

# Load Sensors Based On The Magnetostrictive Delay Line Technique

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**Abstract** - In this paper we present results on load sensors based on the magnetostrictive delay technique. The sensors translate the displacement of soft magnetic plate, hard magnetic disk and aluminium disk into force with respect to three different magnetostrictive delay line set-ups. The range of displacement determines the range of measurable load. Stainless steel springs have been used as active core supports. The best results both in sensitivity and repeatability have been obtained using soft magnetic plate as active core.

## I. Introduction

Sensors and transducers have an increasing interest because of their importance in many technological applications [1, 2].

Mass sensors are divided into three main categories: the load cells, the pressure sensors and the torque meters; the flow meters and mass flow meters are a derivative sensing application. All these devices can be based on position or strain sensors detecting indirectly the applied stress. The most classical example is the strain gauge. However, there are magnetic materials and corresponding arrangements, which can detect directly the applied stress and therefore the load, pressure and torque on them, using the magnetization change caused by the stress-induced anisotropy.

Load cells measuring tensile stress directly are mainly based on inductive arrangements using as ferromagnetic core, a material sensitive to tensile stress. Such a core is usually a positive magnetostrictive material. The permeability decreases dramatically with stress, so that the output of the coil decreases correspondingly. Accelerometers can also be based on such arrangements. A number of load sensors, mainly based on inductive arrangements, have been presented in the past [3–9].

The MDL technique [1, 10-16] has also been involved in direct stress measurement. Typical values of sensitivity and uncertainty of these devices are 10-100 ppm and 100-300 ppm respectively, with an average cost of 1 kEuro/sensor. Pressure gauges have also been proposed based mainly on thin film arrangements, using the piezomagnetic effect. Today's load sensors are based on miniaturized elements fabricated by lithography techniques, thus allowing better performance and a drastic reduction in their cost. Recently, the MDL technique has been used for some interesting applications of load and derivative size measurements, with sensitivity better than the strain gauge arrangement. In this paper we present results on load sensors based on displacement sensors presented in the past [17-20].

## II. Soft magnetic plate setup

The first of the sensors presented in this paper is shown in Figure 1. A soft magnetic plate (1) supported by a stainless steel spring (2) is used as the active core (AC) of the sensor. This plate is placed close to the crossing point (PO) of the MDL (3) and a pulsed current conductor (PCC, 4). A receiving coil (RC, 5) is used to detect any acoustic pulse generated along the MDL as a voltage pulse. Pulsed current transmitted orthogonal to the MDL through the PCC causes a pulsed magnetic field along the axis of the magnetically soft ribbon, resulting in a mechanical strain at the region of the PCC-MDL crossing point PO due to the magnetostriction effect. So, an acoustic pulse occurs propagating in both directions, which is detected by the receiving coil RC around the MDL due to the inverse magnetostriction effect in the form of a pulse. The peak of this pulse  $V_o$ , is the output of the sensor. If the core AC is absent, the magnetic flux density in the MDL is maximized. By placing a load (6) on the magnetic plate, the spring is elongated and the core AC approaches the MDL, causing the magnetic flux density in the MDL to decrease due to the magnetic coupling between core and MDL. From the geometry, one can arrive at the following conclusion: the closer the core AC is to the MDL (i.e. the largest the load placed on the magnetic plate), the less magnetic flux in the delay line exists, resulting in a decrease of  $V_o$ . The displacement of the active core AC, and therefore the load placed on the AC, could be calculated with respect to the detected output  $V_o$ . It was experimentally observed that the presence of the core AC results in a change of the caused acoustic pulse for MDL-AC distance less than 2 mm.

Sensor response is presented in Figure 2. The results illustrated were produced using  $Fe_{74}Co_2Si_8B_{16}$  ribbon for active core construction,  $Fe_{78}Si_{17}B_{15}$  ribbon for the MDL and a stainless spring with  $k=150$  N/mm. Sensor sensitivity varies between 0.13 and 0.28 mV/N and is higher in the region 30 – 75 N and lower for regions 0 – 30

N and 75 – 180 N. This non – linearity in sensor response is due to both the non linear behaviour of the microstrain function of the MDL and the non – linear magnetic coupling between the MDL and the active core.

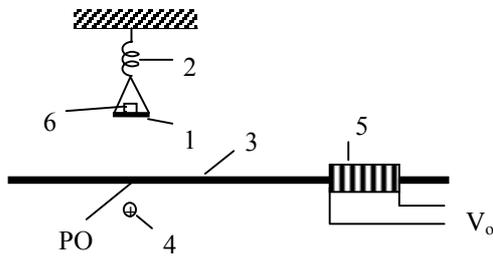


Figure 1: Load Sensor based on soft magnetic plate MDL set-up

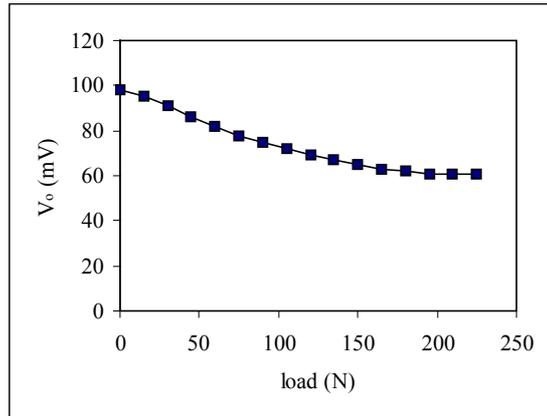


Figure 2: Soft magnetic plate sensor response

### III. Hard magnetic disk setup

The sensor arrangement is presented in Figure 3. A FeSiB amorphous ribbon is used as the magnetostrictive delay line (MDL), (1). Two coils are set around the ends of the MDL. The left one acts as the exciting coil (2) while the right one acts as the receiving coil (3). Pulsed current is transmitted through the exciting coil, generating a pulsed magnetic field along the length of the delay line. Two NdFeB permanent magnets in a form of pellet having a magnetic anisotropy parallel to their axis are placed over the coils. The first one is fixed above the receiving coil in order to maximize its output (biasing magnet, 4). The other one (5) is supported by a stainless steel spring (6) and acts as the sensor core. If a load (7) is placed on this magnet the spring elongates and the magnet is moving against the exciting coil, vertically to the MDL. This movement causes magnetic flux changes in the receiving coil, inversely proportional to the magnet distance from the exciting coil. These changes affect the biasing point of the  $\lambda(H)$  function of the MDL at the acoustic pulse point of origin. Therefore, transmitted pulsed current along the exciting coil results in a generated microstrain, the amplitude of which is dependent upon the above mentioned biasing field. Therefore, the amplitude of the corresponding propagating elastic wave and the detected pulsed voltage output depend on the mentioned biasing field, or the displacement of the moving permanent magnet from the receiving coil and is therefore inversely proportional to the load in question.

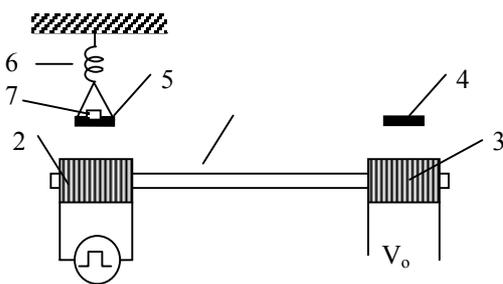


Figure 3: Load Sensor based on hard magnetic disk MDL set-up.

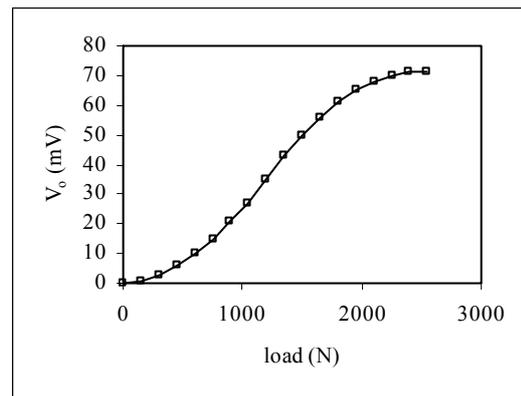


Figure 4: Hard magnetic disk sensor response

In order to compare sensor sensitivity and accuracy with the other arrangements, the stainless spring used to support the load has been chosen to have the same constant as the one used for the soft magnetic plate set-up, i.e 150 N/mm. Sensor response is illustrated in Figure 4. The sensor output is monotonic and presents a rather linear region for loads between 600 and 1650 N. In this region, sensor sensitivity is about 0.04 mV/N.

#### IV. Conducting disk setup

The arrangement of this sensor is shown in Figure 5. The delay line (1) which is free of stresses and preferably made of amorphous magnetostrictive wire in order to be more sensitive. A detecting coil (2) is set around the MDL at the one end of it. The whole delay line is biased along its axis in order to avoid the interference of the presence of ambient magnetic fields. A pair of current conductors (3) is set parallel to the MDL and is used for pulsed current transmission. A conducting disk (4), supported by a stainless steel spring (5) is used as the sensor core. In the absence of the movable conducting disk, pulsed current causes pulsed magnetic field orthogonal to the delay line. Such magnetic field causes no mechanical strain in the MDL. So, the output of the receiving coil equals zero. By placing a load (6) on the conducting disk, the spring is elongated and the conducting disk approaches the MDL-conductor arrangement, causing eddy currents in the disk. Keeping unchanged the pulsed current and the biasing field along the MDL, the amplitude of the pulsed eddy current in the disk increases as the distance between disk and MDL decreases. Such eddy current causes pulsed magnetic field along the length of the MDL, and consequently a pulsed voltage output, induced in the detecting coil. This pulsed voltage is the output of our sensor. The higher the eddy current, the higher the magnitude of the detected voltage output. The delay time between voltage output and exciting pulse also defines the distance between conducting disk and receiving coil. So, the change of the distance between conducting disk and MDL, and therefore the load in question is determined by the amplitude of the pulsed voltage output, while the change of the distance between conducting disk and receiving coil is determined by the delay time between exciting current pulse and pulsed output of the receiving coil. The resulting sensor response is illustrated in figure 6. Again, for comparison, the stainless spring used had a constant of 150N/mm. Sensor output is linear for the whole range of measured load and its sensitivity is 0.007 mV/N. The results presented above indicate that the sensors based on conducting disk setup and hard magnetic disk setup offer wider measurement range than the one based on the soft magnetic plate setup. However, the later offers significantly better sensitivity and accuracy.

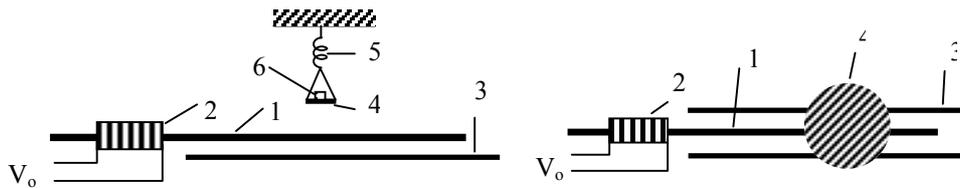


Figure 5: Load Sensor based on conducting disk MDL set-up

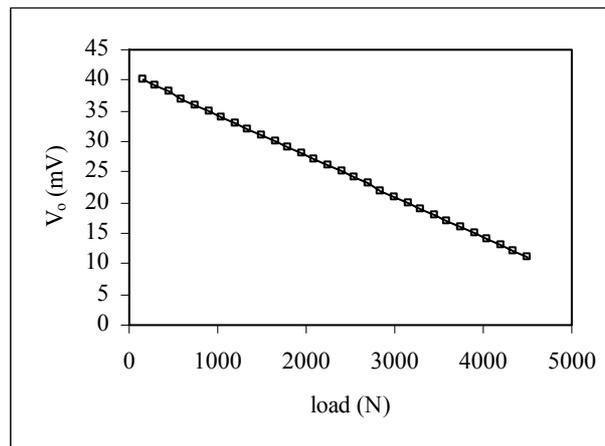


Figure 6: Conducting disk sensor response

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