Simulation of Radiation Field Effects on a Maritime Ship upon an Electric Model of the Human Body

Alexandru BACIU, Nicolae JULA, Alexandru SOTIR, Georgiana MARIN

Romanian Nautical College
baciualx@gmail.com
Military Technical Academy, Bucharest
Naval Academy "Mircea cel Bătrân", Constanta
*Research Center for Navy, Constanta*INTRODUCTION

Abstract **— The subject of the present paper subscribes to the trend of nowadays research in the field of EMC (Electromagnetic Compatibility) regarding the identification of some negative aspects of the electromagnetic field upon human body. More precisely, the paper presents a physic electrical model with concentrated parameters of the human body exposed to the electromagnetic field on board of a navy ship. Based on the measurements done on board it is analyzed how the electric currents induced "into the body" obey the international standards regarding the admissible limit values, so that the health of the personnel on board not to be affected.**

Index Terms **— electric physical model, electromagnetic environment, human body, navy ship, negative effects.**

I. INTRODUCTION

Identifying the negative effects of the electromagnetic field upon the human body and the adequate protective means has lately become one of the most important problems of EMC (Electromagnetic Compatibility) [2], [3], [5], [6], [7], [8], [15].

For a navy seagoing ship such an issue is a priority, taking into consideration the very high electromagnetic power density due to functioning together of a great number of electric and electronic equipment in a limited space [4].

Because *in vivo* measurements upon the human body are not possible, there was designed and made a physical electric model, with concentrated parameters, for such a body, that was subjected to the action of the electromagnetic field of radio antennas situated on board ship.

The experiment had a double purpose namely:

a) to verify the relevance of such a model for the issue analysed;

b) to provide data, based on measurements onboard ship, about the levels of the currents induced in the "body" and the ways these are according to the limit values admitted by the standards or not.

II. A PHYSICAL ELECTRIC MODEL OF THE HUMAN BODY

According to the reference books studied [8], [11] [18], [19], [20], there were identified a series of constituent parameters (ε, μ, σ) both for different parts of the body (hand, trunk, leg) or organs (heart, liver, muscle, kidney) and of the body as a whole (such as, for example, conductivity σ, whose values are between 0,2 and 0,6 S/m [8], [11].

At the same time there could be identified some electric models of the human body [1], [2], [8], [11], [16], [17] such as, for example, that referring to the study of the electrostatic discharge of a person and the effects of this discharge upon the electronic components and circuits.

Based on the information gathered, it has been designed an electric model with concentrated parameters of a human body, excluding the head, whose form and material structure requires another type of model (see, for example, the references [22], [23]). It was considered that the person holds a metallic object with both hands, for example a wrench, and is repairing an electric installation having both feet on the framework of the installation, the motor being insulated from the metal deck. It was also estimated that the electric resistance between the person's feet and the metallic work of the installation is not significant to obtain maximum values for the currents induced in the body.

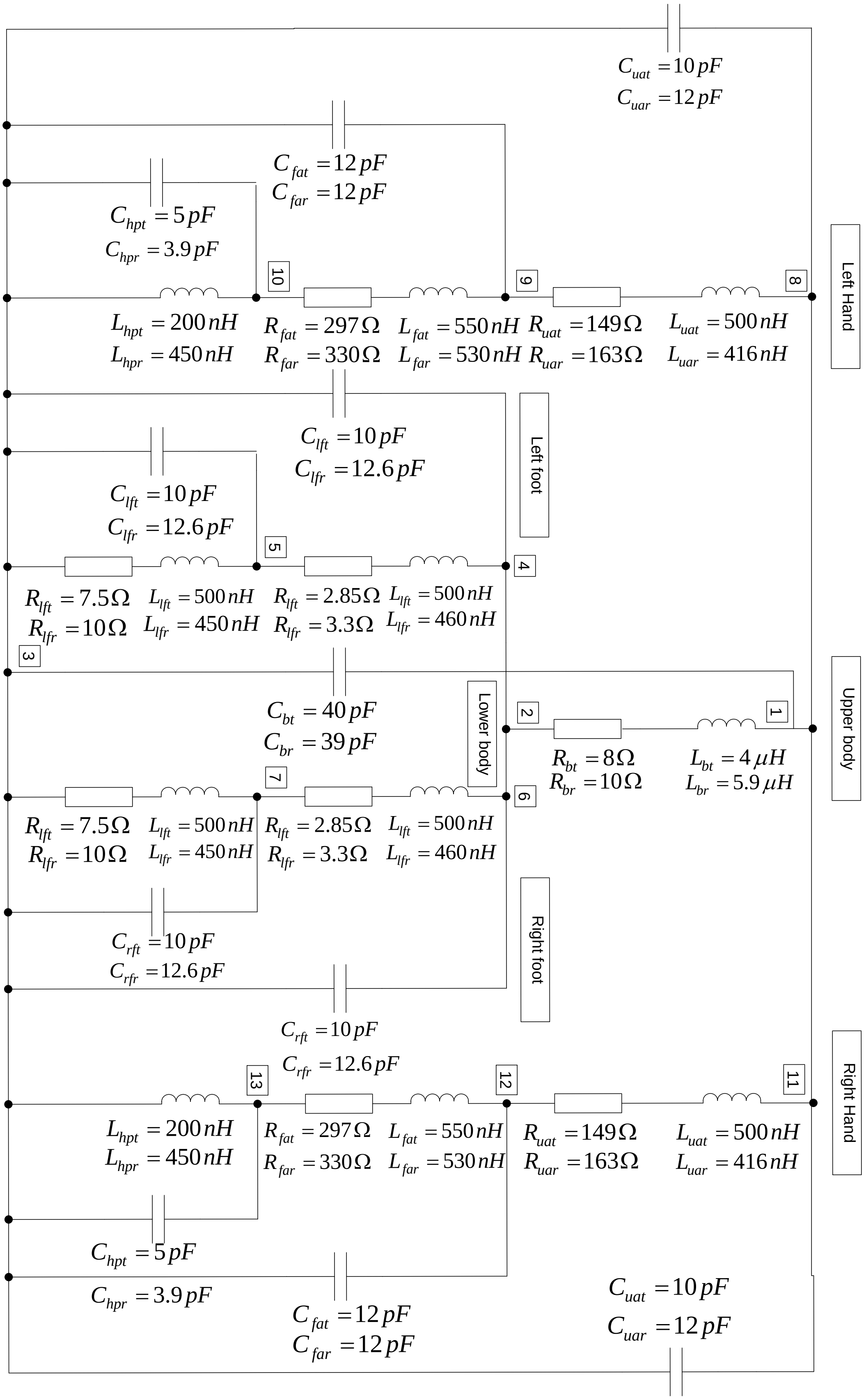

Fig.1 – Electric scheme with concentrated parameters of a human body (both the theoretical (index t) and real (index r) values are indicated)

Establishing the values for the electric parameters concentrated for different parts of the body (trunk, upper arm, forearm, hand, thigh, calf, foot) was done starting from the values of the constituent or concentrated parameters shown in the references [17], [18], [19], [20], [21] and also from the average geometric dimensions of the considered body (Table I).

TABLE I. THE AVERAGE GEOMETRIC DIMENSIONS OF THE HUMAN BODY USED AS A MODEL

Part of the body	Geometric parameter	Dimension (m)	Part of the body	Geometric parameter	Dimension (m)
Whole body	h	1.75	Hand	d_m (average diameter)	0.075
Trunk	d_m (average diameter)	0.35	Hand	l_m (average length)	0.19
Upper arm	d_{ab} (average diameter)	0.12	Thigh	l_{ps} (average length)	0.40
Upper arm	l_{ab} (average length)	0.30	Calf	d_{pi} (average diameter)	0.12
Forearm	d_b (average diameter)	0.10	Calf	l_{pi} (average length)	0.50
Forearm	l_b (average length)	0.30			

Accordingly, there were given values for inductivities and capacities of the parts of the "body", whose scheme is shown in Fig. 1, and there were calculated the electric resistance values for these parts, starting from their conductivity known values. Thus, for the trunk it was considered for calculation an average resistivity of 130 Ωcm, and for the skeleton muscles, of 140 Ωcm.

To simplify it was considered that all these parts have cylindrical shape or that they consist of more "current ways" of cylindrical shape, connected in parallel; thus the resistance of the trunk was considered as a parallel equivalent resistance of 12 cylindrical current channels, with the diameter of 10 cm and the length of 60 cm, representing as many identical resistances (the value of a resistance of 120 Ω). The skin effect was also neglected, considering that the current distribution into the body is uniform, to obtain maximum values for the induced currents.

Based on the theoretical electric model shown in Fig. 1, there was made a physical electric model, on a printed circuit plate with dimensions of 0.420 m × × 0.300 m.

The calculated values of the resistances of the parts of the "body" and the values of the inductances and capacities, taken from the reference for the frequency of 30 MHz, are shown in Table II.

III. THE EXPERIMENT DONE ONBOARD SHIP

The physical model was subjected to the direct action of the radiation of an electromagnetic field from an omni directional monopole antenna (Pr = = 400 W; f = 29.975 MHz), placed onboard a seagoing navy ship, the antenna has transmitting continuously during the experiment.

As the distance to the antenna (r) was of 6 m, it was considered that the electric model was mainly subjected to the far field (radiation field) of the antenna because the condition EMC for such a field was fulfilled, that is $r > \lambda/2\pi$; for this particular situation r = 6 m > $\lambda/2\pi \cong$ 1.6 m [2].

TABLE II. THE VALUES OF THE ELECTRIC PARAMETERS OF VARIOUS "PARTS OF THE BODY" FOR A FREQUENCY OF 30 MHz

Parts of the body/ parameters	Diameter (cm)	Length (cm)	R (Ω)	L (μH)	C (pF)	ρ (Ω cm)
Forearm (with elbow) side 8-9	9	30	148.61/163	0.5/0.416	10/12	150
Arm side 9-10	9	30	279.24/330	0.270/0.530	20/12	150
Hand with metal object side 10-3	7.5	12	-	0.02/0.45	5/3.9	150
Trunk side 1-2	35	60	7.96/10	4/5.9	40/39	130
Thigh side 4-5	17	40	2.85/3.3	0.5/0.46	10/12.6	150
Calf side 5-3	13	50	7.28/10	0.5/0.45	10/12.6	150
Skeleton muscle	-	-	-	-	-	150

O b s e v a t i o n: The real values of the parameters on the equivalent electric circuit are those from the denominator of the fraction from Table II.

For measurements it was used an oscilloscope having the following characteristics: Tektronix TDS 2014, 100 MHz Bandwidths, Sample Rates up to 2 GS/s, 4 channels, 2.5 k Points Record Length, Dual Time Base, Advanced Triggering, 11 Automatic Measurements, Waveform and Setup Memories.

Prior to any set of measurements, the background values of the tensions induced into different parts of the "body" by the ship's electromagnetic environment were registered.

IV. THE RESULTS OF THE MEASUREMENTS

There were made 60 measurements onboard ship. The obtained values for three of these, considered to be representative, are given in the Table III.

TABLE III. THE VALUES OF THE TENSIONS MEASURED FOR DIFFERENT PARTS OF THE TESTED "BODY" (AVERAGE VALUES – RMS IN mV)

No. channel		Channel 1 left forearm, [mV]	Channel 2 right forearm [mV]	Channel 3 trunk, [mV]	Channel 4 left calf, [mV]
Measurement no. 1	Background values (Scale 5 V/div.)	58	22	10^{-3}	80×10^{-3}
	Measured values (Scale 500	U_{8-9} = 780	U_{11-12} = 820	U_{1-2} = 840	U_{5-3} = 180

	mV/div.)				
No. Channel		Channel 1 left thigh	Channel 2 right thigh	Channel 3 left arm	Channel 4 right arm
Measurement no. 2	Background values (Scale 500 mV/div.)	18	1.60	19.7	24.6
	Measured values (Scale 500 mV/div.)	U_{4-5} = 480	U_{6-7} = 220	U_{9-10} = 120	U_{12-13} = 220
No. Channel		Channel 1 left hand	Channel 2 right hand	Channel 3 trunk with leg	Channel 4 left forearm and upper arm
Measurement no. 3	Background values (Scale 500 mV/div.)	18	1.60	19.7	24.6
	Measured values (Scale 500 mV/div.)	U_{8-3} = 4,000	U_{11-3} = 2,340	U_{1-3} = 140	U_{8-10} = 3,600

These values refer to the electric tensions appeared on the different sides of the circuit (respectively – "parts of the body") as a result of the EMT induced by the time variable electromagnetic field of the antenna.

Knowing the tensions and the parameters of sides of the circuit there were calculated the currents induced into the sides and, accordingly, the current densities.

The values of the currents and current densities in the sides of the physic model are given in Table IV.

TABLE IV. THE VALUES OF THE CURRENTS AND CURRENT DENSITIES INTO "THE BODY"

Parts of the "body"	**Induced current values, [mA]**	**Induced current density values, [mA/m²]**	**Notices**
Trunk	82.35	10.49x10³	For only one "channel of current"
Thigh	5.14	291	
Calf	17.64	1,560	
Forearm	5.02	444	
Upper arm	0.074	942	

O b s e r v a t i o n: According to "The basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz" [9], [10], [12], [13], [14], the limit of the current density for the head and trunk is *f*/100 mA/m², RMS values, where *f* is the frequency, [Hz], mentioning that it was taken into consideration the same value as for 10 MHz.

V. THE COMPARATIVE ANALYSIS OF THE OBTAINED RESULTS

The results obtained for the current densities were compared with the limit admitted values into the human body, imposed both by the European standard [12], and by the STANAG NATO standard [14], as basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz. As these standards do not give values for the current density for more than f = 10MHz, it was taken into consideration the same limit for f = 30 MHz too.

So, for general public exposure, both standards indicate a limit admitted value for current density for head and trunk of f/500 mA/m² (RMS values), where f is the frequency, [Hz]. It results:

$$\frac{f}{500} = \frac{30\times10^6}{5\times10^2} = 6\times10^4 \text{ mA/m}^2 . \qquad (1)$$

This value is 5.72 higher than the maximum value of the current density resulting from on measurements (10.490 mA/m²), but with the same order of magnitude!

Calculating SAR (Specific Absorption Rate) using the formula [10]:

$$\text{SAR} = \frac{J^2}{\rho\sigma} \text{ W/kg}, \qquad (2)$$

where: J, [A/m2] – the density of the current induced into the analysed part of the body; ρ, [kg/m³] – the mass density of the analysed part of the body; σ = = 0.2...0.6 S/m – the average conductivity of the analysed part of the body and taking into consideration the current density value measured on the "trunk", J = = 10.49 A/m², it results:

SAR = 0.1834 W/kg, for σ = 0.6 S/m; SAR = 0.5502 W/kg, for σ = 0.2 S/m.

It is necessary to observe that in the second case SAR value is 1.375 higher than the limit value admitted by the standards [10], [12], [13], [14], respectively 0.4 W/kg, meaning that there is a risk of getting sick, in time, for the personnel onboard who works on the decks of the ship. Taking into consideration the circumstances, adequate actions of protecting the personnel are necessary.

VI. CONCLUSION

The physical model designed for simulating the behaviour of a human body exposed to the electromagnetic field onboard a seagoing navy ship "responded" positive to the proposed analysis, offering a viable way of research for such an approach, as long as in vivo measurements cannot be done.

At the same time, the authors realize the fact that the electric model of the human body can be improved. Further more, if such a model is completed with another one designed for the research of the behaviour of a person's head into an electromagnetic field, we consider that a very useful investigation instrument for this type of research can be ensured.

Finally, such a model could be used for other researches (respectively fields of activity) where there is an increased awareness of protecting the person against the harmful effects of the electromagnetic field.

REFERENCES

[1] Ignea, A., *Measurements and Tests for Electromagnetic Compatibility*, Waldpress Publishing House, Timişoara, 1996

[2] Sotir, A., Moşoiu, T., *Electromagnetic Compatibility*, Military Publishing House, Bucharest, 1997

[3] Gary, C., *Les effects biologiques des champs magnétiques. Que peut direl`électricien à ce sujet?*, Revue "Energetica", p. 41, nr.2-B, 1993

[4] Mataluno, G., *Le radiazioni elettromagnetiche a bordo*, Rivista marittima, anno CXXI – Dicembre, Roma, 1988

[5] Nair, I., *Biological Effects of Electric and Magnetic Fields: What do we know ?*, 15 Febr. 1993, Department of Engineering and Public Policy, Carnegie Mellon University (not presented at Stockholm Conference of EMC)

[6] Calotă, S.V., Deliu, N., Licurici, M., Ferastraeru, C., Contulescu, A., *Studiu privind expunerea profesională la radiaţii neionizante de înaltă frecvenţă şi riscul pentru sănătate*, Institutul de Sănătate Publică, Bucureşti, 1998

[7] King, W.P.R., *Fields and Currents in the Organs of the Human Body when exposed to Power Lines and VLF Transmitters*, IEEE Transactions on Biomedical Engineering, vol.45, no. 4, April 1998

[8] Ianoz, M., *Biological and Health Effects of Electromagnetic Fields*, conference, "Politehnica" University of Bucharest, Energetically Department, Research Center TICEM , march 2003

[9] *** *Human Exposure to Industrial Frequency Electric and Magnetic Fields*, Romanian Standard Project: SR EN 50166-1, IRS, Bucharest (according to EN 50166-1/1994 standard)

[10] *** *Human Exposure to Electromagnetic Frequencies of 10 kHz-300 GHz Frequency Domain*, Romanian Standard Project: SR EN 50166-2, IRS, Bucharest (according to standard EN 50166-2/1994)

[11] Zamfirescu, M., Sajin, I., Rusu, I., Sajin, M., Kovacs, E., *Biological Effects of Radiofrequency and Microwaves Electromagnetic Radiations*, Medical Publishing House, Bucharest, 2000

[12] *** European Standard ICNIRP – *GUIDE LINES FOR LIMITING EXPOSURE TO TIME-VARIING ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS (UP TO 300 GHz)*

[13] *** 96/98/EC *Norm for Air and Sea Radio Communication Apparatus*, Transposed in Romania by the Order of the Public Works, Transport and Housing Minister no. 582/2003

[14] *** NATO Standard: STANAG – *Evaluation and Control of Personnel Exposure to Radio Frequency Fields – 3 kHz to 300GHz*

[15] Deviatcov, N.D., Betskii, O. V., *Biological Aspects of Low Intensity Millimeter Waves*, Edited by Academician Deviatcov, N.D.and Professor Betskii, O. V., Moscow, 1994

[16] Richman, P., *An ESD Circuit Model with Initial Spikes to Duplicate Discharges from Hands with Metal Objects*, in EMC Technology, vol 4, no. 2, 1985

[17] Crist, A., Klingenbock, A., Samaras, T., Member IEEE, Goiceanu, C., Kuster, N., Member IEEE, *The Dependence of Electromagnetic Far-Field Absorbtion on Body Tissue Composition in the Frequency Range from 300 MHz to 6 GHz*, in IEEE Transactions on Microwave Theory and Techniques, vol. 54, no. 5, May 2006

[18] Rajewsky, B., *Ultrakurtz wellen Ergebnisse der Biophysikalischen Forschung*. Bd. I., Ed. Georg Thime, Leipzig, Germany, 1938

[19] Schwan, H. P., Foster, K.R., *RF-Field Interactions with Biological Sistems: Electrical Properties and Biophysical Mechanisms*, Proc. IEEE, Jan. 1980, p.104

[20] Herrich, H., et al, *Dielectric properties of tissues importanant in microwave diathermy*, Med. Proc., Vol 9, p. 60. , 1950

[21] Oswald, K., *Hochfrequentz, Electroacustic*, Vol. 49 , p. 40., 1937

[22] Kriticos, H. N., Schwan, *Hot Spots Generated in Conducting Spheres by Electromagnetic Waves and Biological Implications*, IEEE Transactions on Biomedical Eng., p. 53, 1972

[23] Miclăuş, Simona., Bechet, P., Demeter, Ş., *Determining the Radiofrequency Power Distribution Absorbed into a Spherical Biological Model*, Scientific Bulletin no. 1/2004, "Nicolae Balcescu" Land Forces Academy, Sibiu.