Student report

NUMERICAL CALCULATION OF FORCE IN ELECTROMAGNETIC FIELDS

Mladen ZEC[1], Mićo GAĆANOVIĆ[2]

Abstract: This paper presents one of the aspects for calculating force between two conductors and describes its influence on electrodynamics intension in energetic systems (ES).

Keywords: Electromagnetic force, Numerical integration, Electromagnetic field, Superposition.

INTRODUCTION

Electrodynamics intension between two conductors is caused by their interaction or by their position in foreign electromagnetic field. These intensions are very important in dimensioning electrical devices and equipment. Following laws are used in order to determinate intensity of electromagnetic force (EMF) [1]:

- Lorentz force law
- Energy variations of current contours

In this paper we will use LaPlace law.

LORENTZ FORCE LAW

Lorentz force is the force on a charged particle in an electromagnetic field. The particle will experience a force due to electric field of $q\mathbf{E}$, and due to the magnetic field $q\mathbf{v} \times \mathbf{B}$. Combined they give the Lorentz force equation (or law)[2]:

$$\mathbf{F} = \Delta Q(E + \mathbf{v} \times \mathbf{B}) \tag{1}$$

Where **F** is the force, **E** is the electric field, **B** is the magnetic field, q is the electric charge of the particle, and **v** is the instantaneous velocity of the particle. Equivalently, we can express the Lorentz force law in terms of the electric charge density ρ and current density **J** as [2]:

$$\mathbf{F} = \int \rho S dl \cdot E + idl \times \mathbf{B} \tag{2}$$

This is the intensity of EMF on wire segment, with current density **J**, located in magnetic field **B**.

Magnetic field is that part of the electromagnetic field that exists when there is a changing electric field. A changing electric field can be caused by the movement of an electrically charged object, as in an electric current of other contours. By Biot-Savart's Law in the magnetostatic approximation, the magnetic field can be determined from the current **I** if all current densities **J** are known: [2]:

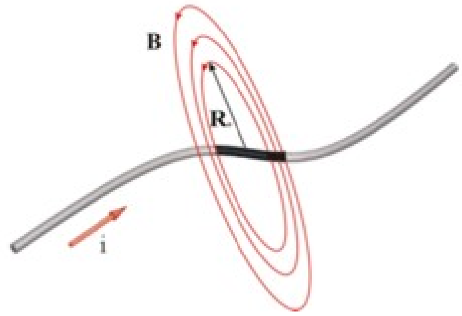

Fig.1 – ***Biot-Savart's Law [2]***

$$d\mathbf{B}(r) = \frac{\mu}{4\pi} \cdot \frac{i_2 \cdot (d\mathbf{l}_2 \times \mathbf{r})}{r^3} \tag{3}$$

Where **r** is the distance from the current element to the field point, dl current element. Using this law we can determinate EMF on the wire segment (1) and vice versa.

$$\mathbf{F}_{12} = \frac{\mu}{4\pi} \oint_{C1} \oint_{C2} i_1 \cdot i_2 \cdot d\mathbf{l}_2 \times \left[\frac{d\mathbf{l}_1 \times \mathbf{r}12}{r_{21}{}^3} \right] \tag{4}$$

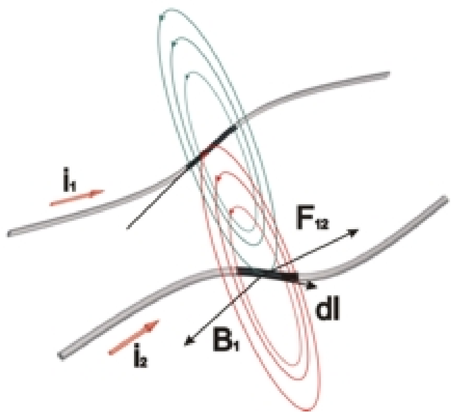

Fig.2 – *Force intensity* **[2]**

[1] University of Banja Luka, Faculty of Electrical Eng,., Patre 5, 78000 Banja Luka, Bosnia and Herzegovina, E-mail: zmladen@gmail.com
[2] University of Banja Luka, Faculty of Electrical Eng,., Patre 5, 78000 Banja Luka, Bosnia and Herzegovina, E-mail: bilchy@blic.net

NUMERICAL CALCULATION USING MATLAB 7.0

In order to do this we will consider conductor's cross-section to be a rectangular. The basic idea is to perform an axial partitioning of conductors in wire segments, for which the mentioned equations are applicable. Now, using the principle of superposition that applies to linear systems of algebraic equations, linear differential equations, or systems of linear differential equations, we can calculate resultant force between conductors [3]:

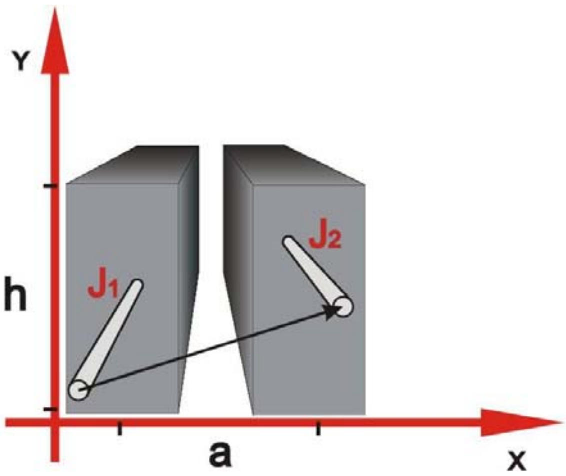

Fig.3 – *wire segments* **[3]**

$$dF_x = \frac{\mu}{2\pi}\frac{I^2}{b^2h^2}\frac{dxdydx'dy'}{(x-x')^2+(y-y')^2}(x-x') \quad (4)$$

$$dF_y = \frac{\mu}{2\pi}\frac{I^2}{b^2h^2}\frac{dxdydx'dy'}{(x-x')^2+(y-y')^2}(y-y') \quad (5)$$

$$F_x = \frac{\mu}{2\pi}\frac{I^2}{b^2h^2}\int_0^h\int_0^b\int_0^h\int_a^{a+b}\frac{dxdydx'dy'}{(x-x')^2+(y-y')^2}(x-x') \quad (6)$$

$$\boldsymbol{F} = \boldsymbol{F}_x + \boldsymbol{F}_y \quad (7)$$

RESULT ANALYSIS

To complete calculation we need to enter dimensions of a conductor, and the intensity of current. For example: a=0,05m; b=0,01m; h=0,10m; I=50KA

The reason we entered this intensity of current is that we considered that there has been a short circuite in the part of opserved energetic system. That is when we have the most dangerous intensions for which systems must be contrived.

Fig.4 below shows how step of the integration effects the result. Smaller step we take will have more precise result but that effects the time of calculation.

On the *Fig.5* we see how force between conductor decreases with their distance. This is a parabolic function due to the fact that the intensity of electromagnetic field decreases with ~1/r^2.

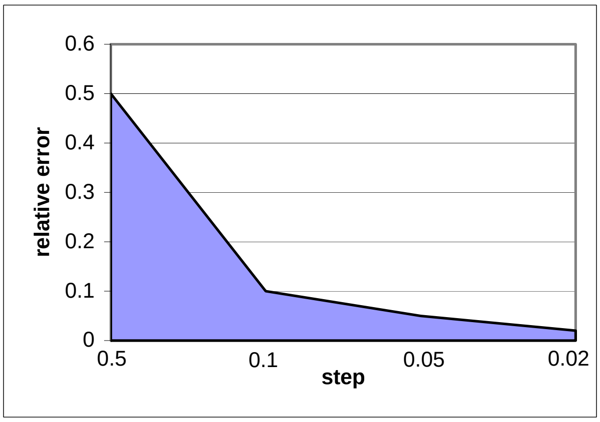

Fig.4 – *relative error%*

Exact value is F[N/m]= 7061.

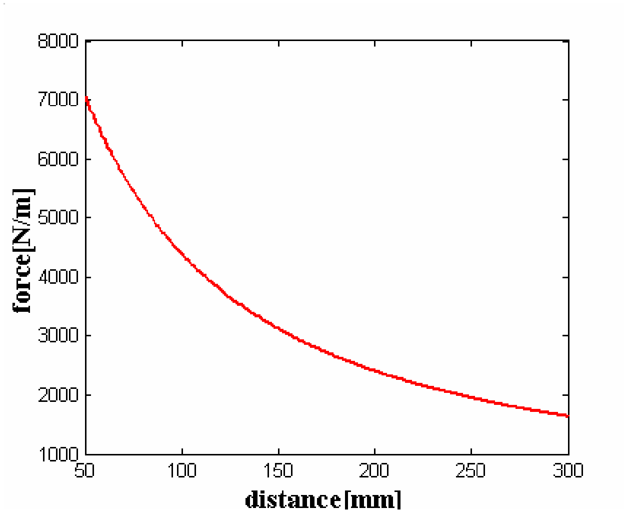

Fig.5 – *force intensity as a function of distance* **[3]**

CONCLUSION

The result analysis shows that this numerical calculation gives relatively good results and can be used in order to calculate intension in energetic systems. For more accurate computation we need smaller step size, but it reflects on algorithm's execution time. This algorithm can also be used for other conductor profiles such as L, Π, ⊥.

REFERENCES

[1] Surutka J. V.; Osnovi elektrotehnike, prvi deo, Elektrostatika, Naučna knjiga, Beograd, 1980.

[2] Surutka J.; Elektromagnetika, građevinska knjiga, Beograd, 1975.

[3] Veličković D. M.; Metodi za proračun elektrostatičkih polja, knjiga prva, Niš, 1982.

[4] Crowley J. M.; Fundamentals of applied electrostatics, JohnWiley & Sons, New York - Chichester - Brisbane - Toronto - Singapore, 1984.

[5] Метод расчета лектростатичких полеџ М., Всша школа, 1963. Авт.: Н.Н. Миролбов, М.В. Костенко, М.Л. Левинштеџн Н.Н. Тиходеев

Mladen Zec was born in 1983. in Bihać. He finished the Technical School „Nikola Tesla" in Banja Luka. During the high school he participated in several contests of mathematics and he was pronounced to be the best student of the generation in his school. Now he is on the 4th year of Faculty of Electrical Engineering department of Power Engineering in Banja Luka. He speaks English and French.

Dr Mićo Gaćanović was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production.

He received many prestigious world-known awards and certificates for his creative work. Hence, he is included in the work of world groups of creativity, research and new technology in Brussels, Moscow, Pittsburgh and other world cities. He is also involved in research projects from the field of theoretical electrical engineering in Germany, Belgium and Russia.