Improving the Efficiency of a Transcutaneous Energy Transmitter and the influence of the Specific Absorption Rate

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Abstract — A Transcutaneous Energy Transmitter (TET) uses electromagnetic field to transfer power from outside the body to an artificial organ inside the body. A range of TET parameters was studied, using Finite Element Method through Flux2D to simulate the efficiency of the device and the power and induced current on the skin. The data was exploited with genetic algorithm to maximize the efficiency, using surrogate functions. Moreover, the optimized data was again simulated by FEM to assure that specific absorption rate (SAR) and induced current are within the limits allowed by ICNIRP.

I. INTRODUCTION

With the advancement of technology and medicine, human beings are having more and more chances to live longer with the help of artificial organs. Some artificial organs can be used externally and some completely inside the body, but the main problem of the latter is the supply of power. For this reason, several researchers had explored different ways of transferring energy to inside the body. It is known that percutaneous leads can cause infections due to wire passing through the skin. For this reason, one possible option would be the use of transcutaneous energy transfer (TET).

TET supplies energy from outside to inside the body by means of electromagnetic fields without direct electrical connectivity, providing more flexibility to patient daily activities . Thus, there are several techniques to implement that, considering the efficiency, the specific energy absorption rate (SAR), thermal effects, among others.

This paper explores a TET geometry using techniques for minimizing the efficiency by changing the frequency, core geometry and wire turns. In order to simulate the magnetic effects, the finite element method (FEM) was used through the Flux2D software, using a magnetodynamic approach.

II. PRINCIPLES

A. Transcutaneous Energy Transmission

Fig. 1 shows a block diagram of the considered TET, which can be composed of the following subsystems:

a. DC power outside the body, which can be supplied from a battery.

b. Switching Control Circuit outside the body, which converts the DC power from the battery to AC with frequency varying from 100 kHz to 300 kHz in order to be induced magnetically.

c. Magnetic transformer with a primary coil outside the body for energy transmission, using electromagnetic induction, to the secondary coil inside the body.

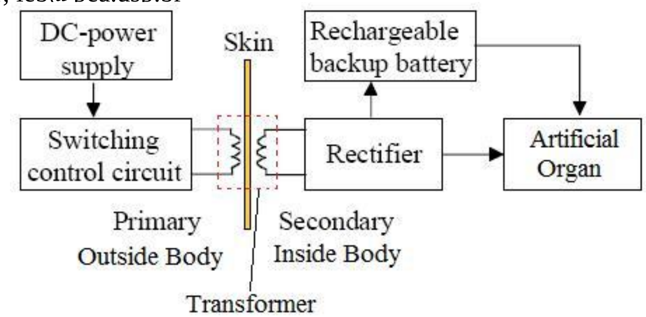

Fig. 1. Block Diagram of the considered TET

d. Rectifier inside the body, which transforms the AC back to DC power in a way that it can recharge a backup battery and/or energize the artificial organ.

e. Rechargeable backup battery, which is used to supply power to the artificial organ when the transmitter is not positioned.

B. The transformer

The considered transformer to be optimized has the geometry as shown in Fig. 2.

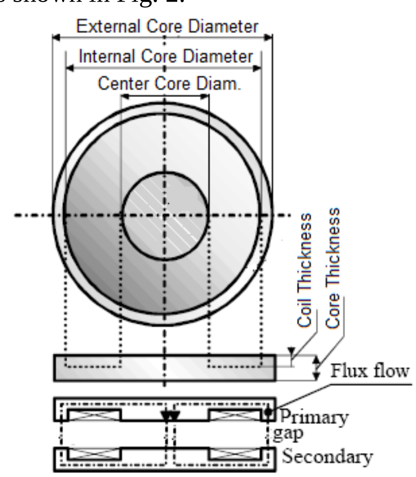

Fig. 2. Geometry of the considered transformer

TABLE I
THE DESIGN PARAMETERS OF THE TRANSFORMER

Primary		Secondary	
Parameter	Range (mm)	Parameter	Range (mm)
Center Core Diameter	[8 24]	Center Core Diameter	[8 24]
Coil thickness	[1 4]	Coil thickness	[1 4]
Wire turns	[23 45]	Wire Turns	[23 45]
Frequency: [100 300] kHz			

It is a planar transformer constructed in a cylindrical shape from ferrite cores and Copper coils. The parameters for external and internal core diameters, coil diameter, core thickness and gap between primary and secondary were set to 50 mm, 40 mm, 5 mm and 3 mm respectively. Table I shows the ranges, for optimization purposes, of Center Core Diameter, Coil thickness, wire turns as well as the frequency.

C. Electromagnetic Effects

Electromagnetic effects on biological tissues can be minimized by restricting the specific absorption energy rate and the current density.

The SAR is the rate at which the electromagnetic energy is absorbed into biological tissues per unit mass, expressed in W/kg. It can be used as an index of the thermal effect, which means, the increase of temperature due to Joule heat generated in the biological tissue. Thus, SAR can be expressed as

$$SAR = \sigma . E^2 / \rho \quad . \qquad (1)$$

In this equation, E is the root mean square (RMS) electric field (V/m); σ is the electrical conductivity of the biological tissue (S/m); and ρ is the density of the biological tissue (kg/m^3).

Current density is the current magnitude flowing through the surface expressed in Ampere per square meter (A/m^2) and can be used as an index of stimulant action, or the neural or muscle excitation due to the induced current. It can be expressed as

$$J = \sigma . E \quad . \qquad (2)$$

Due to this importance, ICNIRP defined limitations on SAR and current density for frequencies between 100 kHz and 10 MHz [6] as shown on Table II.

TABLE II
ICNIRP BASIC RESTRICTIONS FOR FREQUENCY RANGE 100KHZ TO 10MHZ

Exposure characteristics	Current Density (mA/m^2) (rms)	Average SAR (W/kg)	Power Density (W/m^2)
Occupational Exposure	f/100	0.4	50

D. Optimization

For the process of optimization, the collected data, using Flux2D while varying the parameters within the range as shown in Table I, was used. A surrogate aproach (Kriging model) was adopted only to save computation time [7].

Thus, genetic algorithm technique on Matlab was applied to maximize the efficiency and an optimal parameter set was obtained.

III. RESULTS

The core geometry shown in Fig. 1 was built on Flux2D with the wet skin electrical properties (electrical conductivity and the relative permittivity) defined by Institute for Applied Physics [2]. The SAR was calculated using skin density value as $1000kg/m^3$ and the magnetic permeability as 1. With this simulation, it was possible to get the power on the external and internal coils and the induced current on the skin.

As the optimal set of parameter was obtained with a surrogate function, there is a uncertainty on these data. Thus, optimal data was analyzed through a new simulation on Flux2D, in order to verify the actual value of the efficiency and also that the SAR and the induced current were within the allowed ranges.

In order to calculate the SAR, the power density on the skin was used divided by the skin density, reaching a maximum of 6.8mW/kg, which is below the maximum value allowed by ICNIRP.

The current density was also calculated through Flux2D, getting a value of $2.1A/m^2$, which is below the limit of $3A/m^2$ allowed by ICNIRP for occupational exposure. The obtained efficiency value is equal to 96.22%. The Kriging model shows a very good reliability: its approximated value was 96.06%.

IV. CONCLUSION

The attained parameters generate SAR and induced current within the ICNIRP limits and promote the maximum efficiency of TET for the studied ranges. In future research, the optimization of SAR and the induced current is planned to be performed considering minimization of volume and use of different materials for core and coil.

V. REFERENCES

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