Applications of Electromagnetic Phenomena in Electrical and Mechanical Systems
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A Permanent Magnet Repulsive Type Magnetic Bearing Balance System

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Abstract

The conventional mass measurement instruments have the problems of less sensitivity due to contact friction, so our purpose is to make a more sensitive balancer for measuring small masses by removing the contact. Magnetic bearing system does not produce friction due to its non-contact nature, so it can be used for designing such high precision measurement instruments. We consider the repulsive type magnetic bearing (RTMB) because it is simple and suitable for smaller systems. Also there will be only one direction needs to be controlled. In this paper, the configuration of the RTMB balance system which is already fabricated in our laboratory and its operating characteristics will be presented. A modification in the system design will be introduced so as to increase the present system sensitivity. From the experimental results, it is confirmed that the modified system has a higher measuring sensitivity.

1. INTRODUCTION

Magnetic bearing does not produce noise and has less vibration, also no energy consumed by bearing friction and no need for lubrication. So the operating costs is reduced and as a result, it is becoming attractive for many applications such as, high speed rotation machinery (turbo molecular pumps, natural gas pipelines compressors, fly wheel energy storage systems,...,etc.) [1]. Magnetic bearing can be passive, where the suspension relies on permanent magnet or electromagnets with constant field, or active, where the resultant force generated in electromagnets is modulated by control of coil current [2]. The Repulsive Type Magnetic Bearing (RTMB) using permanent magnet for levitation and radial control is one of magnetic bearings which has been considered in our laboratory. It is simple and suitable for smaller systems. Also there will be only one direction needs to be controlled [3].

In general, the conventional balance systems have a mechanical friction and this friction decreases the detection sensitivity. To solve this problem, we used the RTMB balance system which has a non-contact nature.

A balance system for mass measurement using RTMB is designed and fabricated in our laboratory. In this paper, we measure the relation between the exciting current and additional weight using this system, and compare the characteristics in case of using an electromagnet with the characteristics in case of using Voice Coil Motor (VCM) for balance beam control.

2. SYSTEM CONFIGURATION

The structure of the RTMB balance system is shown in Fig.1. The system consists of an axial shaft part and balance beam part. Each part is controlled independently by individual controller.

2.1 Configuration of the axial shaft part

Fig.2 shows the structure of axial shaft part which includes RTMB using permanent magnet. Two permanent magnets are placed in the middle of the shaft and the repulsive forces between the stator magnet and levitator magnet generate a lifting force to keep it stable along the radial direction; however the axial direction is unstable. An iron plate is placed at one end of the shaft and a weight for keeping the level with ground is placed at the other end. By using the information from the axial displacement sensor which is fixed at one end of the shaft, the attractive force generated by the electromagnet which is placed beside the iron plate could be adjusted through a control system to keep the axial direction stable. The displacement sensor used here is composed of a light emitting diode and a photodiode, this type of

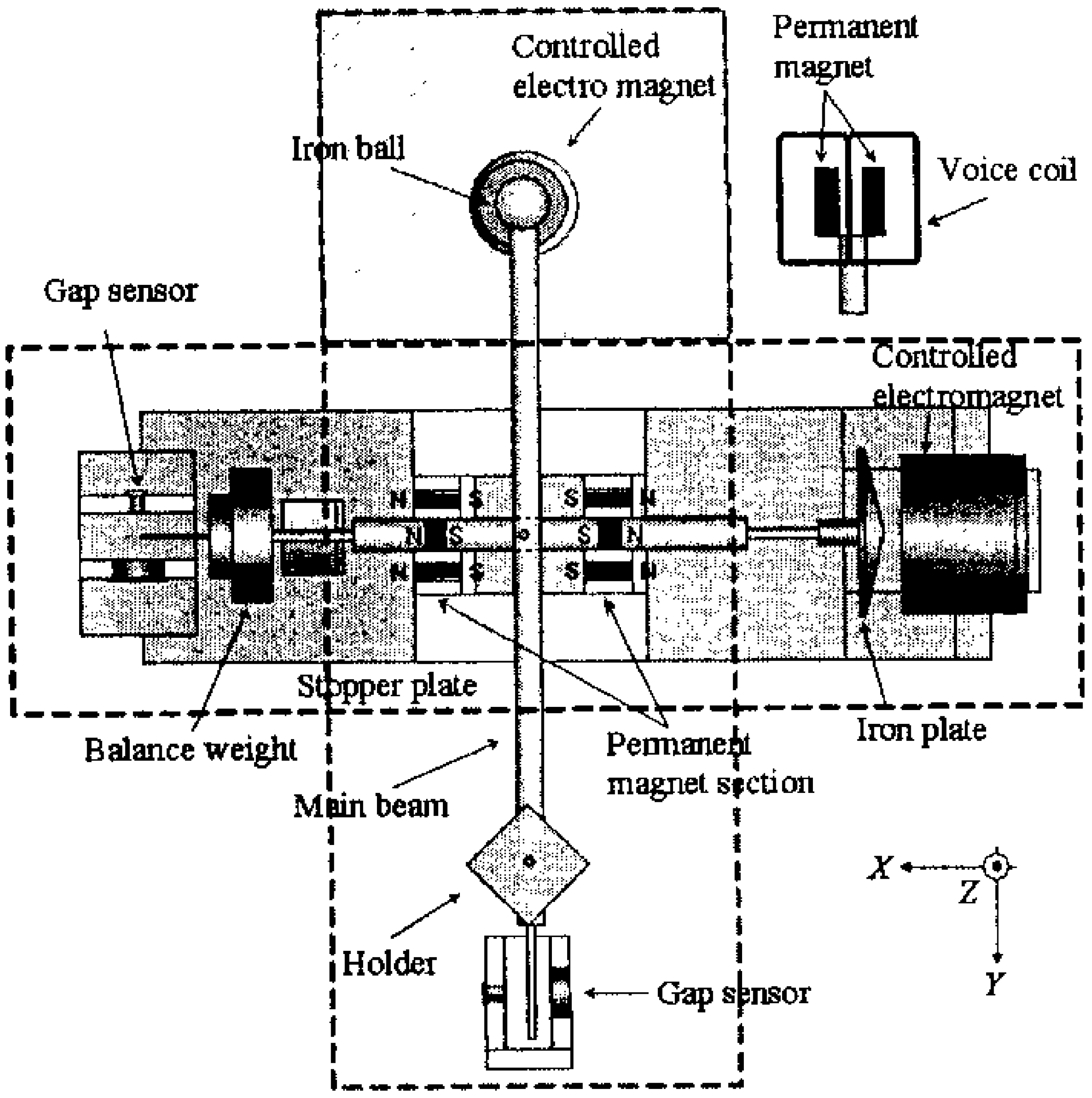


Fig.1 A repulsive type magnetic bearing balance system

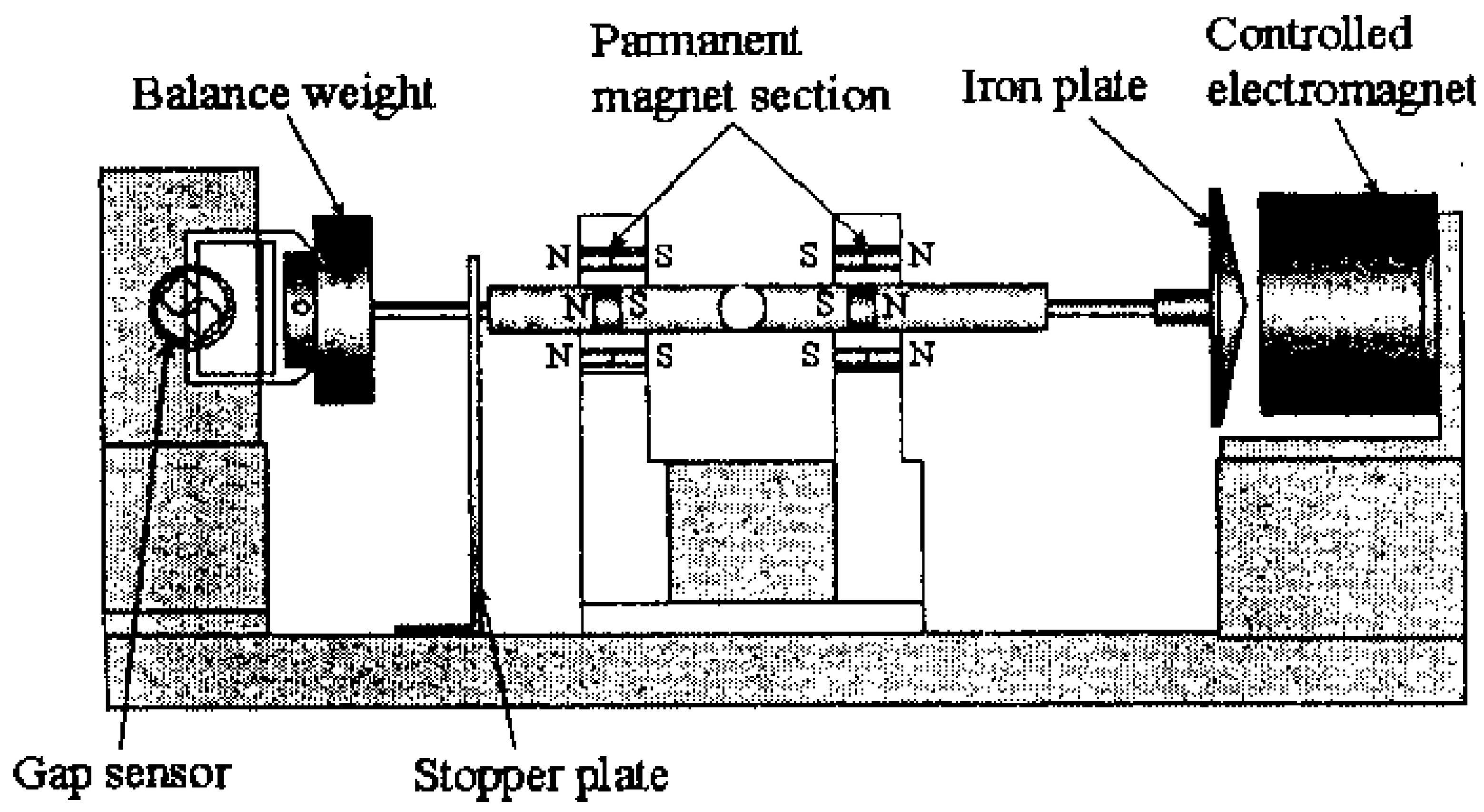


Fig.2 Structure of axial shaft part

diode is advantageous because it is cheap and magnetically independent [4].

2.2 Configuration of the balance beam part

2.2.1 In case of using an electromagnet

The balance beam part is designed as shown in Fig.3. There is an iron ball at one end of the beam and a mass holder at the other one, where a gap sensor is fixed to detect the vertical displacement. By using the information from the gap sensor, the attractive force generated by the electromagnet which is placed under the iron ball could be adjusted to keep the beam in a horizontal position. When a mass is added to the holder, the iron ball goes up, so the electromagnet current is increased and also the attractive force to return the beam to its original position, so the additional weight is transferred to the control current.

2.2.2 In case of using a VCM

Fig.4 shows the balance beam part configuration using the VCM. The detailed structure of VCM is shown in Fig.5. The balance beam has a VCM at one end instead of the electromagnet and a holder at the other one, where a gap sensor is fixed to detect the vertical displacement. By using the information from the gap sensor, the attractive force generated by the VCM could be adjusted to keep the beam in a horizontal position. When a mass is added to the holder, the iron yoke goes up, so the VCM current is increased and also the attractive force to return the beam to its original position, so the additional weight is transferred to the control current.

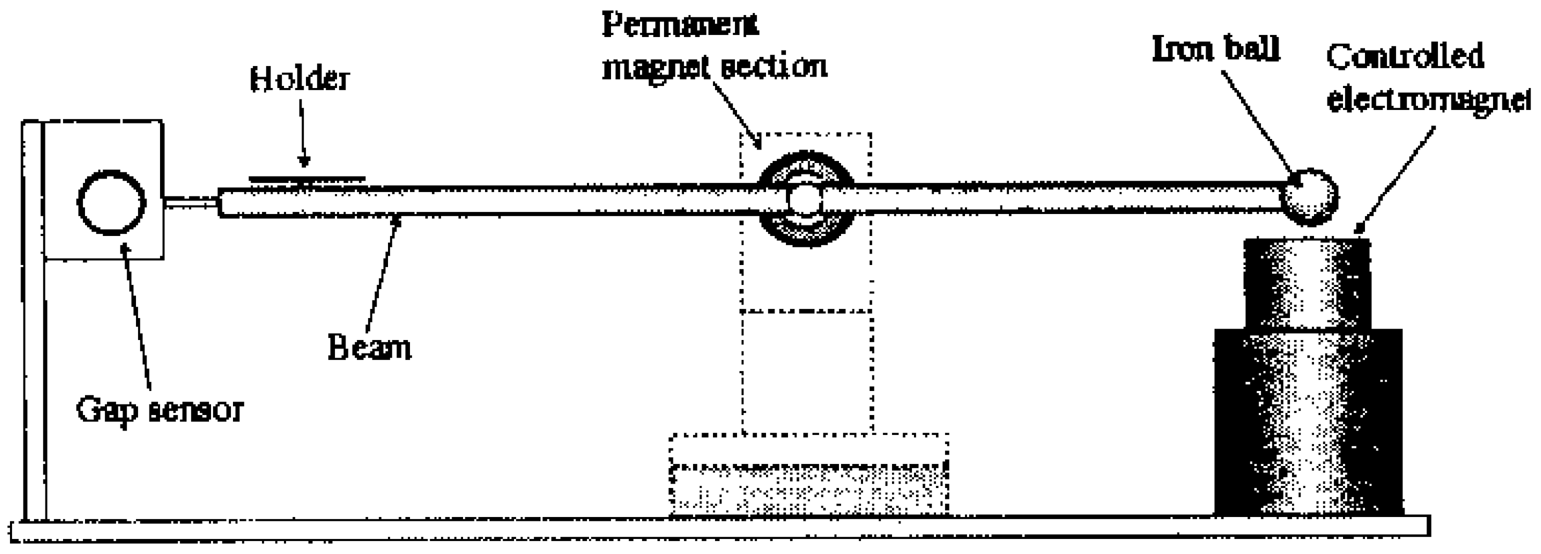


Fig.3 Structure of balance beam with an electromagnet

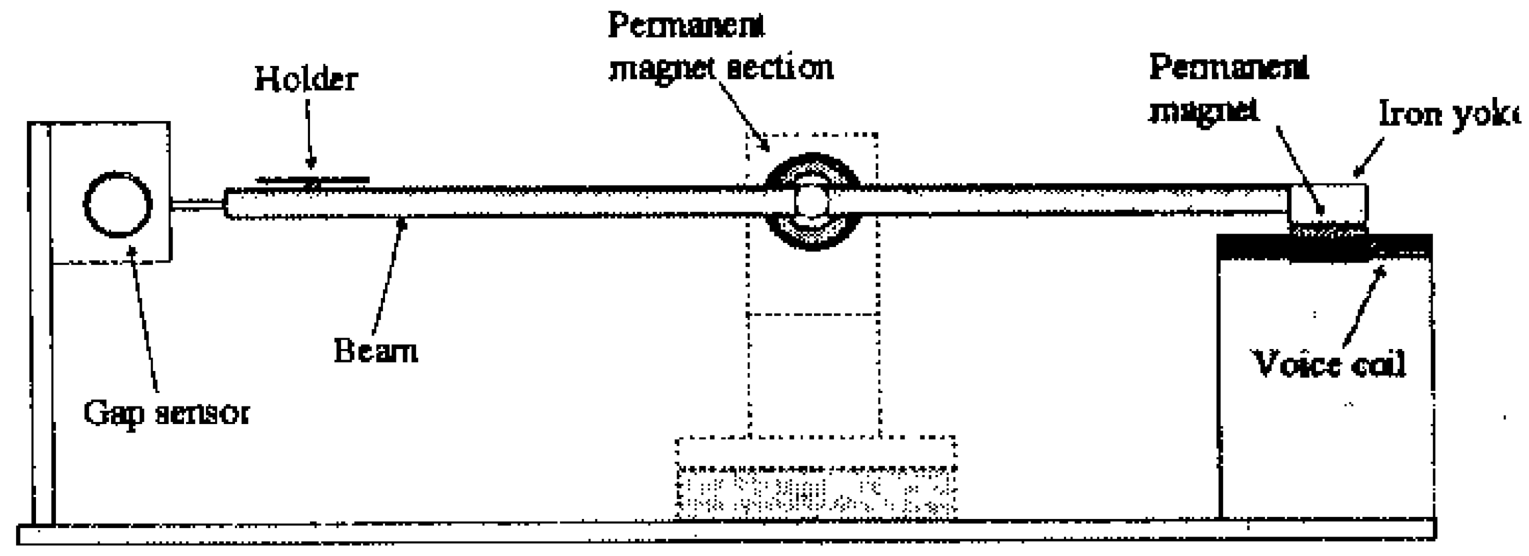


Fig.4 Structure of balance beam with a VCM

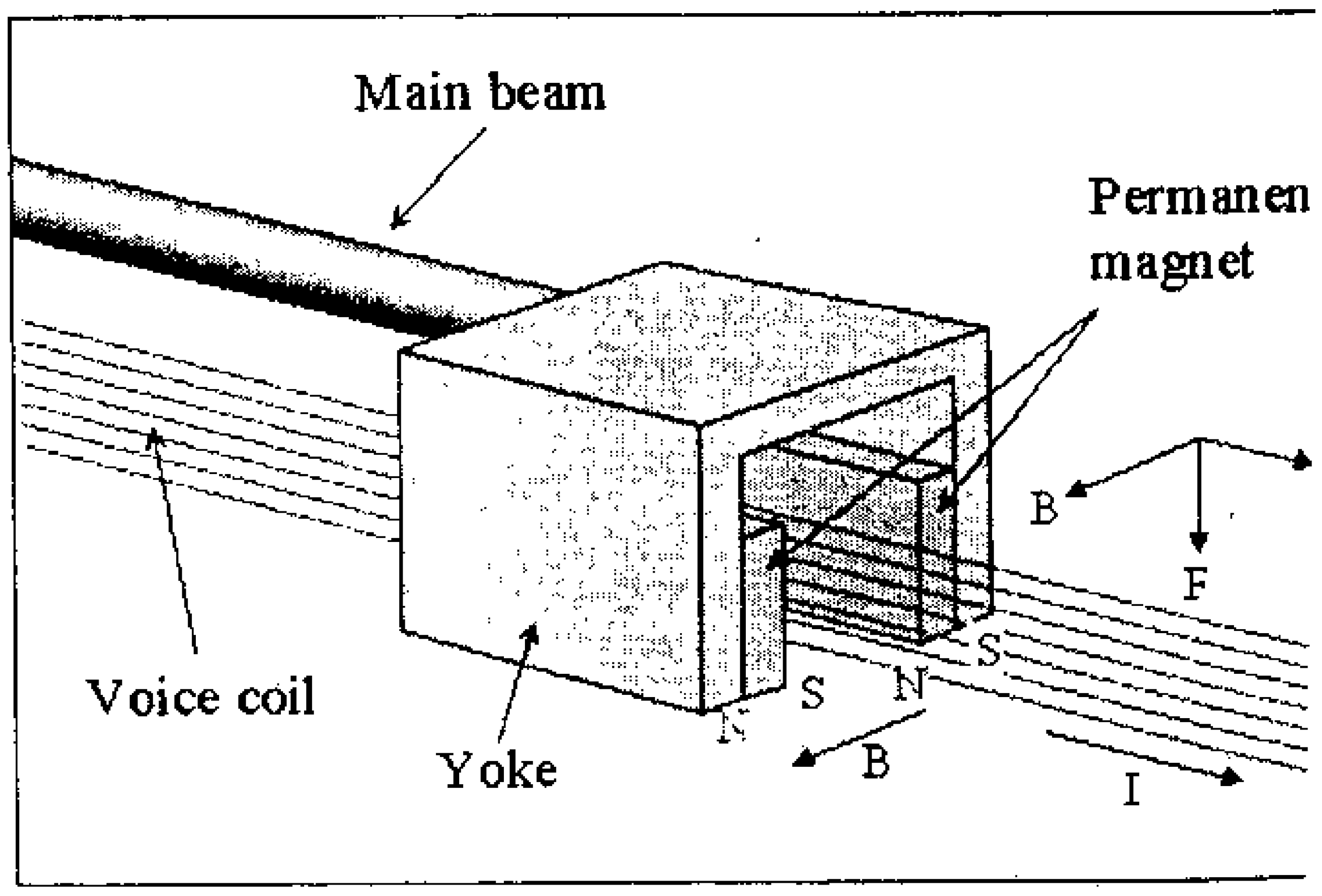


Fig.5 Structure of VCM

2.3 Control system design

The axial shaft control system is designed as shown in Fig.6, where a Linear Quadratic Gaussian (LQG) optimal controller is used to achieve the non contact levitation condition of axial shaft. The "lqg" MATLAB command is used for designing such controller, and it is verified that the non contact levitation condition of axial shaft is achieved using this controller.

The balance beam control system is designed as shown in Fig.7, where an integration type optimal servo controller is used for keeping the balance beam in a horizontal position. By using "lqr" MATLAB command, we could design such controller. The kalman filter is used for state estimation.

The block diagram of the controlled system is shown in Fig.8. The controllers are implemented around a digital signal processor (DSP) and the system has been simulated by the help of MATLAB. The position signals of the gap sensors are used as inputs to the controllers through the A/D port of the DSP. The DSP outputs go to the power amplifiers through D/A for adjusting the current of the electromagnet and VCM. By the help of these controllers the axial shaft and the balance beam have been stabilized.

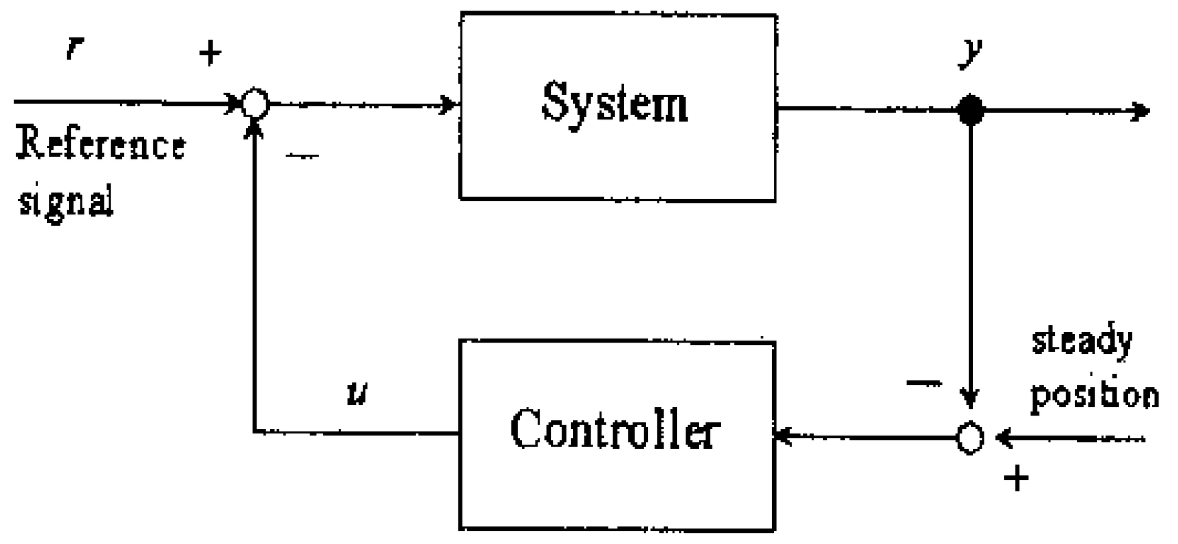


Fig.6 Controller block diagram of axial shaft

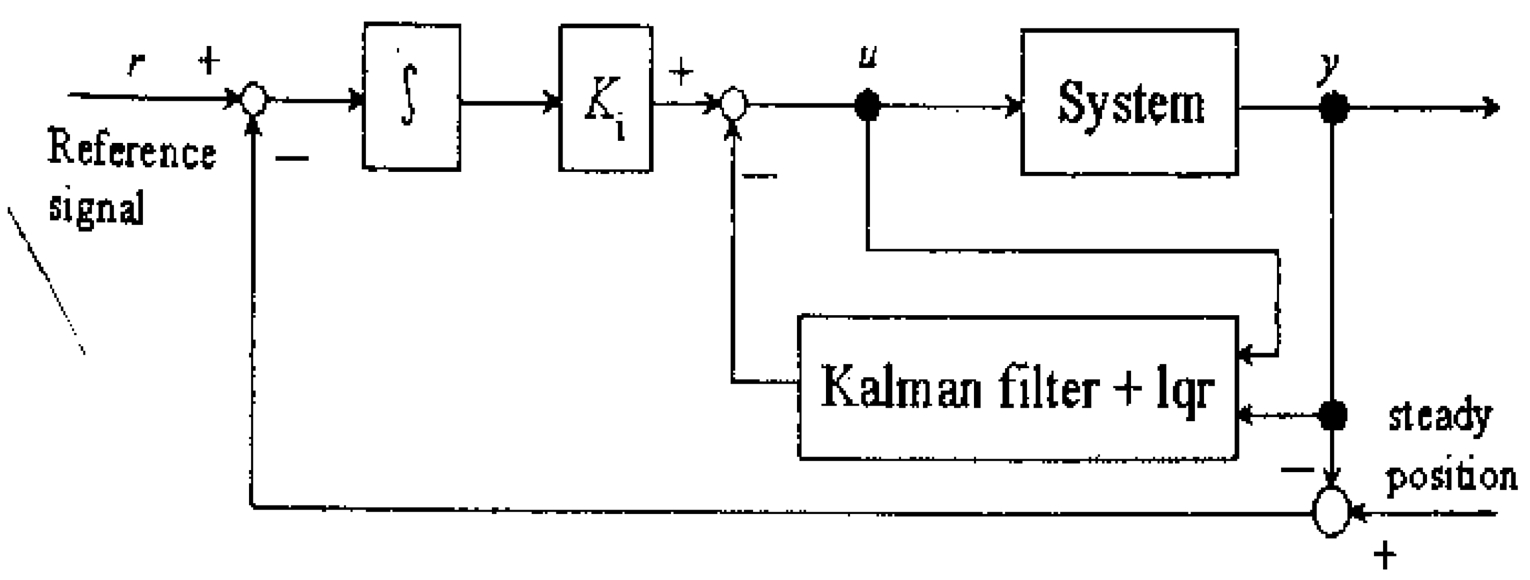


Fig.7 Controller block diagram of balance beam

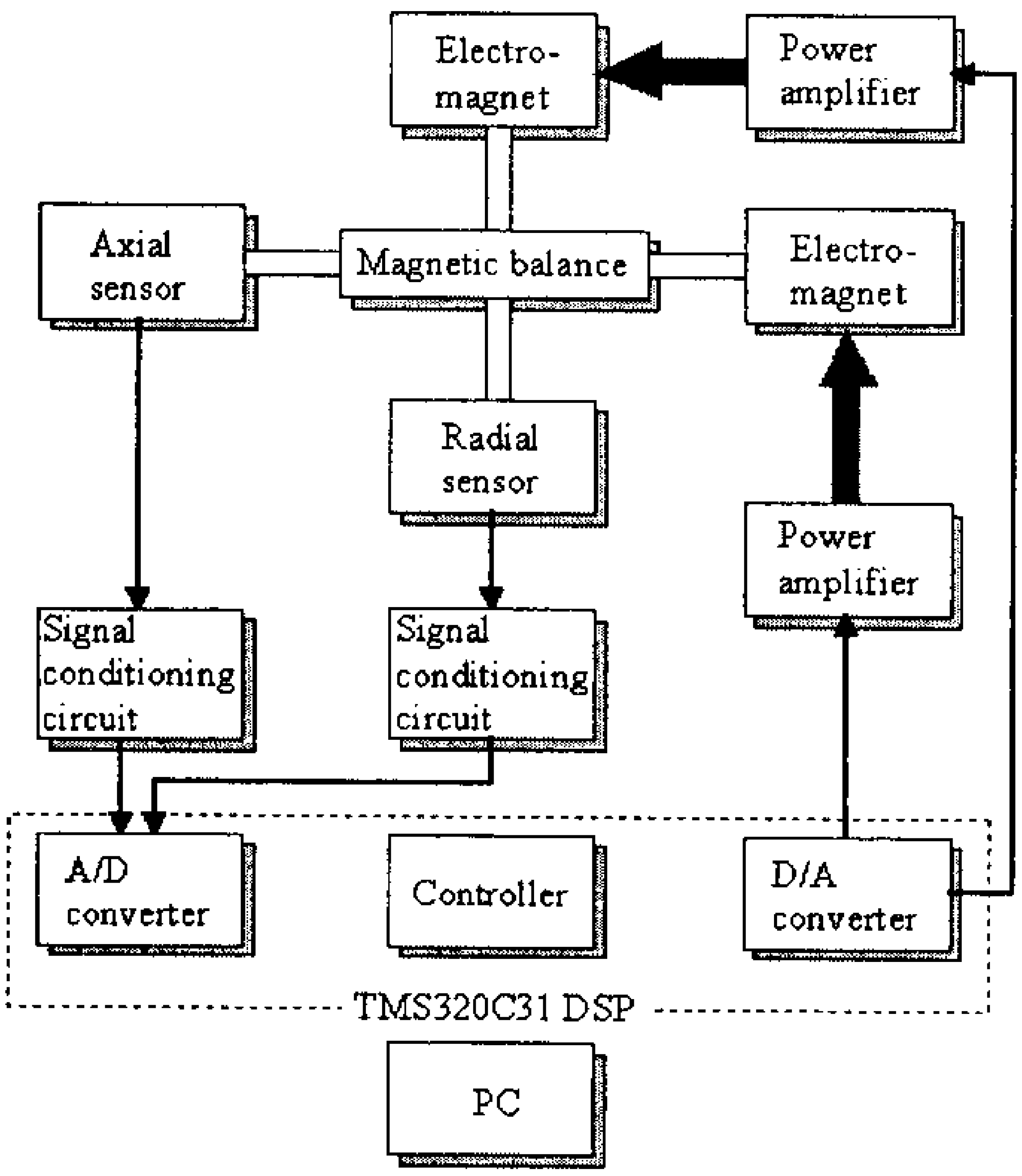


Fig.8 Control-flow diagram

3. EXPERIMENTAL RESULTS

3.1 In case of using an electromagnet

The experiments are carried out for measuring small masses. We first set the system and adjust the steady levitation condition. The masses are added gradually and carefully to the holder, and in each time the control current of the electromagnet is measured. Fig.9 shows the characteristics of the control current of the electromagnet and vertical displacement of the iron ball vs. additional weight. It is noticed that the relation between control current and additional weight is not linear.

In order to measure the hysteresis error, the control current is measured while increasing and decreasing the weight as shown in Fig.10. From this figure, it is noticed that there is difference between the control current while increasing weight and the one while decreasing weight. It seems that this difference comes from the magnetic hysteresis characteristic of electromagnet's iron core. The maximum hysteresis error resulted during this measuring was 730 μg, and this value is less than 1% of 100mg that is the full weight.

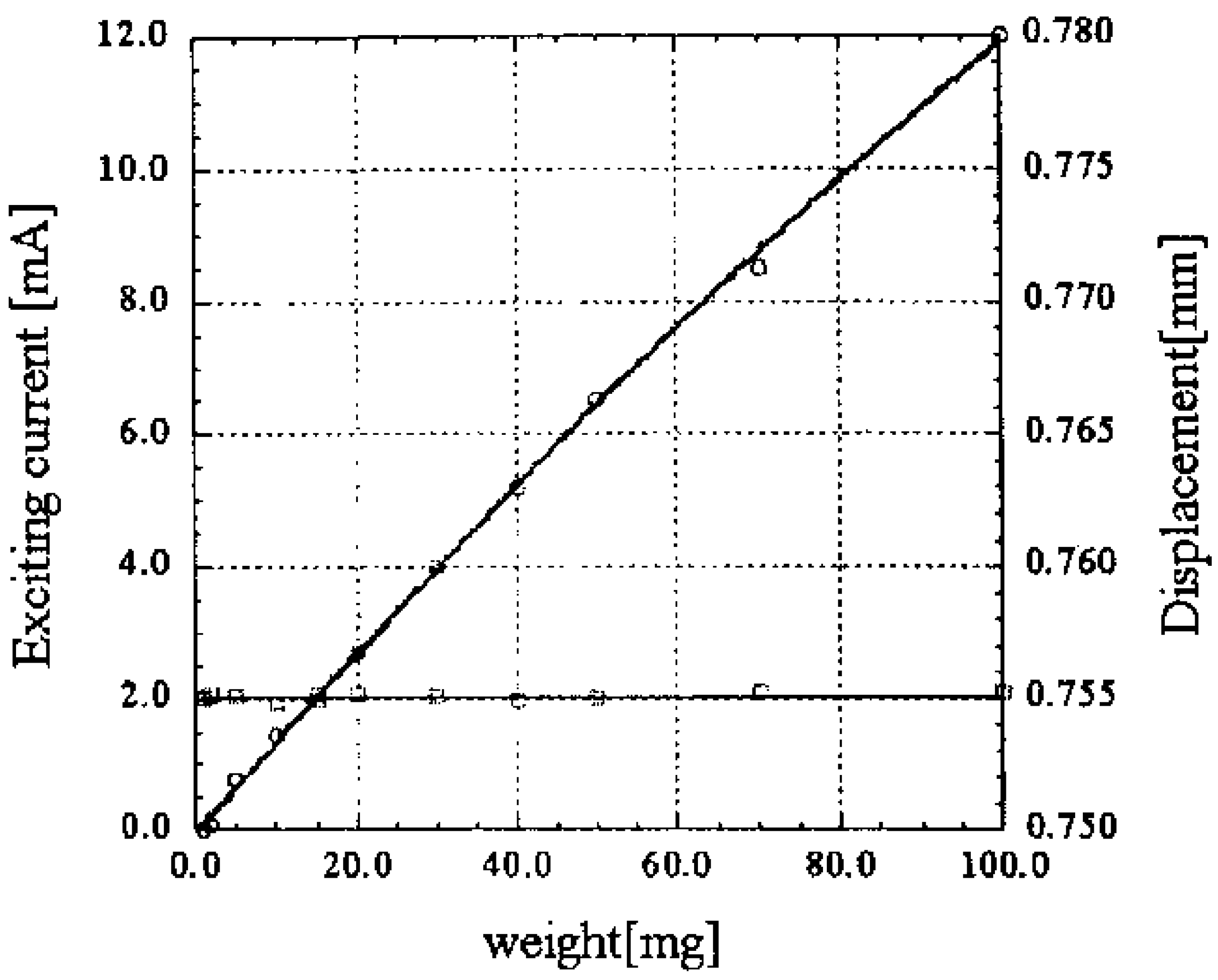


Fig.9 Control current of electromagnet and Displacement vs. weight characteristics in case of increasing mass gradually.

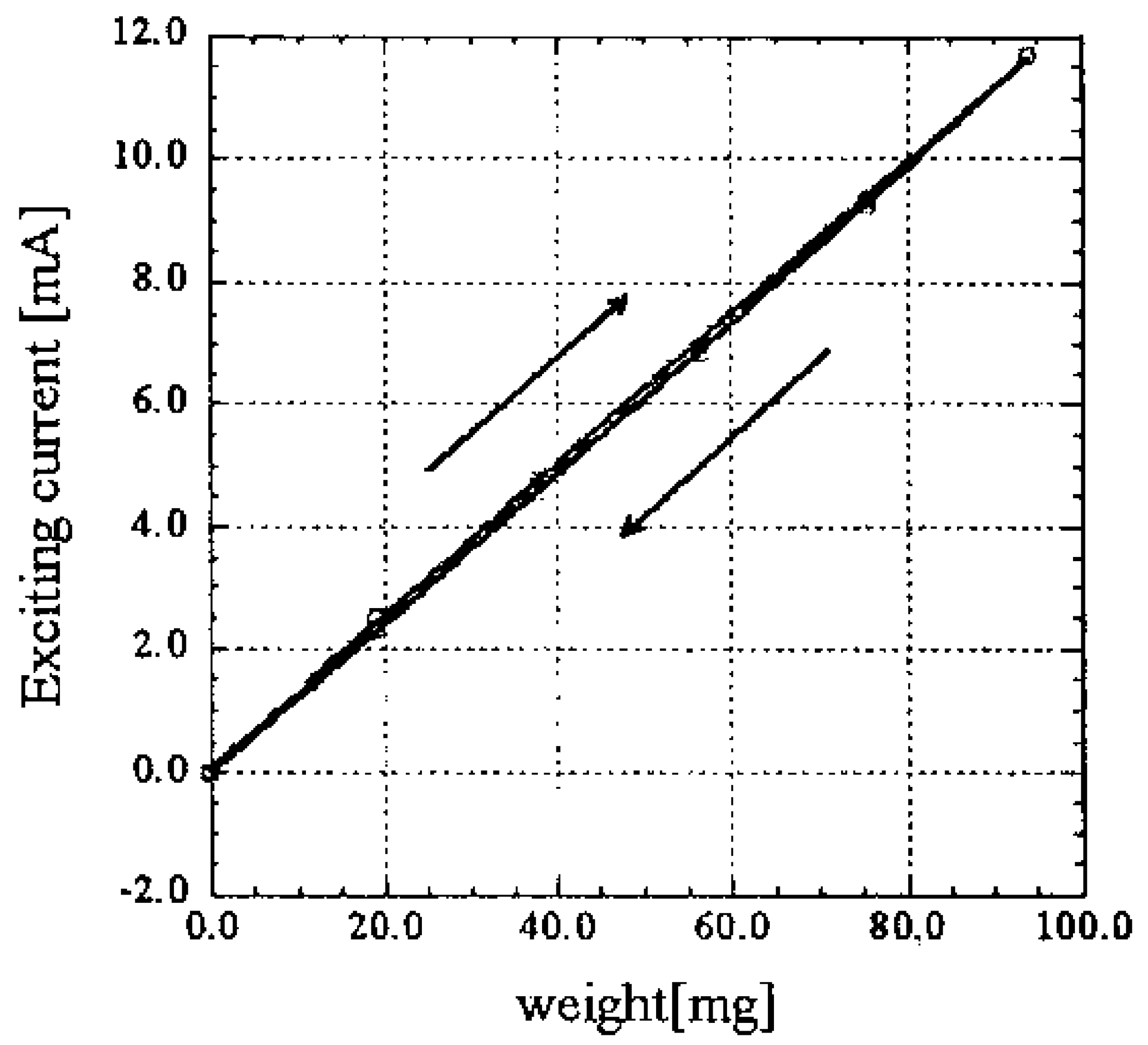


Fig.10 Control current of electromagnet vs. weight characteristics in case of increasing and decreasing mass.

3.2 In case of using a VCM

In order to decrease the hysteresis error and get more satisfactory measuring sensitivity, the system design should be modified. We replace the electromagnet used for control the vertical displacement of the balance beam by a VCM to avoid the error due to non-linearity of the force-current relation of the electromagnet.

$$F_m = k\,(\,i\,/\,x\,)^2 \qquad (1)$$

(F_m: attractive force, k: coefficient, i: electromagnet current, x: gap displacement)

We first set the system and adjust the steady levitation condition. The masses are added gradually and carefully to the holder, and in each time the control current of VCM is measured. Fig.11 shows the increase in VCM current vs. additional weight. In this plot, the control current increases linearly as the weight increases, this means that the system could be used as a mass measuring device by transferring the additional weight to the control current. From the following formula, it is clear that the relation between control current and additional weight is linear.

$$F_m = iBl * N \qquad (2)$$

(F_m: attractive force, i: coil current, B: flux density, l: length of a coil, N: number of turns)

In order to measure the hysteresis error, the control current is measured while increasing and decreasing the weight as shown in Fig.12 (a). Fig.12 (b) is an enlarged view of Fig.12 (a) around 20mg weight where the maximum error occurred. It is found that, the maximum hysteresis error is 48 μg, this means that the modified system is more precise and efficient than the previous one (730 μg). This value, 48 μg, is less than 0.05% of 100mg, which is the full weight.

4. CONCLUSION

This paper has presented a modification in the design of a permanent magnet repulsive type magnetic bearing

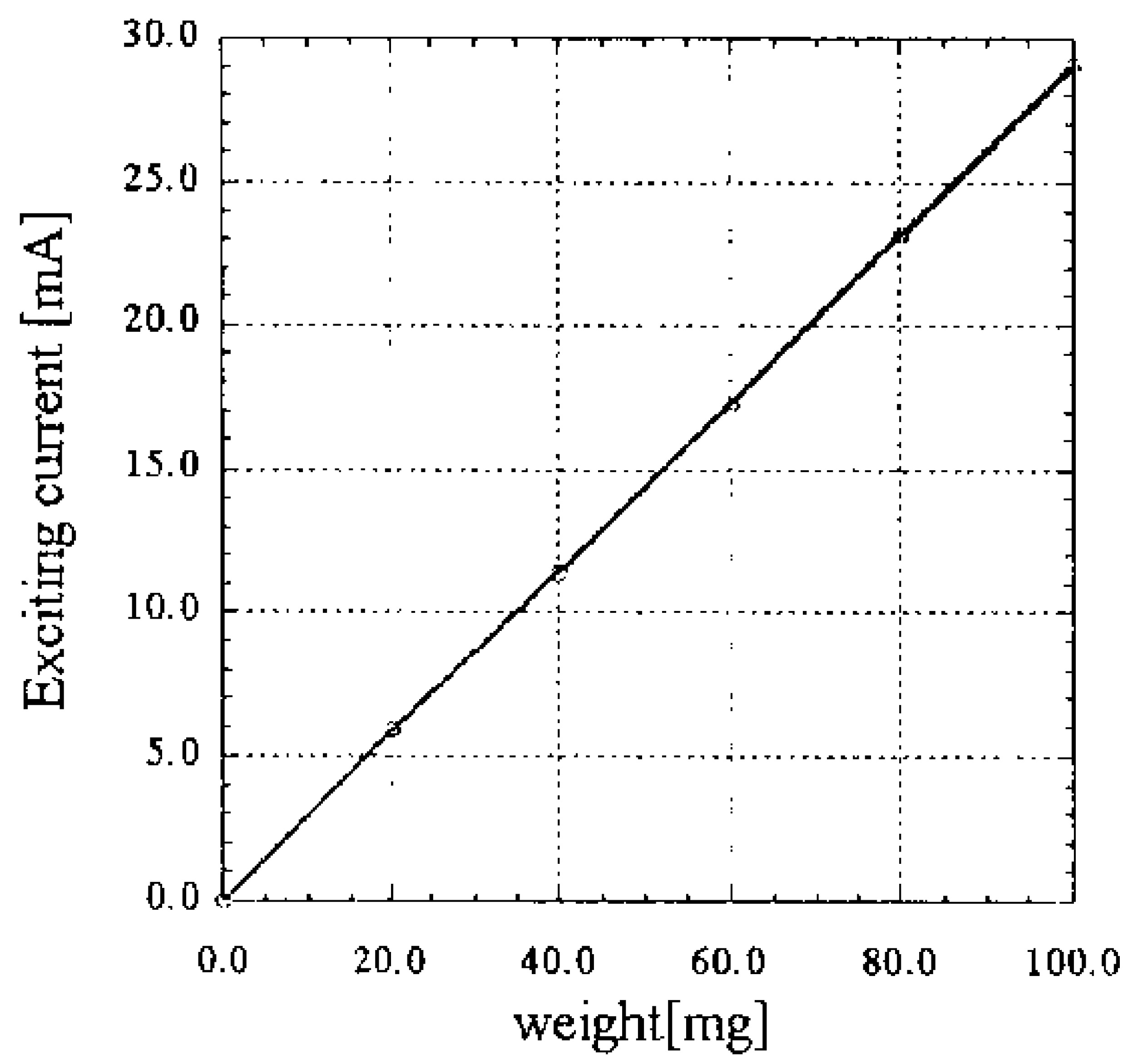
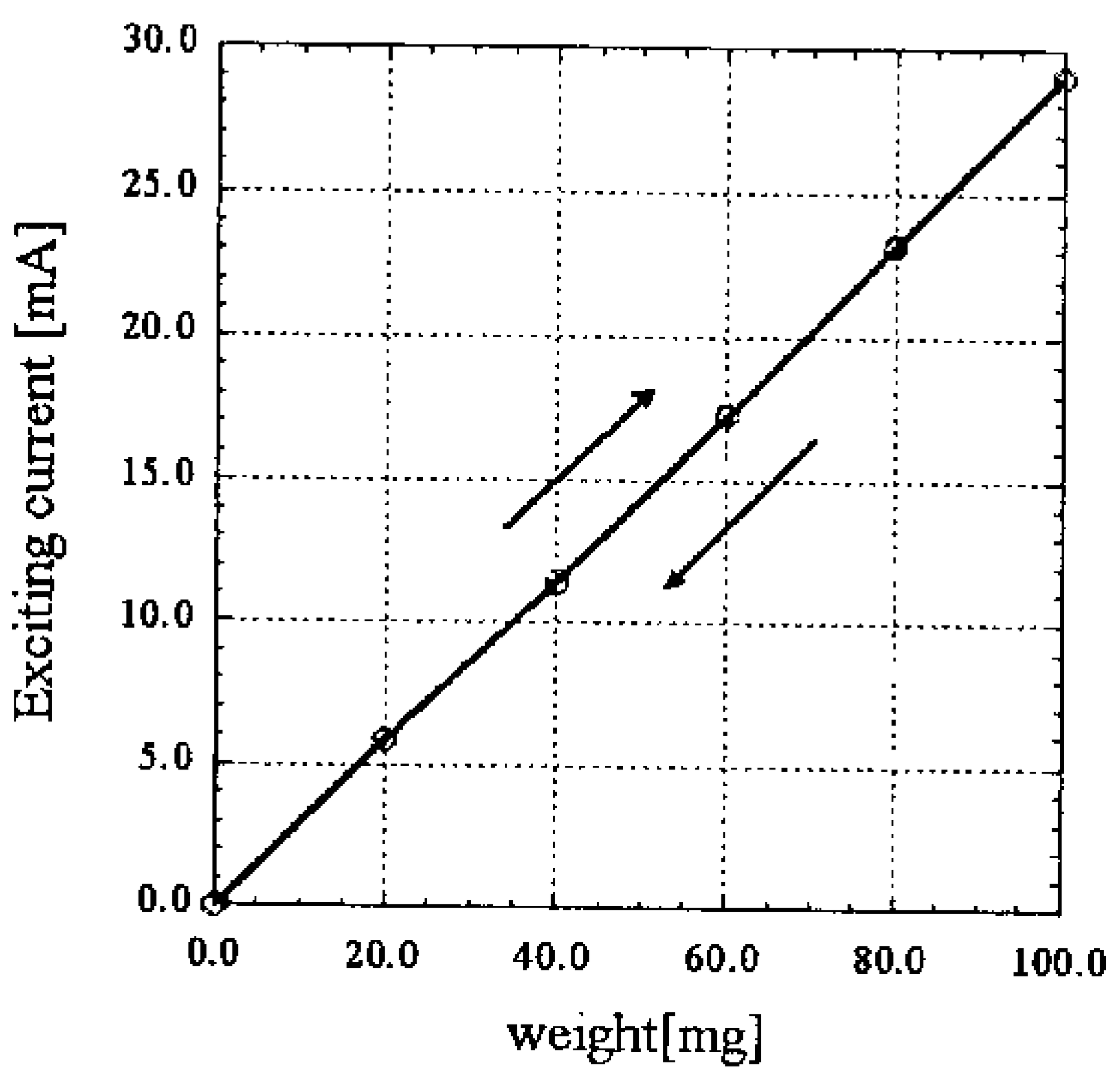
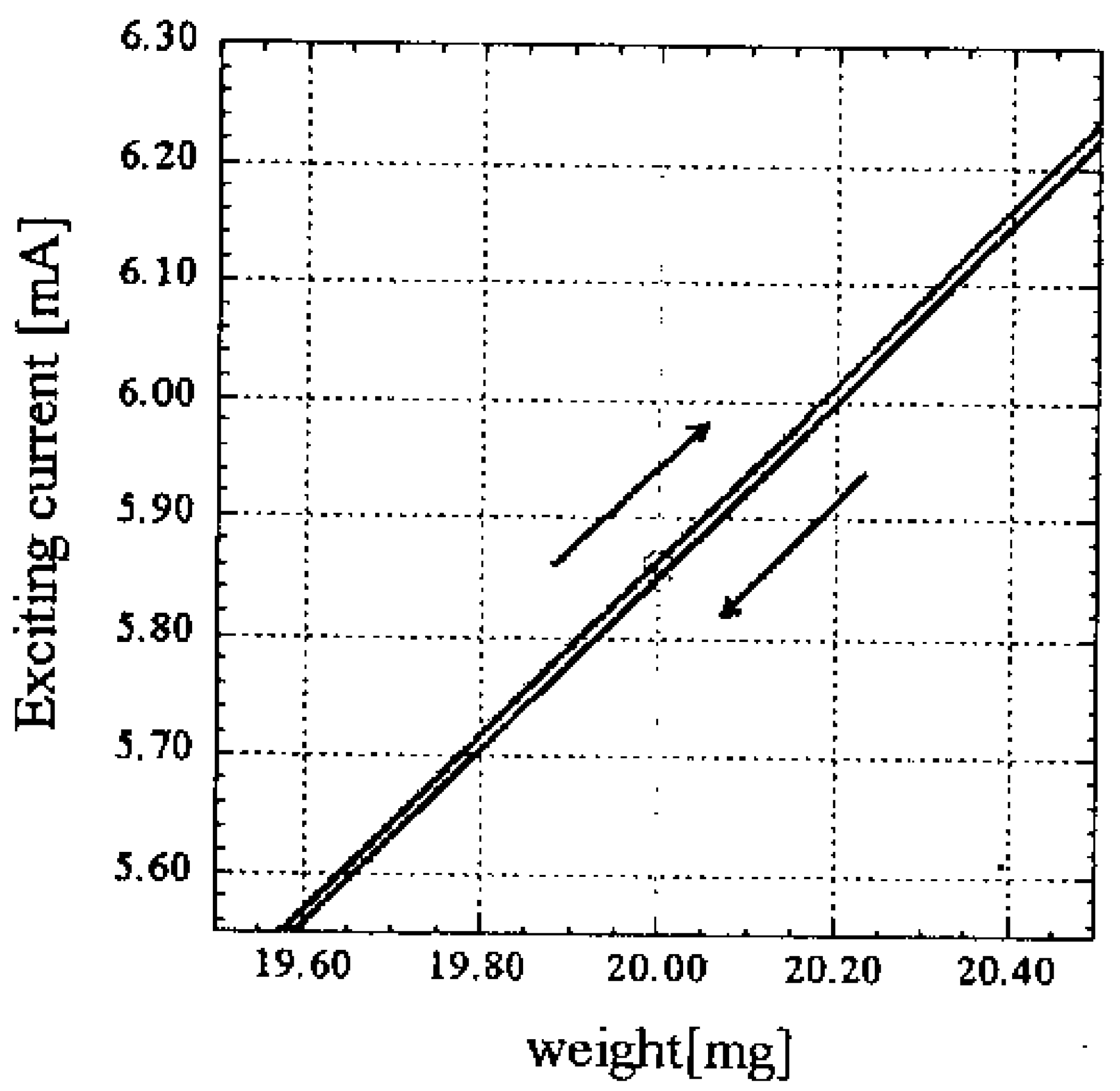


Fig.11 Control current of VCM vs. weight characteristics in case of increasing mass by 20mg.



(a) 0~100mg



(b) Close-up view around 20mg

Fig.12 Control current of VCM vs. weight characteristics in case of increasing and decreasing mass by 20mg.

balance system. The characteristics of that present system are much better than the characteristics of the previous one, where the maximum additional weight for both was 100mg. The maximum hysteresis error for the previous design was 730 μg; this means that the minimum weight can be measured is less than 1% of maximum weight. On the other hand the maximum hysteresis error of the modified design is 48 μg; this means that the minimum weight can be measured is 0.05% of maximum weight. Moreover, in case of using a VCM, there is an advantage that the control current increases linearly as the weight increases.

We could not remove the hysteresis error completely by using VCM because there is many expected reasons for generating such error. Some of these reasons could be due to the going down of the axial shaft while the weigh is increased, the noise generated by the electric circuit, the error of the control system design and disturbances like static electricity and turbulence.

In the future, we will design a new system taking into consideration the possible reasons of generating such hysteresis error, and try to overcome all these reasons to reach the error to be in order of nanogram.

5. REFERENCES

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