September 10 - 12, 2003
Pilsen, Czech Republic

INFLUENCE OF SUBSTRATE ON MAGNETO-ELASTIC SENSOR TRANSFER CHARACTERISTICS

ING. MOJMÍR KOLLÁR, PHD. – DOC. ING. VLADÍMÍR JANČÁRIK, PHD. – DOC. ING. JAN BYDŽOVSKÝ, PHD. [1]

Abstract: Calculation of the dynamic eletromagnetic field in a two-coil strain sensor with amorphous ferromagnetic ribbon core is presented. Open-core set-up and material properties are considered of a model, the reluctivity of which depends on the mechanical stress being measured.

Keywords: amorphous magnetic alloys, eddy currents, leakage magnetic flux, FEM

1 Introduction

Excellent mechanical properties, corrosion resistance and suitable magneto-elastic parameters makes the soft magnetic amorphous alloys, prepared by planar flow casting as thin ribbons, suitable for outdoor application as the strain magneto-elastic transducers [1]. Designed magneto-elastic strain [2] sensors operate as unloaded, open-core transformer with a digital feedback ensuring the secondary voltage be constant while the permeability of the magnetic core changes with applied stress. The output signal of such a sensor, proportional to the magnetizing current, is linear function of strain up to 3500 ppm. For the sake of its robustness and handling, the sensor with amorphous ribbon (6 mm wide, 20 μm thick) embedded in a two-coil system is fixed to a bearing plate, Fig.1. The influence of material parameters of the plate, and the distance between the magnetic ribbon and the bearing plate on the strain-voltage transfer characteristics were measured and modelled using numerical, FEM based, calculations.

---

[1] KTEE FEI STU, Ilkovičova 3, 812 19 Bratislava, e-mail: mkollar@elf.stuba.sk, vlado@iris.elf.stuba.sk , biki@iris.elf.stuba.sk

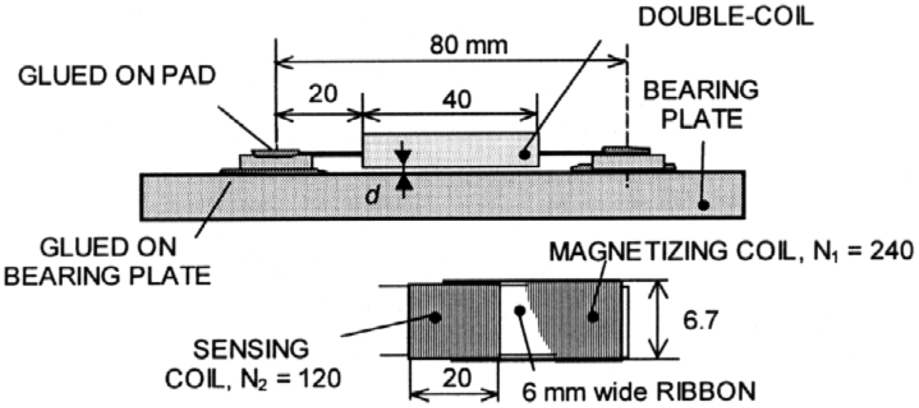

Fig. 1 Amorphous ribbon with magnetizing and sensing coils glued on the pads glued on bearing plate. Distance d is measured from the coils bottom to the plate.

2 Modelling

Since the sensor operates as an open-magnetic circuit at working frequency of 5 kHz, the electromagnetic field outside the magnetizing coil is influenced by the material properties of pads and bearing plate. Namely it makes difference if these are magnetic or nonmagnetic conducting or non-conducting what in all situations results in a trade-off of the magnetic flux closure and eddy currents effects. To make it simpler we were confined to the worst case of a zero pre-stressed tape ($\sigma = 0$) when the stress induced reluctivity changes are the greatest. In all calculations the more or less equivalent 2D case was considered, in which instead of a magnetizing coil (with rectangular cross-sections approx. 7×1 mm) two semi-infinite current carrying stripes (of about 1 mm separation) were used. This must clearly lead to an upper limit estimation because the induced magnetic free poles and eddy currents which influence the field, say in the central point of the configuration, are spread over a surface infinitely long in one dimension in calculations, while limited to a width comparable with the transverse dimension (7 mm) or some of its multiples in the real sensor. However, it is not so simple to estimate an appropriate correction factor which even seems be different for the eddy currents and the magnetic flux-closure (free-poles) effects and their respective combinations. To throw some light on this problem we evaluated separately the four distinguished cases of a ribbon ($\mu_r = 2010$) above the bearing plate, which might be: a) non-conducting and non-magnetic, b) non-conducting but magnetic, c) conducting but non-magnetic and d) conducting and magnetic. The results of calculations may be compared with experimental data gained from the brass, SiFe, and a construction-steel bearing measurements. The presence of pads was not taken into the account, what may not negligibly influence the results too, namely in the cases of combined effects. Figure 2 shows the vector potential lines of all four above mentioned cases a) to d). Although not accustomed as the frequently used field intensity lines, their density still bears a piece of information about the field character. Note the flux-closure effect resulting in a pronounced attracting of the field lines to the bearing volume in case b) and the eddy-current effect leading to their expelling in case c). In case d), as a compromise, there are A-lines visible also in the conducting (and magnetic) bearing. Cases a) and b) show the static DC field (no remarkable difference was found at 5kHz), while case c) and d) correspond to 5kHz sine time-alternation. Here, in case c) only the real part of A-lines are shown, in case d) both the real and imaginary A-lines are indicated.

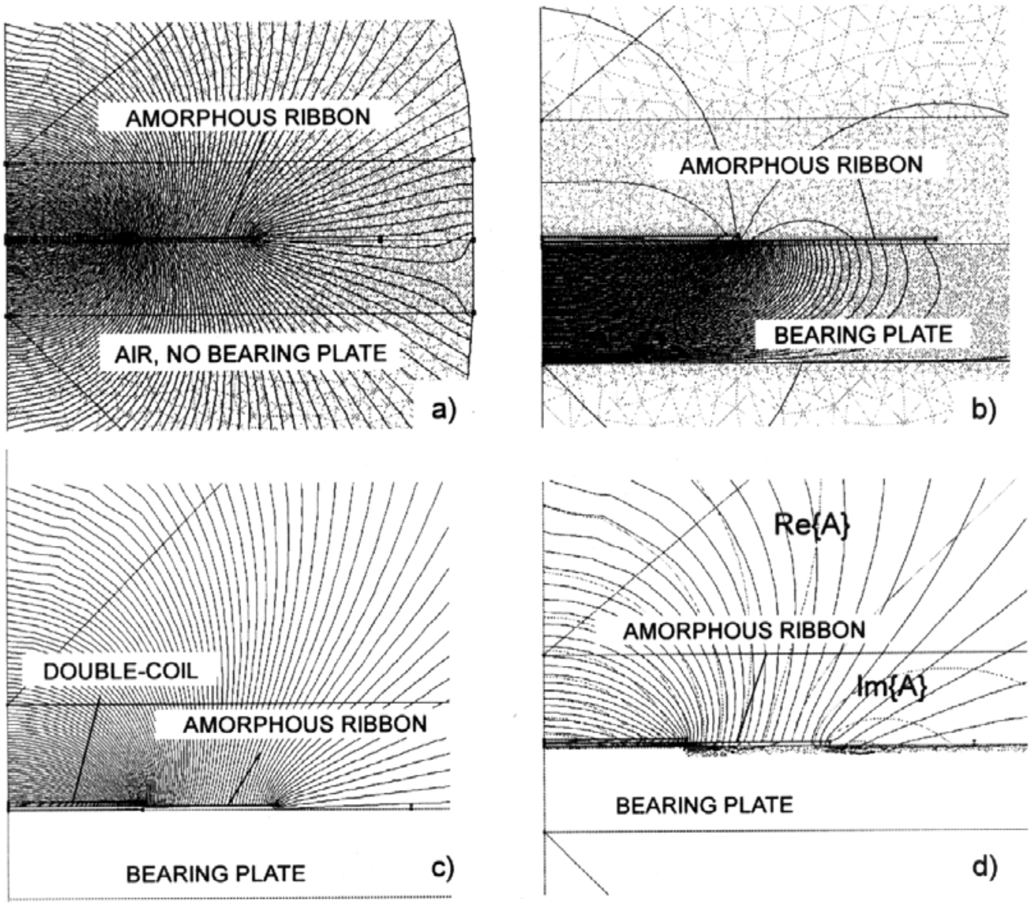

Fig. 2 Vector potential (A- lines) in case: a) - in air, b) - magneto-dielectric bearing plate, c) - conducting, and d) - ferromagnetic bearing plate, calculated for $d = 0$.

3 Discussion

With no ribbon no plate, at current of 4.75 mA RMS, in inside central point $H_t = 40$A/m. The high stray fields at the coils, and ribbon edges, may partially be a computational artefact. According to our calculations in case c) the eddy currents cause a substantial reduction of H_n, while enhancing the negative H_t in central part under (Fig. 3), and lowering its positive value inside the coils, Table 1. The discrepancy, comparing to experimental values is here greater, Table 2, and the reason for it is not clear. In cases d1), d2) the eddy currents effects are eliminated by the flux-closure, and the change may even alter its sign

Table 1 Calculated at $f = 5\text{kHz}$, $d = 0$ by FEMM (http://femm.berlios.de)

Bearing plate	b)	c) Brass	d1) Steel		d2) SiFe		
μ_r :	5000	1	5000	5000	5000	7000	7000
σ (MS/m) :	0	12.5	10	5	3	3	2
ΔH_t or ΔB_t (%)	+70	-28	-2.9	+7.8	+15	+20	+25

Table 2 Experimental data

d (mm)	Brass		Construction steel		SiFe	
Ribbon μ_r	2375	1722	2375	1722	2375	1722
0	- 14.5	- 9.8	+ 5.8	+ 4.8	+ 13.6	+ 9.5
2	- 7.6	- 5.3	+ 2.5	+ 2.3	+ 6.6	+ 5.1

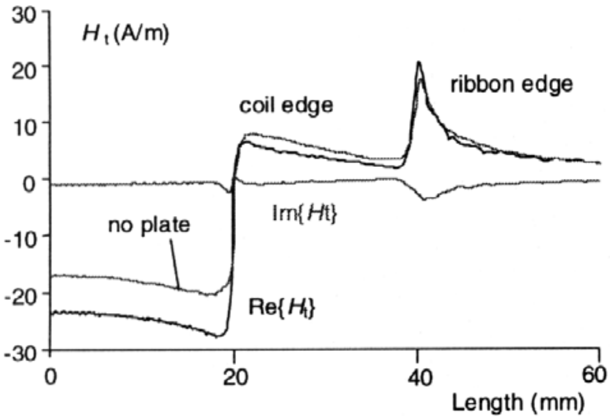

Fig. 3 H_t-field at the surface of a brass bearing plate compared to no-plate case

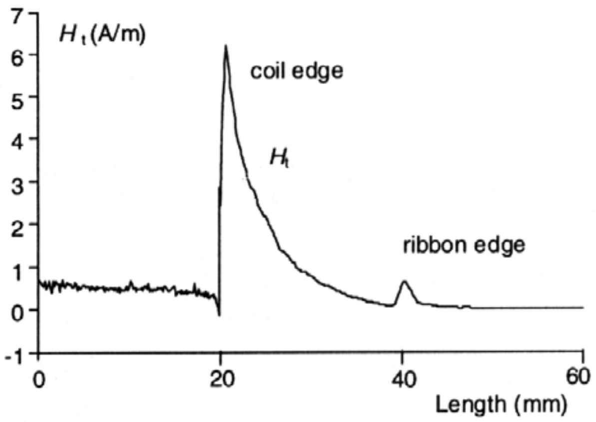

Fig. 4 Magnetic field H_t at the surface of a magneto-dielectric bearing plate

depending on the conductivity (σ) and permeability (μ_r) values, Table 1. It should be stressed that while $B(H)$ loop of the ribbon is highly linear, that of bearing plate is not. The case b) - perhaps rare in practice, of non-conducting but magnetic plate (*eg* ferrites) shows outside: a dramatic lowering compared to no-plate state under, almost unchanged at the edges (Fig. 4), and a substantial rise of the intensity and/or magnetic induction inside the coils due to the free-pole reduction at the surface near the coils edges, Table 1. The latter was not verified by experiment. As a conclusion one may state that the differences between the measurements and calculations are mainly due to 2D task formulation, which was a must in virtue of more than 60 000 mesh-nodes needed to provide smooth enough solutions in a structure with dimensions ranging from 20 μm to 80 mm.

Support of NATO SfP 973649, VEGA 1/0143/03, and VEGA 1/0142/03 grants is gratefully acknowledged.

References

[1] J. M. Barandiaran, J. Gutierrez, Sensors and Actuators A **59** (1997), 38-42
[2] J. Bydžovský et al., Proc. of EUROSENSORS XVI Conference, Prague, 2002,1213-1216