Numerical Study of Coupling between Coagulators and Electrodes of Cardiac Pacemakers under Consideration of the Human Body

Markus Schick and Friedrich M. Landstorfer
Institut fuer Hochfrequenztechnik, Universitaet Stuttgart
Pfaffenwaldring 47,
70550 Stuttgart, Germany
Email: schick@ihf.uni-stuttgart.de

Abstract

The paper presents a numerical, worst-case study of the coupling between coagulators and cardiac pacemakers under consideration of the human body. For this purpose two special body models have been implemented. With these models whose electrical properties correspond to a weighted average of those of different tissues of the human body the influence of the latter can be taken into account in the computations. Different parameters such as position of the pacemaker and its electrode, coagulation frequency, and coagulation point on the surface of the human body are considered. Based on results of previous investigations simplified approaches to account for the dielectric coating of the coagulator electrode and housing of the pacemaker can be used. The investigation shows, that for the scenario described above, strong peaks occur in the resulting graphs arising form resonance effects on the coagulator cable.

Introduction

The increasing use of electronic devices in operating theatres and intensive-care units leads to possible interactions of such devices and consequently to serious immunity problems. Particularly critical are scenarios, where extremely small patient-related electrical signals are registered. These signals can be heavily influenced by currents in the tissue of the patient or by radiation coupling originating from other devices acting on the patient. Cardiac pacemakers are implanted medical devices controlling the rhythm of the heartbeat and giving electrical stimulation to guarantee a steady pulse. By the influence of electromagnetic fields, a malfunction of the pacemaker might happen. Devices producing such disturbances are, for example, RF surgery devices. One of them is a coagulator. Measurements inside the human body are not feasible. For dealing with these EMC-problems, simulation models have to be developed and numerical computations have to be carried out, to determine the coupling effects between coagulators and cardiac pacemakers. A near field worst-case study of these effects considering the properties of the human body is described in the following.

Human Body Models

For this analysis, appropriate model for numerical calculations representing the influence of the human body has to be generated. In order to achieve results of general validity, different scenarios need to be considered within the numerical investigations. To limit the extent of memory requirements and computation time, it is necessary to perform the investigations with simplified models. For this examination, two models have been used. The first is called Hy26 and was developed following the measures given in DIN 33 402 part 2 ([1], [2]). It is a flattened body model including shoulders and head (see Fig. 1 left) representing a male person between 41 and 60 years old. It consists of canonic structures and was especially developed for the field computation program used in this study: FEKO ([3], [6]).

FEKO is a field computation programme considering objects of arbitrary shape. It is based on a full wave solution of Maxwell's equations in the frequency domain. The accurate Method of Moments (MoM) formulation is used to solve for the unknown surface currents. Asymptotic techniques, Physical Optics (PO) and Uniform Theory of Diffraction (UTD), have been hybridised with the MoM in order to solve electrically large problems. The MoM has also been extended to solve problems involving multiple homogeneous dielectric bodies, thin dielectric sheets and dielectric coated wires.

The second model was converted from a CAD model, segmented for FEKO and is called Ergoman (see Fig. 1 right). It satisfies the same conditions as Hy26. The former is more flexible regarding changes in the modeling, the second has a more humanlike shape and has less corners and edges.

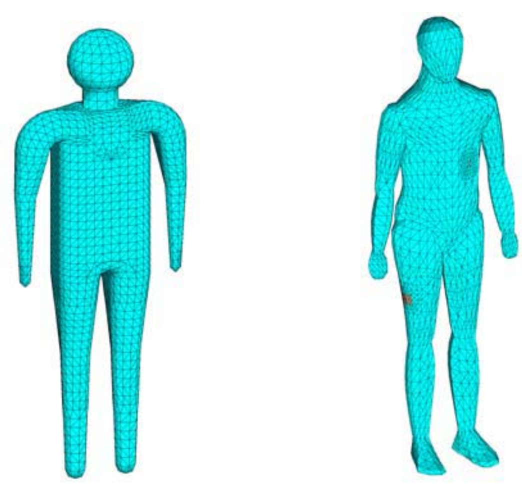

Fig. 1. Human body models Hy26 (left) an Ergoman (right).

Additionally the electrical properties of the human body have to be taken into account. As these models are homogeneous, weighted average values for the relative permittivity and the conductivity of the tissues are used for modeling. Depending on frequency, the values for the single tissues (muscle tissue, bones, lungs, heart, stomach) are chosen according to [4] and [5] and weighted according to [7].

Coagulator

The coagulator is a RF-surgery device using high frequency currents e.g. for cutting tissues. But in contrast to a scalpel, the cut with a coagulator shows no bleeding as the egg white in the cells is coagulated by the current flowing and consequently seals the cells.

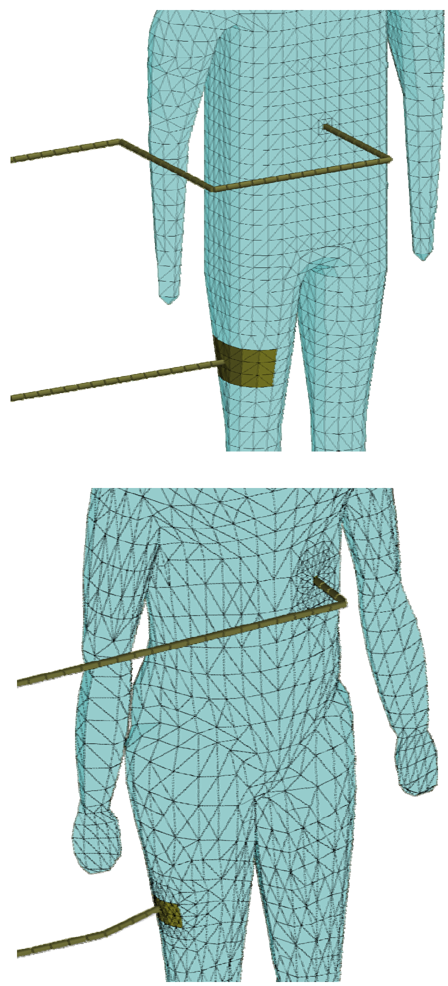

Fig. 2. Coagulation point in the chest area and position of the opposite electrode on the femoral.

The coagulator can be operated in two different modes, the monopolar and the bipolar mode. With the latter a pair of tweezers is used whose halves are identical with the two electrodes. Here the current flow is local in the human tissue. In case of the monopolar mode, a special shaped electrode is used for cutting, and a large opposite electrode is usually placed on the femoral (see Fig. 2). In this case the current flows from the coagulation point over the human body to the femoral. For investigating the worst-case input voltage at the input of the cardiac pacemaker the normally used monopolar mode is considered in this study, because of the large-scale distributed body currents created in this approach. With the bipolar mode only a very local current flow between the ends of the tweezers is to be expected, with hardly any influence on the pacemaker.

The length of the coagulator cable is chosen to 8.6 m with the voltage source placed 3.3 m after the coagulation point. The area of the neutral electrode on the body model is varied from 50 cm² to 180 cm² and is attached on the outer side of the femoral. Most of the cable routing is done in the y-z-plane on the right side of the body model.

Cardiac Pacemaker and Electrode

As a second object for consideration, a cardiac pacemaker is regarded in this study. It consists of a housing containing the electronic circuits for regulating the heard beat and an electrode leading the electrical signals to the heart. In a pre-investigation ([8]), the influence of different housings of the pacemaker was determined. In this study mentioned above a calculation method combining the Method of Moments (MoM) and the Multiple Multipole Method (MMP) was used to numerically determine the influence of electromagnetic waves on cardiac pacemakers in the frequency range from 50 MHz to 500 MHz. First a layered planar model was used. For taking body resonances into account, a 3-dimensional model of spheroidal shape was introduced. A realistic body model for comparative measurements has been built up, and showed only small differences to the computation results. Several typical scenarios have been investigated and worst-case input voltages have been determined. For the cardiac pacemaker 2-dimensional and 3-dimensional models are taken into account as well as different geometrical shapes. Since all housings considered give nearly the same input voltage, a 2-dimensional model with a shape approximating a real pacemaker (see Fig. 3 down) is used in this study. For obtaining reliable results, it is mandatory to model the pacemaker's electrode appropriately and to take its insulation into account. The dimensions are 0.5 mm for the radius of the wire and 0.5 mm for the thickness of the insulation, which was assumed to consist of silicone, and, consequently, the conductivity and relative permittivity of the latter are used in the calculations.

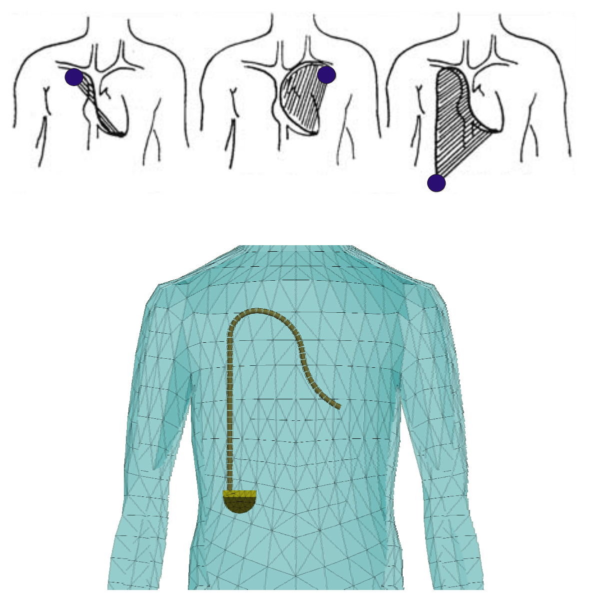

Fig. 3. Different positions for implanting a cardiac pacemaker (above) and model of the implanted cardiac pacemaker (below).

The resulting lengths of the electrodes in these three cases are 25.8 cm, for the pectoral case and 88.1 cm for the abdominal case, respectively. The housing has a height of 3.5 cm and a width of 5 cm and is placed 6.5 cm inside the body model. Three different positions are usually used for implanting a cardiac pacemaker: right pectoral, left pectoral and abdominal (see Fig. 3 above). All three were taken into account in the examinations described below.

Examinations

To investigate interferences of coagulators with pacemakers, the following interference model (described in [8] and introduced in [9]) consisting of two sub-models is used. The sub-model "coupling" describes the relation between the interference source (coagulator) and auxiliary quantities such as e.g. the voltage at the electrode leading to the cardiac pacemaker. In this study this model is considered under worst-case assumptions. The sub-model "compatibility" describing the effect of the interference with the circuit of the pacemaker is not investigated here.

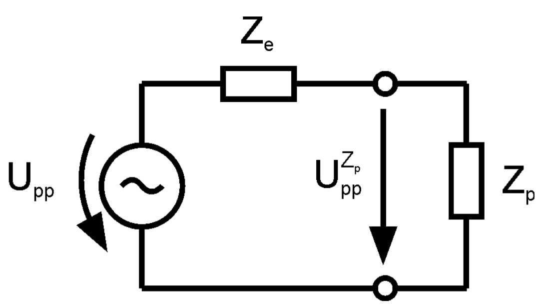

Fig. 4. Equivalent circuit diagram for the coupling model.

Figure 4 shows the equivalent circuit of the coupling model. The implanted pacemaker can be completely characterised by the complex internal impedance of the electrode Z_e and the input impedance of the pacemaker circuitry Z_p. To gain a more general validity of the coupling model, the (fictive) open circuit peak-to-peak voltage U_{pp} is determined (with $Z_p \to \infty$) in the computations.

The study deals with a typical application: coagulation in the chest area (e.g. cutting or sealing an artery). In the investigations the position of the pacemaker and the resulting lengths of the electrode, as well as frequency in the range from 100 kHz to 100 MHz, and the point of coagulation are varied. The input voltage on the electrode at the entrance of the cardiac pacemaker is calculated. To achieve values for the input voltage two computations are necessary. The first is to determine the current I_{el} in the ultimate element on the pacemaker's electrode at the entrance of its housing when feeding the coagulator cable with a voltage source with $U_0 = 1\,\mathrm{V}$. The second computation is for determining the impedance Z_{el} of this very element. With these two values the voltage at the pacemaker's entrance can then be calculated with $U_{in} = Z_{el} \cdot I_{el}$.

Results

As an example for the results obtained the voltage on the electrode at the input of the cardiac pacemaker for the model Hy26 is shown in Fig. 5 and for Ergoman in Fig. 6. In both cases the voltage for all three implantation positions are displayed. For both models the abdominal implantation leads to the highest values for the voltage at the entrance of the cardiac pacemaker. A comparison between the two models for abdominal implantation is shown in Fig. 7. Comparing the two curves it is obvious that the curves are similar for lower frequencies but differ much more for frequencies over 10 MHz, especially in the peaks that appear there. Ergoman has only one peak (62 MHz) compared to Hy26 with four peaks (26 MHz, 38 MHz, 56 MHz, 91 MHz).

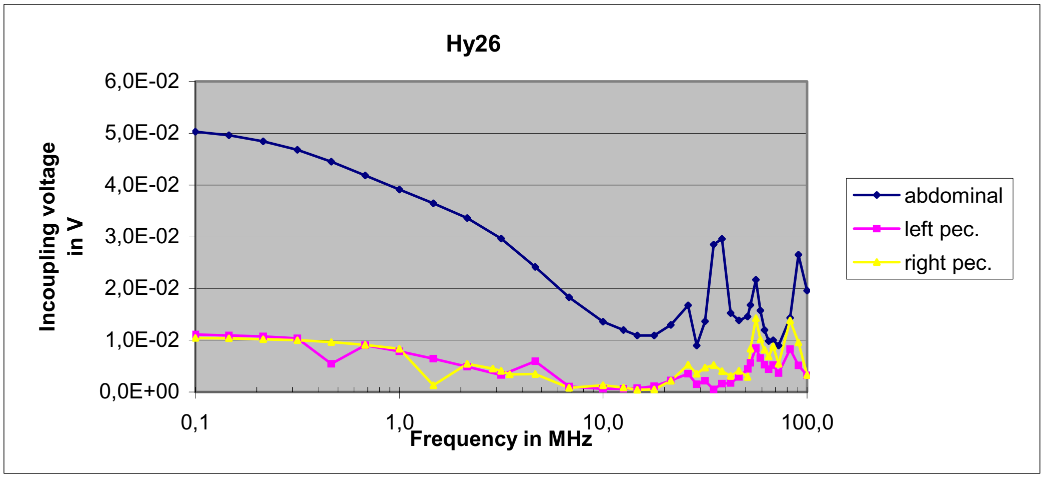

Fig. 5. Voltage on the electrode at the entrance of the pacemaker in V for the model Hy26.

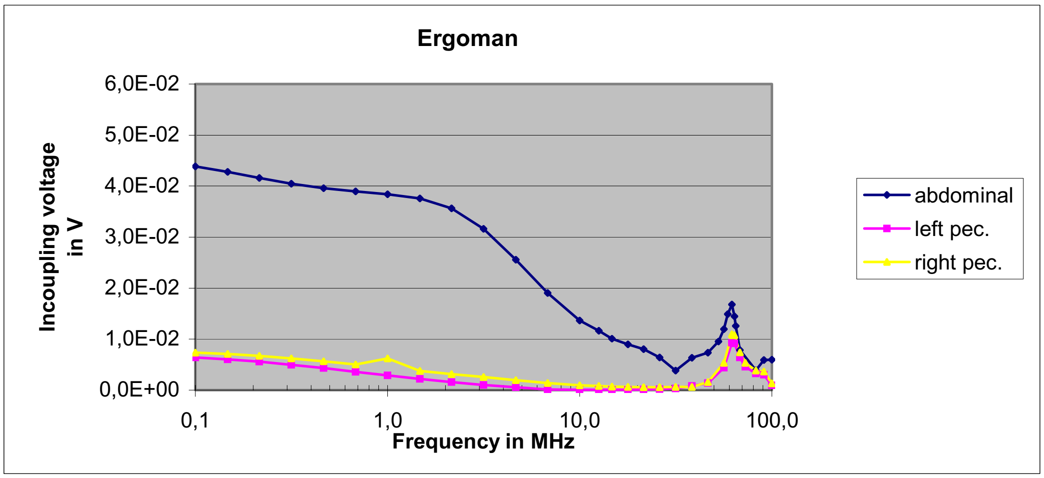

Fig. 6. Voltage on the electrode at the entrance of the pacemaker in V for the model Ergoman.

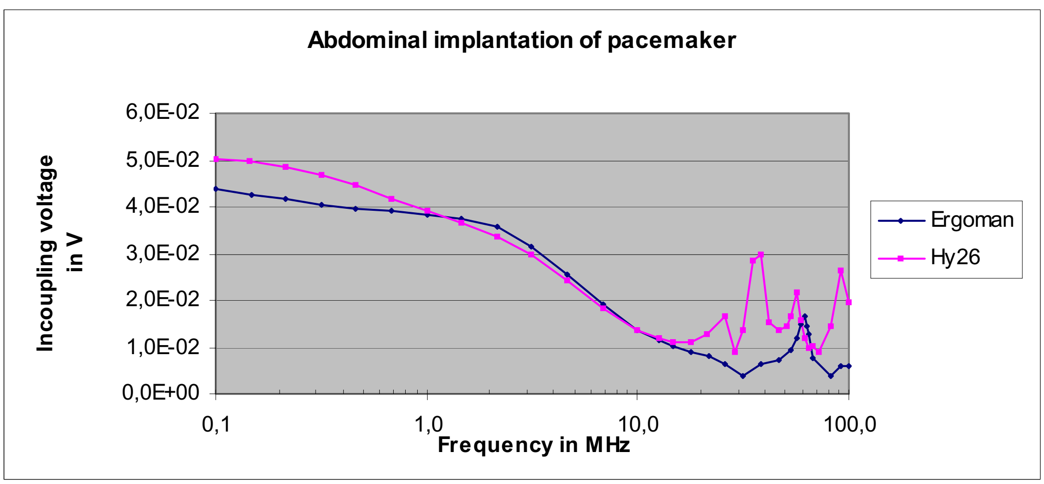

Fig. 7. Voltage on the electrode at the entrance of the pacemaker in V for abdominal implantation for both models.

One reason for these peaks is resonance effects on the coagulator cable. A relation between the resonant frequencies and the appertaining wavelengths, respectively, and the length of the cable can be determined. Variation of the cable length showed a very good agreement of the theoretical determined frequency corresponding to a wavelength resonance and the first resonance in the results for all the computed cable lengths. The size of the neutral electrodes area has almost no influence on the results. Also the variation of the coagulation point in the chest area showed no significant differences in the results.

The body model itself influences the magnitude of the voltages only but not their resonance frequencies. Resonances are taking place on the surface of the human body not inside, because of the strong attenuation of the tissue. The fact that the resulting curve of the model Hy26 has more peaks compared to that of Ergoman arises from the form of the model itself as it contains edges and corners due to adding parts of canonical structures. In contrast Ergoman has a more smoothed shape. The distances between these edges on the human body model are in the order of half a wavelength of the resonance frequencies observed in the graph.

The validation of the computational method is given in [8], where measurements where performed for comparison with the computational results and very good agreement was achieved.

Conclusions

A near field study is presented to determine the influence of a coagulator operated in monopolar mode in the presence of a cardiac pacemaker. Two human body models have been developed with corresponding electrical properties of human tissues. Different positions of pacemakers and points of coagulation are taken into account. Resonances can be found in the resulting curves and with comparing these they can be deduced from resonances on the coagulator cable.

Acknowledgement

The work for the paper was carried out within the scope of a project of the 'Sonderforschungsbereich EMV' of the 'Deutsche Forschungsgemeinschaft (DFG)'. The authors would like to thank the DFG for supporting their work.

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Markus Schick was born in Düsseldorf, Germany in 1973. He received the Dipl.-Ing. degree in electrical engineering from the Universität Stuttgart, Germany, in 1998.

He is now a staff member of the Institut für Hochfrequenztechnik of the Universität Stuttgart, Germany. His main interest is in solving electromagnetic problems with the Method of Moments and hybrid methods, accelerating computations over large frequency ranges as well as dealing with electromagnetic compatibility problems especially in medical areas.

Friedrich M. Landstorfer (SM'79–F'95) was born in Munich, Germany, in 1940. He received the Dipl.-Ing. and the Dr. Ing. degrees in electrical engineering from the Technical University of Munich, Germany, in 1964 and 1967, respectively. In 1971, he became a Lecturer and in 1976 he became a Professor at the Technical University of Munich, Germany. In 1986 he moved to Stuttgart to become Professor and head of the RF-institute at the University of Stuttgart, Germany. His research interests include antennas, microwaves, electromagnetic theory, wave propagation in connection with mobile communication, navigation, and electromagnetic compatibility.

Dr. Landstorfer received the award of the NTG (Nachrichtentechnische Gesellschaft im VDE, now ITG) for the optimization of wire antennas in 1977 and was Chairman of the 21st European Microwave Conference in Stuttgart, Germany, in 1991. For eight years he headed the antenna group of the NTG/ITG and has been a member of URSI. He was awarded Honorary Professor of Jiaotong University in Chengdu, China, in 1993.