

EMF Shielding Effectiveness of Knitted Fabrics of Metallized Threads

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Abstract – The aim of the study is to clarify the EMF shielding effectiveness (SE) of textiles with metallized yarns depending on their combinations and the position of samples with respect to the radiation source. For developing of the samples 3 types of metallized threads were used. Single and double jersey samples were made with manual flat knitting machines (gauges E7 and E10). To measure SE, two methods were used. The samples were placed between the radiation source and the detector and radiated with frequencies of 1.161 GHz and 870 MHz. The average result of SE is 92 % for all knitted fabrics produced in this study.

Keywords – knitting, metallized threads, shielding effectiveness

I. INTRODUCTION

Electromagnetic shielding is protection of devices/people from electromagnetic waves which have negative influence, using special shields, screens and electronic equipment (1). Screens and shields are also made of textile materials (fabrics, knitting, non-woven materials) with various structures of conductive yarns/threads, which consist of synthetic and natural fibers as well as of metals, their combinations and even carbon (2).

For measuring the shielding effectiveness (SE) different equipment/methods are used, such as anechoic chamber (3), waveguide and network analyzer (4) or shielding textile bags in which the radiating device is placed, before the difference to the radiation of the unshielded device is measured (5).

Most researches of the SE of textile has been dedicated to woven and coated fabrics, but less to knitted ones. That is why in the study knitted fabrics with metallized yarns are used.

The aim of the study is to clarify the electromagnetic field (EMF) shielding effectiveness of knitted textiles with metallized threads depending on their arrangement, amount, mutual combinations and orientation of samples in relation to the radiation source of frequency 1.161 GHz (GPS, mobile phones, telecommunication) and 870 MHz (wireless sensors).

II. MATERIALS AND METHODS

A. Metallized Threads

Carrying out the selection of metallized yarns, such factors as the conformity to textile threads, the structure and chemical consistency of the thread, the resistivity of metal yarns were taken into account in order to avoid harm to human health and to ensure the possibility to use the threads in a knitting machine. For the development of the samples three types of partly metal

yarns were used: 1 – polyester staple yarn with steel filaments (PES yarn, fine steel filaments FG 5005) where diameter of metal filament was 0.01 mm; 2 – textured polyester multi filament yarn with steel filament (Trevira Neckelman, Nr. S06316 Jet Lavtex conductive, dtex 360F65 x 1), $d = 0.03$ mm; 3 – cotton yarn with Cu filament coated with Ag (Cotton Acier, A067 nm), $d = 0.03$ mm (see Fig. 1).

To achieve smooth density of the knitted fabrics, additionally was used cotton thread.

B. Knitted Samples

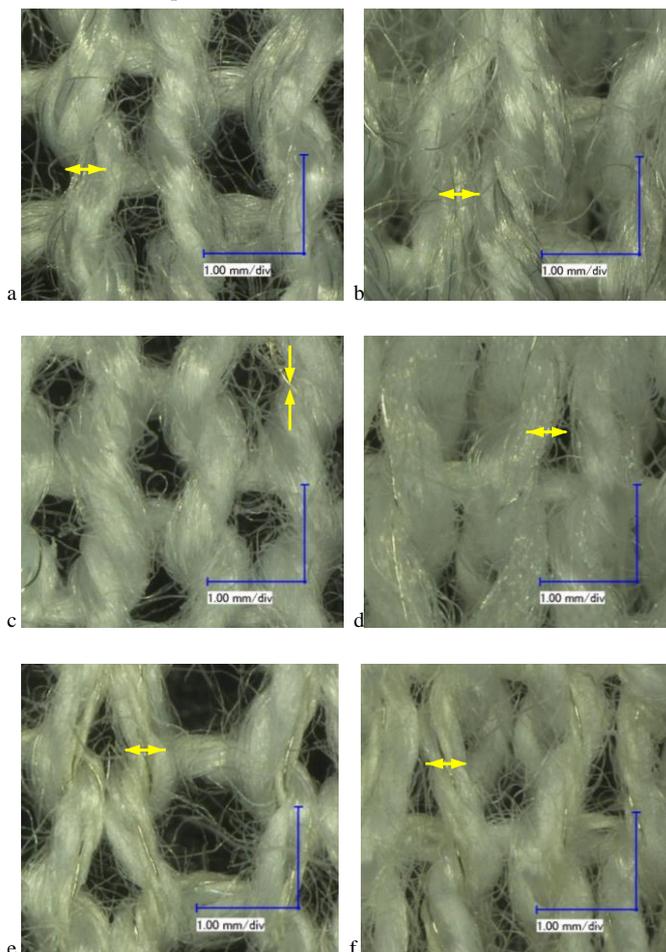


Fig. 1. Micrographic pictures of knitted samples (gauge = E10); (a) single jersey with thread No. 1; b – double jersey with thread No. 1; c – single jersey with thread No. 2; d – double jersey with thread No. 2; e – single jersey with thread No. 3; f – double jersey with thread No. 3. Arrows point to the metallized threads.

Single and double jersey samples were made using manual flat knitting machines with gauge E7 and gauge E10.

The gauge defines the fineness size of the knitting machine and refers to the number of needles per inch or the fineness of the knitted fabric and refers to the number of stitches per inch. The larger the gauge number, the finer is the knitted fabric. For example, knitted fabric with gauge E7 has 7 stitches per inch or 2.54 cm. To obtain the same density of knitted samples, cotton thread was combined with other metallized threads. Combining different metallized threads, pattern types and gauges, totally 28 samples were made (see Table I). For example, the code *7s/co* means that the knitted sample was produced on a knitting machine E7 with pattern type single jersey, using yarn No. 1 and cotton thread.

TABLE I

COMBINATION PRINCIPLE OF METALLIZED THREADS, PATTERN AND GAUGE

Gauge (needles per inch)	Pattern type	Combinations of metallized threads (by code number)		
E7	Single	1 + co	1 + 2	
	Double	2 + co	1 + 3	1 + 2 + 3
E10	Single	3 + co	2 + 3	
	Double	1 + co	1 + 2	
E10	Single	2 + co	1 + 3	1 + 2 + 3
	Double	3 + co	2 + 3	

The samples under examination were oriented in such a way that the courses of metallized threads were parallel (vertically oriented sample, see Fig. 2) and perpendicular (horizontally oriented sample) to E-field polarization plane of the electromagnetic wave.

Horizontally oriented samples showed less shielding effectiveness than the vertically oriented ones that is why the vertically oriented samples are more discussed.

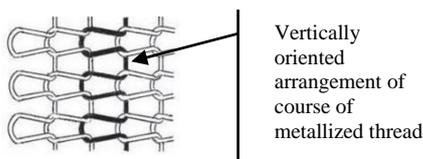


Fig.2. Scheme of metallized thread location in knitted textile (single jersey).

C. SE Measuring Methods and Equipment

1. Waveguides and VNA

To measure the shielding effectiveness, a test set of two similar waveguides and vector network analyzer (VNA) was used. The waveguides were cylindrical with diameter 190 mm and length 400 mm. The cut-off frequency of the waveguide was approximately 1 GHz, which meant that it could not be used for lower frequencies. The linearly polarized wave inside the waveguide was generated with a quarter wave monopole. The monopole was soldered to the central wire of N-type connector (a radio frequency coaxial connector) and placed 70 mm from the wall. Waveguide ports were connected with coaxial cables to the VNA ports. The test set scheme is shown in Fig. 3, where 1 stands for the first waveguide, 2 stands for the second waveguide, 3 stands for the sample and 4 stands for the coaxial cables.

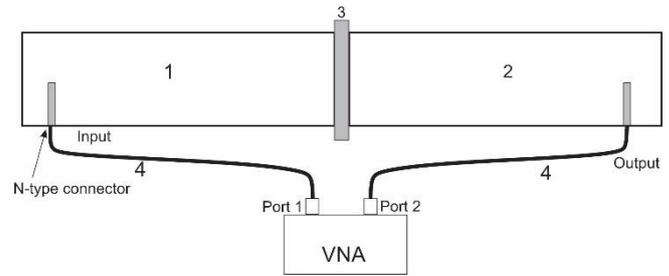


Fig.3. Scheme of waveguide and network analyzer.

Before the SE measurements the waveguide characteristics were tested without a sample. The frequency was swept in the 0.5 GHz – 1.5 GHz range. Fig. 4 shows the amplitude-frequency response (AFR) of the waveguide. These characteristics were used to find more suitable frequency for the tests. Fig. 4a shows the reflection coefficient (S11) of the input; S11 is 0 dB in 500 MHz – 950 MHz frequency range and it means that all power was reflected from the input. The waveguide was not usable on these frequencies. 950 MHz was a cutoff frequency of this waveguide. The waves only with higher frequency than cutoff could be propagated in the waveguide. Fig. 4b shows the AFR of transition coefficient S12, which confirms the existence of cutoff frequency in the range 500 MHz – 950 MHz. Theoretically for the tests we could use all frequencies which are higher than 950 MHz, but practically the high frequency region has some limitations. The most significant limitation was the effect of wave interference which was the source of uncertainty. The effect of interference is demonstrated in Fig. 4a. The AFR curve had a lot of peaks with minimums and maximums in frequency range of 1 GHz – 1.5 GHz. The region which was close to the cutoff frequency of waveguide was the most suitable for tests because of the minimal interference. The power transmission loss in the waveguide was about 1 dB and it is shown with marker MK1 in Fig. 4b. The loss was compensated after the calibration. The best impedance match between VNA and waveguide ports was on a frequency of 1.16 GHz, which was used for the SE measurements. In this research the transition and reflection coefficients of the material were measured. SE was defined as reflection coefficient.

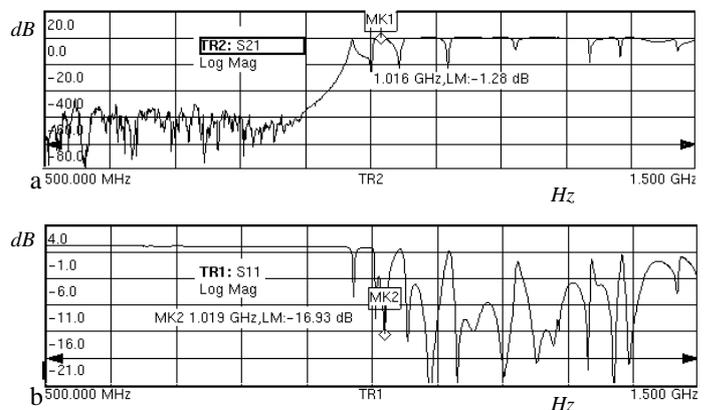


Fig. 4. AFR of the waveguide; a – input reflection; b – transition.

The measurement set was calibrated and normalized using VNA calibration regime. The diagram of reflected and transmitted power is illustrated in Fig. 5. The level of the reflected power was

very low at -71 dB ($7.9e \cdot 10^{-8}$ times less in comparison with input power). The low reflection level allows accepting that the reflection without sample equals to 0. But the level of the transmitted power was almost the same as the input power, as a result the transition coefficient without sample equals to 1.0

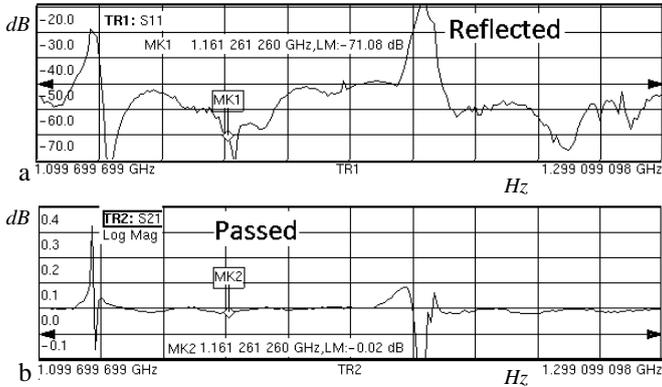


Fig. 5. AFR of the waveguide after normalization; a – input; b – transient.

An object placed between the waveguides will disturb the distribution of the electromagnetic waves, which is shown in Fig. 6, where P1 stands for forward power, P2 is transmitted power, P3 is reflected power and P4 is absorbed power. The sum of P2, P3, and P4 is P1.

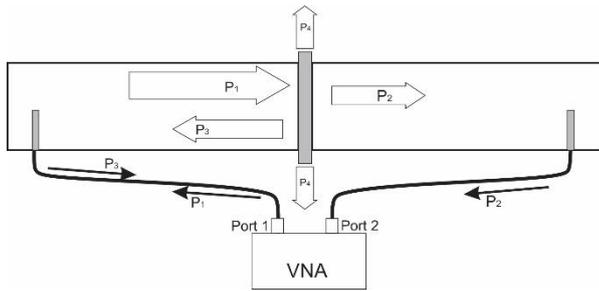


Fig. 6. Scheme of distribution of waves in the waveguide.

Physically the forward radio frequency (RF) power is approximately 1 mW. In this test relative powers were used. P1 is defined as 1.0 (100 %). The VNA detects S-parameters and depicts them in logarithmic scale. S12 is the transition coefficient (1), S11 is the reflection coefficient (2). From S11 and S12 reflected and transmitted relative powers can be extracted.

$$S12 = 10 \log(P2/P1) = 10 \log(P2) \quad (1)$$

$$S11 = 10 \log(P3/P1) = 10 \log(P3) \quad (2)$$

2. Method of two antennas (horn & dipole)

The conductive threads in the material can work as reflector with a simple dipole antenna. We tested this effect using the method of two antennas. The test set is shown in Fig. 7 and consists of a quarter wave dipole antenna marked 3, broadband horn antenna marked 2 and vector network analyzer (VNA) which is connected to antennas using coaxial cables marked 1. The distance between the antennas is 1 m. The tests were conducted on 870 MHz frequency. The path between the antennas was calibrated before the tests without the reflector. The reference level was 0 dB.

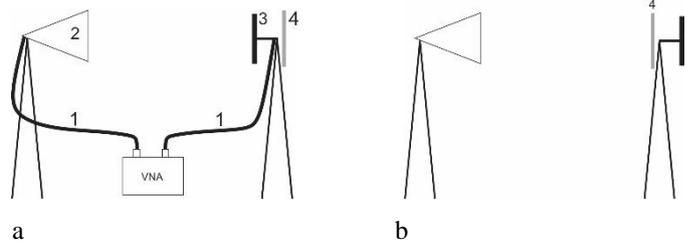


Fig.7. Scheme of the test set: a – measurement of front amplification; b – measurement of back attenuation.

The radiation pattern of dipole antenna without reflector is shown in Fig. 8. It is a circle in E-field polarization of the dipole. The strength of E-field was constant in all directions. The sample of the conductive textile which was placed between the antennas (see Fig. 9) worked as a reflector. This effect is widely used in the well-known Yagi-Uda antenna. The reflector introduced changes in the radiated field. The front radiation was amplified and back radiation was attenuated. The efficiency of field reflection from the sample depended on the difference between front amplification and back attenuation (FB ratio). We measured the attenuation of the signal, for which the results are given in Fig. 14 and Fig. 15.

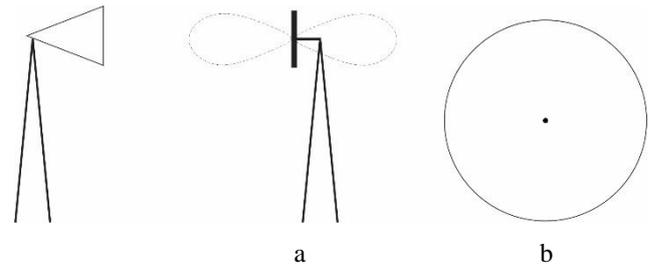


Fig. 8. Radiation pattern (electric filed intensity) of dipole in vertical polarization, without sample: a – cross section side view and b – from above.

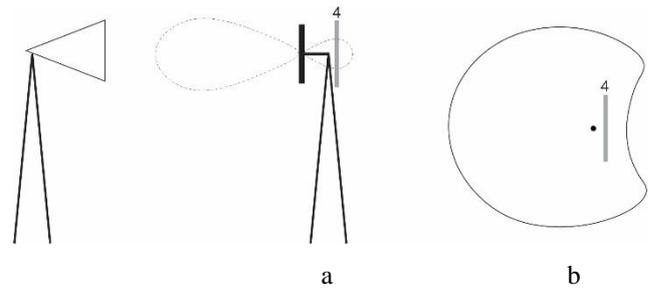


Fig. 9. Radiation pattern (electric filed intensity) of dipole in vertical polarization, with sample: a – cross section side view and b – from above.

III. RESULTS AND DISCUSSION

Double jersey samples with thread No. 2 and samples with No. 3 made with both gauge knitting machines showed lower reflection effectiveness and increased absorption than other double jersey samples.

The average SE of samples 7d2co and 7d3co was 73 % (see Fig. 10), while for other samples it was 92 %. The highest SE (98 %) was demonstrated by the sample of steel and polyester staple fibers (thread No. 1).

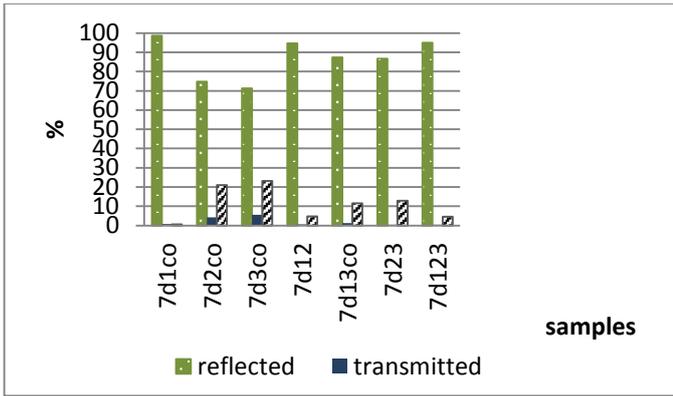


Fig. 10. SE (%) of double jersey samples ($g = E7$) with metallized threads parallel to polarization plane of the electromagnetic wave 1.161 GHz.

Similar tendency was observed for E10 double jersey samples, where the lowest average SE of the samples *10d2co* and *10d3co* was 82 % and of other samples it was 95 % (see Fig. 11). The sample *10d123* where all threads were combined showed by far the highest shielding (99.99 %).

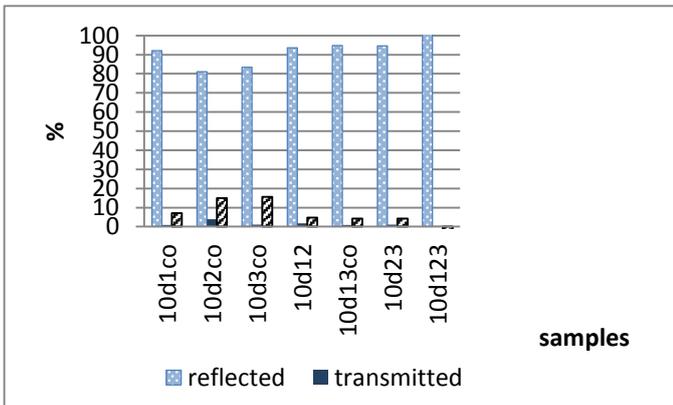


Fig. 11. SE (%) of double jersey samples ($g = E10$) with metallized threads parallel to polarization plane of the electromagnetic wave 1.161 GHz.

Comparing the average results of single jersey samples knitted with gauges E7 and E10, better SE (97 %) was observed for 7 gauge samples. The lowest SE (93 %) was shown again by the sample with thread No. 2 (see Fig. 12), while SE of other samples was high.

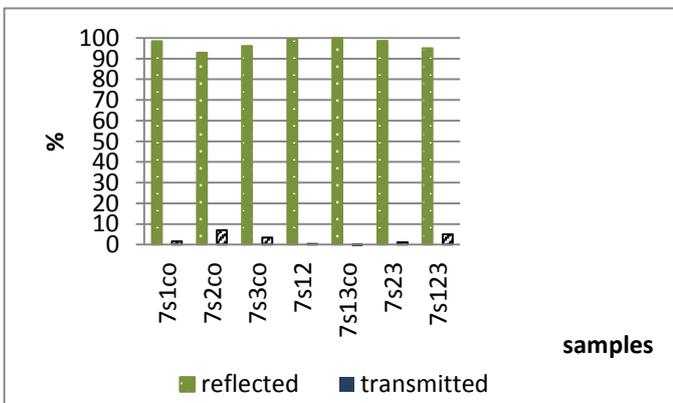


Fig. 12. SE (%) of single jersey samples ($g = E7$) with metallized threads parallel to polarization plane of the electromagnetic wave 1.161 GHz.

The results of E10 gauge single jersey samples were not as good as of E7 gauge samples. Samples *10s1co*, *10s3co*, *10s13co* and *10s123* showed lower SE (91 %) than other samples of this group (see Fig. 13).

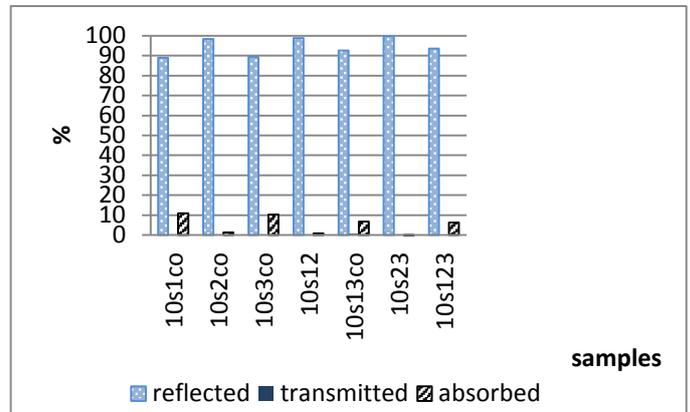


Fig. 13. SE (%) of single jersey samples ($g = E10$) with metallized threads parallel to polarization plane of the electromagnetic wave 1.161 GHz.

The average result of shielding effectiveness was 92 % among all knitted fabrics produced for this study. Better SE was observed in single jersey samples. Analyzing the results of double jersey samples, it can be concluded that the finer the knitting pattern, the better is the SE and the lower is the absorption and transmission. Otherwise single jersey samples had better SE for the samples with $g = E7$ (with bigger loops).

Knitted fabrics take the leading position among textiles for clothing production, especially single jersey. Metallized fabrics can be used in such daily clothing as pullovers, T-shirts, vests and jackets, thus protecting people from electromagnetic waves.

Comparing double jersey samples measured with the horn and dipole antenna method (Fig. 14) high reflection was observed to samples knitted with 10 gauge knitting machine, especially to samples where combination of thread No. 1 and No. 2. and No. 2 and No. 3 were used.

E7 single jersey samples (Fig. 15) had better (twice as high) reflection than double jersey samples (see Fig. 14). This was because the metallized threads in the single jersey pattern were less curved than in double jersey, thus the reflection of waves was better.

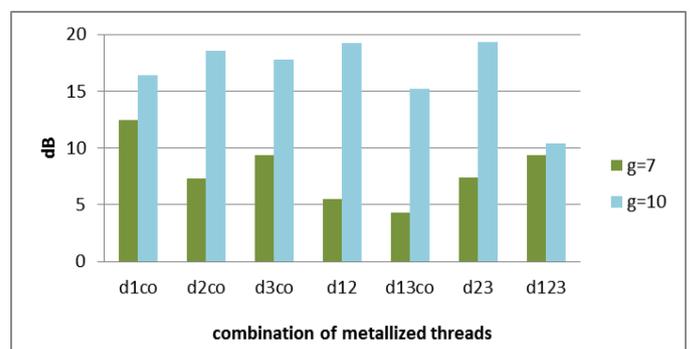


Fig. 14. Reflection of double jersey samples ($g = E7, g = E10$).

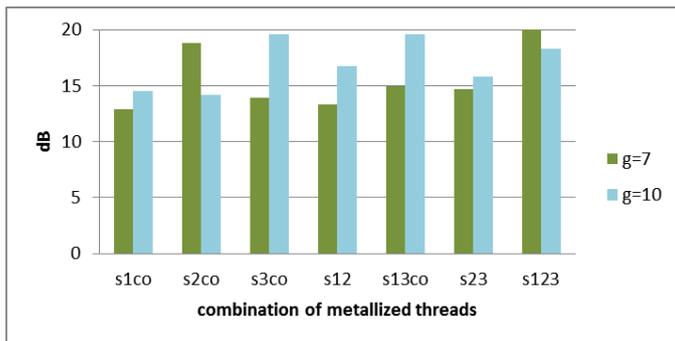


Fig. 15. Reflection of single jersey samples ($g = E7$, $g = E10$).

IV. CONCLUSION

To improve the shielding effectiveness features of textiles, various fabrics, knitted fabrics and nonwovens of different structures, combinations and consistency were modeled and developed using metal/metal coated yarns.

Several methods for measuring shielding effectiveness were used, and the usage of different equipment depended on the radiated waves.

The samples with yarns oriented parallel to the polarization plane of incident electromagnetic waves showed much higher SE (92 %) than perpendicular oriented samples, which was caused by wave polarization.

The reflection coefficient or SE depends on the parameters of the conductor which reflects the waves. This is one of the basic tasks of electrodynamics named – reflection of a normally incident plane wave from a conductor. The incident wave in the ideal conductor induces oscillations of electrons and generates the electromagnetic wave with the same properties but in another direction. The ideal conductor is plane and infinity as a result its impedance is 0. It means that the ideal conductor has no active and reactive resistance. The investigated samples differ a lot from the ideal conductor. The samples have an active and reactive resistance which effects SE.

The SE depends on the knitting pattern, i.e., whether it is single or double jersey. Single jersey (SE~96 %) samples reflect electromagnetic waves better than the samples of double jersey (SE~89 %) which allows the conclusion that the less metal yarns are curved, the less inductivity is observed. We assumed that as the double jersey samples had more curved loops inductivity was higher and as a result had higher impedance. The conductors with higher impedance have worse reflection.

The highest SE is observed for single jersey samples where in combination with other threads the thread of cotton and Cu filament coated with Ag (thread No. 3) was used.

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Marianna Grecka, Oļegs Artamonovs, Juris Blūms, Andrea Ehrmann, Ausma Viļumsone. Adījumu ar metalizētiem pavedieniem elektromagnētiskā lauka ekranēšanas efektivitāte

Strauji attīstoties komunikācijas tehnoloģiju sistēmām, krasi palielinājusies apkārtējās vides piesārņojuma bīstamība ar elektromagnētisko starojumu. Elektromagnētisko viļņu ekranēšana ir nepieciešama ne tikai elektroniskām ierīcēm, bet arī cilvēkiem. Viens no veidiem kā pasargāt cilvēku no EM viļņiem ir ekranējošo tekstiliju izmantošana apģērbā. Tās var būt austās, neaustās, pārklātās un adītās tekstilijas.

Ekranēšanas efektivitātes mērīšanai izmanto vairākas metodes, kuru iekārtu atšķirības galvenokārt nosaka viļņu garumi, ar kuriem apstaro paraugus. Darba mērķis ir izveidot drānas paraugus ar elektromagnētiskā lauka ekranējošām īpašībām, izmantojot trīs dažādus metalizētus pavedienus: 1 pavediens - poliestera un tērauda štāpeļšķiedras pavediens, 2 - multifilamentārais PES pavediens ar tērauda filamentu, 3 - kokvilnas šķiedru un vara filaments, kas pārklāts ar Ag. Paraugi adīti ar 7. un 10. klases adāmmašīnām divos dažādos adījuma veidos – vienkārtas un divkārtu adījumā. No metalizētiem pavedieniem un kokvilnas dzijas kopumā izveidoti 28 paraugi.

Paraugu ekranēšanas efektivitāte mērīta pēc divām metodēm: pirmā, izmantojot divus viļņvadus, starp kuriem novietots paraugs un ar ķēžu analizatoru (raidītā viļņa frekvence 1.161 GHz); otrā, izmantojot rupora un dipola antenas, kas pieslēgtas pie ķēžu analizatora (raidītā viļņa frekvence 870 MHz).

Kopumā salīdzinot adījuma paraugus, vidējs atstarošanas rādītājs ir 92 % no raidītā viļņa. Ar viļņvada-ķēžu analizatora metodi mērītiem paraugiem vislabākās ekranēšanas īpašības raksturīgas vertikāli novietotām drānām, jo viļņa elektriskā lauka polarizācija sakrīt ar ieadītā vadītāja (metalizētā pavediena) orientāciju.

Visaugstākā ekranēšanas efektivitāte ir 7. klases adāmmašīnas vienkārtas adījumiem. Vienkārtas paraugi ekranē labāk par divkārtu paraugiem, jo to metalizētie pavedieni ir mazāk izliekti un ar mazāku induktivitāti, līdz ar to augstfrekvencei ir mazāka induktīvā pretestība. Salīdzinot paraugus, kas mērīti ar rupora un dipola antenas metodi, labāk atstaro smalkāka adījuma (10. klases adāmmašīna) vienkārtas paraugi, īpaši, kur izmantots kokvilnas pavediens ar vara filamentu, kas pārklāts ar Ag.

Марианна Грецка, Олег Артамонов, Юрис Блум, Андреа Эрман, Аусма Вилумсоне. Эффективность экранирования электромагнитного поля вязаний из металлизированных нитей

В связи с быстрым развитием систем коммуникационных технологий, резко возросла опасность загрязнения окружающей среды электромагнитным излучением. Экранирование электромагнитных волн необходимо не только для электронных устройств, но и для людей. Одним из способов защиты людей от ЭМ волн является использование экранирующих текстильных изделий. Текстильный материал может быть тканым, нетканым, вязаным и с покрытием.

Для измерения эффективности экранирования используются разные методики, различие которых в основном определяет длина волн, которые облучают образцы. Цель работы - создать вязаные образцы экранирующие электромагнитное поле, используя три разных металлизированных нити. Первая нить – из полиэстера и стального штапельного волокна, вторая нить – из мультифиламентарного полиэстера со стальным филаментом, третья нить – из хлопкового волокна и медного филамента, покрытого серебром. Трикотажные образцы связаны на машинках 7-го и 10-го класса одинарным и двойным вязанием. Создано 28 образцов из металлизированной и хлопковой пряжи.

Эффективность экранирования образцов измерена двумя способами: первый - с использованием двух волноводов, между которыми расположен образец и анализатора (частота волны 1.161 ГГц); второй - используя рупорную и дипольную антенну, которые соединены с анализатором (частота волны 870 МГц).

Средний показатель эффективности экранирования составляет 92 %. Наилучшая эффективность экранирования характерна для вертикально расположенных образцов, которые измерены методом волновода-анализатора, потому что поляризация электрического поля волны совпадает с ориентацией проводника (металлизированной нити).

У образцов 7-го класса одинарного вязания наблюдается наибольшая эффективность экранирования. Образцы одинарного вязания экранируют лучше, чем образцы двойного вязания, потому что металлизированная нить менее изогнута и поэтому меньше индуктивна, следовательно, у высокой частоты меньше индуктивность. Сравнивая образцы, измеренные рупорной и дипольной антенной, лучше экранируют тонкие (машина 10 класса) образцы одинарного вязания, особенно те, что сделаны из 3-й нити, которая состоит из хлопкового волокна с медным филаментом, покрытым серебром.