On LVDT Response Using Glass Covered Wires

V. Karagiannis, D. Bargiotas, S. Voliotis, C. Manassis

Department of Electrical Engineering, TEI of Chalkis, Psahna, Euboea 34400, Greece

Abstract - In this paper we present results on the response of linear variable differential transformers (LVDT) using FeSiB glass covered wires as active cores. First we demonstrate that the noise level of the sensor decreases with the magnetostriction coefficient of the magnetic core of the wire. Magnetic noise is further decreased after heat treatment, magnetic annealing and stress-current annealing. These results are in relatively acceptable agreement with results presented in the past by other research groups.

I. Introduction

The linear variable differential transformer (LVDT) [1, 2] is well known for its applications in displacement measurements. It is based on a differential transformer with variable coupling between the primary and secondary coils. This variable coupling between the primary coil and the secondary coils depends on the type of magnetic material and the position of a movable magnetic core with respect to the secondary coils.

Conventional amorphous wires have been used as LVDT movable cores. These wires are prospective materials for numerous types of magnetic sensors like magnetic field, current, and torque due to the wide range of possibilities to control their magnetic properties and to their relative easy preparation method [3-4]. Recently developed glass covered amorphous magnetic wires can replace successfully in various applications the conventional amorphous wires, giving the possibility to miniaturize sensor elements and ensuring a high corrosion and mechanical resistance [5-7]. These materials consist of a cylindrical metallic core with diameter of 2-40 µm, covered by glass insulation with a thickness of 1-20 µm. High internal stresses are induced during preparation process in amorphous wire. The coupling between internal stresses and magnetostriction plays a significant role in the domain structure formation. In Fe-rich amorphous wires (positive magnetostrictive wires) this coupling leads in first approximation to a domain structure consisting of an inner core, with axial magnetization, and an outer shell, with radial magnetization.

In this paper we present results concerning LVDT displacement response when FeSiB glass-covered amorphous wires are used as a movable core. The amorphous wires had the diameter of the metallic core between 10 and 27 µm and thickness of the glass cover between 2 and 15 µm and were tested in the as-cast state and after current annealing (Joule heating).

II. Experimental set-up and results

The basic LVDT arrangement is presented in Figure 1. An one layer coil having 140 mm length and 2.5 mm internal diameter was used as the primary coil (1). The two secondary coils (2) of 55 turns each, were set on the top of the primary coil and were connected in series opposition. The primary coil was excited by an alternating current. The primary and secondary coils were made of 0.35 mm enameled copper wire. The distance between the secondary coils was 40 mm and each of them was set at 20 mm distance from the ends of the primary coil. The LVDT output voltage U_o corresponds to the differential voltage of the secondary coils. The glass covered amorphous wires used as active cores of the LVDT (3) were fixed in a 10 mm long glass tube with 2 mm and 1.5 mm external and internal diameters respectively. This tube was inserted into the LVDT, inside one secondary coil and was moved via a micropositioner having 1 µm sensitivity in movement. A signal generator (4) supplying a sinusoidal signal was connected to the primary LVDT coil. The output of the secondary coils was recorded using a digital oscilloscope (5). Due to the small number of coil turns, the thermal noise of the output voltage becomes low for this arrangement, increasing thus the sensitivity of the LVDT. Applying an exciting sinusoidal signal U (Figure 2a) in the primary coil (of minimum 10 mA rms value) in the absence of any ferromagnetic material inside the LVDT, the detected output voltage was zero. By setting a number of glass – covered amorphous FeSiB wires inside the LVDT secondary coil an output voltage Uo is detected (Figure 2b). Due to the large Barkhausen Effect (LBE) of these wires [5-8], the required number of wires is small.

Figure 3 shows the dependence of U_o on the displacement of the moving core made of $Fe_{77.5}Si_{7.5}B_{15}$ glass covered amorphous wires, in the as-cast form and after 100 mA current annealing for 5 min. The sinusoidal exciting current used for these measurements had an rms value of 20 mA and a frequency of 10 kHz. The

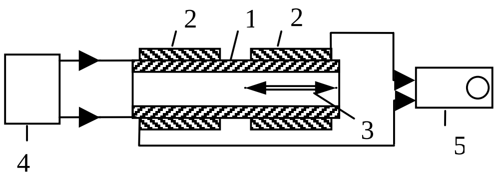

Figure 1. Basic LVDT arrangement. (1) primary coil, (2) secondary coils, (3) active core, (4) signal generator, (5) digital oscilloscope

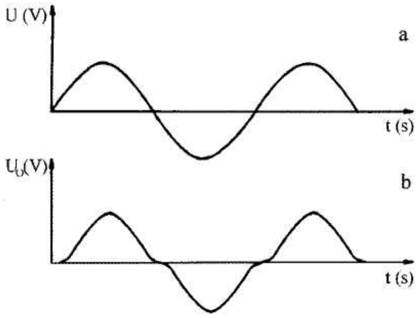

Figure 2. Input (a) and output (b) voltages of the LVDT.

sensor response dependence on the displacement of the moving core along the LVDT is linear for displacement up to about 14 mm, with an accuracy of 1 µm. After current annealing of the amorphous wires, the quenched-in stresses are relieved and an increase of the output voltage up to about two times can be obtained. Using FeCoSiB glass-covered amorphous wires as the active core in the same experimental conditions the LVDT sensitivity is about three times smaller than for core made of FeSiB glass-covered amorphous wires due to the fact that FeCoSiB glass-covered amorphous wires do not present large Barkhausen Effect [5]. The dependence of the peak output voltage U_o on the frequency of the input sinusoidal voltage U is shown in figure 4. The LVDT output voltage increases with frequency for frequencies up to about 180 kHz and then decreases. This behavior can be explained taking into account the changes in magnetic properties of the amorphous material and the losses in the core.

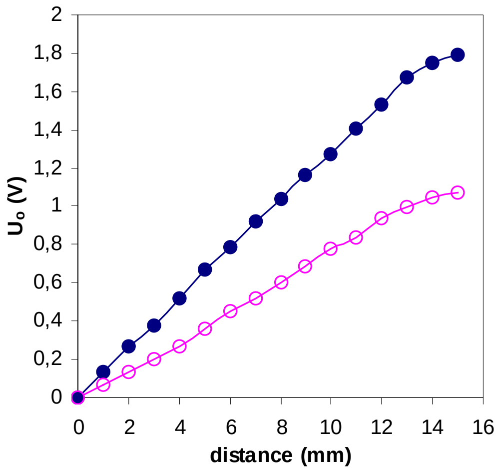

Figure 3: Dependence of LVDT output on the movement of Fe$_{77.5}$Si$_{7.5}$B$_{15}$ glass covered wire active core: (○) in as-cast form, (●) after 100mA current annealing for 5 min.

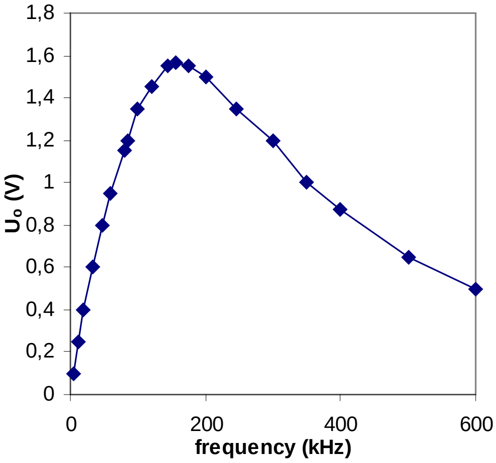

Figure 4: Dependence of LVDT output on the frequency of the input voltage.

The results obtained indicate that the LVDT using glass-covered amorphous wire as active core presents a high sensitivity. The low-noise level of the output voltage assures a good accuracy of the sensor. Furthermore, this sensor arrangement presents good mechanical and corrosion resistance.

III. Discussion

The most popular and probably the most important parameter in the industrialization process of the sensing element is its miniaturization ability [9, 10]. In many cases, miniaturization helps to significantly decrease production costs because of the thin film mass production lines. Sometimes, the quality of the produced devices increases with the decrease of the size of the devices, as in the case of semi-conducting miniatures like VLSI or ULSI chips [11]. However, sometimes miniaturization may be disastrous to the properties of a device. For example, miniaturized LVDTs offer poor sensitivity and larger uncertainty due to the hysteresis effect. Miniaturization is absolutely necessary, provided that the required properties are kept at the desired levels. Practically, this is in agreement with the recent trends in nano-crystalline and nano-structured magnetic materials for sensor and actuator applications, where the magnetic properties and domains still exist in the size of nanometers, before super-paramagnetism appears.

Another important characteristic of the LVDT is the dependence on the ambient field, which is a typical problem in many sensors based on magnetic materials [12-14]. It is the main reason that mechanical sensors based on magnetic materials have not properly found their way to the market. It is also a main reason that the vast majority of high quality field sensors are based on magnetic effects and materials. A usable technique can be applied, according to which independent detection of the ambient field can be used to correct the reading of the under measurement physical size, using look up tables and microprocessor based embedded circuits.

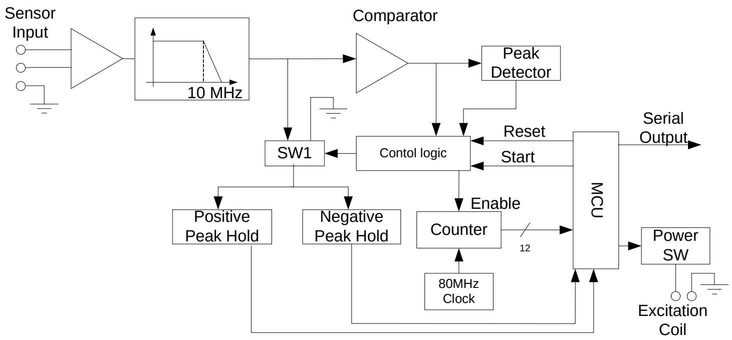

Figure 5: Hardware architecture for signal manipulation

The sensing elements require electronic circuitry for signal conditioning manipulation. A possible architecture of the hardware is depicted in Figure 5. The signal from the sensor input is amplified and fed to a 10 MHz low pass filter. The amplified signal drives a comparator. The analog part consists of two peak hold circuits and a peak detector. There is also a 80 MHz clock and a counter that counts the time from the start until the positive peak of the signal. The Microcontroller unit (MCU) samples the positive and negative peak amplitude as well as the counter value and sends the information to a PC through the serial port interface. It also drives the Power SW for the excitation voltage of the sensor. This circuitry offers an accuracy of 12.5 ns. A typical example of the interface software for the graphical representation of the results, is illustrated in Figure 6.

The diagram illustrated in Figure 7 reveals the hardware architecture for another possible implementation. The analog part of the hardware is kept to a minimum: an amplifier is used for the sensor and a power switch for the excitation voltage. The output of the amplifier is sampled by a A/D converter and stored in the DSP memory. The DSP processes the data and with proper software detects the peaks, or even specific patterns. Two different interfaces will be used. A serial port interface, (RS-232 or RS-485) to easily interface the system with a computer or embedded systems and a graphic LCD port to easily make the proposed system a handheld measurement system.

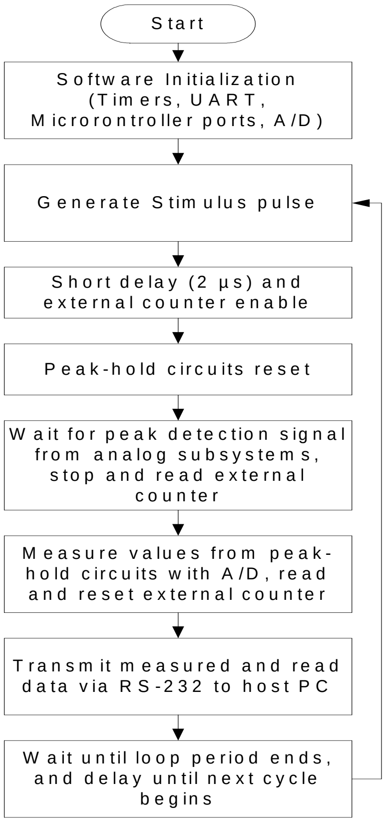

Figure 6: Typical software interface

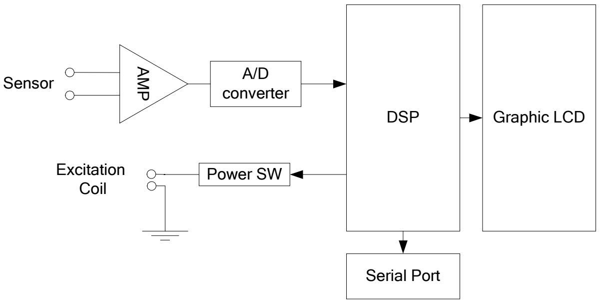

Figure 7: Alternative hardware implementation for signal manipulation

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