Rotational speed measuring digital apparatus using a magnetic amorphous metallic glass as an induction coil

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We describe a rotational speed-measuring device that uses a coil of amorphous metallic glass magnetically coupled to a rotating element, to which a small magnet is attached. The coil is assembled by winding a tape of metglas 2605 SC and attaching to it connecting copper wires by means of silver paint. The output signal from the rotating element is processed and displayed in a liquid crystal display. Provision is also made to connect the signal to a computer.

Keywords: Amorphous materials; digital measuring apparatus; induction

Se describe un dispositivo que utiliza una bobina de un vidrio metálico amorfo para medir la rapidez de giro de cualquier elemento rotatorio al cual se le haya adherido un imán permanente. La bobina se fabrica enrollando una cinta de Metglas 2605 SC con alambres conectores de cobre adheridos mediante pintura de plata. La señal generada en la bobina por el elemento giratorio se procesa y se exhibe en una pantalla de cristal líquido. El sistema también cuenta con una salida para conectar la señal generada a una computadora.

Descriptores: Materiales amorfos; aparato digital de medición; inducción

PACS: 06.70.Dn; 06.70.Hs; 07.55.+x

1. Introduction

Notwithstanding their lack of long range translational order [1], some a morphous materials exhibit unique structural and magnetic properties, that have raise a great deal of interest related to their possible applications. Moreover, the ferromagnetic order observed in some of these materials changed the conception that ferromagnetism required long range translational order, as in the crystalline state. Actually, the magnetic ordering can be understood in terms of the high correlation between neighboring atoms due to the short range exchange interaction between them, and also realizing that the local surroundings of each atom are not much different in the amorphous system than in the crystalline state [2]. In 1960, Gurbanov [3] predicted the existence of ferromagnetism in amorphous materials and short after amorphous structures with ferromagnetic properties were found [4]. From the technological point of view, the $T_{80}M_{20}$ type alloys are the most promising, where T stands for a transition metal and M for a metalloid.

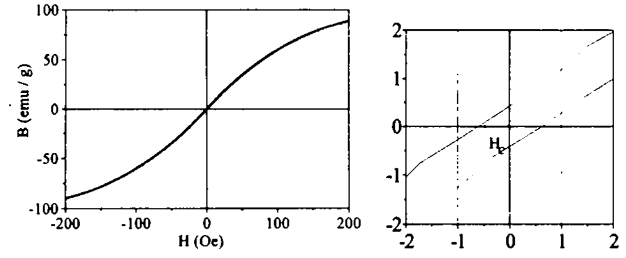
One of the relevant properties of Metglas is that it is a soft magnet, which means very small coercive field, great structural homogeneity and very small magnetic anisotropy. It also implies that grain boundaries, which normally act as pining centers for the magnetic domain walls, are essentially absent in this material. In consequence, it has been used as transformer cores and as sensing device is some applications [5].

In this work we use a coil built with a very thin (25 μm) strip of one of these amorphous alloys, commercially known as Metglas 2605 SC (Allied Chemical Co., USA) and nominal composition of $Fe_{81}B_{13.5}Si_{3.5}C_2$, as a sensing device for any type of rotational movement. The advantage of this coil respect to a conventional copper coil is that, in virtue of the magnetic properties of Metglas [6], the coil acts as if it had a magnetic core, concentrating the magnetic field of the permanent moving magnet, attached to the rotating element. In consequence, the magnetic flux through the coil increases and an improved voltage signal is obtained. Copper coils, with and with out magnetic core, have long been used as sensing devices of magnetic field variations. However, to our knowledge, this is the first time that an amorphous magnetic material is used with this purpose.

2. Experimental

2.1. Metglas characterization

Hysteresis curves at room temperature were recorded on a 2.7 mg sample of as-cast Metglas 2605 SC on a LDJ 9600 VSM vibrational magnetometer. Applying the magnetic field at different directions with respect to the tape it was determined that the easy magnetization direction was along the plane of the tape. In Fig. 1a we show the hysteresis curve (B, H) for this case and in Fig. 1b we show an amplification of the (0,0) region that evidences the small value of the coercive field.



(a) (b)

FIGURE 1. a) Hysteresis curve for as-cast Metglass with the applied magnetic field along the tape plane, b) the (0,0) region.

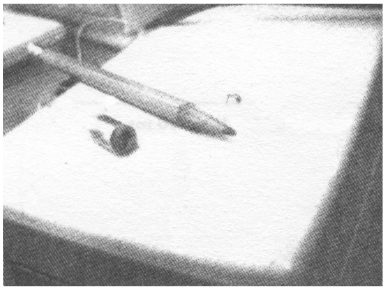


FIGURE 2. Metglas coil.

2.2. Coil assembly

An 8 mm diameter Metglas coil was assembled winding six turns of a 10 cm long, 1 cm wide and 25 μm thick tape (Fig. 2), just as rolling a strip of paper. Electric isolation between each turn was simply achieved with Scotch tape. Two conducting copper wires were glued to the tape, one at each end, using silver paint.

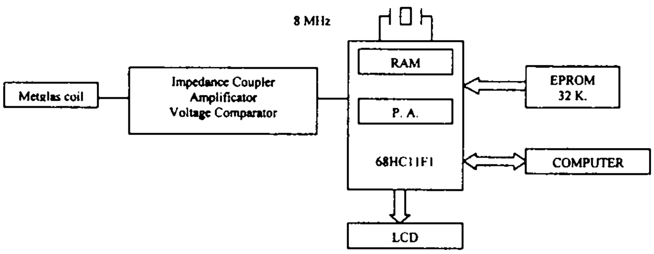


FIGURE 3. Block diagram of the digitizing circuit for the Metglass coil.

2.3. Setup and electronics

The coil was placed 5 mm apart from a common magnet attached to a disc mounted in the shaft of a moto-tool, in such a way that the fast magnetic flux variation generated a bipolar voltage pulse with each turn. This voltage is then sent to an electronic circuit described in the following paragraphs.

In Fig. 3 we show the block diagram of the complete circuit. The first integrated circuit [7] is an impedance coupler between the coil and the following amplification stage. The only important characteristic of the induced voltage is that is sufficiently high as to drive the amplification stage just mentioned, because the amplified signal is then fed into a voltage comparator to generate a square signal, the negative part of which is eliminated by a rectifying diode. No linearity requirements are needed in this operating mode. The pulses so generated are send to the pulse accumulator input of a Motorola 68HC11F1 micro-controller [8] which are then counted and saved in an internal RAM. Finally, the information is send, as frequency, to a two row, twenty column alphanumeric liquid crystal display; an optional computer output is also provided. The complete circuit diagram is show if Fig. 4.

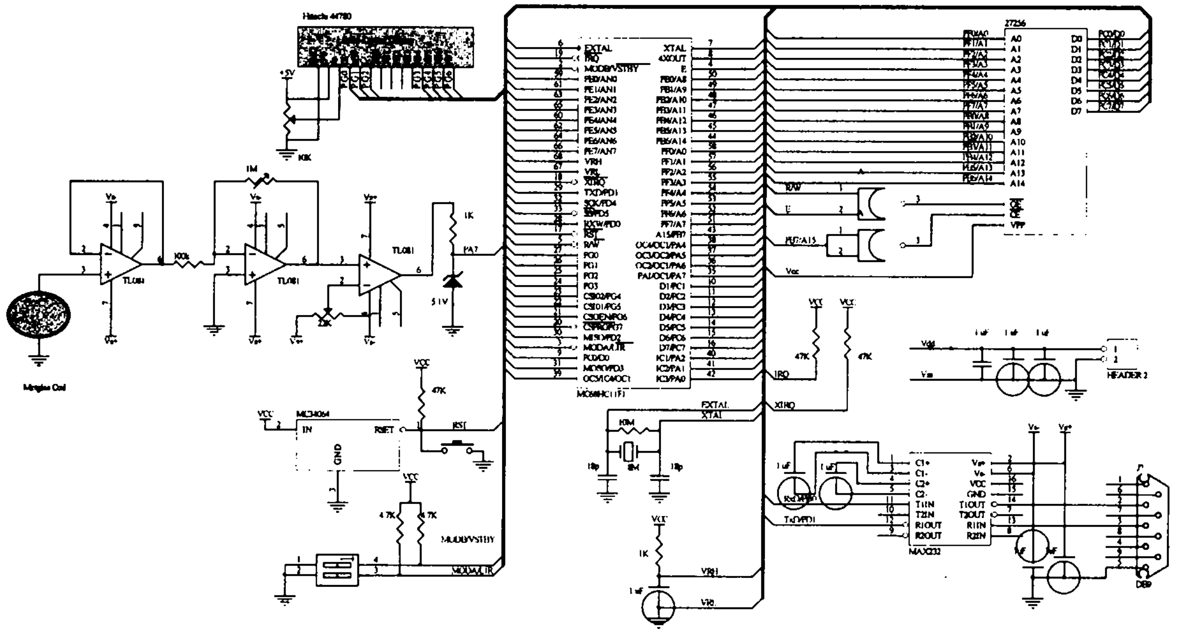


FIGURE 4. The complete circuit diagram.

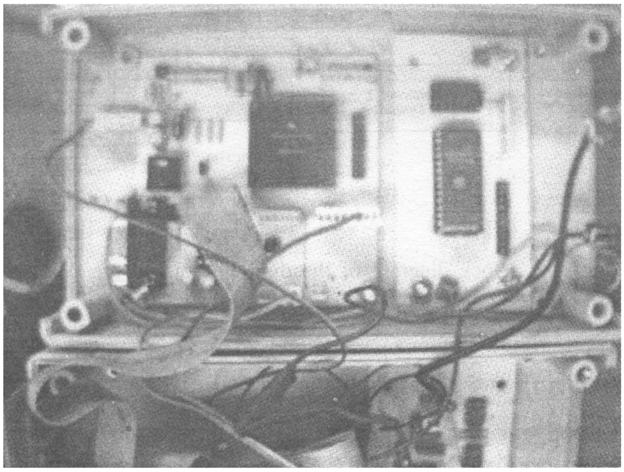


FIGURE 5. Assembled instrument.

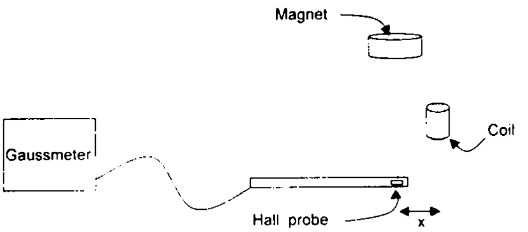


FIGURE 6. Setup to measure the magnetic field intensity as a function of the coil position x.

In order to drive the micro-controller, configured in the extended mode, an external 32 K EPROM, with the pulse counting, frequency conversion and displaying information, is connected to the proper port. An 8 MHz crystal is also connected to provide a time base. To make a portable instrument, a DC-DC converter that works with a 9 V battery was also included. Fig. 5 shows the assembled instrument.

2.4. Coil characterization

The essential feature of the proposed application is the sensitivity improvement of the sensing device due to the easy magnetization along the tape plane. To quantify this effect, the magnetic intensity of a disk shaped magnet (similar to the one attached to the rotating element of our experiment) was measured with the Hall probe of a Bell 610 gaussmeter placed at 3.0 cm from the center of the magnet, as shown in Fig. 6. The Metglas coil was placed with its axis perpendicular to the magnet's plane and to the plane of the Hall probe. The coil was then moved along a line perpendicular to this axis and the magnetic intensity was measured as a function of the distance x between the center of the coil and the center of the magnet; the results are shown in Fig. 7. As can be seen in that figure, the magnetic intensity H when the coil is aligned with the magnet increases to almost twice its value when the Metglas coil is absent.

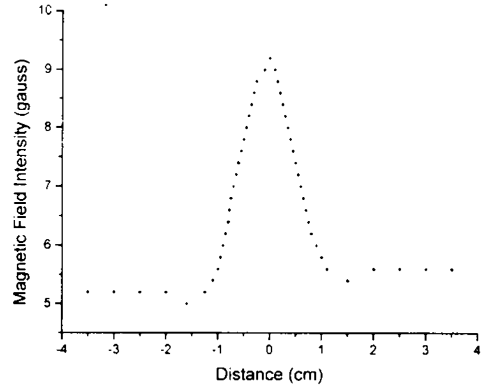


FIGURE 7. Magnetic field intensity as a function of the coil position x.

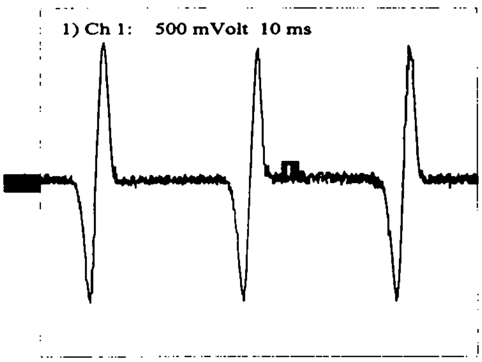


FIGURE 8. Sensor signal at 1 750 RPM.

3. Results

The high sensibility of the device is to be associated with the above-mentioned magnetic properties. That is, the device acts, in the overall, as a conducting coil with a "magnetic core" that guides the magnetic field along the plane of the tape (easy magnetization direction), increasing the magnetic flux and, hence, the induced voltage. Due to the small value of the coercive field, the energy looses associated with hysteresis are very small. Naturally, the magnitude of the induced voltage drops quickly with distance between the coil and the magnet. The precise way this voltage drop takes place depends on the characteristics of the coil and of the magnetic field. In any case, winding a coil with many turns can increase the magnitude of the induced voltage.

To test the system and calibrate the display, the output was connected to a 100 MHz Tektronix oscilloscope (Fig. 8). The device generates useful signals from 1 to 30 000 RPM, which is the highest frequency given by the moto-tool.

4. Technical characteristics

- Operating temperature range:
  - a) Of the coil $-200°C$ to $+200°C$.
  - b) Of the complete device $0°C$ to $+70°C$.

- Frequency operating range 0.5 Hz to 500 Hz.
- Reproducibility better than 0.1%.
- Response time less than 100 μs.

5. Conclusions

Even dough the device can work with common small magnets, the use of tiny rare-earth magnets has two advantages:

a) The magnet can be attached directly into the motor shaft (or any other rotating element) with out altering its rigidity.

b) The strong magnetic field improves the sensibility of the device. The disadvantage is the price of this type of magnets.

Normal rotational speed-meters are mechanical coupled devices that present the following disadvantages:

a) Corrosion and frictional spoliation.

b) The mechanical coupling system always requires some power to drive the device.

c) They are usually heavy and bulky.

d) Their precision is not very good (±10%).

On the contrary, the system presented in this work has the following advantages:

a) The dimensions and weight (0.18 g) of the sensing element allow for its easy location in almost any rotating device (for example, in a bicycle).

b) The output signal can be connected to a computer to control the movement of different laboratory equipment.

c) Essentially no power is required to drive the device.

Finally, the main disadvantage of the device is related to the change of properties of the amorphous material with temperature. Actually, the material used in this work, crystallizes if it is maintained for long periods of time (greater than 12 h) at temperatures well below the crystallizing temperature (4). In our case, the safe working temperature should not be higher than 250°C.

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1. M. Ghafari and R. Gómez Escoto, *Hyp. Int.* **110** (1997) 51.
2. A. Aharoni, *Introduction to the Theory of Ferromagnetism*, (Clarendon Press, Oxford, 1996), p. 44.
3. A. Gubanov, *Fiz. Tver. Tela.* **2** (1960) 502.
4. R. Hasegawa, *J. Magn. Magn. Mater.* **100** (1991) 1.
5. R. Valenzuela *et al.*, *J. Appl. Phys.* **81** (1997) 4301.
6. V. Marquina *et al.*, *J. Magn. Magn. Mater.* **221** (2000) 327.
7. National Semicondutor, *Special Purpose Linear Device*, Manual (1989).
8. Motorola, *HC11F1 Reference Manual.*