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New Type of Textiles with Shielding Properties

Abstract
To render impossible the penetration of interference (disturbing) energy of electromagnetic radiation to sensitive electronic devices, or to protect people against its effects, there is a need of shielding in many areas. The importance of this problem has resulted in a growing number of research works on the optimisation of shielding techniques. Shields made of metal are expensive, heavy, not always convenient or sometimes even entirely unsuitable for application. Investigations into new shielding materials are being carried out, e.g. specially loaded plastics, multilayer films or textile fabrics. Flexible materials shielding against electromagnetic fields (textile fabrics) are more frequently applied in practice, e.g. to cover the walls of rooms or to cover devices in order to decrease emission or to increase resistance to other (foreign) emissions. The Textile Research Institute in Łódź (Poland) has developed and produced samples of new flexible textile fabrics which shield high-frequency electromagnetic energy. This work presents these new materials, their properties and also a simple method for testing shielding effectiveness.

Key words: *textile shields, shielding effectiveness, method of measurements.*

Introduction

Shielding is a very popular method of ensuring electromagnetic compatibility, and of protecting electronic and electrical equipment and human beings against radiated electromagnetic energy. Shields are used either to isolate a space (a room, an apparatus, a circuit etc.) from outside sources of electromagnetic radiation, or to prevent the unwanted emission of electromagnetic energy radiated by internal sources. Traditionally, such shields are based on the use of stiff metallic materials with well-known electromagnetic properties.

Plastics with a conductive coat or with metal fibres injected during the moulding stage are applied more and more often. Recently attention has been paid to light and flexible materials, such as textiles covered with an absorbent layer. These materials, owing to their flexibility and relatively low production costs, are considered promising for the protection of equipment and people from electromagnetic radiation.

At the turn of the 1990s, following on from the technique of metallising textile fabrics on an industrial scale, textile screens appeared which were covered with metal, mainly by chemical methods. The following products are most frequently used for the metallisation of textile fabrics: copper, nickel, silver and combinations thereof.

Some metallised shielding products are:
- Flectron (Monsanto, presently APM, USA),
- Shieldex (Siemens, Germany),
- REMP (REMP, Switzerland),
- Shintron (Shinto Chemitron Co. Ltd., Japan).

The shielding efficiency of metallised textile fabrics mainly derives from energy reflection, and not from its absorption. In many cases, such a phenomenon is not good. Hence, there have been searches for materials with greater capability of absorbing electromagnetic (EM) radiation.

The research works so far carried out have confirmed that the products made of electroconductive fibres produced by the Textile Research Institute, Łódź, also exhibit shielding properties. It was observed that absorption has a considerable share of the total shielding effect.

In recent years many patents have appeared, mainly Japanese, which deal with the problem of producing textile fabrics with ferromagnetic properties. Such products can be applied, among others, in the following contexts:
- as flexible screens for attenuating EM radiation,
- to produce cores in transformers, motors, generators, etc.,
- to produce filters to remove substances showing magnetic properties from air and water.

Among the listed advantages of such products, we may number high flexibility and relatively low price, which allow a wide range of applications (in comparison to other ferromagnetics) in different technical areas, especially in electronics, where miniaturisation is continuously underway. Ferromagnetic textile fabrics can be produced by spreading suitable substances on surfaces, or by their introduction into fibre polymers.

Ferromagnetic substances include:
- metals: iron, cobalt, nickel,
- iron oxides,
- compounds with the general formula $Me_xFe^{+3}yO_2$, where Me is a mono-, bi- or trivalent metal,
- ferrites of the type $BaO{\cdot}Fe_2O_3$ and 9 $BaO \cdot Fe_2O_3$.

Some forms of graphite also have good conductive and absorbent properties.

In our work, we intend to produce the materials with a shielding efficiency above 15 dB, by coating electroconductive nonwoven textiles (manufactured from Nitril-Static fibres, i.e. PAN fibres modified by copper sulphides and produced at the Textile Research Institute Łódź, Poland) with a coating layer incorporating absorbers of electromagnetic fields, and to devise simple method to test them.

The characterisation of absorbing or screening the properties of plastics or fabrics is rather a difficult topic. Many measuring methods have been developed and are used in various laboratories. They differ in frequency range, sample dimensions, measurement conditions, etc. Many producers, while developing such materials, are looking for a reliable, non-time consuming and relatively simple measuring method, allowing quick estimation or relative measurements of their shielding/absorbing properties over the wide frequency range. Additionally they expect a method which, being based on typical and relatively cheap measuring equipment, can be carried out by a technician at a producer's control laboratory.

In the paper the description of the measurement method investigated in the National Institute of Telecommunications is given. The method is based on the measurement of attenuation of a textile sample inserted into a transmission line. For this method, a special test fixture was elaborated, which was investigated within the frequency range from 100 MHz up to 2000 MHz.

Experimental

Samples

To improve shielding efficiency, it was decided to coat stitch-bonded nonwovens incorporating electroconductive fibres (symbol WOM-E) with a polymer layer containing different inorganic compounds as absorbers. Powdered substances can be spread onto electroconductive nonwovens, for example by coating with a paste containing a bonding agent and absorbent material.

This work presents the results of the method where coating was applied by the indirect (transfer) method. The samples (width of c. 30 cm) were prepared on semi-technical continuous apparatus from Nuova ISOTEX S.A. (Italy). The characteristics of these materials are listed in Table 1.

The following materials were used to prepare the paste:

- polyurethane resin (by UCB, USA),
- ferromagnetic powders (by Steward, USA),
- graphite (Polish product).

The main goal of these trials was to achieve the most flexible layer incorporating the maximum amount of ferromagnetic powders. At first, the compositions of the coating paste containing ferromagnetic powders and graphite were established.

All the components were carefully distributed within the resin with the aid of an electric mixer (agitator). Initial trials concerning the proportions of powders in the paste were done by applying the batch method on a Werner Mathis device (of Swiss manufacture). It was decided to add c. 35-40% of powders. At first, the paste was spread onto silicone paper; it was then heated up at 140°C for 3 minutes. The plastic layer with filler was laminated with WOM-E nonwoven using polyurethane glue. The coated layer did not make the fabric stiff.

Attenuation properties

Attenuation of the electromagnetic energy (caused by screening or absorption) is a result of the reflection, absorption and multi-reflection losses caused by a specific material inserted between the source and the receptor of the radiated electromagnetic energy. Generally speaking, this depends on the electric and magnetic properties of the material, its homogeneity and - particularly when comparing various marketed materials - on the measuring method applied.

Attenuation caused by a material may be characterised, depending on the measuring method used, by two quantities: the screening effectiveness (SE) and the insertion loss (A).

Screening effectiveness (SE) is defined as the ratio of electromagnetic field strength (E_0) measured without and with the tested material (E_1) when it separates the field source and the receptor:

$$SE = E_0/E_1$$

or, in decibels,

$$SE_{dB} = 20 \log E_0/E_1$$

This depends on the distance between the source and receptor of electromagnetic energy. In the far field zone, it characterises the attenuation of the electromagnetic wave in the TEM-cell. The measurement carried out in the near field zone characterises the attenuation effectiveness for the electric or magnetic field component only (SE_E or SE_H respectively), depending on the type of antennae used as source and receptor of electromagnetic energy.

Insertion loss (A) is a measure of the losses (or attenuation) of a transmitted signal caused by the tested material being inserted into the measuring channel:

$$A = U_0/U_1$$

or, expressed in dB,

$$A_{dB} = 20 \log (U_0/U_1)$$

U_0 - the channel output voltage without the tested material,
U_1 - the same voltage with the tested material.

Test methods

The measuring methods used for estimating the shielding effectiveness of screened rooms are well-known and have been subjected to standardisation [4-6]. The measurement of the screening effectiveness or insertion loss of plastic or fabrics is rather a difficult topic, and has not up to now been standardised. Many measuring methods have been developed and are used in various laboratories. They differ in frequency range, sample dimensions, measurement conditions etc.

At the designing stage of flexible attenuating materials such as absorbing textiles - i.e. when choosing the substrate fabric, the absorbing material and its graininess, the sticky substance, the layer thickness etc. - it is necessary to have a simple measurement method to enable quick but reliable comparisons of relatively small flexible samples. Additionally, such a method should be based on relatively cheap measuring equipment, and readily usable by a technician in a producer's control laboratory.

In pursuit of such a solution, three methods were investigated:

Table 1. *Characteristic of the new materials (*needled nonwoven: Nitril-Static fibres additionally modified with Ag-compounds).*

Sample WOM-E nonwoven with layer	Sample symbol	Area weight, g/m²	Thickness, mm	Thickness of absorbing layer, mm	Volume resistivity, Ω·cm
WOM-E raw	A	116.0	0.35	-	$8.5 \cdot 10^3$
PU + graphite	B	253.0	0.93	0.27	$1.5 \cdot 10^6$
PU + with ferromagnetic powder	C	272.0	0.85	0.25	$3.5 \cdot 10^9$
PU + inorganic ingredients	D	320.7	0.75	0.27	$4.0 \cdot 10^5$
Nonwoven IGNS*	E	330.0	2.47	-	$2.8 \cdot 10^3$

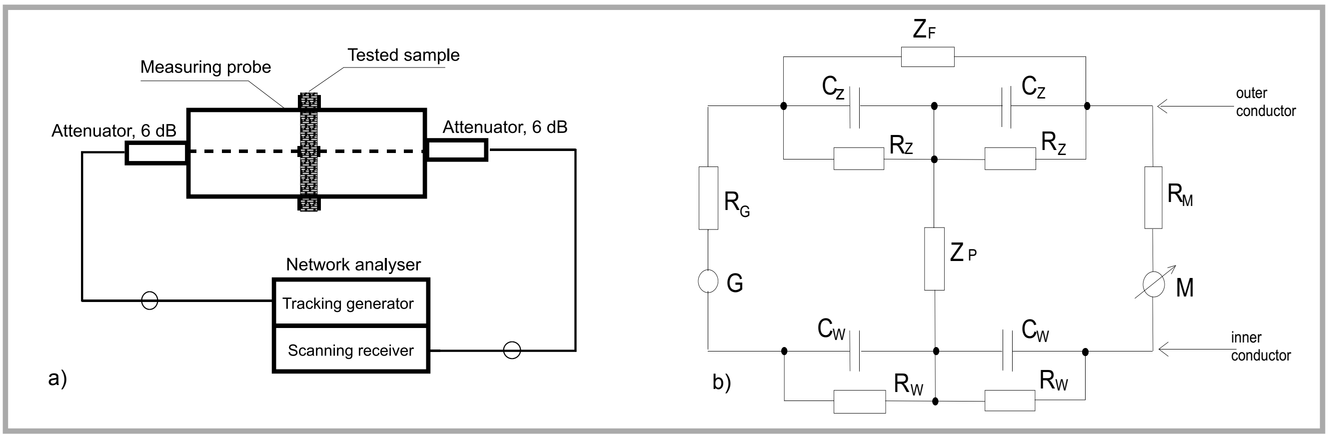

Figure 1. Measuring system: a) scheme, b) equivalent electric circuit diagram .

- two of them are based on the use of a GTEM-cell [7], in which the screening effectiveness (SE) is measured;
- a third method is based on the measurement of insertion loss of a transmission channel (similar to ASTM-D 4935), with the elaborated special test fixture holding the sample of the textile tested.

Test fixture method

The test fixture method to the ASTM-D 4935 was selected as the result of performed comparative tests [3] for the materials produced. As a measure of sample properties, the insertion loss, caused by the tested sample inserted into the transmission line, was chosen. For this purpose, a special test fixture was developed and investigated. The measurement layout is presented in Figure 1a.

The test fixture based on coaxial construction is divided into two identical parts separated by the tested material. An analysis of the equivalent circuit diagram (Figure 1b) [4-6] shows that this method allows measurement of the insertion loss (caused by Z_p) of only this part of the tested sample, which has no direct contact with the test fixture. The influence of coupling impedance in the inner (R_W, C_W) and the outer conductor (Z_F, R_Z, C_Z) of the test fixture is eliminated by the calibration procedure.

Insertion loss of the tested sample is calculated as the ratio (in dB as a difference) of output voltages, measured in two steps:

- calibration (Figure 2a),
- measurement (Figure 2b).

In the calibration procedure (Figure 2a), the tested textile is arranged as a ring which covers the test fixture flanges, and as a disc which covers the surface of the inner conductor's tips. For the measurements (Figure 2b), the sample is formed as a full disc with a diameter equal to the outer diameter of the fixture flanges. In both cases there is no direct electric contact between the two parts of the test fixture, which are pressed against each other with nearly the same force.

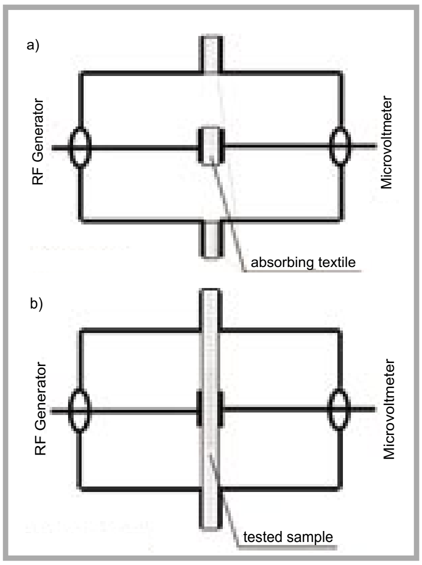

Figure 2. Scheme of calibration (a) and measurement (b).

Table 2. Results measurements of the attenuation (insertion loss) in the special test fixture.

Frequency, MHz	Attenuation of samples (see Table 1), dB				
	A	B	C	D	E
100	8.8	7.0	10.3	13.7	21.5
200	9.1	7.7	10.5	13.7	21.9
300	9.5	7.9	10.7	13.9	22.0
400	9.9	8.3	10.8	14.0	22.2
500	10.0	8.5	11.0	14.4	22.4
600	10.5	9.0	11.7	15.0	23.1
700	11.5	9.9	12.5	16.0	24.4
800	12.0	10.4	13.1	16.5	25.0
900	12.1	10.5	13.3	16.7	25.2
1000	12.6	11.0	13.6	17.2	26.1
1100	12.6	11.0	13.5	16.7	26.3
1200	12.2	12.0	14.8	17.9	29.0
1300	13.6	13.0	15.5	18.9	29.7
1400	15.2	13.1	16.3	19.5	29.7
1500	15.8	13.5	17.0	20.5	30.2
1600	16.1	14.3	17.5	20.2	31.0
1700	17.3	15.3	19.1	21.7	32.8

Results

The results are presented in Table 2, and graphically in Figures 3 and 4. The testing method we have developed allows qualitative assessment of the test materials obtained, and can be applied for their selection. Further research has been performed in local research centres. The results of measurements in the EMC Testcenter, Zürich, confirmed the results of the initial selection performed using the chosen method, and indicated the possibility of applying two nonwovens as shielding materials for physiotherapy (Table 3).

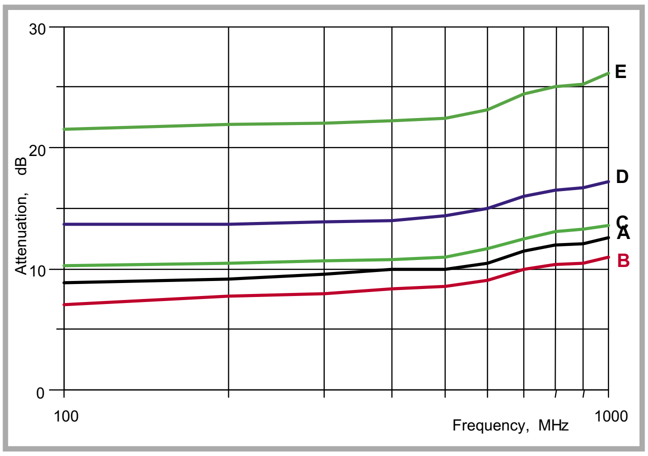

Figure 3. *Attenuation of materials A-E in the frequency range 100-1000 MHz.*

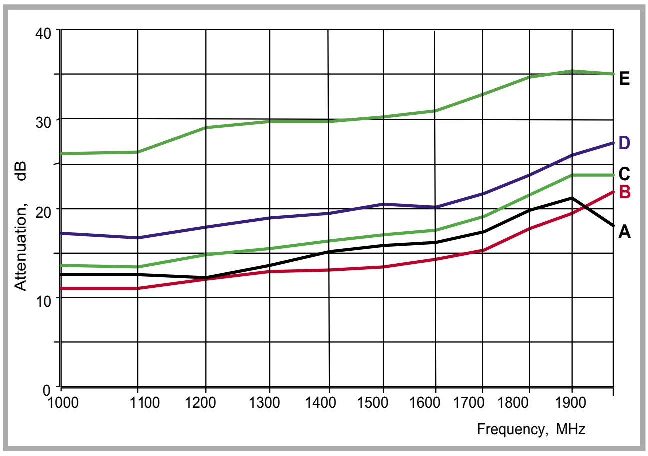

Figure 4. *Attenuation of materials A-E in the frequency range 1000-2000 MHz.*

Applications

Textiles which limit electromagnetic field activity (having an attenuation of 20-35 dB) have already been practically implemented. The coated nonwoven (sample D) was used as a modern support in the new generation of radar camouflage nets, providing camouflage against reconnaissance not only within the scope of the visible area, but also in near-photographic infrared and radar scopes [12].

The nonwovens designated as IGNS (sample E) and WOM-E (samples A, B, C, D) all coated with the security layer - were applied together in physiotherapy, where shortwave and microwave diathermy is used. Owing to the application of shielding materials, the extent of electromagnetic (EM) fields has been restricted to cabins where patients are exposed to EM radiation. This ensures the safety of other persons who may arrive in the vicinity of such cabins, and of the staff working in such an area.

Conclusions

- The process of coating the surface of textile fabrics with layers with special properties (incorporating electromagnetic absorbers) can give way to products of new quality.
- In order to select textile shields with a simple and easy measurement method, the fixture method was examined in this work, with good results. The test fixture method provides an easy and convenient way to measure the attenuation efficiency (insertion loss) of textile samples. The special test fixture as elaborated allows measurements to be carried out up to about 2000 MHz. The method is very convenient for evaluating the textile materials in the process of their development, design and production, development etc. Its superiority is obvious from the comparison presented in the tables.
- The new tested shielding materials can be applied to:
  - the camouflage of military objects, and
  - to restricting the range of fields emitted by devices such as shortwave and microwave diathermy.

***Table 3**. Attenuation of needled nonwoven - sample E (results of measurement in the EMC Testcenter, Zürich) according to MIL-STD-285.*

Frequency, MHz	Attenuation, dB	
	E-field	H-field
0.33 - 0.44	49	4
1.76	49	0.5
27.12	53	4.0
2450	24.5	-

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