MODELLING OF MAGNETIC FIELD OF ELASTOMAGNETIC PRESSURE FORCE SENSOR IN COSMOS/EMS ENVIROMENT

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The article deals with magnetic field modelling which is present in ferromagnetic core of elastomagnetic force sensor (EMS). EMS is based upon utilization of Villari´s effect and belongs to nonlinear systems group. The solution of such field is possible by partial differential equation of vector magnetic potential in nonlinear environment. However, solution of such equation is very difficult, so it is essential to find proper tool. In this case, COSMOS/EMS software, which utilizes the method of finite elements, was used.

Key words: modelling, elastomagnetic sensor, ferromagnetic material, finite element method.

Introduction. In most cases, solving the most of the electrotechnical problems by direct experimentation with real physical system is very difficult. Experimentation with computer model is much more convenient, such experimentation is called simulation. The simulation models are operative, and much less demanding in terms economic and time. They allow us to find an alternatives and suitable parameters of device, sometimes even correction and enhancement of knowledge about the system which we analyze.

One of such example is the modelling of elastomagnetic force sensor followed by simulation of distribution of magnetic field of the sensor, with which this article deals with.

Problem statement. Magnetic and mechanical properties are closely related in ferromagnetic materials. According to Villari's effect, when mechanical force is affecting the ferromagnetic object, then the magnetization changes. The presence of mechanical field is responsible for change in geometric size of ferromagnetic object (deformation), so called Joule effect. These two effects are often used during the design of the sensors. The goal of this manuscript is to design a simulation of magnetic field distribution ferromagnetic core of elastomagnetic force sensor when mechanical force affects it and graphical representation of following function: $м = м(B)$.

Modelling of magnetic field distribution in the core of EMS sensor. Elastomagnetic sensors belong to the group of nonlinear systems. They are operates on the Villari's effect principle, which is based on a change of ferromagnetic material permeability proportionally to acting mechanical stress. The permeability increment Δμ proportional to the mechanical stress у can described by relation [1]

$$Дм = \frac{2л_{ms} м^2}{B_{sef}^2} . у \ , \qquad (1)$$

where $л_{ms}$ is coefficient magnetostriction for $B = B_s$, B_s is the saturation flux density, м is magnetic permeability. Equation (1) is valid in the case that the directions of mechanical stress and magnetic field are collinear.

Practical fabrication of elastomagnetic sensor of pressure force 120 kN, which correspond to 100 MPa pressure, is on fig.1 and geometric computer model created in Solid Works is on fig. 2. Windings placement in the core holes is on fig. 3.

Figure 1 – Elastomagnetic sensor manufactured on KTEEM 120kN

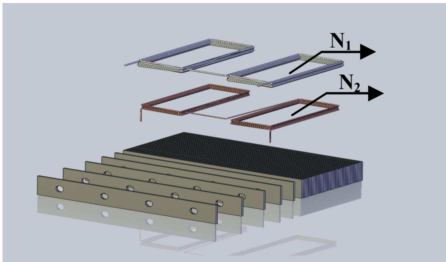

Figure 2 – Design of lamellas and windings

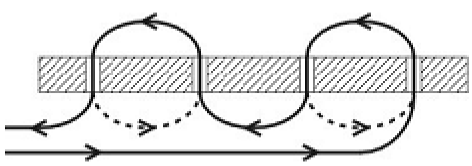

Figure 3 – Placement of windings in the EMS and direction of current flow

Elastomagnetic sensor´s magnetic field solution. For magnetic potential vector **A** of 3D stationary magnetic field, the following equation is valid:

$$rot\left(\frac{1}{м} rot\ \mathbf{A}\right) = \mathbf{J} \ , \qquad (2)$$

where J is current density and μ is magnetic permeability of environment in which the field is solved.

For the plane case we assume that the current flows are parallel to the *z*- axis, it means that

$$J = kA, \tag{3}$$

so only the z component of $\mathbf{A}$ is present:

$$\mathbf{A} = \mathbf{k}\mathrm{A}\,. \tag{4}$$

And the equation (2) we can simplify to the scalar elliptic Partial Differential Equation (PDE):

$$-div\left(\frac{1}{\mu} grad\ A\right) = J\,, \tag{5}$$

where

$$J = J\left(x, y\right). \tag{6}$$

For the plane case, the magnetic flux density **B** can be computed as

$$\mathbf{B} = \mathbf{i}\frac{\partial A}{\partial y} + \mathbf{j}\left(-\frac{\partial A}{\partial x}\right). \tag{7}$$

And the magnetic field intensity **H** is

$$\mathbf{H} = \frac{1}{\mu}\mathbf{B}\,. \tag{8}$$

Definition of areas

Area Ω consist of 3 sub-areas (Fig.4),

- Sub-area Ω_1 , cross-section of wires of primary winding.
- Sub-area Ω_2 , air gap between wire windings and lamella.
- Sub-area Ω_3 , one quarter of lamella's space from ferromagnetic material (possible because of lamella's symmetry).

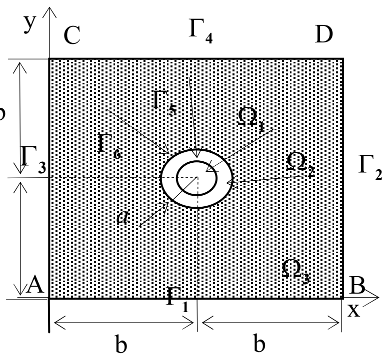

Figure 4 – Definition area of the mathematical model of elastomagnetic sensor

Partial Differential Equation coefficients

For determination magnetic vector potential is used the equation (5) which has in each subdomain the following forms:

- in the subdominant Ω_1 :

$$\frac{\partial^2 A_{(1)}}{\partial x^2} + \frac{\partial^2 A_{(1)}}{\partial y^2} = -\mu_{(1)} J_{(1)}\,, \tag{9}$$

where $\mu_{(1)} = \mu_0$ and $J_{(1)} = 1,039.10^7$ Am^{-2} *;*

in the subdominant Ω_2 :

$$\frac{\partial^2 A_{(2)}}{\partial x^2} + \frac{\partial^2 A_{(2)}}{\partial y^2} = -\mu_{(2)} J_{(2)}\,, \tag{10}$$

where $\mu_{(2)} = \mu_0$ and $J_{(2)} = 0$ A/m^2;

- in the subdominant Ω_3 :

$$-\left[\frac{\partial}{\partial x}\left(\frac{1}{\mu_{(3)}}\frac{\partial A_{(3)}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu_{(3)}}\frac{\partial A_{(3)}}{\partial y}\right)\right] = J_{(3)} \tag{11}$$

and $\mu_{(3)} = \mu_{(3)}\left(B\right)$, $J_{(3)} = 0$ A/m^2, so for the vectorial magnetic potential we must use non-linear differential equation.

Boundary conditions.

The boundary conditions are:

- on the boundaries Γ_1 , Γ_2 , Γ_3 , Γ_4 ,

$$A_{(3)} = 0\,; \tag{12}$$

- on the boundary Γ_5 between subdomain Ω_3 and Ω_2 :

$$\frac{1}{\mu_{(3)}}\frac{\partial A_{(3)}}{\partial n} = \frac{1}{\mu_{(2)}}\frac{\partial A_{(2)}}{\partial n}\,; \tag{13}$$

- on the boundary Γ_6 between subdomain Ω_2 and Ω_1 :

$$\frac{\partial A_{(2)}}{\partial n} = \frac{\partial A_{(1)}}{\partial n}\,. \tag{14}$$

Experimental part and obtained results. The simplified 3D model of ferromagnetic object (sensor core) and primary coil winding was created for the purpose of computer simulation. This simulation shows the distribution of magnetic field in the core of the EMS sensor. The problem was solved as a magnetostatic problem in nonlinear environment for chosen value of current in cases when the pressure force is/is not affecting the sensor. The analysis of magnetic field was realised using the method of finite elements in COSMOS/EMS software. The following pictured progresses and graphs of magnetic field parameters are based on values of current density $J = 2,07875844.10^7$ Am^{-2} in primary winding, $J = 1,0393772.10^7$ Am^{-2} and frequency of feeding current f = 400 Hz (fig. 5, fig. 6, fig. 7, fig. 8, fig. 9, fig. 10, fig. 11, fig. 12, fig. 13, fig. 14, fig. 15, fig. 16).

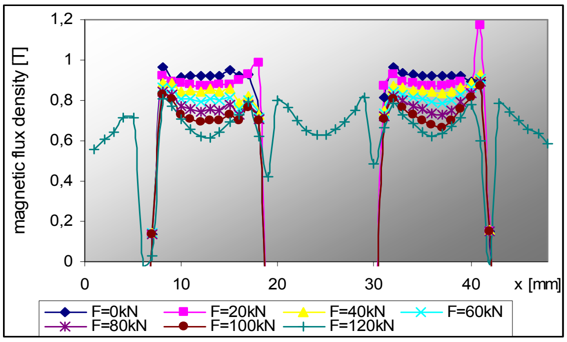

Figure 5 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor

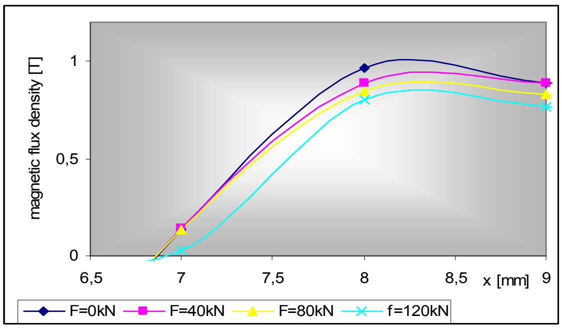

Figure 6 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor

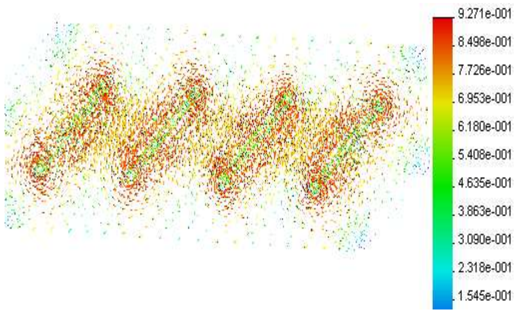

Figure 7 – Distribution of magnetic flux density vector in the dependence on pressure force applied to the sensor, F = 0kN

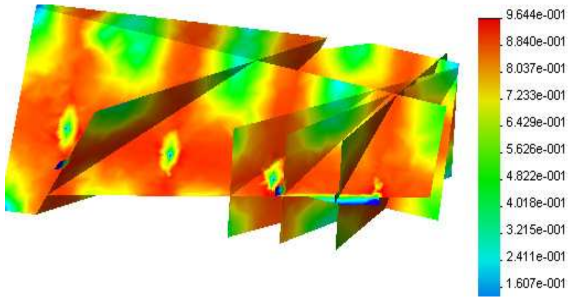

Figure 8 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor, F = 0kN

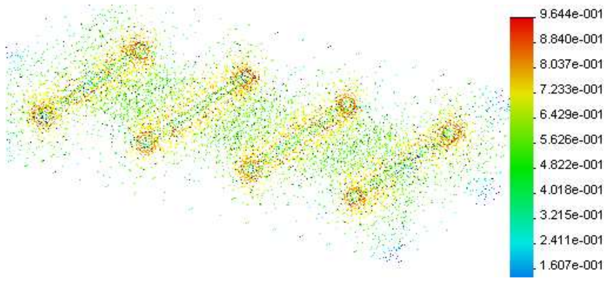

Figure 9 – Distribution of magnetic flux density vector in the dependence on pressure force applied to the sensor, F = 120kN

Similar simulation of large amount of 2D cuts is possible to design for analysis of nonlinear circuits as well [2], [3].

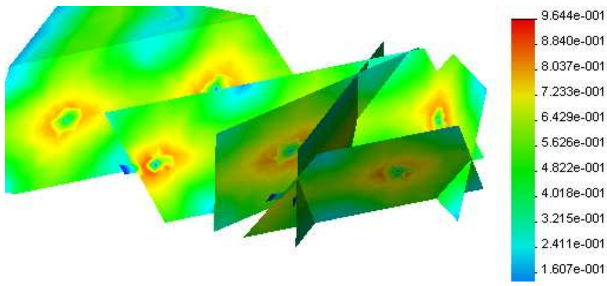

Figure 10 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor, F = 120kN

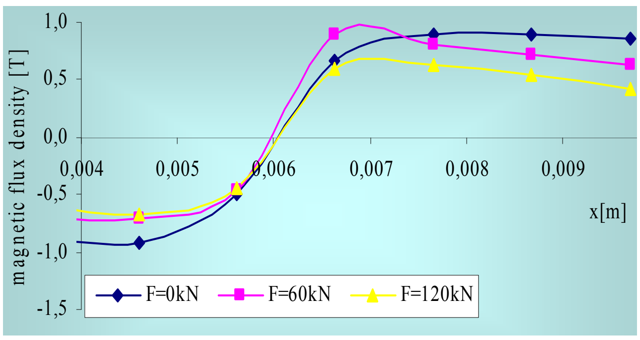

Figure 11 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor

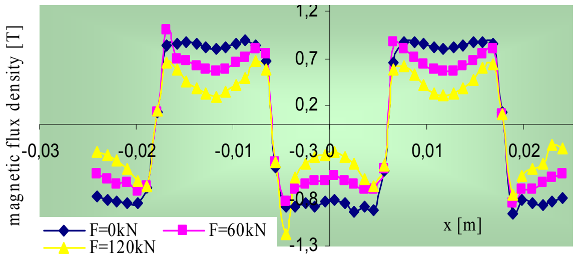

Figure 12 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor

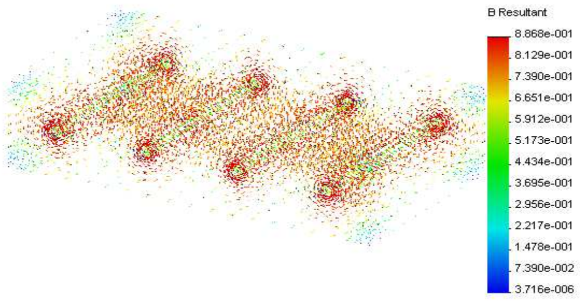

Figure 13 – Distribution of magnetic flux density vector in he dependence on pressure force applied to the sensor, F = 0kN

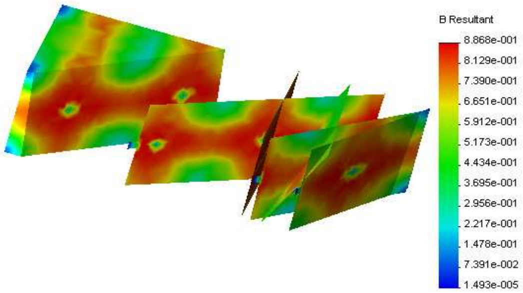

Figure 14 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor, F = 0kN

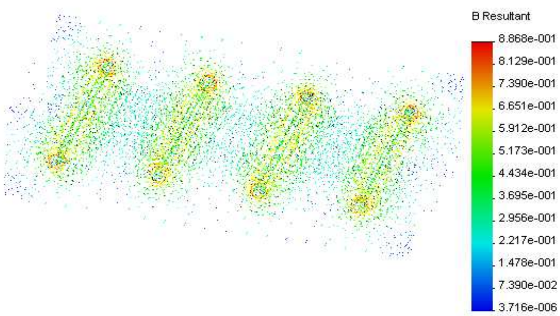

Figure 15 – Distribution of magnetic flux density vector in the dependence on pressure force applied to the sensor, F =120kN

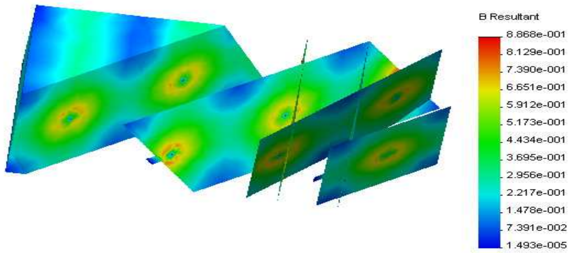

Figure 16 – Distribution of magnetic flux density in the dependence on pressure force applied to the sensor, F = 120kN

Conclusion. The article focused on simulation of magnetic field distribution in EMS core. From pictured progresses we can see the significant reduction of magnetic induction value when the pressure force is affecting the sensor. The magnetic field becomes deformation. This deformation is occurs mainly on air – ferromagnetic dividing line. Program COSMOS/EMS was used for calculation. This program is based upon the method of finite elements. The program has also tools for graphical representation of results.

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МОДЕЛИРОВАНИЕ РАСПРЕДЕЛЕНИЯ МАГНИТНОГО ПОЛЯ В МАГНИТОУПРУГОМ ДАТЧИКЕ УСИЛИЯ

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Рассматривается компьютерное моделирование распределения магнитного поля в ферромагнитном сердечнике магнитоупругого датчика (ems) в случае, когда внешняя сила давления влияет/не влияет на датчик. С этой целью была создана 3d-модель ems. Для расчета параметров поля методом конечных элементов было использовано программное обеспечение cosmos/ems. Магнитоупругие датчики относятся к группе нелинейных систем, их принцип действия основан на использовании эффекта виллари.

Ключевые слова: компьютерное моделирование, магнитоупругий датчик, ферромагнитный материал, метод конечных элементов.

МОДЕЛЮВАННЯ РОЗПОДІЛУ МАГНІТНОГО ПОЛЯ В МАГНІТОУПРУГОМУ ДАТЧИКУ ЗУСИЛЛЯ

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У статті розглядається комп'ютерне моделювання розподілу магнітного поля в феромагнітному осерді магнітопружного датчика (ems) у випадку, коли зовнішня сила тиску впливає/ не впливає на датчик. З цією метою була створена 3d-модель ems. Для розрахунку параметрів поля методом кінцевих елементів було використано програмне забезпечення cosmos/ems. Магнітопружні датчики відносяться до групи нелінійних систем, їх принцип дії заснований на використанні ефекту вілларі.

Ключові слова: комп'ютерне моделювання, магнітопружний датчик, феромагнітний матеріал, метод кінцевих елементів.