

Halina Aniolczyk,
Joanna Koprowska*,
Paweł Mamrot,
Joanna Lichawska*

Nofer's Institute of Occupational Medicine
ul. Teresy 8, 90-950 Łódź, Poland

*Instytut Włókiennictwa (Textile Research Institute)
ul. Brzezińska 5/15 92-103 Łódź, Poland

Application of Electrically Conductive Textiles as Electromagnetic Shields in Physiotherapy

Abstract

The technology of electrically conductive fibre production has been devised at the Textile Research Institute (Łódź, Poland), and has patent protection in Europe and the USA. Electrically conductive nonwovens (stitch-bonded and needled) made from these fibres differ from each other not only in production technology, but also in electric properties. Measuring the shielding effectiveness of these fabrics proved a possibility of their application as electromagnetic shields. Their practical application was presented for physiotherapy where short-wave and microwave diathermy is used.

Key words: *electro-conductive textiles, electromagnetic shields, physiotherapy.*

and considerably lower cost, in comparison with shields made of metal sheets and wire mesh.

Materials of high electrical conductance can act as electromagnetic field shields only in the range of higher frequencies (>300 MHz). In practice, in this case they equally attenuate the electric component E as well as the magnetic component H. For fields of frequency <30 MHz, attenuation of the magnetic component H is very difficult, and is possible only thanks to the use of ferromagnetic materials. For some applications, only the attenuation of the electric component E is satisfactory.

Fabrics made of Nitril-Static (PAN fibres modified by Cu_xS_y) electro-conductive fibres, which have been produced for many years at the Textile Research Institute (Łódź, Poland), also show good shielding efficiency [1]. The attenuation of the electric component EMF ranges from the negligible up to almost 60 dB, and of the magnetic component from 0 dB to 4 dB, depending on the textile type, the degree of their modification, and the EMF frequency range [2].

In the years 1999-2000, research into the applicability of the aforesaid textiles as electromagnetic shields for protection against high-frequency EMF in physiotherapy was carried out in the Institute of Occupational Medicine in Łódź, in co-operation with the Textile Research Institute. The objective of this research work is to demonstrate the suppressive characteristics of conductive fibres in the EMF frequency range used in physiotherapy. Different medical devices generating strong EMF with a dominant electric component are used in this range for therapeutic purposes. On the basis of

measurements and tests conducted previously at the Wrocław Technical University, two types of nonwoven cloths were selected for testing: a stitch-bonded Maliwatt-type nonwoven, and a needled IG-NS nonwoven. The test results are presented in this study.

Electromagnetic Fields in Physiotherapy

The level of the maximum admissible intensity values (MAI) of EMF in the working environment established by Polish law [3] requires the owner of devices producing these fields to monitor their levels and to ensure appropriate protection against their harmful effects on the workers' health. In the vicinity of certain devices applied in physiotherapy, EMF are present in physiotherapists' workplaces. On the basis of our own studies' results, as well as data collected at the Institute of Occupational Medicine in Łódź in the Central Registry of Sources of EMF Emissions, it has been stated that the maximum electric field strength/power density values for EMF in the workplace are:

- in the vicinity of short-wave diathermy working in the frequency range of 27.12 MHz, from the negligible to 235 V/m for 540 examined devices;
- in the vicinity of microwave diathermy working in the frequency range of 2450 MHz, from 0.2 W/m² to 22 W/m² for 4 examined devices.

It has been estimated that the dangerous zone encompasses 80% and 75% of workplaces respectively [4]. In these workplaces there is a need but also an opportunity to use different forms of shielding, including individual protection. During the work of short-wave diathermy (27.12 MHz) and

Introduction

Recently, electrically conductive textiles have been developed for different applications. In one of these areas, we may use their property of attenuating electromagnetic fields (EMF) in the form of textile shielding materials. These are mainly as follows:

- textiles for clothing protective against high-frequency EMF,
- less conductive textiles which carry away static charges from clothing or equipment (as often used in the semiconductor industry),
- shielding curtains and wall covers for protecting rooms in special buildings (military, banks etc.).

Textile shielding materials are mostly produced from metal coated fabrics or metal interwoven fabrics.

One advantage of shields made of electrically conductive textiles is their lightness

microwave diathermy (2450 MHz), EMF occurring in physiotherapy workplaces penetrates not only to the neighbouring physiotherapy rooms with a diathermy room, but also to other adjacent rooms. These are often consulting rooms, rooms for rehabilitation, or corridors.

Characteristics of Electrically Conductive Textiles

Polyacrylonitrile (PAN) fibres with metal salts have been produced under the trade name Nitril-Static at the Textile Research Institute for 15 years. The 3.3 dtex/60mm staple fibres have mainly been subjected to modification processes. Specific through-resistivity is the most important parameter of Nitril-Static fibres. Over 87% of modified fibres have specific resistivity in the range 1-5 Ωcm . Electrically conductive fibres combined with other fibres are in use. Two types of textiles have been examined for shielding effectiveness: WOM-E stitch-bonded with 75% electrically conductive PAN fibres and 25% polyester filament yarn (Table 1), and IGNS needled nonwoven with 100% electrically conductive fibres (Table 2). Both materials significantly different in surface weight and thickness, but have a similar surface resistivity level, and as they are electro-conductive, they qualify as shielding materials.

Shielding effectiveness of electro-conductive textiles

The basic parameter of a shield is its characteristic of shielding effectiveness (SE) as a function of frequency. The measure of SE is attenuation, which defines the reduction of intensity of the electric and/or magnetic field after penetrating the shield. The SE of a given shield at an established frequency

Table 1. Properties of WOM-E nonwoven.

Parameter	Unit	Test method	Value
Mass per unit area	g/m^2	ISO 9073-1	108
Thickness	mm	ISO 9073-2	0.75
Surface resistivity	Ω	PN-P-04871:1991	1.5×10^4

Table 2. Properties of needled nonwoven IGNS.

Parameter	Unit	Test method	Value
Mass per unit area	g/m^2	ISO 9073-1	285
Thickness	mm	ISO 9073-2	3.70
Surface resistivity	Ω	PN-P-04871:1991	2.8×10^3

depends on the shielding material, the thickness of the shielding structure, and the distance between the shielding surface and EMF source. Reflection losses, absorption losses, and mutual multiple reflection losses in shields made of a layer of shielding material are factors contributing to the shielding's complete effectiveness value.

Two basic normalisation documents define the requirements concerning the usage parameters of shields, as well as the methods of establishing these parameters: MILD-STD-285 [5] and their modifications IEEE Std 299 [6]. As of now, these two standards represent the only basis on which research works on measuring the shielding efficiency of materials, including textile materials, have been conducted at different centres in Europe and the USA. The preliminary selection of nonwoven fabric tests for this study was conducted on the basis of the assessment of the shielding efficiency conducted at Wrocław Technical University. The testing methodology developed for the needs of the Textile Institute research works and adjusted to smaller sample sizes than stated in stand-

ard MILD-STD 285 was presented at the EL-TeX Symposiums in Łódź [7,8].

The results of the attenuation measurements of the electric component EMF for stitch-bonded nonwoven WOM-E and needled IG-NS (according to the modified methodology developed at Wrocław Technical University ITA) are presented in Figures 1 and 2.

Electromagnetic Model Screens

Shielding effectiveness testing

Issues of protection against EMF through shielding have not yet found appropriate application, especially in medicine (physiotherapy, some areas of surgery), among other reasons due to high costs and lack of information regarding such possibilities. Furthermore, the complexity and variety of fields existing in the environment of high-frequency devices, interactions between the EMF source and the screen and the complex character of phenomena occurring within the structures themselves mean that this is a very difficult task requiring vast knowledge and experience. The shielding method

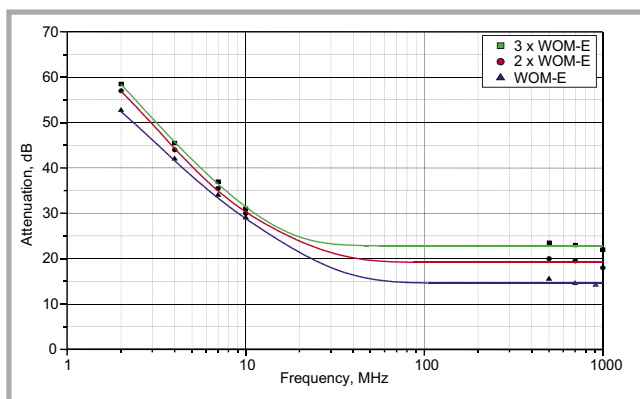


Figure 1. Attenuation of WOM-E nonwoven, one layer (WOM-E), two layers (2×WOM-E) and three layers (3×WOM-E).

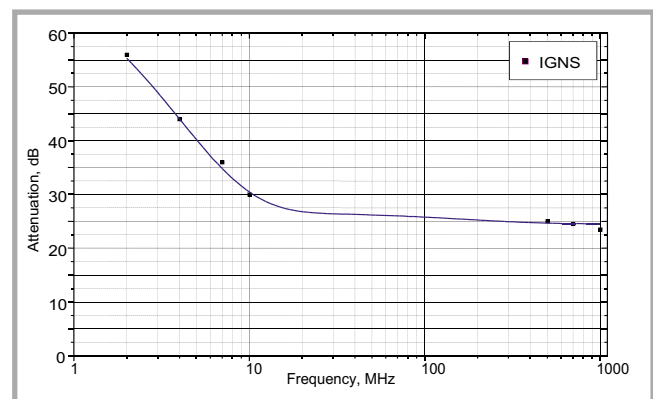


Figure 2. Attenuation of EMF for IGNS needled nonwoven sample.

and the selection of the shielding material depend on the application, type and character of the work, and the technical and physical parameters of the device, the location of the installation (an open space, a closed room), etc. Depending on the aforesaid usage conditions of the device, the application of appropriate shields can be recommended.

In recent years different textile shields have become increasingly available. These shields have a number of advantages in comparison with conventional shields made of metal sheets or meshes, such as lower mass, the possibility of elastic shaping, permeability to air, and a significantly lower price.

For making model shields attenuating EMF for physiotherapy rooms, the WOM-E and IGNS nonwovens were used for this study. The measurements of the attenuation effectiveness of the selected nonwovens were performed:

- in laboratory conditions for model shields which were reconstructions of real walls of physiotherapy rooms, covered with the layer of selected nonwovens, and
- in real conditions, in physiotherapy rooms where walls had been already shielded.

These shields were tested for suppression effectiveness in selected frequency ranges.

Measurement method

Measurements of the shielding effectiveness of the model screens were made at the Textile Research Institute Laboratory in Łódź on previously developed test rigs. Measurements were carried out for two frequency ranges, i.e. 27.12 MHz and 2450 MHz.

The following devices were used as electromagnetic field sources:

- a short-wave G-110 type diathermy, generating a strong electromagnetic field in the 27.12 MHz frequency range, and
- a LUCZ 58-1 microwave diathermy with a tube-type antenna generating a strong electromagnetic field in the 2450 MHz frequency range.

Two MEH series measurement sets made by Wrocław Technical University were used for the measurement of the electromagnetic fields generated. The parameters of the aforementioned measurement sets are presented in Tables 3 and 4.

Table 3. List of broadband measurement apparatus parameters, electromagnetic field intensity and microwave power density, MEH-1a type (1)open space, 2)at 10 cm from primary or secondary sources of radiation).

Probe	Frequency range	Measurement range	Field measurement error
AE-1	0.1 - 300 MHz	3 - 1000 V/m	±10% ¹⁾ , ±3 dB ²⁾
AE-2	10 - 300 MHz	0.4 - 15 V/m	±10% ¹⁾ , ±3 dB ²⁾
3AE-12	1 - 600 MHz	2 - 170 V/m 5 - 30000 V ² /m ² 0.01 - 70 W/m ²	±0% ¹⁾ , ±3 dB ²⁾
AE-43	50 Hz - 50 kHz 1 - 100 kHz	0.2 - 20 kV/m 1 - 1300 V/m	±10% ¹⁾ ±3 dB ²⁾
AM-1 AM-2	0.1 - 10 MHz	0.5 - 10 A/m 5 - 250 A/m	±10% ¹⁾ , ±3 dB ²⁾
AS-1	300 MHz - 3 GHz	0.006 - 100 W/m ²	±10% ¹⁾ , ±3 dB ²⁾
AS-2	400 MHz - 14 GHz	0.01 - 100 W/m ²	±15% ¹⁾ , ±4 dB ²⁾
3AS-2	400 MHz - 18 GHz	0.01 - 15.5 W/m ²	±15% ¹⁾ , ±4 dB ²⁾

Table 4. List of broadband measurement apparatus parameters, electromagnetic field intensity and microwave power density, MEH-25 type.

Probe	Frequency range	Measurement range	Field measurement error
3AE-1	0.1 - 300 MHz	3 - 1000 V/m	±10% ¹⁾ , ±3 dB ²⁾
3AH-1	0.1 - 10 MHz	0.5 - 250 A/m	±10% ¹⁾ , ±3 dB ²⁾

Table 5. Shielding effectiveness of different types of model screens (layer composition) dependin on screen and shielding material type.

Shield type		Layer composition in the model shield	Shielding effectiveness, dB	
			Frequency, MHz	
			27.12	2450
Wall	Cavity brick 8 cm	WOM-E stitch-bonded, 1 layer	-	13.2
		IGNS needled, 1 layer	-	19.4-20.0
		IGNS needled, 2 layers	-	29.6-33.0
		IGNS needled, 2 layers (cut) + plasterboard	-	26.1-28.2
		IGNS needled, 2 layers (separated with wall)	-	34.7-37.5
		IGNS needled, 1 layer + WOM-E, 1 layer	-	24.9-25.4
Partition wall		WOM-E stitch-bonded, 1 layer	13.2-15.6	-
		WOM-E stitch-bonded, 2 layer	16.9-19.3	-
		WOM-E/2001 stitch-bonded, 1 layer	21.4-23.2	-
		IGNS needled, 1 layer	-	23.1
		IGNS needled, 2 layers	-	35.7

The test rig also consisted of a 1W100B power amplifier made by Amplifier Research, which was used for amplification of the signal received from the generator to a level enabling the generation of an electromagnetic field of the desired field density within the frequency range from 100 kHz to 1 GHz.

Measurement results

Shielding effectiveness measurement results for different designed shields, depending on the electro-conductive nonwoven used, are presented in Table 5. As the tests conducted show, the highest values of shielding effectiveness at 27.12 MHz was achieved for the fixed shield in the form of a partition made with the use of WOM-E/2001 nonwoven as the material for electromagnetic field suppression. The shielding effectiveness

reached 21.4 - 23.2 dB. Capacity and induction type short-wave diathermies operate in this range. At the frequency of 2450 MHz, the highest values of shielding effectiveness were obtained for the model shield which consisted of a cavity-brick wall and two layers of needled nonwoven placed on both sides of the wall. The shielding effectiveness reached 34.7-37.5 dB. Microwave diathermies operate at 2450 MHz.

Application of Textile Shielding Materials in Real Conditions

The most unfavourable case (most difficult to shield) was tested in real conditions: the simultaneous operation of two devices radiating EMF of different frequency. Figure 3 presents EMF distri-

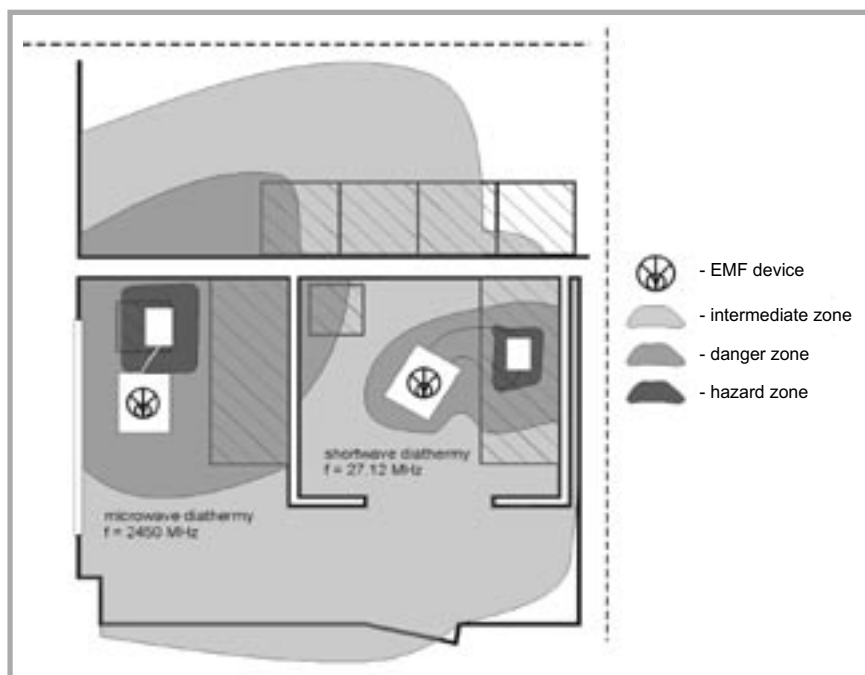


Figure 3. EMF distribution inside and outside physiotherapy rooms before shielding.

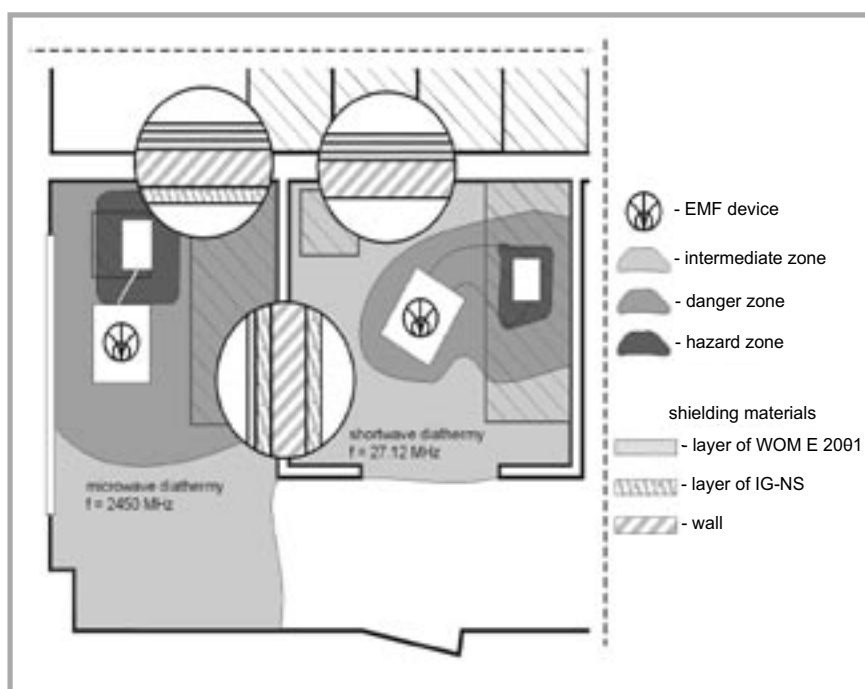


Figure 4. EMF distribution inside and outside physiotherapy rooms after shielding.

bution in the respective protective zones **before** the performance of the designed shielding in real conditions, i.e. in a physiotherapy room. Figure 4 presents EMF distribution in the respective protective zones **after** the performance of the designed shielding in real conditions.

Conclusions

- Our research showed the possibility of applying electrically conductive tex-

tiles produced at the Textile Research Institute as electromagnetic shields in physiotherapy rooms.

- Because of the specific requirements concerning equipment in health-care workplaces (e.g. sterility and colour of the walls, curtains, screens), preparation of the rooms' shielding method required special measures. Installing the shields requires special experience, and periodic control of the shielding's effectiveness is necessary.

- The use of textile shielding materials made of electro-conductive textiles ensures the desired result at a relatively low cost.
- In 2001, textile shields were introduced in the rehabilitation rooms of two hospitals, and one in a medical service unit.

Acknowledgements

The authors are very grateful for their co-operation with Wrocław Technical University in the area of measuring the shielding effectiveness of the textile materials.

References

- Koprowska J., Więckowski T., Kowalski K., 'Influence of textile fabrics structure and of fibre modification method onto electromagnetic field shielding efficiency', Research Report of Textile Research Institute, Łódź, 1999.
- Research Report of EMC-Testcenter Zurich AG, 2002.
- Ordinance of the Minister of Labour and Social Politics from 29 Nov. 2002 concerning MAC/MAI of agents harmful to health in the working environment. Journal of Law No 217, pos.1833, (2002).
- Aniołczyk H., Koprowska J., Mamrot P., 'Application of Electrically Conductive Textiles as Electromagnetic Shields in Physiotherapy and Electrosurgery', Proceedings, Sixteenth International Wrocław Symposium and Exhibition on Electromagnetic Compatibility, June 25-28, 2002 published by the National Institute of Telecommunications, 605-610, (2002).
- MIL-STD-285. 'Attenuation Measure for Enclosures EM Shielding for Electronic Test Purposes', Department of Defence, January 25, 1956.
- IEEE Std 299-1997. IEEE Standard for Measuring the Effectiveness of Electromagnetic Shielding, Enclosures, IEEE Inc., USA, New York 1998.
- Kujalowicz J., Wroczyński R., Warszawski K., 'Measuring the EM Fields Attenuation of Screening Materials', 2nd International Symposium EL-TEX 2002, Łódź, 1996, 197-203.
- Więckowski T., Trzaska R., 'Nonwoven Shielding Effectiveness - Measuring Methods', 3rd International Symposium EL-TEX 1998 Łódź, 168-176.
- Aniołczyk H., Koprowska J., Mamrot P., Politański P.: 'Electro-conductive Nonwovens for EMF in Physiotherapy', Proceedings of the 5th International Symposium EL-TEX 2002; 'Electrostatic and electromagnetic fields - new materials and technologies', Łódź, 14-15.11.2002, 59-66.

Received 24.02.2003 Reviewed 18.03.2004