AMPERE 2019
ISBN: 978-84-9048-719-8
DOI: http://dx.doi.org/10.4995/Ampere2019.2019.9900

ANALYSIS OF HIGH-FREQUENCY C-CORE MAGNETIC FLUX LEAKAGES FOR BONE TUMOR WITH INDUCTION HEATING BY USING MULTI-COIL

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Keywords: high-frequency magnetic core, multi-coil induction heating, bone tumor

High-frequency magnetic field has been developed pervasively. The induction of heat from the magnetic field can help to treat tumor tissue to a certain extent. Normally, treatment by the low-frequency magnetic field needed to be combined with magnetic substances. To assist in the induction of magnetic fields and reduce flux leakage [1]. However, there are studies that have found that high frequencies can cause heat to tumor tissue [2]. In this paper present, a new magnetic application will focus on the analysis of the high-frequency magnetic nickel core with multi-coil. In order to focus the heat energy using a high-frequency magnetic field into the tumor tissue. The magnetic coil was excited by 915 MHz signal and the combination of tissues used are muscle, bone, and tumor as shown in table 1. The magnetic power on the heating predicted by the analytical model in Fig. 1, the power loss density ($2.98e^{-6}$ w/m^3) was analyzed using the CST microwave studio.

Table 1. Material properties of tissue in simulation.

Tissue	Density (kg/m^3)	Conductivity (σ, S/m)	Heat capacity (kJ/K/kg)
Muscle	1050	0.37	3.54
Bone	1040	0.13	1.3
Tumor	1050	2.7	3.82

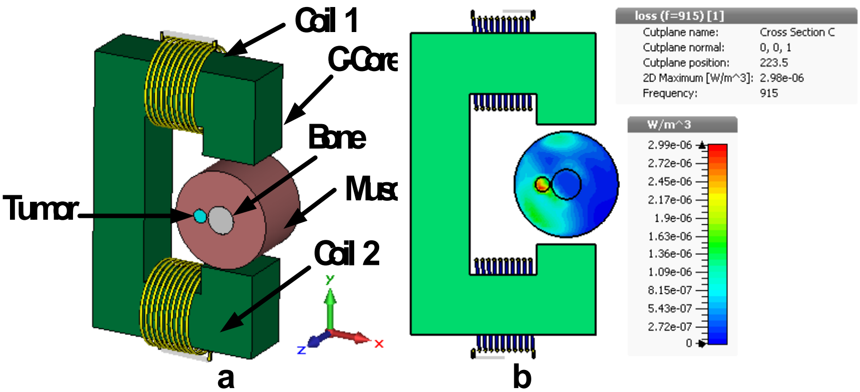

Fig. 1. a) Magnetic induction with multi-coil design and b) power loss density in tissue.

Introduction

Cancer is the leading cause of death in the world. Cancer is a genetic disease that can be inherited from parents to children. Cancer tissue is caused by some changes in genes. Cancer cells are divided rapidly and cannot be controlled. Causing tumors in the body. The tumor is divided into 2 types, Is benign tumors and malignant tumors. Benign tumors will have a mild disease that does not spread to other organs. Malignant tumors will destroy the cells of the organ. And spread to neighboring organs and can also spread through the bloodstream or the lymphatic system to other organs throughout the body such as lungs, liver or bones [3,4]. Bone cancer can occur with bones in all parts of the body. Most of it occurs in the bones that are long, such as the bones, arms, and legs. Bone cancer makes the bones that are close to the cancer cells very strong. Causing the bones to break easily Bone cancer can be divided into 2 types, Primary bone cancer and Secondary bone cancer the primary bone cancer begins to cause abnormalities in the cells that are attached to the bone. And secondary bone cancer will cause abnormalities of cells from other places Is already another type of cancer and the spread of cancerous tissue to the bone [5].

Due to the above treatment has many side effects and use the time to rest the floor for a long time the authors, therefore, propose methods of treatment with hyperthermia. Is a method of heating within cancer cells used for primary bone cancer in the early stages without damage to normal tissues. Hyperthermia therapy uses the principle of high-frequency transmission. Induce the target tissue to increase the temperature up to 42-43 °C [6]. For a period of not less than 40 minutes, the cancerous tumor will be destroyed. Causing cancer cells to atrophy cannot grow and spread to other parts of the body within the primary cancer cells there is a large concentration of blood vessels. Causing poor blood circulation like normal body cells which will make the cancer cells sensitive to temperature changes and retain heat the form of cancer treatment by heat therapy has many characteristics, such as radio frequency, microwave, or ultrasonic waves. The main components of the system of heat treatment include Generator, Computer, Applicator, and feedback temperature to process on the computer in order to be able to control the temperature within the cancerous tumor [7].

Treatment of malignant tumor cells by heating with magnetic fields. In most cases, magnetic nanoparticles are added into the target tissue as well to increase the induction of heat. Can use hyperthermia treatment in combination with other forms of treatment for better performance [8,9]. In the past year, people have designed the magnets for magnetic hyperthermia applications in large models. In the form of a c-core magnetic core using a frequency of 200 kHz [10]. The selection of frequencies will affect the heating of the tissues for the hyperthermia system at a very high frequency. It is necessary to have magnetic nanoparticles. Helps to cause heat Because the normal tissue of the body has the ability to absorb magnetic fields is not good. But if using high frequency, the heat generated from eddy current can be achieved and can generate enough heat to destroy cancerous tumor cells without having to give magnetic nanoparticles enter the body before hyperthermia heat.

Materials and Methods

For winding the coil on the ferrite core in a circular motion when a current is supplied to the coil, where the core made from the ferromagnetic material causes the intensity of the magnetic field Increased from zero. Which the density of this magnetic force line will increase until the density of the magnetic force line is constant which are saturated.

Calculations for magnetic circuits have a calculation principle similar to the calculation of electrical circuit from Ampere's Law. If there is no effect of the leakage line outside the ferrite core. And the magnetic force line is constant in the ferrite core along the length of the ferrite core, resulting in the density of the magnetic force line constant. And when the ferrite core has air gap in Fig. 2.

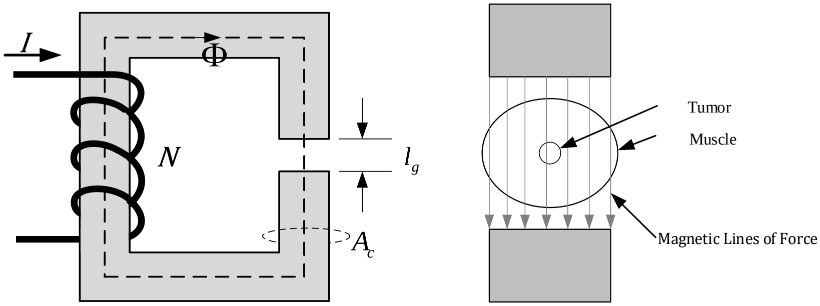

Fig. 3. a) The Schematic of c–core magnetic induction heating system.
b) Modeling the muscles between the air gap.

will receive the magnetic force equation within the magnetic core and in the air gap as

$$\Phi = \frac{NI(\mu_0 A_c)}{l_g} \tag{1}$$

where Φ is magnetic lines of force (Wb), N is number of turns (Turns), I is current (A), μ_0 is permeability of free space (H/m), A_c is cross-sectional area of ferrite core (m^2), and l_g is the length of air gap. Therefore, the density of the magnetic force line moving through this air gap can be obtained from equation 2, but the area where the magnetic force line moves through this air area is uncertain. Which will vary according to the length of the air and will change according to the pattern of the cross-sectional area of the magnetic core as well

$$H = \frac{\Phi}{\mu_0 A_g} \tag{2}$$

where H is magnetic flux density (Wb/m^2). Induction heating is heated by the magnetic force that moves through the ferrite core. The basic properties of human tissue are the infiltration of the magnet near the vacuum. Causes the magnetic field to have a slight effect on the heat generated by human tissue. A common method for creating magnetic stimulation models from Ampere's Circuital Law with the Coulomb gauge [11]. Will receive the magnetic field produced by the coil current and modified using the equation of Laplace vector

$$-\nabla^2 A = \mu_0 \times J \tag{3}$$

where J is the current density vector that flows within the source coil and A is the vector magnetic potential ($H = \frac{1}{\mu_0}\nabla \times A$). High frequency alternating magnetic field produces heat inside the body. When the magnetic is present, eddy currents conductive power loses. Which is created from the current density vector shown as [12]

$$P = \frac{J^2}{\sigma} \tag{3}$$

where P is power density (W/m^3), and σ is conductivity of tissue (S/m).

In human body has a circulatory system, there are a lot of blood vessels in many parts of the body. The circulatory system will maintain the body's temperature and pH. The circulatory system will have blood as a heat carrier. In which the blood is liquid consisting of blood, red blood cells, white blood cells, and platelets. Which the heart functions through the tube system when there is a part of the body that has abnormal temperature from other parts the circulatory system will adjust the body temperature. Where the heart will pump blood throughout the body consisting of various parts to transfer heat through the blood to various parts of the body and make the body temperature balance. The Penne's heat equation is the basis of the heat diffusion equation. Which is used very well for heat transfer of various biological tissues [13-14]. The Penne's equation combines the main factors that affect temperature change only. Which there are some factors that are not used in the calculation will get the equation of heat dissipation as equation [15]

$$\rho C \frac{\partial T}{\partial t} = \nabla(k\nabla T) + \rho_B C_B \omega_B (T - T_B) + A + P \tag{3}$$

where ρ is tissue density (kg/m^3), C is specific heat of tissue (J/kg°C), T is temperature of tissue (°C), t is time (s), k is heat conduction of tissue (W/m°C), ρ_B is blood density (kg/m^3), C_B is specific heat blood (J/kg°C), ω_B is blood distribution rate (Hz), T_B is temperature of blood (°C), and A is heat from the energy metabolism of the body (W/m^3). For this experiment, it is not thought of as the heat from the energy metabolism of the body fields because of the small amount compared to the results from other parts.

The design of the ferrite core in the form of a c-core with air space the c-core ferrite core is a loop. There is a section that allows the magnetic force line to move through the airless. Causing the loss of the magnetic force line as well and the air gap is the direct release of the magnetic field to the simulation tissue causing the c-core ferrite core to have a very small loss. The purpose of the use is a set of magnetic fields created for the human body in the organ that found bone cancer by focusing on the bones, arms and leg bones, so the size of the ferrite core that acts as a magnetic resonator must be the size that is appropriate for that particular organ. Therefore, designed the size of the ferrite core to be the form of c-core, the size that can control the part of the human arm and has the shape of the model and size shown as Fig. 4.

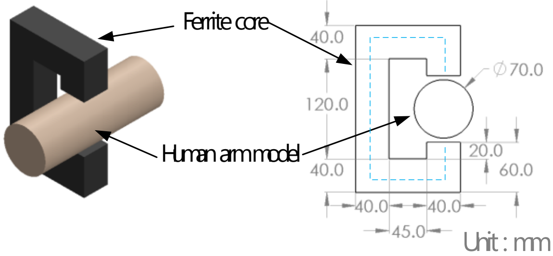

Fig. 4. The analytical model of c–core magnetic induction heating system.

Results

In this section, we investigate the magnetic flux density, which can be controlled by c–core magnetic induction heating system. In order to resolve the problem of the heating region and local heating can be controlled by varying the air gap size of the c–core magnetic induction system. Moreover, the investigation showed that the position of the heating region can be relocated by changing the position of the tumor tissue with c–core magnetic induction system in the x-axis direction. The construction of c–core magnetic induction heating system to verify the field distribution on the heating model, full wave 3-D numerical simulation was performed using the finite difference time domain method.

From these theoretical investigations, one effective method to control a heating region in the bone was found. Hence, the temperature in the heating body can be controlled by the size of the air gap size of the c–core magnetic. Electric loss density for the heating model was evaluated. The ferrite core is excited by 915 MHz signal. The air gap sizes in the simulation are 5 cm. Electric loss density images for heating region shown in Figure 5.

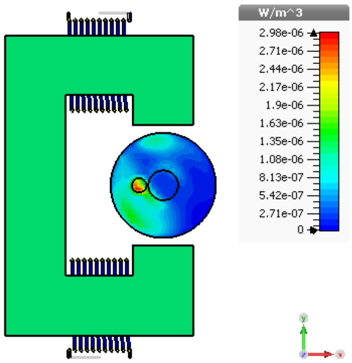

Fig. 5. power loss density in tissue in left-position.

Fig. 5 the simulation results show that the heating efficiency is related to the c–core magnetic. It can be seen that the maximum heat occurs between c–core magnetic in the position of tumor tissue. Furthermore, the result of c–core magnetic also has a role in reducing heat distribution in neighboring tissues of breast phantom but midpoint heating are increasing. As mentioned, if the diameter of the tumor tissue is changed as left, right and center. The distributions of the power absorption per volume are changed as shown in Fig. 6

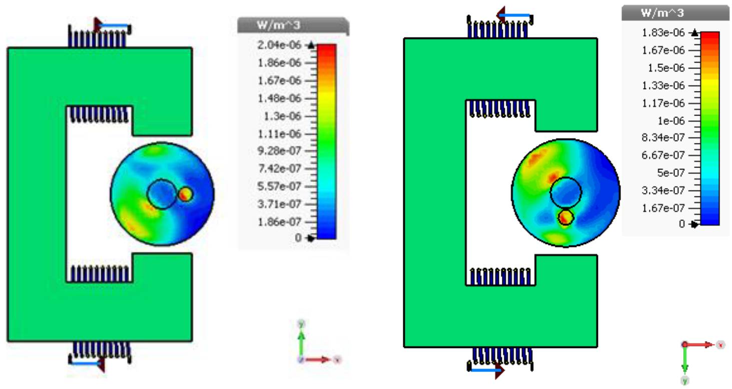

Fig. 6. a) power loss density in tissue in right-position, b) power loss density in tissue in center-position.

According, Fig. 5, and 6 the heating results show that the efficiency is related to the tumor tissue position, which the maximum heating area was inside the bone.

Conclusion

In this paper, the induction heating for hyperthermia with high-frequency c–core magnetic system was conducted to determine the heat distribution in the dielectric loads or tumor tissue. For analyzing the process, the c–core magnetic was excited by frequency 915 MHz, Then the c–core magnetic is considered by an air gap to investigate the difference of power loss density in the dielectric material. The simulation found that power loss density can be increased while the heating area is narrowed. Nevertheless, the power loss density changes as a function of tumor tissue diameter also. This research is believed to be effectively applied to control the size of the heating area for hyperthermia cancer treatment.

Acknowledgment

This work was supported by Suranaree University of Technology (SUT) and by the Office of the Higher Education under NRU project of Thailand

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