

Whisker sensor based on magnetostrictive material modeling

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A whisker sensor based on magnetostrictive material is being investigated by using the finite element software LS-DYNA. The sensor's behavior is based on the interaction between external force loadings and electromagnetic response. The material model includes different nonlinear B-H curves which depend on external stresses allowing the sensor to detect the effect of displacement. The numerical tool relies on intrinsic coupling between LSDYNA's mechanical and electromagnetic (EM) solvers. During the simulation, geometry, mesh positions and material properties are given to the EM solver which uses this information to compute and update electromagnetic quantities (permeability, magnetic flux density, etc.). The EM solver returns electromagnetic forces to the mechanical solver that will subsequently apply as loading.

Index Terms—Magnetostriction, whisker sensor, FEM-BEM, implicit, explicit, coupling phenomenon.

I. INTRODUCTION

RECENTLY, whisker sensors have been widely investigated for tactile sensing in bionic robots, automatic vehicles and so forth, due to their advantages of working under static or low frequency. The working principle of magnetostrictive whisker sensors relies on the modification of material permeability with an external applied stress. The change in permeability can be measured by conventional magnetic field sensors like Hall sensors.

In this paper, a whisker sensor is simulated using LS-DYNA mechanical [1] and EM [2] solvers, with “magnetostrictive” non-linear B-H curves depending on the external stress.

II. SENSOR STRUCTURE

The structure of the whisker sensor presented in this paper consists of a galfenol/beryllium-bronze/galfenol cantilever beam and a fixed magnet [3]. The presence of the magnet introduces the magnetic field in the galfenol beams. The dimensions of the device are presented in Table I

TABLE I
DIMENSION OF THE DEVICE

Item	Material	Dimensions(mm)
Beam 1	Galfenol	30 x 4 x 0.2
Beam 2	Beryllium-Bronze	80 x 4 x 0.3
Beam 3	Galfenol	30 x 4 x 0.2

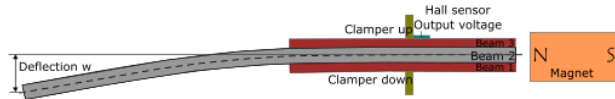


Fig. 1. Structure of magnetostrictive whisker sensor.

Fig1. presents the structure of the whisker sensor described in [3], and which will be simulated in this paper. The clampers allow to guide the movement of the cantilever beams. Fig2. shows the hexahedral mesh used in the simulations, with 5 layers through thickness solid elements in the beam structures.

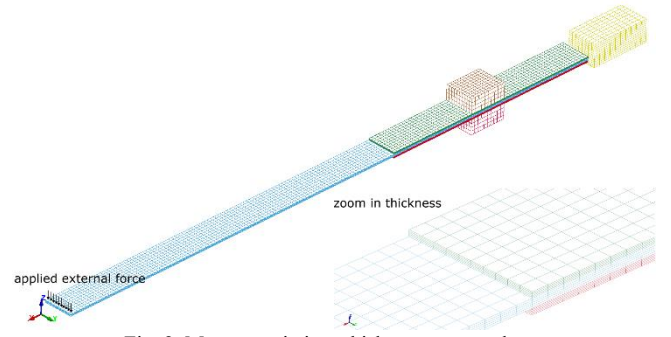


Fig. 2. Magnetostrictive whisker sensor mesh.

III. WORKING PRINCIPLE

A loading deflection is applied at the beryllium-bronze beam's free end which induces some stress in the galfenol magnetostrictive beams. Since the permeability and B-field of the galfenol material depends on the applied stress, the magnetic flux density B in the galfenol beams generated by the magnet will depend on the applied deflection. The B-field can then be measured by a Hall sensor. Fig. 3 shows the B-H curves of galfenol for different stresses [4].

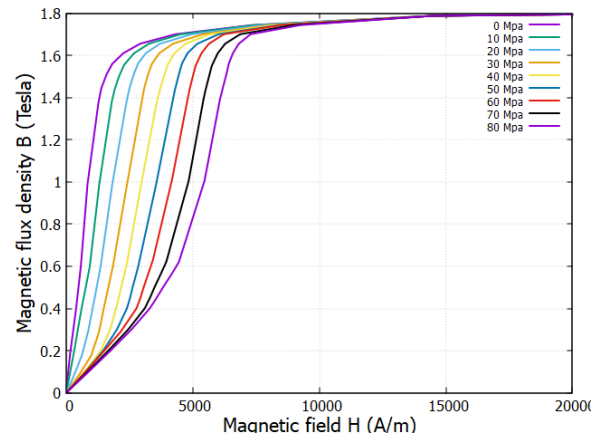


Fig. 3. B-H curves dependent on applied stress.

In LS-DYNA, each B-H curve is approximated by spline functions [5], allowing an easy interpolation when the stress dependency is added. The permeability is computed at each

element of the mesh, allowing the assembly of the FEM stiffness matrix in the conductors, while the EM fields in the air are treated via a boundary element method (BEM) resulting in a coupled monolithic magnetostatic FEM-BEM solve [6].

IV. SIMULATION

As presented in [1], an external force is applied to the sensor, leading to the deflection of both the beryllium-bronze beam and the galfenol beams. A mechanical implicit simulation is done to get the shape and stresses of the deflected beams, and the EM solver is then used to get the B-field at the sensor's locations. Given the sensibility of the Hall sensors, this B-field can be compared to the experimental sensor voltage.

A. LS-DYNA implicit solver

The process presented above can be repeated for several deflections allowing to get a sensor voltage vs deflection curve. Some of results are presented in Fig. 4

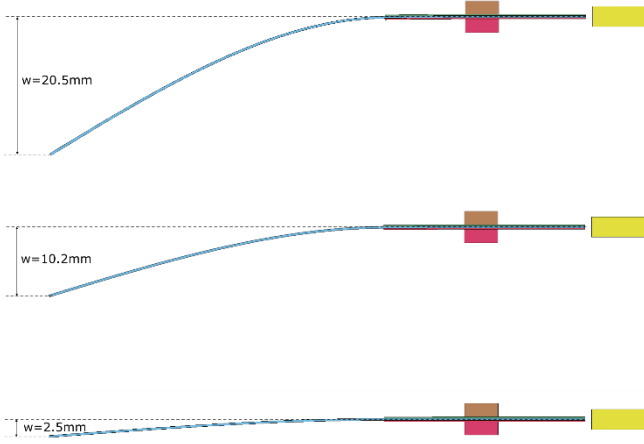


Fig. 4. Deflection of the sensor for different loading force curves.

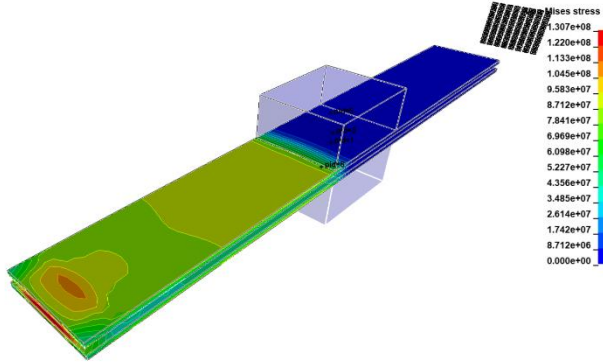


Fig. 5. Stress in galfenol beams obtained by implicit solver in case of $w=20.5\text{mm}$.

B. LS-DYNA Electromagnetism solver

Fig. 6 shows the relative permeability at the maximum deflection ($w=20.5\text{mm}$) in the galfenol beams. The distribution of the relative permeability corresponds to the stress in the galfenol beams presented in Fig 5. The highest stress gradient is in the limit borders between the clampers and the galfenol

beams. Considering a Hall sensor with a sensitivity of 13mV/Gauss [7] ($1\text{T}=10000\text{G}$), for each simulated deflection point w , a voltage is obtained by multiplying the magnetic flux density with Hall sensor sensitivity. The results are presented in Fig. 6.

Relative permeability

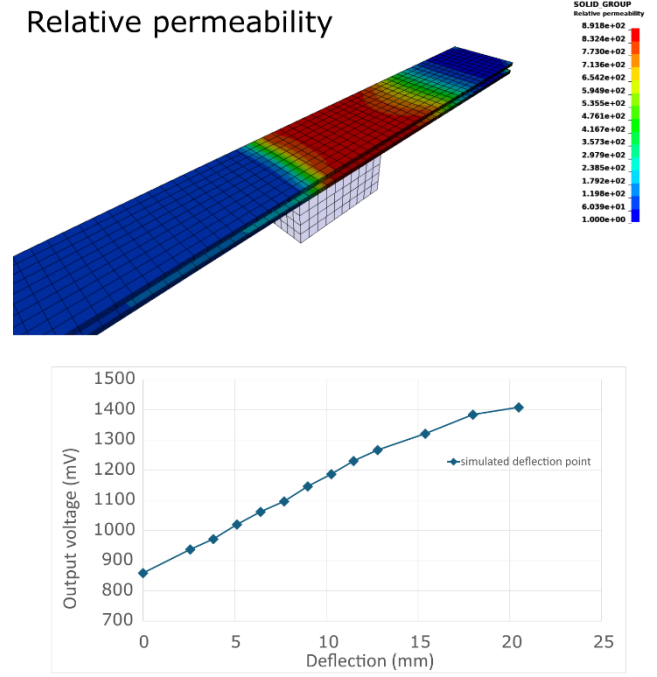


Fig. 6. Relative permeability at maximum deflection and output voltage (mV) in Hall sensor as a function of deflection (mm).

V. FUTURE WORKS

These simulations will be tested for different magnetostrictive B-H curves and/or different sensor structures. The simulation process will be used then to optimize magnetostrictive sensors for different applications such as bionic robots and automatic vehicles, realize tactile perception, hydrodynamic measurement, and shape sensing

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