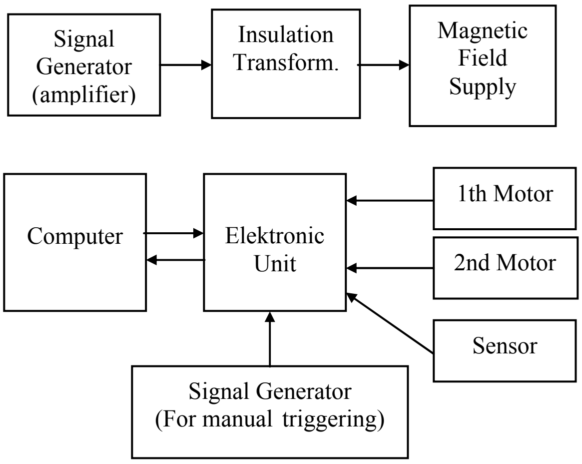


Figure 6. Connection scheme of the system

Figure 7. Magnetic anomaly measurement system

3. CALIBRATION OF THE MAGNETIC ANOMALY MEASUREMENT SYSTEM

System calibration is realized in three phases in our work. The first is determined whether there is any loss of step in the 2D scanner system stepper motors controlling each axis, while the system is in motion. In this respect, trials have shown that there is no loss of step in either axis. In the second phase of calibration control is made to see whether the sensor used in the system receives the same data in the same position provided that the magnitude of the magnetic field in the scanning field remain unchanged. Average standard deviation value is determined as $\sigma = 0.015\ mV$ in the repeated measurements. As for the third phase of the system calibration, in any given position of the scanner, it is determined whether the output voltage values of the sensor are the same or not in what the voltmeter reads and that transferred to the computer. Data transferred to the computer and written in the text file is also written on the monitor. Thus, during the experiment output voltage of the sensor is monitored via both voltmeter and computer monitor, and is found to be the same.

4. SENSITIVITY OF THE MAGNETIC ANOMALY MEASUREMENT SYSTEM

Measurement sensitivity of the magnetic anomaly measurement system depends primarily on two factors. The first is the positional sensitivity where the scanner system designed is able to move with a 98.5 μm sensitivity on x and y axes. Therefore, the ferromagnetic material attached to the scanner changes position with the same degree of sensitivity.

The other factor is the sensing sensitivity of the system. In the system, output voltage of the sensor is amplified 400 times. In addition to this, if the amplified voltage value is below 19.5 mV, this value cannot be transferred to the computer. More specifically, if the output voltage of the sensor is below 19.5 / 400 = 48.75 μV, this value is transferred to the computer as 0 V. Hence, sensing sensitivity of the system is 48.75 μV.

5. APPLICATION RESULTS

The first thing in the experimental stage of our study was to test whether the magnetic field, which the magnetic field source creates in the scanning field, is homogeneous or not. To this end, an oscillator produced AC signal with a frequency of 200 Hz and 1V amplitude was given through an amplifier to the solenoid, and a magnetic field was created in the solenoid. The magnetic field in the solenoid was, by the help of an iron core fastening as in Figure 2, interpolated between soft iron plates placed beneath the solenoid. Then, a coil sensor of 500 coils, 0.5 cm diameter, and 5 cm length was fixed on the moving castamid rod of the 2D scanner. Through the assistance of the scanner system, the sensor was moved with intervals of 19.7 mm on the x axis and 98.5 mm on the y axis of the scanning field, and voltage values on the sensor were determined. In the light of the values obtained, voltage-change graph was drawn according to the x and y positions. (Figure 8). This graph shows that in a scanning field of 1mx1m the voltage produced at the sensor is constant, and it is 0.294 mV. This clarifies that the magnetic field in the scanning field is homogeneous. Moreover, it can be said that the magnitude of the field is 3.4×10^{-5} W/m^2 by the relation $B=V/(4.4\times\pi\times N\times A)$ [16]. This value has also been verified through measurement with teslameter.

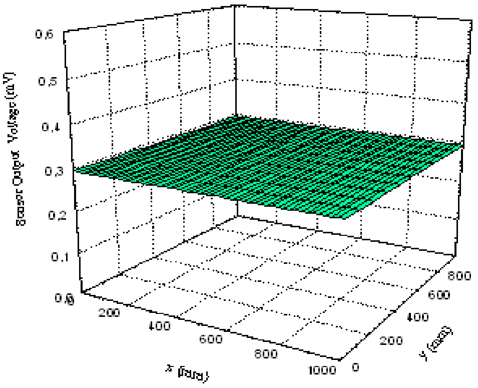
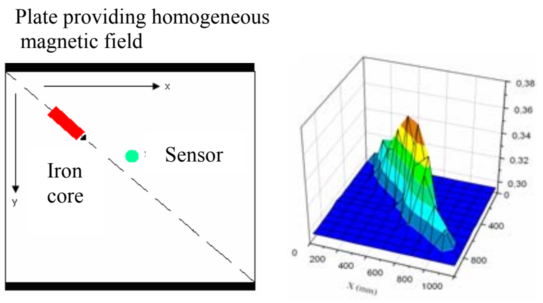


Figure 8. The change in the sensor output voltage in the scanning field.

After the homogeneity test of the magnetic field, the sensor is fixed at a support tool and is placed in the scanning field as shown in Figure 9a. Then a 15×4×4 cm iron core is fixed at the castamid rod on the scanner. This iron core is made by the scanner to make a cross linear motion similar to the one in Figure 9a. During the motion the change in the output voltage of the sensor is measured, and the data obtained is presented with respect to change in position in Figure 9b.

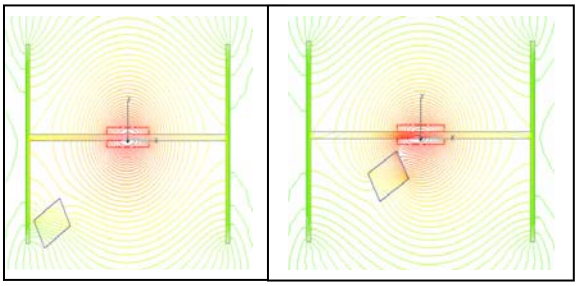


(a) (b)

Figure 9. During the cross motion, a) the route of the iron core, b) change in the sensor output voltage with respect to position

As shown in Figure 9b. as the iron core approaches the sensor, output voltage of the sensor begins to increase. The reason for this is the distortion of the homogeneous magnetic field within the scanning field due to the motion of the core, and the flux completing its circulation passing over the core. As the iron core approaches the sensor, sensor output voltage increases since the flux line passing through the cross section of the sensor increases. Furthermore it becomes clear that a straight line to be drawn according to maximum points of sensor output voltage is collinear with the motion of the iron core. Therefore, it is seen that the direction of the motion can be determined considering the effect, on the sensor, of the magnetic anomaly produced by the motion of the iron core.

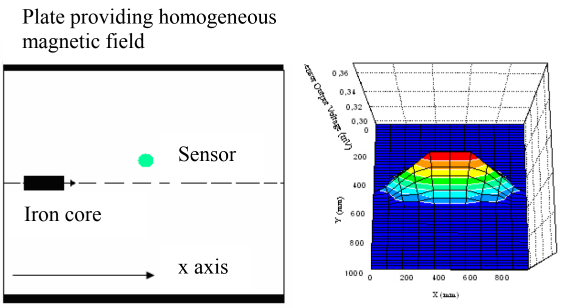
The 2D Finite Element Model [17] (FEM) of the experimental apparatus in Figure 2 has been set as in the one in Figure 10. 1 A of DC has been applied to the coil that is used as the magnetic field source. The boundary conditions have been defined as 6.5 times that of the coil length, where the energy is assumed to be zero. FEM analysis results for this type of motion are seen in Figure 10a. and Figure 10b. show that the moving object, independent of the magnetic field density, collects the magnetic flux on itself throughout its motion. Therefore this material acts like a source of magnetic field.



(a) (b)

Figure 10. Finite Element Analysis results for diagonal motion

In the next step of our study one more experiment is performed in order to support this fact. In this experiment, the iron core is moved along only x axis in the same magnetic field, and voltage changes in the sensor are determined (Figure 11).



(a) (b)

Figure 11. During the motion along the x axis a) route of the iron core, b) Change in the sensor output voltage with respect to position

As seen in Figure 11b, a straight line that can be drawn according to maximum points of sensor output voltage is collinear with the motion of the iron core. This verifies the preceding experiment. During the experiments the iron core is also moved along only the y axis, and similar results are obtained. Moreover, the interval between the sensor and the iron core is expanded provided that the motion of the iron core be the same, and observation is made with the change in the output voltage of the sensor as the same, but decrease in the values of the sensor output voltage. This shows us that sensing of the magnetic anomaly produced by the motion of the iron core is related to sensing sensitivity of the sensor. Therefore, this result lays bare the fact that sensitivity of the sensor is an effective factor in determining direction by magnetic anomaly.

Finite Element Analysis results related to the type of motion are seen in Figure12. The figures show that analysis results comply with the experimental results.

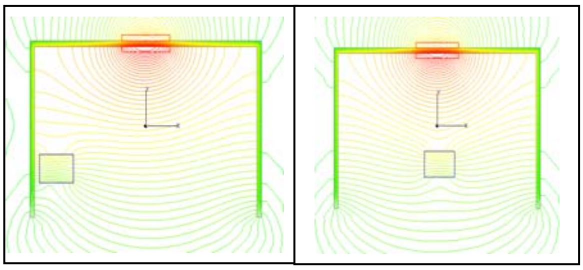


Figure 12. Finite Element Analysis results, during the motion along the x axis

6. CONCLUSION AND SUGGESTIONS

Magnetic anomaly measurement system developed in our study shows that the direction of the motion of objects produced from ferromagnetic materials such as iron, nickel, and cobalt, and moving in a constant and homogeneous magnetic field, can be detected through the sensing of the magnetic anomaly created by the motion of the objects. However, sensitivity of the magnetic sensor employed for this issue must be higher. In the light of the experimental results, one daily issue that whether the same method can be used to determine the direction of a submarine moving in a steady magnetic field of the Earth is self evident. If magnetic sensors of higher sensitivity are placed at points within likely routes of the submarine, moving direction of the submarine can be detected. Additionally, type of the steel that each country uses for submarines is different. Therefore, these products are different in their magnetic permeability. If the same mass is taken from these different steels, and their effects on the same sensor and motion are determined in advance, or rather, if it is calibrated taking the type of the steel into consideration, both the direction and flag (nationality) of a submarine can be detected and identified remotely.

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