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FEM Model of a Tactile Sensor Based on Inductance Measurements and Magnetosensitive Elastomer

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Summary:

This paper presents a concept of a tactile sensor based on multiple planar coils with overlapping regions and a magnetosensitive elastomer layer. The sensor setup is simplified to a two-dimensional problem. Experimental investigations are compared with an electro-mechanical model. This model is able to simulate inductance changes of less than 0.1% caused by a deformation. The trend of the modeled curves fits the experimental data in a way to draw conclusions about the range and dependency of the inductance change on the depth of indentation.

Keywords: magnetosensitive elastomer, adaptivity, tactile sensor, FEM simulation, electromechanics

Introduction

Magnetosensitive elastomer (MSE) consists of an elastomer matrix with embedded magnetic particles. Several technical applications have been proposed that utilize MSE as a transducer for sensor applications or as actively controlled soft element. Kawasetsu et al. proposed a tactile sensor based on MSE and planar coils and investigated their size dependency [1, 2]. In this paper, a tactile sensor concept based on an electromechanical model is presented. This concept uses the MSE as a tunable compliance and multiple planar coils for sensing its deformation. The behavior of multiple overlapping coils is rather complex to analyze and simulate. Hence, this first approach is limited to model a single coil and the magnetic interaction with a deformed MSE layer. All simulations are based on two-dimensional finite element method (FEM).

Sensor Concept

The setup of the sensor concept is shown in Fig. 1. It consists of multiple layers incorporating an MSE. The base plate is constructed by a circuit board holding multiple planar coils with overlapping regions. Sequenced inductance measurements of these coils provide data on a deformation of the MSE caused by an indenter. Each measurement is done by driving the coil as part of an oscillating circuit at its resonance frequency. Due to the high frequency and low amplitude of this oscillation, the alternating magnetic field can be superposed with an additional external quasi-static magnetic field. This field is used to control the compliance of the MSE. The effect of the sensor is based on measuring inductance changes of less than 0.1%. Therefore, the simulations need to be accurate enough to reproduce these small changes.

Theory of Operation

An indentation results in an inductance change depending on three variables. The first two are the planar coordinates of the deformation relative to the center of the coil (*x*- and *y*-position). The third variable *h* is given by the indentation depth. At least three inductances have to be measured for every indentation, in order to obtain those variables.

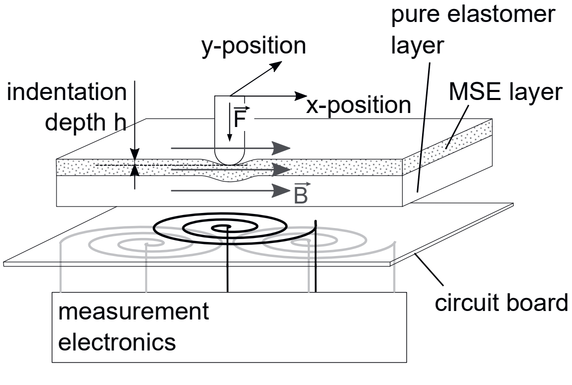

Fig. 1. Concept of the tactile sensor.

Experiments

The measurement electronics consist of three modules: an “Inductance-to-Digital” converter driving the coil as part of an oscillating circuit at its resonance frequency, an analog multiplexer and a microcontroller used for sequencing all coils. In order to compare the experimental results to the simulations, the setup shown in Fig. 1 is simplified using only one hexagonal planar coil with a two layer winding. The experiment is performed by a linear shifted indentation of constant depth *h* along the small semi-axis of the coil.

Electromechanical FEM Model

The simulations are done with ANSYS Workbench 19.1. The model is built by two not coupled modules. Firstly, a two-dimensional static mechanical FEM component models the deformation of the cross-section. Secondly, a two-dimensional magnetostatic Maxwell component models the inductance of the cross-section of a single coil. The indentation depth *h* and the *x*-position of the experiment define the dimensions of the plane of both models. The indenter is modeled as a rigid body and the two elastomer layers as incompressible linear elastic material. The simulated deformed contour is post-processed with MATLAB R2018b and transferred to the Maxwell 2D simulation. The purpose of this step is to obtain the contour by calculating the displacement for every node of the mesh. Furthermore, the inductance is found by a Maxwell 2D Simulation including the imported area of the deformed MSE layer. The FEM Maxwell model is parametric for the *x*-position of the deformation and the depth of indentation *h*. Every cross-section of the coil winding is considered to be extended along a straight infinite line. The parameters for the simulation are listed in Tab. 1.

Tab. 1: Parameters of the simulation

parameter	value
relative magnetic permeability of the MSE	2.7
Poisson’s ratio of the elastomer	0.4999
coil turns per layer	40
coil diameter	26.2 mm
MSE thickness	2 mm
pure elastomer thickness	6 mm

Results

In Fig. 2, the experimental results are compared to the simulations. The area of the coil with sufficient sensor signal is present around the peak at the center. Regarding the qualitative trend, both curves are similar. Furthermore, the simulated curves picture the increasing signal with increasing indentation depth occurring also in the experiment. The error for a central deformation ranges between 5.6% and 102.7%.

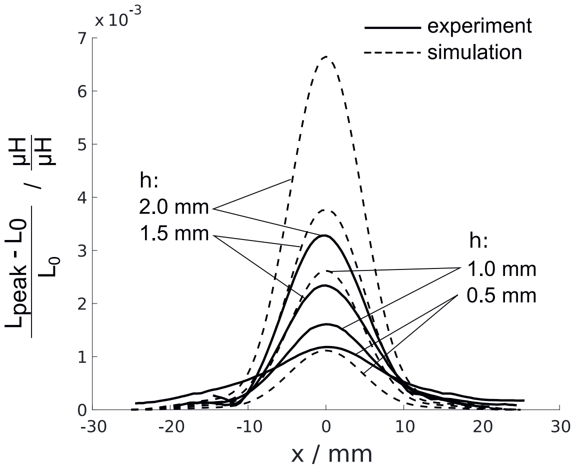

Fig. 2. Simulation and experimental results for a shifted indentation of alternating depth h.

Discussion and Conclusion

The proposed concept is based on the spatial distribution of the magnetic field of a single planar coil. Hence, the setup requires only a small number of parts and is cost-efficient to manufacture. Firstly, the model proves to be capable of reproducing inductance changes of less than 0.1%. Additionally, the magnitude and the qualitative trend of the simulated inductance change correspond to the experiment. This can be used to estimate the width of the area with sufficient sensor signal. Further investigations will focus on error reduction. The deviation of the model is assumed to be caused by simplifications regarding the size of the coil in the third dimension. In a next step the FEM model will be extended by considering dielectric properties of the material influencing the parasitic capacity of the planar coil. Additionally, the geometry of the model will be improved to include the shape and symmetry of the real planar coil.

References

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