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Adequacy of Mathematical and Physical Model of Oscillating Mechatronic Device

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Introduction

Mostly used mechatronic devices are electrical energy converters into mechanical energy. Because of this reason it is very important to research them. One of the research types are mathematical mechatronic drive models.

Most common mathematical models are mechatronic device parameters, such as rotor mass, inductance, electromagnetic force and etc. Electromagnetic force could be described using the order function [1], because drive's magnetic circuit mostly is not linear or only the first degree in the order function is used [2]. Drive's winding inductance depends on the coordinate of the moving part, because of that it could be described using linear, sinusoidal or hyperbolical functions. These parameters could also be calculated using finite elements method (FEM).

This article explores the use of finite elements method experimenting with mechatronic device – oscillating electrical motor.

The Object of the Research

It was investigated the mechatronic device – oscillating electrical motor that is used in the drive of the saw. The picture of the drive is displayed in the Fig. 1. The drive has stator 1, to which using springs 2 is attached the moving part 3 with core and inside the stator's fixed magnetic core 4 with windings. The static part can move vertically, according to the image.

The way it works: the electrical pulse is going through the motor windings 4 (Fig. 1), is created magnetical source, because of which magnetic core inside the moving part 3 is affected by the electromagnetic force – the moving part starts moving towards stator's magnetic core (according to the picture 1 – up); if the force is discontinued in the winding of stator, motor moving part magnetic core's electromagnetic force doesn't work anymore, because of that the moving part affected by springs is moving to the opposite direction. So the pulsating current going through motor's winding makes the motor's moving part to move.

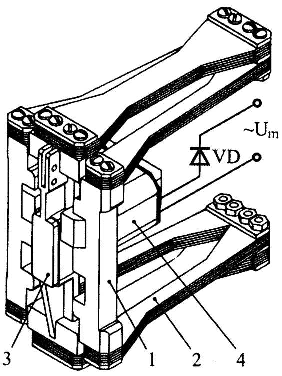

Fig. 1. Oscillating electrical motor: 1 – stator, 2 – spring, 3 – the moving part, 4 – magnetic core with the winding

This research explores the simplest oscillating electrical motor's case – one stator magnetic core, which winding is fed using the negative electrical force, and the pulsing force is created into electrical circuit turning on the semiconductor diode.

The Method of the Research

Mechatronic drive is explored using numerical model's method. For calculations is used "GNU Octave" software [5]. In the mathematical model semiconductor diode is considered ideal and only the electrical losses in the drive of the motor are taken into the account.

The equivalent electrical scheme of the drive is shown in the Fig. 2: U – the negative electrical source, U_n – diode which is explained using non linear source of the energy, R – motor's winding resistance, R_{ekv} – that explores the change of motor's inductance L – dynamic motor's winding inductance.

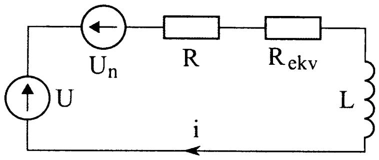

Fig. 2. Equivalent electrical motor's scheme

The system of drive's differential equations:

$$\begin{cases} \dfrac{\mathrm{d}i}{\mathrm{d}t} = \dfrac{1}{L}\left(u - u_n - iR - iv\dfrac{\mathrm{d}L}{\mathrm{d}h}\right); \\ \dfrac{\mathrm{d}h}{\mathrm{d}t} = v; \\ \dfrac{\mathrm{d}v}{\mathrm{d}t} = \dfrac{1}{m}\left(F_{em} - R_{mch}v - ch\right); \end{cases} \tag{1}$$

here u – the source of the negative energy, $u_n = \Psi(i)$ – volt-amps diagram of diode, F_{em} – the electromagnetic force that affects motor's moving part, m – motors moving parts mass, h – motor's moving parts coordinate, in the central position $h = 0$, v – the speed of motor's moving part, R_{mch} – drive's mechanical resistance, c – the resilience of motor's spring.

In the equation's system (1) electromagnetic force can be expressed using this equation [3]:

$$F_{em} = \frac{1}{2} i^2 \frac{\mathrm{d}L}{\mathrm{d}h} . \tag{2}$$

Motor's winding inductance can be described using linear dependency:

$$L(h) = L_0 + kh, \tag{3}$$

here:

L_0 – inductance when motor's moving part is in a central position,

k – the coefficient of the proportion.

Inductance derivative according to the coordinate:

$$\frac{\mathrm{d}L}{\mathrm{d}h} = k . \tag{4}$$

These parameters (2), (3) also can be calculated using finite elements method. For this purpose we used the „FEMM" software [4].

Motor's magnetic circuit model is used for finite elements method and is shown in the Fig. 3. Magnetic circuit is symmetrical, so to diminish the time used for calculations, only half of symmetrical circuit is simulated. Because motor's static part is 90 degrees to stator's magnetic core and „FEMM" software only works with 2-dimmensional models, so stator and static part core are drawn next to each other, and for the "movement" of magnetic source we use periodic boundary condition. On the left side of the model (Fig. 3) is motor stator's magnetic core with windings and on the right – motor's moving part. As an interesting fact the length of the moving part's magnetic core is 38 mm, half square – 10 mm, and the gap between stator and moving part's magnetic core – 0.5 mm.

As necessary, the calculated electromagnetic force that affects motor's moving part depends on model's partitioning level (Fig. 3, right side), with a few present moving part's coordinates, shown in the Fig. 4. The force becomes stabile when the net's height is 0.2 mm or less. For the further calculations models net's height is 0.125 mm.

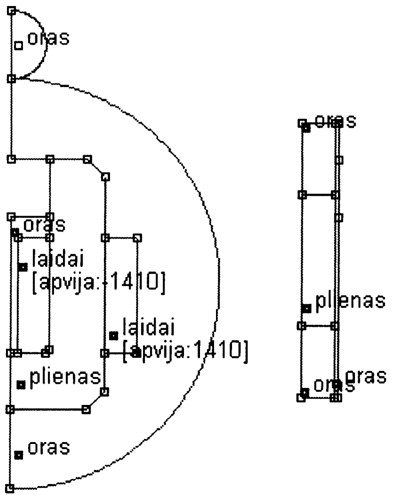

Fig. 3. Magnetical circuit model

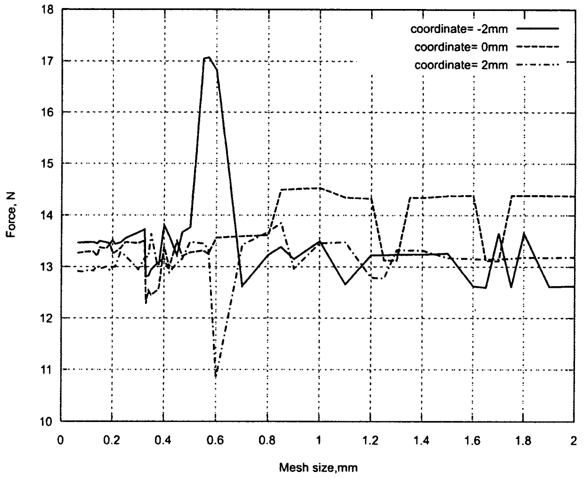

Fig. 4. Calculated force dependence on model's partitioning level

There are two possible methods of drives' models using the finite elements method. The first method is solving drive's differential equations (1) we could use „FEMM" software for calculations of force that affects motor's moving part and motor winding inductance. As it is known finite elements method is famous for the long calculations, which duration is growing when the model partitioning mesh size is lowered. Because of that the first method is not very "attractive", when for example we have to model the same drive to various energy sources, or when we want to watch the behavior of the drive while changing the voltage and form of the source. So we can in the beginning calculate using „FEMM" software the surfaces $F_{em} = f(i,h)$ and $L = f(i,h)$, after that, solving drive's differential equations (1), parameters F_{em}, L and $\frac{\mathrm{d}L}{\mathrm{d}h}$ approximately calculate from the results of the surfaces. The later method is used in this research.

The calculated dependency $F_{em} = f(i,h)$ of the drive is shown in the Fig. 5 and $L = f(i,h)$ in the Fig. 6.

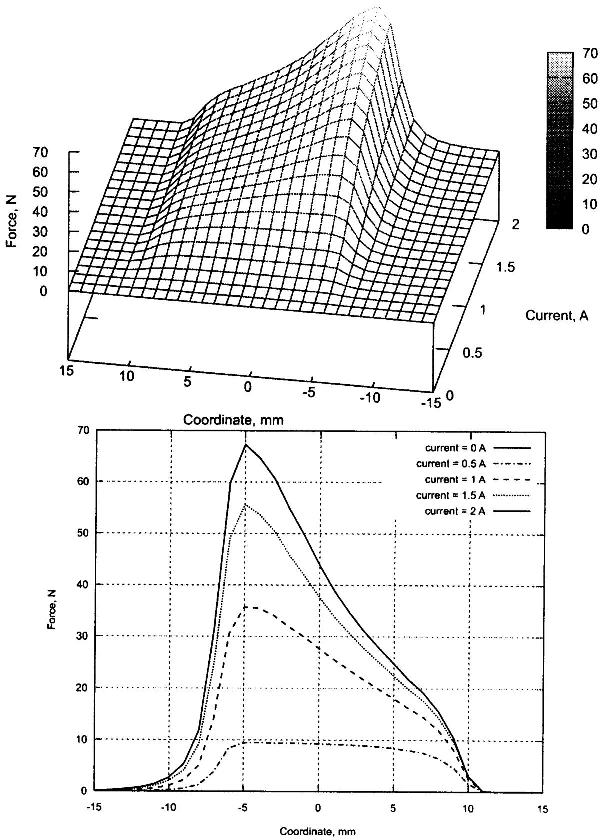

Fig. 5. The electromagnetic force that affects motor's moving part, dependence on moving part's position and motor's winding current

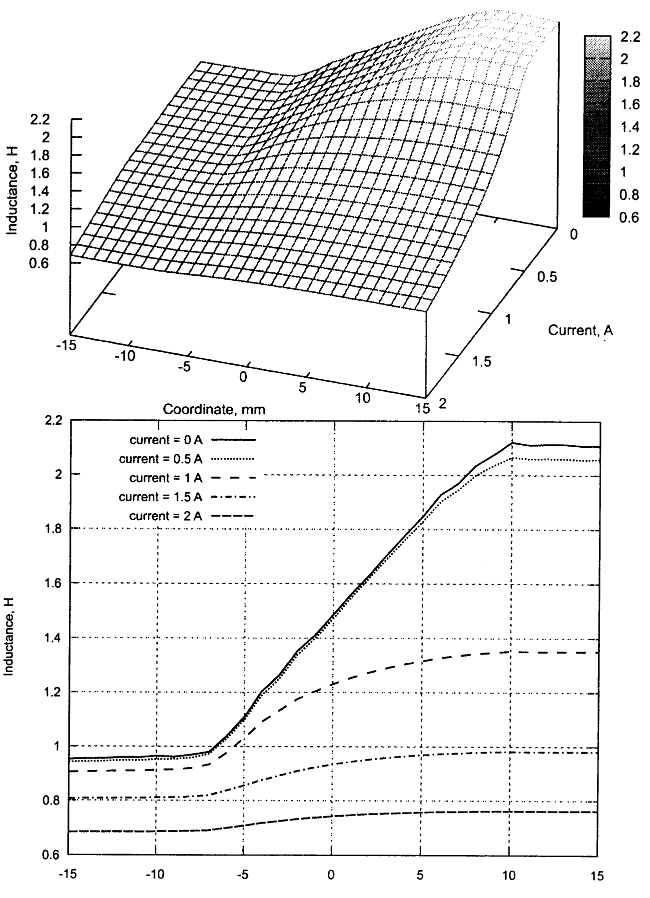

Fig. 6. Motor's winding inductance dependence on moving part position and the motor's winding current

The Result of the Research

The research of drive was concluded using three methods: performing a physical experiment, performing a mathematical model, electromagnetic force, winding‘s inductance solutions by calculating (2), (3), (4) dependence and performing mathematical model when the values are approximate from previously calculated dependency surfaces. The voltage of the energy source that was feeding the drive was changed and monitoring of motor moving part's oscillating amplitude and force in the circuit.

Motor moving part's oscillating amplitudes comparison graph, using previously mentioned experiment methods shown in Fig. 7, and motor's winding current comparison graph is shown in Fig. 8.

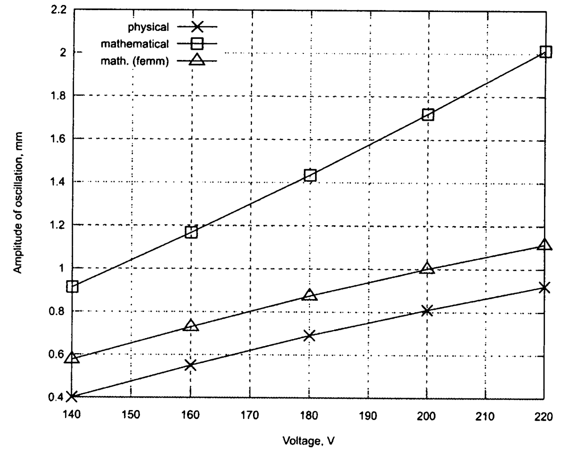

Fig. 7. The graph of amplitudes comparison

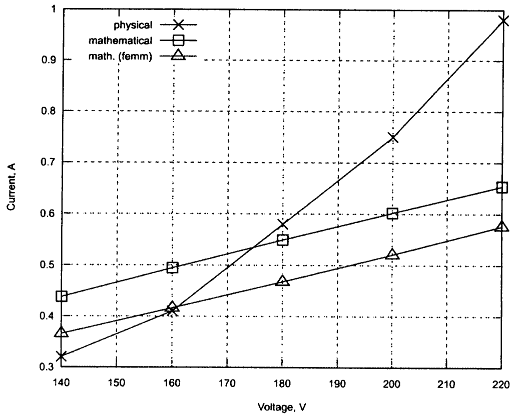

Fig. 8. The graph of force comparison

Comparing oscillating amplitudes it was noticed that mathematical models, using finite elements method, result is graph which is similar to graph received during physical experiment.

Comparing forces that are in motor's winding it was noticed that the graph behavior result received from physical experiment is different from mathematical model. We believe that this happened because during the construction of the model we didn't pay close attention to the damages that happen because of eddy currents forces inside the motor's magnetic core, or another reason could be that the residual induction was not accounted in, because the force inside the motor's winding is always one sign (negative or positive.)

Conclusions

During the mathematical model, using finite elements method, the results are closer to the physical model than mathematical model, when electromagnetic force is calculated taking the first degree of the order function. Because of that reason mathematical model, using finite elements method is acceptable.

Both curves of currents in the circuit graphs received from both mathematical models are similar, though their characteristics are different from physical model graph. This could have happened because we didn't take into an account the damages in core, or the residual induction were not taken into the account either. This should be explored more in the future.

It is worth to explore finite elements method usage in mathematical model.

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V. Jankūnas, E. Guseinovienė, L. Urmonienė. Adequacy of Mathematical and Physical Model of Oscillating Mechatronic Device // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 7(87). – P. 69–72.

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В. Янкунас, Э. Гусейновене, Л. Урмонене. Исследование адекватности физической и математической моделей колебательного мехатронного устройства // Электроника и электротехника. – Каунас: Технология, 2008. – № 7(87). – С. 69–72.

Рассматриваются широко используемые мехатронные приводы – преобразователи электрической энергии в механическую. Один из методов исследования – математические модели привода. В этой работе исследуется возможность применить метод конечных элементов при исследовании мехатронного устройства. Привод был исследован тремя способами: осуществляя физический эксперимент, осуществляя математическое моделирование, производя расчеты электромагнитной силы, индуктивности обмотки, а также производной индуктивности по уравнениям (2), (3), (4) и производя математическое моделирование, когда параметры аппроксимируются из поверхностей ранее рассчитанных зависимостей. Меняя величину напряжения питания привода измерялась амплитуда подвижной части двигателя и ток в цепи. Результаты математического моделирования используя метод конечных элементов более близки к физической модели нежели математическому моделированию, когда электромагнитная сила рассчитывается используя первый член порядковой функции. Поэтому математическое моделирование используя метод конечных элементов приемлемо, целесообразно и дальше его использовать. Ил. 8, библ. 5 (на английском языке, рефераты на английском, русском и литовском яз.).

V. Jankūnas, E. Guseinovienė, L. Urmonienė. Švytuojamooщ judesio mechatroninės pavaros fizinio ir matematinio modelių adekvatumo tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 7(87). – P. 69–72.

Plačiai naudojamos mechatroninės pavaros – elektrinės energijos keitikliai į mechaninę energiją. Todėl jas tirti yra aktualu. Vienas iš tyrimo būdų – matematiniai mechatroninės pavaros modeliai. Šiame darbe tiriama galimybė baigtinių elementų metodą taikyti mechatroninei pavarai tirti. Pavara tirta trimis būdais: atliekant fizinį eksperimentą; atliekant matematinį modeliavimą, elektromagnetinę jėgą, apvijos induktyvumą ir induktyvumo išvestinę skaičiuojant pagal (2), (3), (4) priklausomybes, ir atliekant matematinį modeliavimą, kai pastarųjų parametrų vertės aproksimuojamos iš anksčiau apskaičiuotų priklausomybių paviršių. Buvo keičiama pavarą maitinančios įtampos vertė ir matuojama variklio judžiosios dalies švytavimų amplitudė bei srovė grandinėje. Matematinio modeliavimo, naudojant baigtinių elementų metodą, rezultatai artimesni fiziniam modeliui nei matematinio modeliavimo rezultatai, gauti kai elektromagnetinė jėga apskaičiuojama imant pirmąjį laipsnių eilutės narį. Todėl matematinis modeliavimas, naudojant baigtinių elementų metodą, yra priimtinas. Ir toliau tikslinga tirti baigtinių elementų metodo taikymą matematiniam modeliavimui. Il. 8, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).