Integration of the Read-After-Write Method for Gentelligent™ Applications

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Summary: The main goal of the gentelligent™ approach is to create components which are able to store production data on their own surface, to find their way independently through the industrial environment and to monitor their own condition. Magnetic data storage directly on the component's surface is carried out by an inductive write head. A data storage process requires components with magnetic characteristics. In case of non-magnetic materials such as magnesium, the magnetic properties can be achieved by integration of magnetic micro particles. This material is developed for the gentelligent™ approach and is called magnetic Mg, where the magnesium matrix is filled with hard magnetic γ-Fe_2O_3 particles. For the readout of stored data from the gentelligent™ component from a distance the magneto-optical method is used. To guarantee data security and to avoid data loss during the writing process a field sensor is integrated in the writing system. This approach is based on the read-after-write method where written data is immediately checked by the sensor after the writing process. Due to challenges on the particle storage medium, special techniques are required for analysis of the sensor output signal. This paper presents the first readout experiments for the gentelligent™ approach by usage of the GMR-sensor. To improve data safety and to reduce errors caused by particle distribution in the magnetic Mg, the sensor output signal analyzing techniques in this work are combined and specially optimized.

Keywords: GMR Sensor, Data Storage, Gentelligent, Hard Magnetic Particles.

1. Introduction

Gentelligent™ (GI) components avoid the physical separation of components and corresponding information. The term "gentelligent" is a combination of two words: "genetic" and "intelligent" and describes the inherent connection of the components with their own product information and their characteristics. The GI components are both genetic and intelligent. The genetic information is statically stored on the components themselves. This information can be used for the reproduction of the component and describes a component's geometry and material properties. Furthermore, it can be bequeathed to the next generation of the components. This method is based on biological principles of bequeathing information and of lifelong learning during the period of usage. As product information is embedded in a product itself, GI components allow self-authentication, thus finding a way through an industrial environment without external control [1], [2]. This intelligence feature of GI components during the production process uses dynamic data storage.

The GI approach allows the marking of the components without usage of bar codes and Radio Frequency Identification (RFID) systems. The static and dynamic data storage on the surface of the GI component can be accomplished by a magnetic write head. For the readout process from a distance the magneto-optical Kerr effect (MOKE) is used [3]. For increasing of data recording security the recorded data has to be checked directly after the writing process. For this purpose the read-after-write method was developed and integrated in the write system.

2. Storage Material

A new material called "magnetic magnesium" has been developed for the data storage on the GI component's surface. Magnetic Mg consists of hard magnetic γ-Fe_2O_3 particles which are fully integrated in a Mg matrix by the application of powder metallurgy. Mg as basic material is blended with the magnetizable material in powder form, pressed to form and sintered at high temperature. For the magnetic data storage and further readout the sintered segment is cast directly into a functional component near the surface [4].

3. Data Storage Principles

The GI technique uses a data storage system which is based on the conventional hard disk drive data storage technology. The write head consists of a soft magnetic MnZn core with high permeability, two coils, and an air gap [5]. The coils generate the magnetic flux. During the data storage process the magnetic head device is moved over the recording medium's surface. A spreading magnetic field is produced in the air gap, which magnetizes the hard magnetic particles in the storage medium. The direction of magnetization of the entire bit-cell can be changed by means of reversal of the current direction in the coils. Depending on the direction of magnetization, one can distinguish between "0" and "1" (Fig. 1). By this method the information can be stored directly on the component's surface as a magnetization track. The horizontal H-field component produced by the head in the air gap must exceed the coercivity H_C of the storage medium. A field equals to 2.5 times H_C is commonly used to reverse all the magnetization in the storage material [6]. The magnetic coercivity H_C of the magnetic Mg is 23 kA/m.

4. Read-after-write

The main idea of the read-after-write method is to enable data security by a magnetic field sensor which allows checking the stored data information immediately after the write process. For the read-after-write approach, the magnetic field sensor based on the multilayer Giant Magneto Resistive (GMR) effect is placed behind the magnetic write head (Fig. 1).

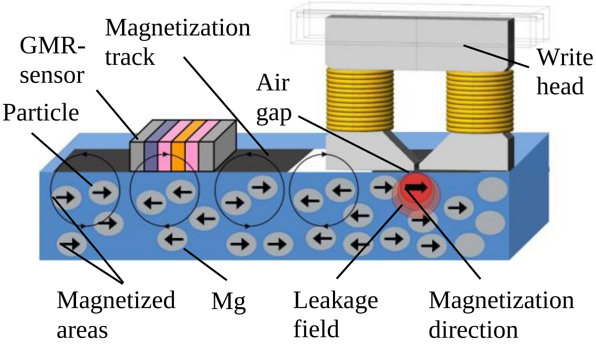

Figure 1. Schematic principle of read-after-write.

To enhance sensitivity, the GMR-sensor consists of a Wheatstone bridge with on-chip flux concentrators. The output signal of the device is the DC voltage. When the sensor is guided over the magnetic Mg surface without magnetization tracks the desired output signal has to be the constant reference level which is depicted in figure 2a. However, the actual reference signal over the magnetic Mg is not constant and is presented in the figure 2b. The challenges are twofold. First, the output signal of the sensor is dependent on particle distribution in the storage material and this distribution is not homogeneous. Second, the write head carrier causes small vibration during the guiding over the storage surface and changes the distance between the sensor and the surface. Both effects have strong influence on the output signal of the sensor. The impact of these effects on the measured output signal is depicted in figure 3 on the sequence "10101100". To make the readout of stored data information by the GMR sensor possible, four special techniques were applied.

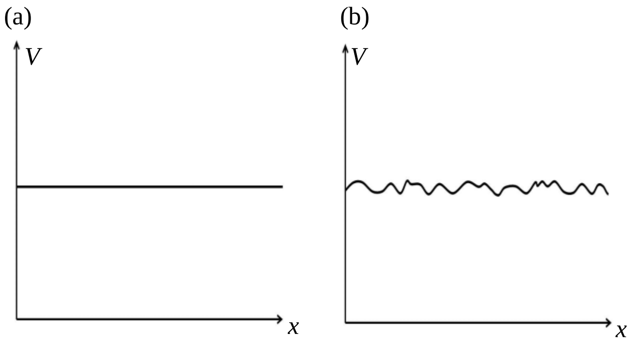

Figure 2. Reference output signal (a) desired, (b) actual.

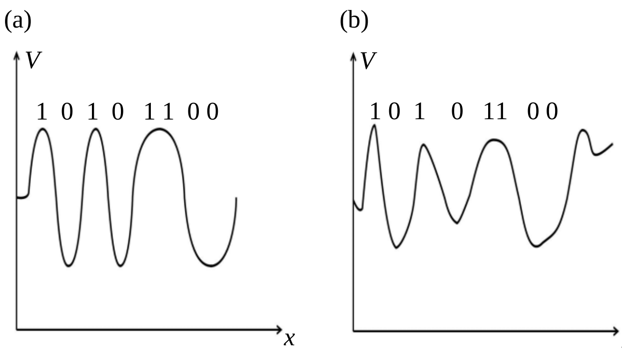

Figure 3. Output signal (a) desired, (b) actual.

4.1. Setting the starting point

The first task is to find a starting point of a magnetization track of 8-bit data patterns. For this purpose, a start sentinel was employed which in our case was a simple "101" pattern. This technique in spite of reducing storage density allows accurate finding of the starting point by the GMR sensor in a readout process.

4.2. Determination of the gradient

Determination of the gradient was the first technique used here for differentiation between "0" and "1" logic level. Due to the air gap length of the write head, the optimized minimum length of the bit is 100 µm. Based on a starting point, the GMR sensor was set to a readout position. An offset between a readout area and a writing area was carefully set in order to increase readout accuracy (Fig. 4a). From the readout position, 20 data points were sampled in 5 µm intervals. The gradient was calculated for each interval. For a data bit, a summation of 20 gradient values was evaluated and interpreted as a "0" or "1" logic value. However, the gradient method requires a constant data width. Ideally, a desired distance between the maximum and the minimum data point is constant. In reality the distance between peaks is vary due to an inhomogeneous distribution of hard magnetic particles inside Mg (Fig. 4b). The variable threshold level of the gradient value, dynamically adjusted by software, was required to eliminate this problem.

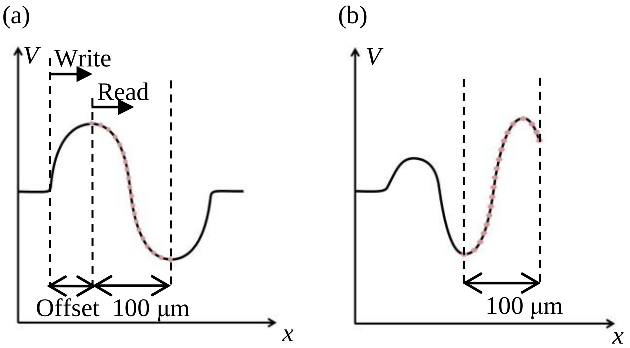

Figure 4. Output signal with sampling points (a) desired constant bit area, (b) actual variable bit area.

4.3. Extremum, Curve and State machine

In the case, where the gradient technique fails, the determination of extreme values was applied. This behaviour of the output signal is depicted in the Figure 5a where positive gradients cancel out negative gradients. The gradient method identifies the output signal neither as "0" nor as "1". The solution is to check the minimum and maximum point of the curve. In this case, the identification of the extreme point clearly reveals a "0" logic level. Also this method can be combined with the curve analysis to increase accuracy. For example, if the output signal shows the extreme values which are not high enough, the curve behaviour is investigated. In some cases both the gradient and extreme values fail. An example is a flat region above a reference. Then the application of the state machine technique is required. The state machine checks the previous signal state and evaluates a new signal state. Figure 5b depicts how the algorithm distinguishes between curve analyzing and the state machine. The areas which are marked with "c" show the extreme values which are not high enough for the analysis by extreme technique. So, the curve behaviour was employed. In the area with a flat signal above the reference, the state machine was used. This is marked with “s”.

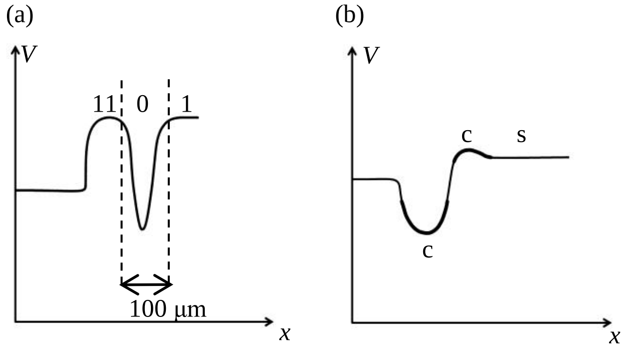

Figure 5. Example of the output signal which requires (a) extreme values method, (b) curve analyzing and state machine method.

5. Experimentals

For the readout process, the GMR-sensor was placed behind the write head. Both devices were fixed on the carrier positioned over the magnetic Mg surface (Fig. 6). Due to 8-bit pattern consisting of “0” and “1”, 2^8 -combinations were tested by the write and readout processes. During tests estimated 2% of the read patterns failed during the readout because of different failure sources. The remaining patterns showed error-free behaviour. Thus redundant patterns for failure correction are necessary.

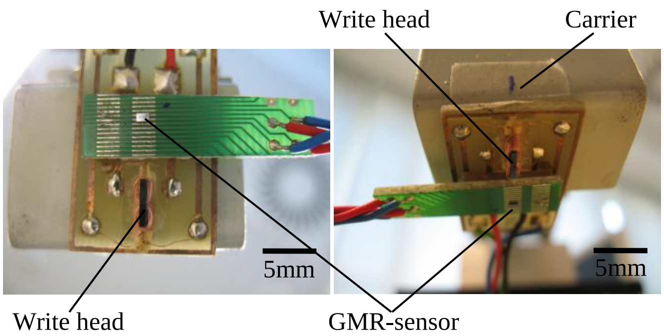

Figure 6. Read-after-write setup.

6. Conclusions

The feasibility of the readout of stored information on the surface of gentelligent™ products by the GMR sensor was demonstrated in this work. Due to inhomogeneous distribution of the hard magnetic γ-Fe_2O_3 particles in the Mg matrix, the direct decoding of the sensor output signal is not possible. The combination of the four analyzing techniques provides a powerful method for the GMR-sensor readout and distinguishing between “0” and “1” with 98% accuracy. Critical parameters e.g. data width area, signal threshold levels and an offset between write and readout positions were optimized. This approach makes the integration of the GMR-sensor and increasing data security for the gentelligent™ applications possible. The optimization on the storage material and the write and read processes will achieve the further increase of the readout accuracy and data density.

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