Evaluation of the knitted fabrics stiffness through dynamic testing

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Abstract. The paper aims at introducing a qualitative method for the evaluation of warp knitted spacer fabrics stiffness, through the measurement of their natural frequencies, considering the direct relationship between natural frequencies of the textile fabrics and their stiffness. Additionally, the goal of this work was to comparatively evaluate the results obtained by two testing methods that utilise different measurement principles. The experimental design included the free vibration method, employed to measure the natural frequencies of the spacer mesh structures produced on K. Mayer RD 6 N double needle bar machine, manufactured in two variants of thickness and widths.The natural materials frequencies have been recorded coursewise, walewise and perpendicular on the fabric surface. The testing results confirmed the influence of the fabric thickness, the samples having lower thickness being characterized by the highest level of natural frequencies and stiffness. In parallel, the analysis of the knitted spacer fabrics' flexibility was performed, allowing a comparison of fabrics stiffness and validating the dynamic test results.

1. Introduction

Warp-knitted spacer fabrics are three-dimensional textile structures formed by two parallel-knitted fabrics connected by a yarn layer called as spacer yarn. Spacer yarn plays an important role on the fabric's properties such as high compressibility, breathability, impact resistance and elastic recovery characteristic. In the production of warp knitted spacer fabrics, especially polyester multifilament and monofilament yarns are used as surface layers and spacer yarn, respectively. These fabrics are taken from the knitting machine in the form of closed structures. After knitting process, the warp knitted spacer fabrics are normally subjected to a heat-setting treatment in order to increase the structural stability and to achieve a determined open form [1].

The stiffness of the textile fabrics can be in some cases a basic feature, determining their suitability for a specific end use. Generally, rigidity is defined as the capacity of one material to resist under the influence of different forces, such as: uniaxial tension, compression, bending, shearing and vibration. Most methods described and used in textile laboratories are based on the principle of indirect stiffness assessment by determining the dependence of strain and the force that induces this strain. Some methods use tensile testing machines for precise measurement of the dependence of the force and strain of textile fabrics [2].

The researchers have focused their interest on the knitted fabrics characterization through their natural frequencies, which were determined by employing the free vibrations method [3-5]. The results confirmed that knitted fabrics can be engineered and exploited as structures with vibration absorption capabilities. The weft spacer fabrics containing monofilaments as spacer yarns, have been subjected to the dynamic testing and the results indicate that the differences of the materials natural frequencies are related to the spacer monofilament yarns diameter, patterning of the spacer yarns, threading of monofilaments per needle and machine gauge [3]. In case of warp spacer knitted fabrics, it has been found that number of spacer yarn connections in the unit area are contributing to a higher rigidity of the fabrics on perpendicular testing direction, while the natural frequencies measured wale and course wise are comparable. The finishing process, by its chemical agent's action proved a certain influence on the higher natural frequencies values of the tested fabrics. The consolidation process of yarns contacts is taking place, determining a lower yarns friction and thus an increased rigidity of the structure [4]. The level of natural frequency of each material is giving indications about its rigidity, the higher is the natural frequency the higher rigidity is expected [5].

This relationship was used in the present study and warp knitted spacer fabrics were investigated through the free vibration method, for measuring their natural frequencies. In parallel, the flexibility analysis was carried out for the same fabrics, to establish the stiffness materials hierarchy. The aim of this work was to comparatively evaluate the stiffness of the warp spacer knitted fabrics, determined by two testing methods using different measurement principles, in order to validate the dynamic testing results.

2. Material and method

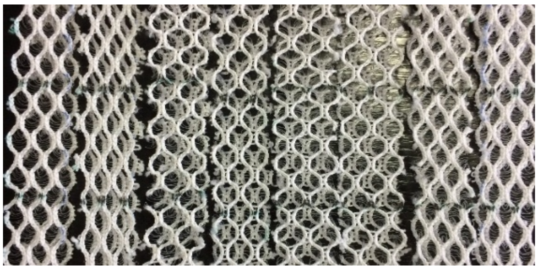
2.1. Materials used

Spacer fabrics were knitted on a Karl Mayer RD 6 double-needle bar Raschel machine equipped with six yarn guide bars (GB). While a 150D/48x4 polyester PTY and 300D/72x3 polyester PTY multifilaments were used to create the top outer and bottom outer layers, a polyester monofilament of 0.243 mm in diameter was used as spacer yarn to connect two outer layers. The chain notation of the guide bars are displayed in Table 1.

Table 1. The chain notation of the guide bars

GB1	2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 //
GB2	0-1 / 1-1 / 1-0 / 0-0 //
GB3	0-1 / 0-1 / 1-0 / 1-0 //
GB4	0-1 / 0-1 / 1-0 / 1-0 //
GB5	0-0 / 0-1 / 1-1 / 1-0 //
GB6	1-1 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 0-0 / 0-0 / 2-2 / 2-2 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 / 1-1 / 3-3 / 3-3 / 1-1 //

Brückner (Vn-Sfp-24/ 6-Q99) heat-setting machine was used to increase the structural stability and to achieve a determined final width (stretching). The samples were horizontally (course-wise) pinned on the sliding aluminium frame pins and heat set at the temperatures of 150°C and 180°C for time durations of 1.8 and 3 min. The tension applied to the samples during heat-setting was arranged so that the final width of the samples was 110 and 160 cm while the width of unset fabrics which refers to the fabric width after knitting process was 60 cm [1]. After heat-setting, the fabric samples were allowed to cool down at room temperature for 24 hours. The samples obtained with these parameters are represented in Figure 1.



1 2 3 4 5 6 7 8

Figure 1. Variants of spacer fabrics

The mass per unit area values are determined according to the TS EN12127 standard. Fabric density was calculated by dividing fabric weight to fabric thickness. The porosity characteristic of the fabrics is calculated by using Equation (1):

$$\varepsilon = \frac{\rho}{\rho}\ (\%) \qquad (1)$$

Where: ε is the fabric porosity (%), ρ_a is the fabric density (g/cm^3) and ρ_b is the fibre density (g/cm^3).

The details of production process and the characteristics of the samples are presented in Table 2.

Table 2. Fabric details and characteristics

Fabric code	Thickness (mm)	Temperature of thermosetting (^{0}C)	Stretching width (cm)	Mass per unit area (g/m^2)	Fabric density (g/cm^3)	Porosity (%)
F1.	13	150	110	737.952	0.0533	96.14
F2.	10	150	110	721.888	0.0697	94.95
F3.	13	150	160	588.832	0.0435	96.85
F4.	10	150	160	570.912	0.0531	96.15
F5.	13	180	160	577.824	0.0424	96.93
F6.	10	180	160	515.264	0.0523	96.21
F7.	13	180	110	716.736	0.0564	95.91
F8.	10	180	110	711.854	0.0744	94.61

The stretching parameter affected the mass per unit area and the fabric density values significantly. The higher the stretching (samples F3-6), the lower the mass and fabric density values of the fabrics. For the same fabrics, their porosity increases with the stretching parameter increasing. The thicknesses of all fabrics are smaller than the distance set (12.5 and 15 mm) between the two needle bars of the machine. This is an expected situation because after the knitting process, the spacer yarns tended to relax into bended forms, conducting to the decreasing of the fabric thickness, respectively to 10 and 13 mm [6].

2.2. Testing method and equipment

2.2.1. Fabrics natural frequencies measurement

The vibration tests of warp knitted spacer fabrics were conducted by using the free vibration method [3-5]. According to the system theory, an elastic system out of the position of stable equilibrium then released, produces free vibrations. In the presence of friction forces, mechanical energy is dissipated and the vibration is damped by a certain number of cycles. Free vibration frequencies depend on the mass, stiffness and damping of the system. They are independent of the initial conditions of the motion and of the system external forces. Therefore, their frequencies are called natural frequency of vibrations. For a given system, they have constant values well defined [7].

In this study, the natural frequencies of the spacer knitted fabrics have been measured by testing the dynamic behaviour of one metallic piece, 30x70x30 mm dimensions, fixed through an adhesive, directly on the fabric’s surface. The textile material is also fixed on the heavy plate, the relative movements between the piece-knitted fabric-plate being avoided. The exciter used was an impact hammer Piezotronics and frequencies were measured with an accelerometer PCB B52 Piezotronics type. The signal was processed with one data acquisition card 6023 National Instruments. In order to determine the natural frequencies of the system, the Fast Fourier Transformation-FFT has been applied and the Spectrum Analyzer application from the LabView 8.2 software has been employed.

2.2.2. Fabrics flexibility measurement

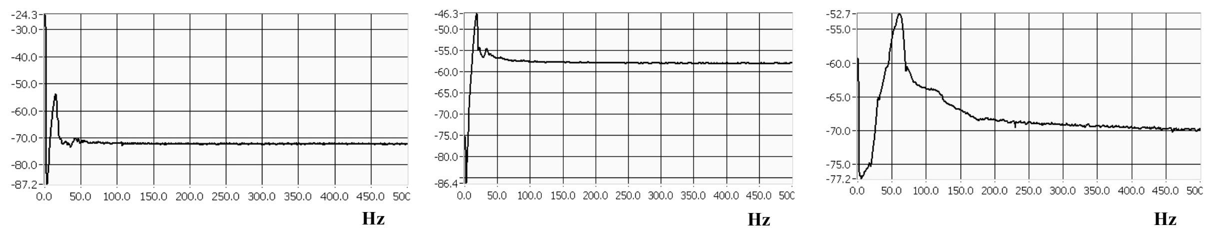
Fabric stiffness tester provides a quick and accurate method of determining the fabric flexibility according to internationally recognized test standard ASTM D1388-2007. Employing the principle of cantilever bending, a rectangular specimen (200mm x 25 mm) is supported on a smooth low-friction horizontal platform. A weighted slide is placed over the specimen and advanced at a constant rate, allowing a narrow strip of fabric (10mm) to bend under its own weight. As the leading edge of the specimen projects from the platform, it bends under its own weight. For each bending length of 1cm, the material flexes and touches the bending angle that allows an easy read of the corresponding angle fabric bends. The higher the bending angle, the more flexible is the fabric.

$$H = \frac{A}{A_{abs}} \cdot 100 = \frac{1}{9}\left(\ddot{\ }_1 + \ddot{\ }_2 + ... + \ddot{\ }_9 + \frac{\ddot{\ }_{10}}{2} \right)\% \quad (2)$$

Where: H is fabric flexibility (%), A represents the area of the "bending angle variation diagram" for the testes sample, Abs is the corresponding are of the "bending angle variation diagram" area for the absolutely flexible specimen. In this case, the bending angle is 90^0 and corresponds to any free length of the specimen from 10 mm to 100 mm.

3. Results and discussions

Three readings of the frequencies have been done and the average has been considered. The vibrations were produced and measured on three directions: wale wise, course wise and perpendicular on the fabric surface. The frequency at the highest peak represents the natural frequency of the fabric, as shown in Figure 2.



a) Course wise b) Wale wise c) Perpendicular

Figure 2. Natural frequencies of the spacer warp knitted fabric [Hz]

The values of the natural frequencies measured for the warp spacer fabrics are illustrated in Figure 3. The results indicate that perpendicular on the fabrics surface, the measured values are higher compared to other two directions. This can be justified by the position of the spacer yarns, which play an important role on the fabric's properties, such as: compressibility, breathability, impact resistance and elastic recovery characteristic. In this case, the monofilaments positioning inside the fabric layers influence the assembly behaviour to the dynamic testing, by increasing the fabric rigidity and level of natural frequencies recorded on this direction. With these special properties, spacer fabrics have great potential use against vibration protection applications.

On perpendicular and wale testing direction, it can be observed that the fabric's thickness is influencing the level of natural frequencies, the thinner fabrics have higher values of the frequencies and are consequently higher rigidity. This is also confirmed by the flexibility measurements for these fabrics on wale direction, which has lower values for the same fabrics.

With the increase of the final width of the samples, the size of holes on fabric surface of the samples increases also. The fabrics with 160 cm width have lower values of the frequencies and higher values of flexibility, against the samples with 110 cm. Among them, those with the thickness of 10 mm have higher values of the frequencies compared to the 13 mm thickness ones.

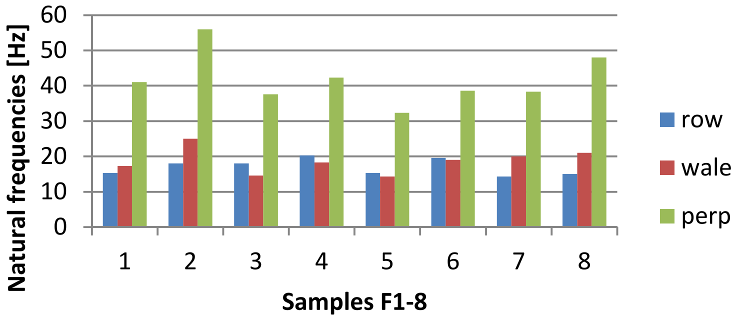


Figure 3. Natural frequencies of the warp spacer fabrics (Hz)

Heat-setting under drawing of spacer fabrics increases the porosity and air permeability of sample while decreases the thickness and mass per unit area of sample [8]. In this study, the analysed samples with higher heat-setting temperature were manufactured with 2 values of thickness and 2 different mass per unit. On wale direction, the fabrics F7-F8, which are heavier than F5-6, have a higher stiffness and a lower flexibility, as shown by the measurements displayed in Figure 4. Wale wise, the fabrics F4 and F6 with 10 mm thickness, show a higher rigidity and lower flexibility in comparison with the pair F5 and F7, with 13 mm value of thickness. The highest values of the natural frequencies have the fabrics F2 and F8, manufactured with the lower thickness and lower stretching width, which are also characterized by a higher fabric density and bigger mass per unit.

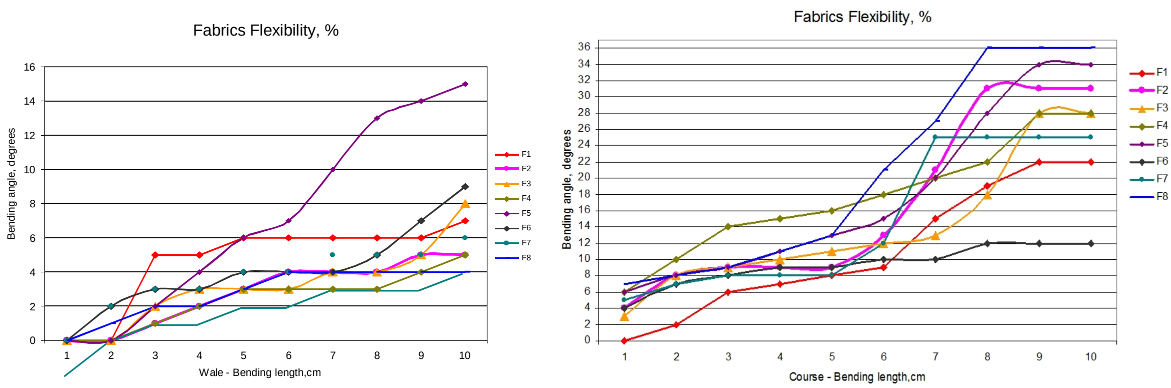


Figure 4. Fabrics flexibility (%)

Figure 4 reveals a different flexural behaviour of the fabrics, walewise being more stable, due to the particular warp knitting principle, with the parallel yarns manufactured on vertical direction. On wale direction, the hierarchy of the samples starts with those having 13 mm thickness and 160 cm width after stretching and ends up with the variants of 10 mm thickness and 110 cm width. On course direction, the materials having 10 mm thickness and 110 width are more flexible, compared to ones produced with 13 mm distance between the layers. It can be concluded that thickness and stretching width are adjustable influence parameters for controlling the knitwear flexibility.

Figure 5 presents the values of the fabrics stiffness determined by the two described methods in the paper. The shape of the two graphs demonstrates the indirect relationship between the measurements, when the fabric has a high value of the natural frequency and consequently high stiffness, the measured flexibility is low.

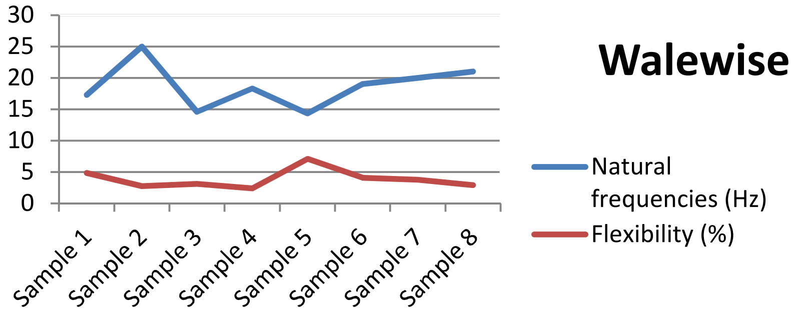


Figure 5. Warp knitted spacer fabrics stiffness

This fact validates the assumption and results of the stiffness evaluation of the fabrics, strengthening the sampled hierarchy and recommending the method of free vibration for the qualitative evaluation of the warp spacer knitted fabrics stiffness.

4. Conclusions

This study reports an investigation on the warp spacer knitted fabrics stiffness determined through the method of free vibrations. Within this method, each recorded curve consists of a certain number of waves, the highest peak of the first one in horizontal direction, being the natural frequency of the fabric, measured in [Hz]. The level of natural frequency for each material is giving indications about its rigidity, the higher is the natural frequency the higher rigidity is expected. It has been found that the fabric's thickness is influencing the level of natural frequencies, the thinner fabrics have higher values of the frequencies and are consequently higher stiffness. More, the samples with a lower stretching width and bigger mass per unit demonstrated higher level of frequencies and higher stiffness. In order to confirm and validate the results of this method, a second method known in the textile field, based on the principle of cantilever bending, has been used to determine the fabrics flexibility. The measurements confirmed the fabrics hierarchy concerning their stiffness obtained through the vibrations testing.

The method of free vibrations found its utility in mechanical engineering field and to the best of our knowledge, in textile field it has been applied so far only by the authors, with the purpose of characterizing the textile materials in their selection for vibration isolation purposes, such as people protection during a particular work or sensitive devices protection during transportation.

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