Effects of different conductive yarns’ knitting structure on electromagnetic shielding effectiveness

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Abstract. Recently, increasing number of studies are performed on protective fabrics containing conductive yarns for electromagnetic shielding purposes. In this paper, several weft knitted fabrics were developed with conductive yarns of the same yarn count and their conductivity and electromagnetic shielding effectiveness (EMSE) were measured. The variations in EMSE as well as reflection, transmission and other physical properties of knitted conductive fabrics were investigated considering conductive yarns and knit structure. It is observed that an increase in the conductive yarns content significantly alters conductivity while all samples demonstrate sufficient EMSE in high frequency bands; Measurements results are presented herein and future research directions are provided.

Keywords: electromagnetic shielding effectiveness; knitted fabrics; conductive fabrics.

1. Introduction

Wireless devices, Wi-Fi, and electronic security systems, that are some of the newer devices, which are implementations of electromagnetic (EM) fields, have been common in recent years. These applications, use industrial, scientific and medical (ISM) band of 2400 MHz. In this regard, various research teams have examined if the EM fields have possibly effects on human health. So, it is important to create public concern about the safety of these EM fields (1). Conductive fabrics can easily be the shielding material in addition to a number of other advantages. Fabric is the friendliest and most widely used material by humans. Conductive fabrics are lightweight, flexible and inexpensive.

For a few years conductive fabrics have been used for various shielding applications by the electrical and electronic industries, instead of electrically conductive metal sheet or wire mesh. Previous research that used selected copper as a conductive filler to produce copper core yarns with cotton fibre as sheath material to make plain and twill woven fabrics, observed an increase in shielding effectiveness with an increase in the number of conductive fabric layers, finer yarn count, warp density, weft density, cover factors and a decrease in shielding effectiveness with copper wire diameter (2). It measured the electromagnetic shielding effectiveness of these fabrics in the frequency range of 20–18,000 MHz with coaxial transmission equipment.

Roh et al. (3) used metal composite yarns, which were used in the construction of plain woven metal composite fabrics, and were produced with commercially available metal filaments and polyester (PET) filaments. Planewave shielding properties of the composite fabrics were measured between 30-1500 MHz using the coaxial transmission line method. They observed that while the
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overall EM shielding effectiveness increased with metal content, different frequency dependence related to the aspect ratio of metal grid structure.

Duran et al. (4) investigated the electromagnetic shielding effectiveness of 3/1 twill woven fabrics with electromagnetic competence test device in 5 different frequencies; 200MHz, 400MHz, 600MHz, 800MHz and 1GHz. While 100% cotton yarns was used as warp yarns, two different weft yarns, copper/cotton core yarns and 100% cotton yarns were used in two different weft densities. It was observed that fabrics woven with copper/cotton core yarns had considerably higher electromagnetic shielding effectiveness values than the fabrics woven with 100% cotton wefts. The results showed that weft density had only a slight effect on the electromagnetic shielding property of the fabric produced with core yarns, whereas it did not have any effect on the electromagnetic shielding property of 100% cotton fabrics.

Palamutçu et al. (5) developed an electromagnetic shielding efficiency measurement set and tested its reliability with two cases, the electrically conductive plain knitted and plain woven fabrics. In these fabrics, Co/Cu and Co/Cu/Ag yarns with different ratios were used. For woven specimens at the 860MHz-960MHz frequency range the highest level of average EMSE value was found to belong to the specimen which had the lowest level (finest conductive fiber) of conductive fiber content. For knitted specimens at the 860 MHz -960 MHz and 1750 MHz - 1850 MHz frequency the level of average EMSE value was found to be similar among all four knitted specimens. Average attenuation values of all knitted specimens were found to be lower than those of the woven specimens for both frequency ranges. It was also observed that the highest attenuation was obtained at 1790 MHz with the woven specimen, which had the finest conductive fiber.

Sandrolini and Reggiani (6) tested five electrically conductive woven and non-woven fabrics by circular coaxial transmission line holder in the frequency range 300 kHz-3.6 GHz. The results showed that a low surface resistivity value was a requirement for a higher shielding effectiveness especially for woven materials.

Özdekir et al. (7) were examined the electromagnetic shielding effectiveness of twill and cellular woven conductive fabrics made with stainless steel core yarns at different weft densities by free space measurement technique at horizontal polarization of the antenna. It is observed that woven fabric samples, which have been positioned so that the weft yarns have been parallel to the antenna polarization, have shown good electromagnetic shielding performances in high frequency band, namely industrial, scientific and medical band.

In this study it is investigate the EM shielding effectiveness of single jersey fabrics and to compare those with different conductive yarn density in the structure.

2. Materials and Methods

2.1. Materials

The yarns used in the tests (conductive and cotton) are shown in the Table 1.

| Materials          | Yarn count | Composition       | Conductivity |
|--------------------|------------|-------------------|--------------|
| Conductive yarn    | 12/1x275/100z | Bekinox VN Stainless steel | 1 Ω/cm      |
| Background yarn    | 30/2Nm     | 100% Cotton       | -            |

The experimental samples were still knitted on a STOLL CMS computerized flat knitting machine (H. Stoll GmbH & Co.KG). To make the sample specifications uniform, the knitting parameters for producing the samples were as listed in Table 2.
Table 2. Sample specifications

| Sample | Knit structure | Composition          |
|--------|---------------|----------------------|
| 1      | Single jersey | 2/2 (Cotton/SS)      |
| 2      | Single jersey | 4/2 (Cotton/SS)      |
| 3      | Single jersey | 8/2 (Cotton/SS)      |
| 4      | Single jersey | 16/2 (Cotton/SS)     |
| 5      | Single jersey | 32/2 (Cotton/SS)     |

In this research, 5 types of knitted fabric samples on five types have been produced in STOLL CMS computerized flat knitting machine (H. Stoll GmbH & Co.KG) 100% using cotton and stainless-steel yarns. The specifications of yarns are given in Table 1. Knitted patterns are shown in Figure 1. The conductive yarns have inserted in certain intervals to obtain different open grid structures of conductive yarn within the fabrics, which resulted in different conductive yarn densities. In the sample No 1 there a repetition of 2 cotton yarns after 2 conductive yarns, in the sample No 2 there are a repetition of 4 cotton yarns after 2 conductive yarns, in the sample No 3 there are a repetition of 8 cotton yarns after 2 conductive yarns, in the sample No 4 there are a repetition of 16 cotton yarns after 2 conductive yarns and in the sample No 5 there are a repetition of 32 cotton yarns after 2 conductive yarns. The characteristics of the conductive fabrics are shown in Table 2.

2.2 Measurement of Transmission Coefficient and Electromagnetic Shielding Effectiveness (EMSE)

Electromagnetic shielding effectiveness (EMSE) is defined as the ratio of the incident to transmitted power of the electromagnetic wave [8]:

$$EMSE_{dB} = 10 \log \left( \frac{P_i}{P_t} \right) = 10 \log \left( \frac{E_i}{E_t} \right)^2 = 20 \log \left( \frac{E_i}{E_t} \right)$$,

(1)

where $P_i, P_t$ are the incident and transmitted power in W/m², and $E_i, E_t$ are the incident and transmitted electric field in V/m, respectively.

The transmittance or $S_{21}$ scattering parameter of the material is defined by [9]

$$S_{21} = \frac{E_t}{E_i}$$.

(2)

As such, the transmittance of the material in dB is equal to

$$S_{21}_{dB} = 10 \log \left( \frac{E_t}{E_i} \right)^2 = 20 \log \left( \frac{E_t}{E_i} \right)$$.

(3)

Therefore, the EMSE and the transmittance of the material are related with the following equation:

$$EMSE_{dB} = -S_{21}_{dB}$$.

(4)

From the above discussion it can be deduced that a large EMSE corresponds to a low $S_{21}$ and, hence, better electromagnetic shielding.

Furthermore, the well-known transmission line technique (with a waveguide) was used to measure the EMSE of the provided fabric samples. We used a Vector Network Analyzer (VNA), model Rohde & Schwarz ZVA24 together with a WR430 (WG9) waveguide set of components (straight waveguides and coaxial to waveguide adaptors). The technique consists in launching a radiofrequency (RF) signal at the one end of the waveguide apparatus and measuring the output signal at the other end, as illustrated in Figure 1(a). The fabric sample is placed in between two straight waveguides. The transmitted signal is measured both with and without the fabric sample in place and the EMSE is calculated as the difference between $S_{21}$ for the two different measurements.

A photo of the testbed with a fabric sample placed between two straight waveguides is displayed in Figure 1(b). It should be noted that according to widely accepted guidelines, the metallic part of the waveguides should be electrically insulated vs. the fabric sample. For this reason, the inner part of the waveguide flanges attached to the samples were covered with a thin plastic insulator film.
Figure 1: (a) Schematic of the testbed used for EMSE measurements and (b) photo of the testbed with the fabric sample placed and secured between two straight waveguides

3. Results and discussion

The transmittance for the 2-3.5 GHz frequency range of fabric samples according to the orientation of conducting threads in parallel or in perpendicular to the large dimension of the waveguide cross section has been examined.

Figure 2: Transmittance of fabric samples #1 to #5 for the 2-3.5 GHz frequency range; orientation of conducting threads parallel to the large dimension of the waveguide cross section
Figure 3: Transmittance of fabric samples #1 to #5 for the 2-3.5 GHz frequency range; orientation of conducting threads perpendicular to the large dimension of the waveguide cross section.

Figures 2 and 3 demonstrate the transmittance or, equivalently, the EMSE of the five provided fabric samples for the 2-3.5 GHz frequency range with the transmission line technique. Since the conductive threads in the provided samples are forming parallel lines, it was decided to measure the transmittance for both parallel and perpendicular orientation of the lines with respect to the large dimension of the waveguide cross section. This choice was proven to be valuable since there is a significant effect of orientation to the resulting EMSE.

Indeed, Figure 2 illustrates that the maximum EMSE is equal to ~1.9 dB for a frequency close to 2 GHz and sample #4. It can be seen that EMSE diminishes with increasing frequency; this should be expected since for larger frequencies the corresponding wavelength is smaller and, thus, it can be easier transmitted for a given conducting threads grid.

On the other hand, Figure 3 illustrates the maximum EMSE is equal to ~16 dB for the same frequency and sample #. Even more, all samples exhibit larger EMSE for this orientation.

4. Conclusions
In this paper, the electromagnetic shielding effectiveness of single jersey fabrics produced on STOLL CMS computerized flat knitting machine (H. Stoll GmbH & Co.KG) 100% using cotton and stainless-steel yarns. have been investigated. The setup includes the positioning of the fabric samples according to the orientation of conducting yarns in parallel or in perpendicular to the large dimension of the waveguide cross section. It has been proved that the orientation of the conductive yarns has play a significant role in the EMSE. Nevertheless, the EM shielding properties of these fabrics should be improved especially in low and medium frequency bands. Moreover, it is supposed to model the EMSE of conductive knitted fabrics with simulation programs to clear up the circumstances referred above.

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