MAGNETORESISTIVE TRANSDUCER FOR ABSOLUTE POSITION DETECTION

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Abstract

In this paper a new method is presented for the measurement of absolute linear or angular position. The digital position information is recorded serially into one track of a suitable hard-magnetic medium. The stray field of this information layer determines the angular magnetisation distribution in a ferromagnetic (permalloy) detection strip which is positioned parallel to the track but with its plane perpendicular to the hard-magnetic layer. The bit pattern representing the position co-ordinate is regained by detection of the planar magnetoresistance effect in the sensor strip.
Experiments have been performed using sensors with a resolution of 250 μm and 1 mm respectively and longitudinally recorded audio tape. Suitable sensor output signals could be measured without hysteresis.

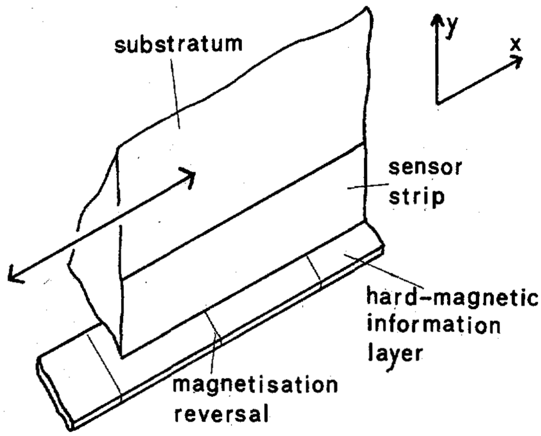

Fig. 1: Basic principle of the method.

Introduction

Usually a digital magnetic position detection device is based on an incremental principle. In that case a magnetic scale is used which has been recorded with magnetic transitions at equal distances. In many cases the resolution is improved by application of a interpolation scheme. A problem in incremental systems can be the error counts persisting in the position output until a new "reset" of the counting electronics takes place.

An absolute position detection system without the need of parallel tracks has been described by Jones [1]. The position information is coded serially by means of a maximum length sequence of 2^n bits. The position co-ordinate can be derived from the response of a sensor array detecting a series of n adjacent bits.

We propose to compose an absolute position detection system using a ferromagnetic (permalloy) sensor strip which is positioned parallel to the track but with its plane perpendicular to a hard magnetic information layer (fig. 1). This layer is recorded with a suitable magnetic bit pattern representing the position data.
The stray field of the hard-magnetic layer determines the angular magnetisation distribution in the permalloy strip and thus the local change of the electrical resistivity in the strip as a result of the anisotropic magnetoresistance effect. The original bit pattern can be reconstructed detecting the resistance pattern in the permalloy strip.

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Realisation

In the first instance we have chosen for a hard-magnetic layer (magnetic scale) with a bit pattern realised by longitudinal saturation recording. In this case a "one" is represented by a magnetisation reversal; a "zero" correspondents with the absence of such a reversal (fig. 2a). The permalloy sensor strip (with easy axis parallel to strip axis) is divided into a number of sensor elements by means of conductive stripes. In the neighbourhood of a magnetisation reversal in the magnetic scale the accompanying stray field results in a rotation of the magnetisation vector in the sensor strip and a reduced resistance value of the concerning element can be measured (fig. 2b). In general one needs at least two sensor elements for every bit to be detected, in order to produce reliable results in a static situation.

The actual angle of the magnetisation vector in a point of the sensor strip is determined by the external applied field, the anisotropy field H_K, the surrounding magnetisation distribution and the history of the magnetisation. The direction of the magnetic stray field has been sketched in fig. 2a. In the first instance the angular magnetisation distribution in every point of the strip can be derived by locally minimising the total magnetic energy conformable the single domain model [2].
If the stray field of a magnetisation reversal passes underneath a certain point of the sensor the field vector rotates over about 180° in that point (fig. 2a). In order to coherently rotate the magnetisation vector, the amplitude of the stray field must be well above the anisotropy field value H_K in these points. Anyway, at the edges of the

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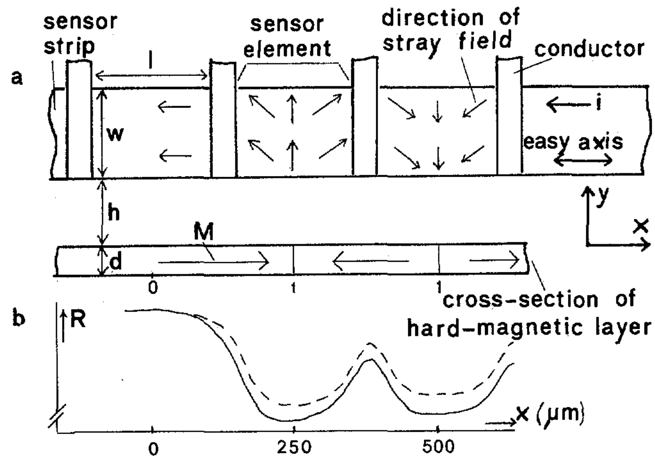

Fig. 2: a. Sensor strip divided into sensor elements, positioned in the stray field of a hard-magnetic information layer.
b. Output of a sensor element with l=200 μm, w=50 μm, h=0 μm and tape coating thickness d=10 μm.
(——— measured, ----- calculated)

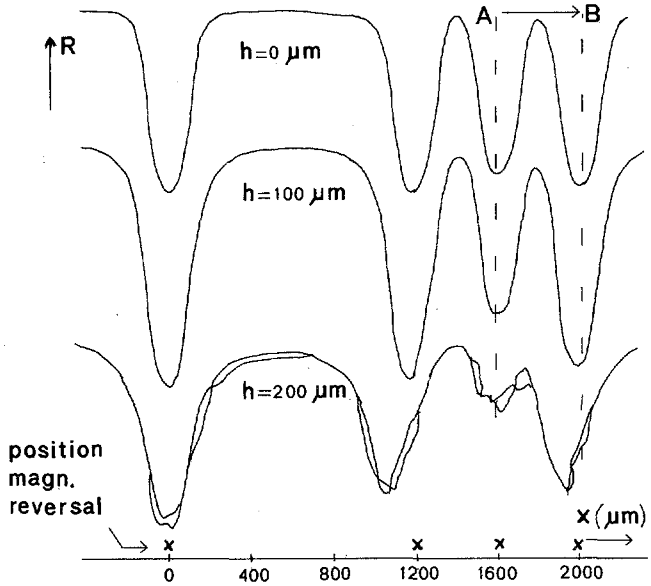

Fig. 3: Experimental output of a sensor as described in fig. 2b for 3 values of the separation h.

strip demagnetisation effects are expected to give rise to domain wall clusters as predicted by van den Berg [3]. Beforehand it is not clear to what extent these domain walls in the permalloy strip affect the distribution of the resistivity.

It can be ascertained that for a precise calculation of the angular magnetisation distribution a single domain model is not adequate and more advanced techniques have to be used.

Experimental results

Experiments have been performed with two types of transducers with permalloy thickness 50 nm and strip width w = 50 μm and 225 μm respectively. The aspect ratio l/w (length/width) of the sensor elements was about 4. The sensor strip was vacuum evaporated on a glass subtrate and covered over with another glass block. For the hard-magnetic layer Fe_2O_3 audio tapes were chosen with coating thickness d = 6 μm and 10 μm respectively.

For the four combinations of sensors and tapes the output of one sensor element has been recorded as a function of the position with respect to a bit pattern in the magnetic scale for various values of the separation h between sensor and magnetic layer. Typical output curves are shown in fig. 2b and fig. 3.

We have found that for h- values up to approximately 2w, a smooth sensor output appears without hysteresis. For example in fig. 3 for $h \leq 100$ μm the curves taken backwards and forwards are exactly identical while for h = 200 μm hysteresis can be observed.

In fig. 4 the calculated trajectory of the stray field vector in a point at the upper edge of the sensor strip has been drawn for 4 values of h. It can be seen that in the point where the magnetic field vector crosses the y-axis its amplitude is well above the value of H_k (about 1000 A/m) for $h \leq 100$ μm. However, for h = 200 μm this condition is not fulfilled and obviously magnetic wall clusters are formed which can give rise to hysteresis phenomena in the sensor output voltage.

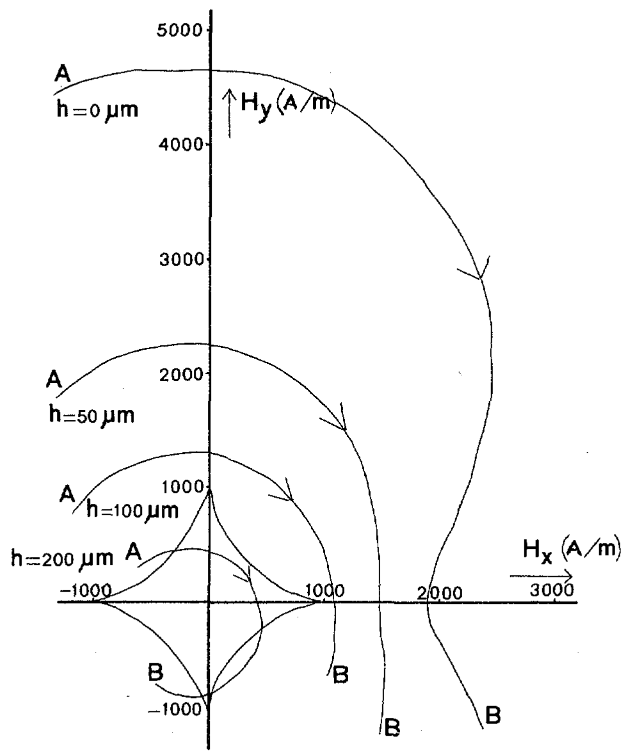

Fig. 4: Calculated trajectory of the stray field vector at the upper edge of the strip with respect to the Stoner-Wohlfarth asteroid for a displacement as indicated in fig. 3 and a bit period of 400 μm.

Reconstruction of the position information can be performed by level detection of the sensor signals using two sets of sensors with a shift of (n + 1/2) bit period.
Consequently only the sensor output along one half bit period has to be detected by a sensor element. In this interval the difference between the lowest value of a "one bit" and the highest value of a "zero" bit (the detection distance) must be maximised for optimal detection reliability.
This can be visualised with the help of a so called "eye pattern" which is drawn in fig. 5 for a bit period of 250 µm and 3 values of the separation h. In this example we see that the detection distance decreases with increasing value of h. At the same time we have found that the detection distance increases with increasing value of the bit period, especially for h > 100 µm.

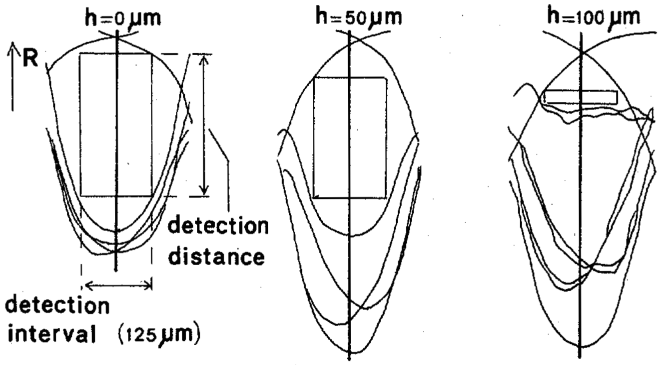

Fig. 5: Eye patterns, constructed from measured curves for various values of the separation h and a bit period of 250 µm.

We can conclude that for low values of h an invariable magnetisation pattern in the strip runs fixed to the bit pattern in the magnetic layer.

Computer calculations

A simple computer simulation program has been written on the basis of the Stoner-Wohlfarth model ignoring effects of the magnetisation divergences in the strip and at the edges.
For this purpose the sensor elements are divided into rectangular subelements and the angle of the magnetisation with respect to the easy axis is computed by minimising the magnetic energy in every subelement. Next the resistance of the complete sensor element can be determined.
The calculated sensor responce has been compared with the measured curves. A reasonable agreement was found with respect to the form of the calculated and measured curves (see for an example fig. 2b). However, the amplitudes showed deviations up to some tens of percents, which could not be fitted by means of a single correction factor. This simple model thus predicts the response qualitatively well, but a more sophisticated model must be developed for a precise optimisation procedure.

Conclusion

A new method for magnetic measurement of absolute position is presented. The serially recorded data is detected by a sensor array which can be realised in one permalloy strip and fabricated by means of photolithographic processes. Positioning of the transducer with respect to the azimuth is not critical in first order and in principal contactless detection can be implemented. Basically there is no necessity to expose the sensor to an initialising procedure and to apply (linearising) auxiliary fields.

The resolution of the position measurement is related to the pitch of the sensor elements. The number of different position co-ordinates that can be (de-)coded is determined by the sensor array length and is not restricted in principle.

The performance of the method is dependent on the angular magnetisation distribution in the sensor strip caused by the stray field near the magnetic scale. Modelling this process mathematically is not elementary.
Experiments have been performed with two types of sensors, combined with magnetic tapes which were recorded by longitudinal saturation recording. It was found that suitable sensor outputs can be obtained without "jumps" and hysteresis. A simple computer simulation model only can produce a first order approximation of the sensor response curves. Supplementary research is needed to obtain more detailed information concerning the magnetisation distribution in the sensor strip.

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