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The Impact of Applicator Size on Distribution of Electromagnetic Field Used In Magnetotherapy

***Abstract**. Electromagnetic field is used in magnetotherapy. The therapy effectiveness depends on the value of magnetic induction and its distribution in applicators. An important problem is an appropriate choice of an applicator to be used in the therapy. The results presented in the paper shows that the applicators size determines the magnetic induction distribution inside the solenoid, generated for the same excitation conditions.*

Streszczenie.** Pole elektromagnetyczne jest używane w magnetoterapii. Skuteczność terapii zależy od wartości indukcji magnetycznej i jej rozkładu wewnątrz aplikatora. Istotnym problemem jest odpowiedni wybór aplikatora zastosowanego w terapii. Wyniki przedstawione w artykule pokazują, że rozmiar aplikatora ma wpływ na rozkład indukcji magnetycznej wewnątrz solenoidu przy jednakowych warunków wzbudzenia. **(Wpływ rozmiaru aplikatora na rozkład pola elektromagnetycznego stosowanego w magnetoterapii)

Słowa kluczowe: pole elektromagnetyczne, magnetoterapia, symulacja komputerowa, MES
Keywords: electromagnetic field, magnetotherapy, computer simulation, FEM

Introduction

Electromagnetic fields are commonly used for medical purposes [1-3]. Their conscious use requires a deep cooperation between medical personnel and engineers. The role of electrical engineers relies in development of modern equipment and constant monitoring of admissible EM field levels.

The present paper focuses on the proper choice of the size of magnetic field applicators, which are used in magnetotherapy. Magnetotherapy is one of the most popular methods of physical therapy, which helps in the treatment of many diseases. It relieves pain and shortens the healing time. On a large scale it is used in orthopedics, rheumatology or treatment of internal diseases [4].

The magnetotherapy devices consist of a control device and applicators. In Poland, the most commonly used as applicators are coils with diameters ranging from 20 cm to 70 cm and a width of approx. 20-30 cm (Fig.1).

Fig. 1. Examples of solenoid applicators

In use there are also elliptical applicators and mats, created from a single coil or multiple coils of various dimensions, mounted e.g. in a mattress or pillows applied to selected parts of the patient's body [5,6]. The electromagnetic field used in magnetotherapy generated by the solenoid has a frequency from 10 to 100 Hz and magnetic induction from 0.1 mT to 20 mT, There are also devices with induction up to 40 mT, however these devices are not often applied. The induction of the field generated by the coil depends on its dimensions, the number of winding and the current value. To obtain inductions of the order of mT, the current in the winding should reach a value of several dozen amps. The most often used waveforms of the signal are: sinusoidal, rectangular or triangular (full or with one-side straightening).

The effectiveness of therapy with using the electromagnetic field depends mainly on the value of magnetic induction and its distribution inside the applicator. Simulation and graphical visualization of the field distribution in appropriate choice of the user's specific needs [7-9].

The aim of the paper is to develop several numerical (FEM) models of applicators used in real-life treatment therapies. The models differ in geometry. It is shown in the paper that magnetic induction profiles differ significantly. The results are compared with experimental data.

Numerical Analysis

The Finite Element Method is a common simulation tool for engineers [10,11]. Numerical models are usually used in these situations when carrying out tests on the real object is costly or even impossible due to some limitations. However in order to develop such a model, it is necessary to adapt a number of simplifying assumptions, what makes it possible to describe the phenomena of interest with a limited number of mathematical equations.

This paper examines the results of FEM simulation in Ansys 18.1.1 Academic Research + EM, in terms of simulation study of the electromagnetic field distribution of applicators. Numerical models of applicators with radii 9.5 cm, 15 cm and 24.5 cm were developed. The assumed values refer to dimensions of real-life devices. In order to simplify the model, the excitation coil was modeled as a single-turn cylinder with appropriate boundary conditions applied. The Author is aware that this is merely an approximation of reality, however it is quite hard to determine the true number of coils in a real-life device, as they are sealed within the case which cannot be opened without destroying the unit. Thus the cylinder may be treated in the first modeling attempt as a single shorted and elongated coil. The same value of excitation current was assumed for all developed models. Significant differences between the maximum values of induction were observed (Figs. 2-4).

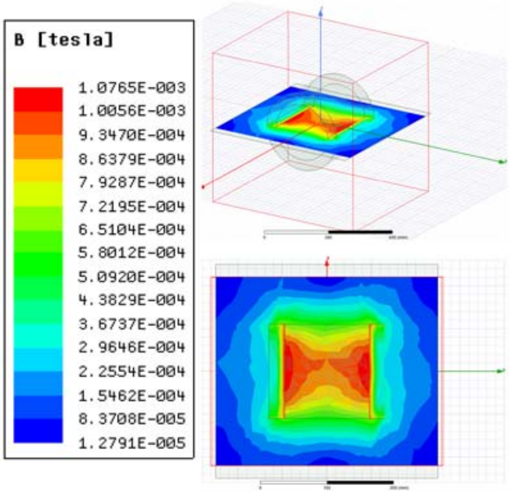

Fig. 2. The distribution of induction module inside the applicator with radius 9.5 cm

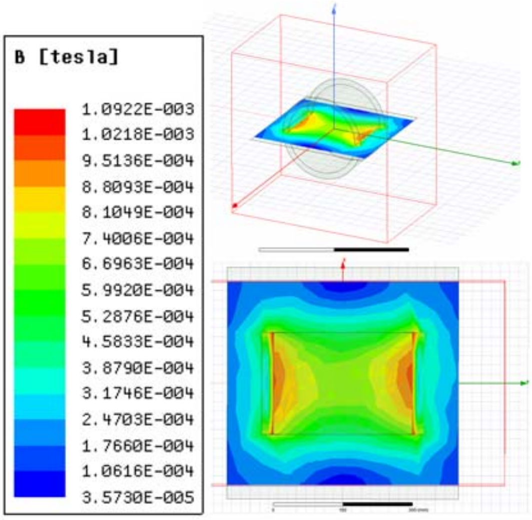

Fig. 3. The distribution of induction module inside the applicator with radius 15 cm

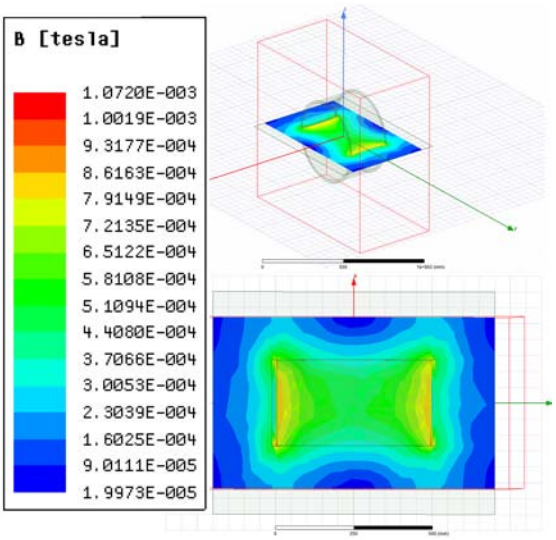

Fig 4. The distribution of induction module inside the applicator with radius 24.5 cm

The profiles of magnetic induction along the fundamental directions were also examined (Figs 5 and 6).

It was noticed that the value of induction module inside the analyzed applicators does not change significantly. However, the difference in value at the edge and inside the solenoid increases with the increase of the solenoid radius. The distribution of the magnetic induction module allows one to observe the changes in the induction value inside the applicator. The maximum value of induction is observed at the edge of the solenoid in its half-length.

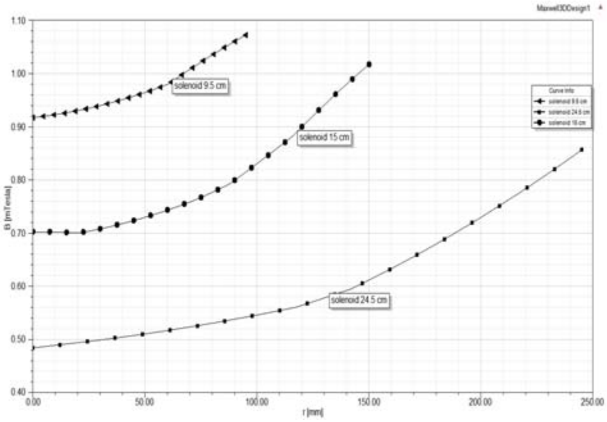

Fig. 5. The distribution of induction module along radius of applicators – numerical model

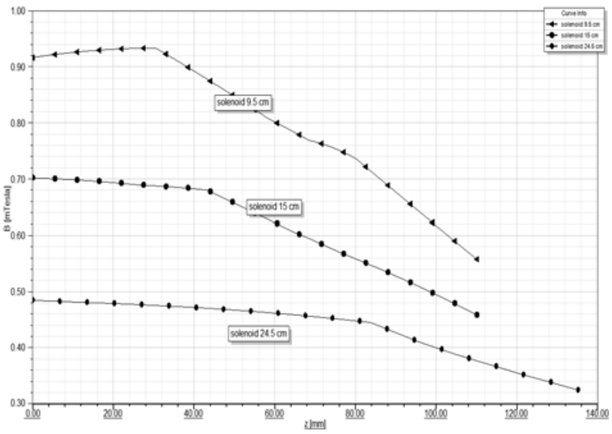

Fig. 6. The distribution of induction module along z axis of applicators – numerical model

The induction values were highest for the smallest applicator, more than twice as much as those for the applicator with the largest diameter. This is an important conclusion from the study, since the appropriate choice of the size of the applicator is crucial for the effectiveness of the therapy. In practice the size of the device is chosen according to the size of the treated limb of other part of the body. Since the applicators are usually supplied from the same control device which does not have any measurement device for monitoring the admissible values, this can result in a situation when the treatment conditions are not optimally chosen.

Model Verification

In order to verify the numerical model, the measurements of induction distribution inside chosen solenoid applicators used in magnetotherapy were carried out. In the tests, the MAGNETRONIC MF-10 power supply (usually used in magnetotherapy) and solenoid applicators with different diameters were applied. The measurements of magnetic induction were made using the CK-1 Halleter teslameter.

Magnetic field induction were measured for applicators with radii 9.5 cm, 15 cm and 24.5 cm. For all applicators, the same parameters such as waveform shape (sinusoidal), frequency (50 Hz) and intensity (maximum according to the manufacturer's scale) were used.

The measurements were made along the *z* axis of the applicator and its radius (in the direction perpendicular to the surface of the coil housing). The variability of magnetic field levels in these directions determines the spatial distributions of the magnetic field in the applicator. It is a consequence of the fact that the distribution of the magnetic field of low frequencies is practically independent of the influence of surrounding elements, with the exception of massive ferromagnetic objects.

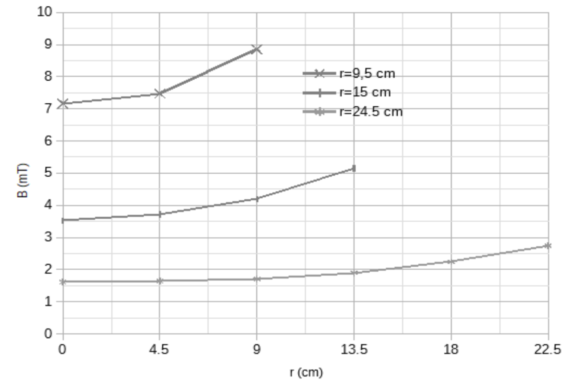

Fig. 7. The distribution of induction module along radius of applicators – measurements

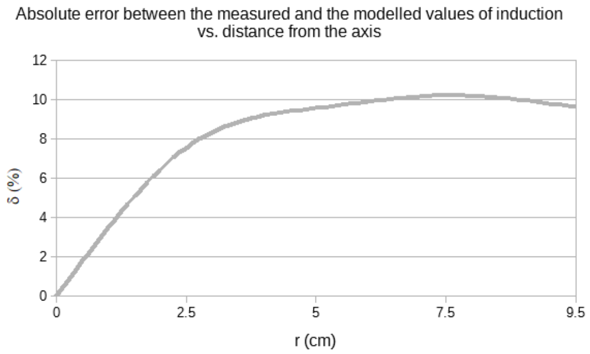

Fig. 8. Absolute error between the measured and the modelled values of induction vs. distance from the axis - the applicator with radius 9.5 cm

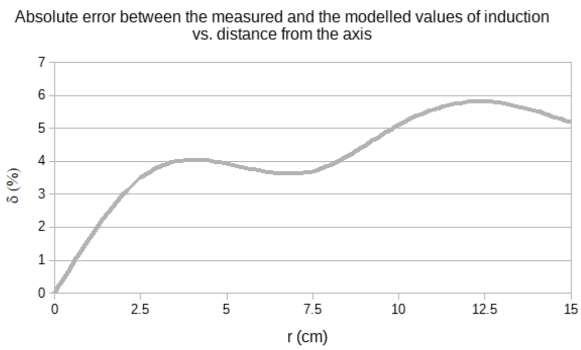

Fig.9. Absolute error between the measured and the modelled values of induction vs. distance from the axis - the applicator with radius 15 cm

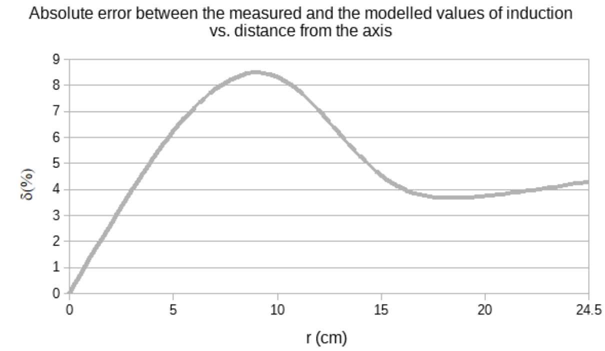

Fig. 10. Absolute error between the measured and the modelled values of induction vs. distance from the axis - the applicator with radius 24.5 cm

It was noticed that the measured values behave in a similar manner like those from numerical simulation. The induction value at the edge and inside the solenoid increases with the increase of the solenoid radius. Thus in order to depict the discrepancies between the measured and modeled values, the Author assumed the measured value at the edge of the applicator (the maximum possible value of induction) as reference. All other values were referred to the aforementioned one.

Figure 7 illustrates the inhomogeneity of magnetic induction along the radial direction. It can be noticed that for the applicator with radius 24.5 cm the induction distribution is practically uniform. Figures 8-10 depicts the absolute error between the measured and the modeled induction values (referred to the value at the edge) for different running radii. The accuracy of the numerical model is highest for the biggest applicator.

Conclusions

In the paper FEM-based models of applicators used in magnetotherapy were developed. Simulations of magnetic induction were carried out. It was noticed that distributions of magnetic induction were less uniform for smaller devices. Moreover it was noticed that the numerical model was most accurate for the biggest applicator. The practical conclusion from the study is that the applicator size should not only be chosen in accordance to the size of the body part being treated. Smaller devices exhibit higher levels of induction in their working space, thus this remark should be relevant to therapists operating such devices. It is also important to take into account that the induction values are smallest in the axis of the applicator and highest at the edges. Thereby, the appropriate choice of the therapy parameters allows one to achieve an expected therapeutic effect. With well-chosen excitation parameters and bad selection of the applicator size and improper limb placement, the therapeutic effect may be insufficient.

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