Measuring the natural frequencies of knitted materials for protection against vibrations

DOI: 10.35530/IT.073.01.202057

MIRELA BLAGA
NECULAI EUGEN SEGHEDIN
CRISTINA GROSU

ABSTRACT – REZUMAT

Measuring the natural frequencies of knitted materials for protection against vibrations

In this study, the use of knitted structures as potential vibration isolators or parts of protective equipment is proposed. Four types of knitted structures were made from different yarns by varying the stitch depth. By combining these variables, a series of 48 patterns were tested for vibration isolation using the free vibration method to measure their natural frequencies. Knowledge of the natural frequencies of textiles is necessary when designing a material to protect it from vibration, in order to avoid the phenomenon of resonance that occurs when the excitation frequency of an external force overlaps with the natural frequency of the system. From the recorded values of the frequencies, it is possible to infer some properties of the knitted materials. The value of the natural frequency of any material gives information about the stiffness of the material. The higher the natural frequency, the more stiffness can be expected. The shape of the natural frequency curve is relevant to the material's ability to dampen vibrations. The smoother the shape, the higher the damping capacity of the material. The study shows that the yarn type and the structural parameters of the fabric affect the vibration behaviour. The tightness of the fabric is one of the most important variables affecting the level of natural frequencies of the material. This research is expected to support the development of knitted fabrics as good vibration isolators for humans by also showing their comfort level compared to alternative materials used so far.

Keywords: *weft knitted structures, natural frequency, free vibration, raw materials*

Măsurarea frecvențelor naturale ale materialelor tricotate destinate protecției împotriva vibrațiilor

În acest studiu, se propune valorificarea tricoturilor ca potențiali izolatori împotriva vibrațiilor sau ca părți componente ale echipamentelor de protecție. Cercetarea s-a efectuat asupra unui număr de 48 de variante de tricoturi, rezultate din tricotarea a patru structuri, fiecare fiind obținută din patru fire diferite și cu trei valori diferite ale adâncimii de buclare. În vederea caracterizării capacității de izolare a vibrațiilor, au fost măsurate frecvențele naturale ale tricoturilor, determinate prin metoda vibrațiilor libere. Cunoașterea frecvențelor naturale este necesară încă din etapa de proiectare a unui material, astfel încât acesta să poată oferi protecție la vibrații, evitându-se astfel fenomenul de rezonanță, care apare atunci când frecvența de excitație a unei forțe externe se suprapune cu frecvența naturală a sistemului. Valorile înregistrate ale frecvenţelor naturale pot oferi informații privind anumite caracteristici ale materialelor tricotate, precum rigiditatea acestora. Cu cât frecvența naturală este mai mare, cu atât rigiditatea acestora este mai crescută. Forma curbei naturale de frecvență este relevantă pentru capacitatea materialului de a amortiza vibrațiile. Cu cât forma este mai aplatizată, cu atât capacitatea de amortizare a materialului este mai mare. Cercetarea arată că tipul de fire și parametrii structurali ai tricotului determină comportamentul acestuia la vibrații. Compactitatea tricotului este una dintre cele mai importante variabile, care influențează nivelul frecvențelor naturale ale acestuia. Această cercetare confirmă capacitatea de protecție a structurilor tricotate împotriva vibrațiilor, care, împreună cu nivelul ridicat de confort al acestora, pot constitui alternative ale materialelor utilizate până în prezent.

Cuvinte-cheie: *tricoturi din bătătură, frecvențe naturale, vibrații libere, materii prime*

INTRODUCTION

Vibration is a mechanical phenomenon that describes the physical energy of a vibrating object. Handling a vibrating instrument transfers the energy produced by the source to the body. The shocks generated by vibration gradually lead to physical discomfort, ranging from brief discomforts, such as kinetosis sourced from mild shocks to severe injuries, such as gangrene on the worker's fingers sourced from severe shocks [1, 2].

It has been found that the number of workers affected by occupational vibration exposure is high and varies in different countries depending on the industry. For example, it is estimated that 8–10 million workers in the USA are exposed to occupational vibration on a daily basis, while Eurofound reports that 20% of European workers are regularly exposed to vibration during at least ¼ of their working hours [3, 4].

To control the negative effects of vibration on the human body, two conditions are required: limiting the exposure time and using personal protective equipment (PPE), which acts as a damper by dissipating the energy generated by friction between internal components.

Recent studies have brought to light the ability of various textile fabrics as cushioning materials, which have also been shown to be superior in comfort and environmental friendliness to foam or rubber, which have been used abundantly in PPE construction in recent decades. Considering the high percentage of people who work with hand-held power tools, special attention has been given to the research of anti-vibration gloves so far.

LITERATURE REVIEW

A relevant number of patents disclose various models of anti-vibration gloves in which one or more layers are made of textile materials, particularly knitted fabrics, generally shielded with various impact-resistant materials, such as silicone protrusions, foam, nubs, or rubber cavities filled with compressed air. The most commonly used textile materials for patent models are cotton for the inner and core layers, high-performance yarns such as para-aramid, Kevlar or high-density polyethylene for the outer layer, and various elastic yarns to improve elasticity in the wrist or backhand areas of the glove [5–9].

Recent researches have investigated the vibration behaviour of various knitted spacer fabrics or new prototypes of gloves made of knitted materials by subjecting them to objective tests, namely air permeability, vibration isolation, compression or trial tests. Some of them were evaluated in comparison with various commercial anti-vibration gloves and obtained very good results. Polyester is the most commonly used raw material for anti-vibration knitted fabrics, especially for spacer fabrics. Nevertheless, few studies have aimed to investigate the influence of raw materials on the response to vibration. Seghedin et. al. found differences of (20–80) Hz between the responses of synthetic fabrics made from PES or PP and natural fabrics made from cotton or PAN [10]. In addition, a significant influence of the type of spacer yarn was found. In a group of warp knitted fabrics made of PES or PA yarns for the outer layers and mono/multifilaments from PES or monofilaments from PA as spacer yarns, the highest frequency level was found in the fabrics with monofilaments from PES as spacer yarns [11, 12]. Many other experiments investigated the vibration isolation performance of different knitted structures from PES, but the focus was on other features that affect this performance, such as fabric thickness, stitch density, spacer thread arrangement, or test direction [12–15].

Polyamide is the second option in raw materials for antivibration products. A prototype antivibration glove containing a spandex/nylon spacer fabric for the outer layers and polyester monofilament for the spacer yarn as the cushioning layer showed better performance than 3 other commercial antivibration gloves in wear tests and exposure to vibrations from a hammer drill [16]. Chen et al. investigated the vibration isolating effect of spacer fabrics with outer layers of nylon yarns or nylon/spandex yarns [17, 18]. No significant differences in damping performance were found for spacer fabrics with outer layers of 100% nylon yarn and nylon/spandex yarn [16]. However, better vibration isolation for spacer fabrics was achieved by the elastic yarn insertion technique, which consists of a feeding device attached to the side of the knitting machine, than the conventional method in which the elastic yarn is knitted together with the surface yarns. Yu et al. investigated the vibration isolation behaviour of spacer fabric with elastic insertion for the first time [19]. Based on the basic mechanical theory that to achieve good vibration isolation, it is necessary to reduce the dynamic stiffness of the isolation material to obtain small resonant frequencies during vibration, it was deduced that the use of thicker fabrics is strongly recommended for this purpose in the knitting field. In order to achieve a relatively high thickness without compromising flexibility, Chen applied a steam treatment to the weft-knitted spacer fabrics constructed with nylon and elastic yarns in the two outer layers. As a result, the elastic yarns shrank and the fabric became thicker [17].

High-performance yarns, such as Kevlar or Dyneema, have been used to provide gloves with anti-vibration, cut-resistant and fire-resistant properties for specialized applications. The samples in three-layer sandwich form consist of the top layer of 100% Kevlar or Dyneema, various spacer fabrics or silicone as the inner layer and 100% cotton fabric as the underlining. The samples with silicone or spacer fabric as the inner layer showed significant antivibration properties in the frequency range of 10–200 Hz, with the best damping performance in the range of 50–130 Hz. It was observed that the dexterity and hand comfort of the gloves increased significantly when the silicone layer was replaced with knitted spacer fabric [20].

Natural fibres, such as cotton, are widely used in the antivibration glove market because they offer higher comfort and warmth. Nevertheless, few studies have looked at their ability to reduce the transmission of vibrations. Most of these products consist of a normal glove knitted using conventional technologies with an anti-vibration layer applied to the palm, generally made of foam or rubber [21].

An innovative e-textile product designed to measure vibration has shown high performance after being evaluated under real vibration conditions by workers handling an electric drill. A textile dosimeter consisting of a small triaxial accelerometer incorporated into the core of a textile yarn was used to develop a vibration-measuring glove. Data acquisition was performed with a computer and data analysis was performed with Fast Fourier Transformation [22–24].

The experiments in this study aimed to investigate the influence of yarn type and fabric structural parameters on the performance of weft knitted fabrics in insulating against vibration.

MATERIALS AND METHOD

Tested materials

The studies were conducted with knitted fabrics of different yarns types, with a count 20/1 Nm: Cotton (CO), Polyester (PES), Acrylic and Polypropylene (PP). The selected knitted structures were: single jersey (SJ), interlock (I), sandwich 1 (SW1) and sandwich 2 (SW2) manufactured on electronic flat knitting machines, CMS 530 E6.2, Stoll. The knitted sections are listed in table 1.

For the present study, the stitch depth was set in three levels. The variation of the stitch depth was done by changing the position of the stitch cam using the NP values, which could be set in the knitting program of the M1 plus® software before manufacturing. The minimum and maximum values of the stitch depth were selected according to the machine gauge and the fabrics were defined as tight (NP=12.0), medium (NP=13.0) and loose (NP=14.0). Each structure was made from the four yarns with the three values of stitch density, resulting in a number of 48 samples in the experimental matrix that were subjected to analysis.

After knitting, the fabrics were relaxed in the dry state and the values of the fabric's structural parameters related to vertical density in cpc and horizontal density in wpc were determined. The mass per square meter (g/m^2) was determined using an electronic balance (KERN ABT 320-4M) and the average of five measured values for each structure was calculated. Fabric thickness was measured using a Lab Mesdan device with a resolution of 0.01 mm under a compressive force of 10 cN/mm^2 in accordance with ASTM D1777-96(2019) Standard Test Method for Thickness of Textile Materials.

Testing method

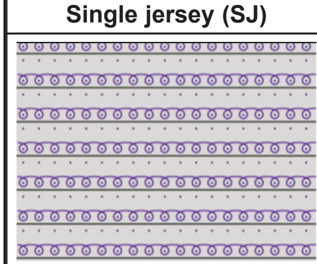
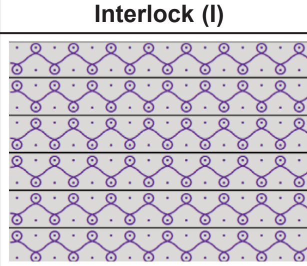
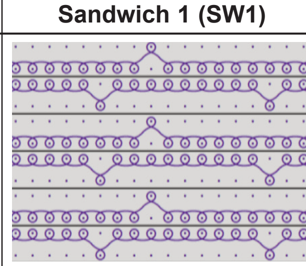
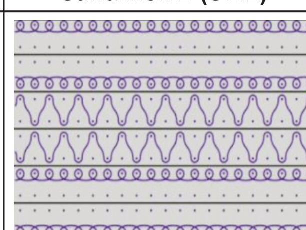
To analyse the vibration behaviour of a system, it is important to determine its natural frequencies, which are free vibrations that occur when an elastic system is released from its equilibrium position. In the presence of frictional forces, the mechanical energy is dissipated and the vibration is damped by a certain number of cycles. The frequencies are independent of the initial conditions of the motion, so they are called natural frequencies of vibrations [25].

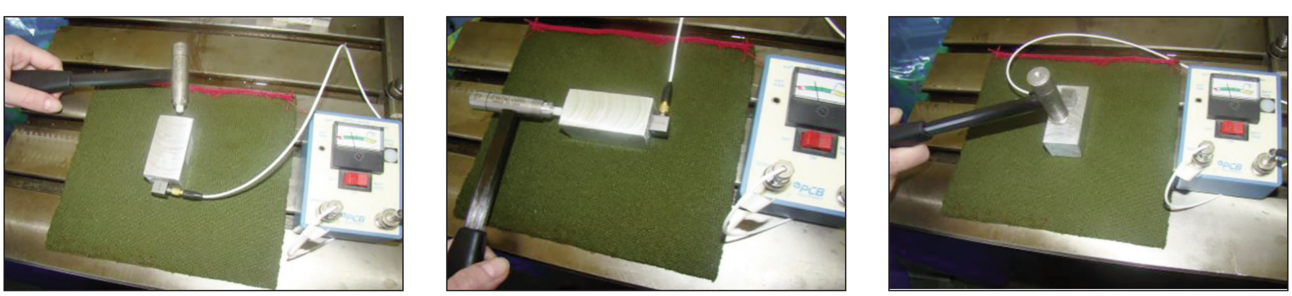
The dynamic performance of knitted fabrics has been studied by testing the dynamic behaviour of a piece of metal weighing 395 g and measuring 30×70×30 mm, attached directly to the surface with an adhesive [10–12, 26], while the textile material is attached to a heavy plate to avoid relative movements between the piece of fabric and the plate. Because the knitted fabrics are characterized by a highly anisotropic structure and different mechanical behaviour in various directions, for each sample the vibration was generated and measured along with three directions: walewise, coursewise and perpendicular on the fabric surface (figure 1).

The vibrations are measured with a PCB Piezotronics accelerometer and the signal is processed by a data acquisition system. The Frequency Spectrum Analysis is the basis of any diagnostic process that uses vibration measurement and consists of the signal decomposition into a sum of frequencies, each corresponding to a certain level of vibration, by applying Fast Fourier Transformation (figure 2).

Each curve consists of a certain number of waves, where the highest peak of the first wave in the horizontal direction is the natural frequency of the material, measured in Hz. The magnitude of the natural

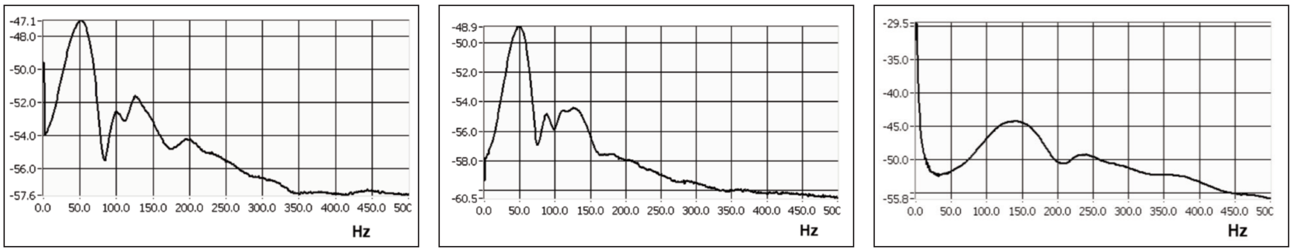
Table 1

KNITTED STRUCTURE SECTIONS			
Single jersey (SJ)	**Interlock (I)**	**Sandwich 1 (SW1)**	**Sandwich 2 (SW2)**
			



a *b* *c*

Fig. 1. Measurement method of the natural frequencies [10]: *a* – walewise; *b* – coursewise; *c* – perpendicular



a *b* *c*

Fig. 2. Recorded natural frequencies of knitted fabrics: *a* – coursewise; *b* – walewise; *c* – perpendicular

frequency for each material provides information about its stiffness. The higher the natural frequency, the more stiffness is expected [26].

RESULTS AND DISCUSSIONS

Testing direction influence on fabric's natural frequencies

Knitting direction has been shown to affect some mechanical properties of knitted fabrics, therefore, it was considered in the present study to determine its effects. The experimental data of natural frequencies were analysed for each yarn type and structure. The example presented in figure 3 displays the four structures from PES and the frequency range for the three testing directions. The comparable frequency level of all fabrics in the transversal (38–58) Hz and longitudinal directions (40–59) Hz at low seismic weight, can be attributed to the vibrational mechanism, which in this case does not involve any movement or distribution of yarn within the structure. The highest values of the natural frequencies of the fabrics were recorded in the perpendicular direction (97–160) Hz, demonstrating the high stiffness of the system. The high ability to damp the vibrations well in this direction, is confirmed by the shape of the frequency curve with low peaks and a smooth profile (figure 2, *c*).

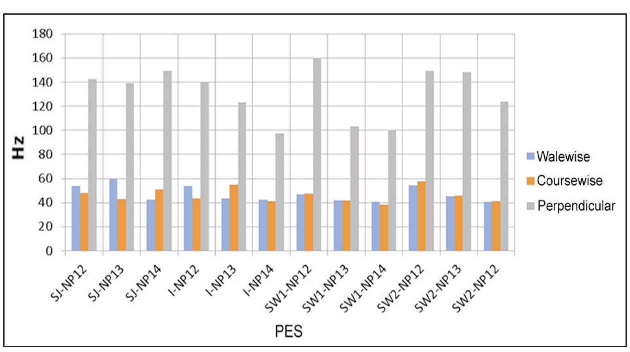


Fig. 3. Natural frequencies measured on different directions (Hz)

Yarn type influence on fabric's natural frequencies

Knitted fabrics made of natural and synthetic yarns have different values of the natural frequencies, regardless of their structure. The type of yarn affects the response of the fabrics in the dynamic tests. Knitted fabrics made of Acrylic, which imitate natural fibres, and of cotton have lower values of their natural frequencies for all structures, all test directions and all stitch densities.

Analysis of experimental data selected for all fabrics in the perpendicular test direction, shown in figure 4, *a* and *b*, reveals a significant difference of (20–100) Hz between the frequencies of synthetic fabrics made of PES or PP and natural fabrics made of CO or PAN. The structure of natural yarns is made from staple fibres, their warm feel and soft handle indicate a less stiff knit and a lower level of natural frequencies. Synthetic yarns are very durable and mechanically resistant, and the knitted fabrics made from them are stiffer and have higher natural frequencies.

It can be observed the differences in the structures from different yarns. Single jersey has the highest stiffness when made from PP yarns, while interlock and sandwich fabrics are very stiff when made from PES. It can be assumed that the natural frequencies of fabrics for a particular knitted fabric can be controlled at the design stage by the raw materials used.

Fabric tightness influence on fabric's natural frequencies

Stitch depth influences the value of the stitch length and the stitch density, which has a major impact on the characteristics of the knitted fabric, such as dimensional stability, weight, comfort, mechanical properties. On electronic flat knitting machines, the tightness of the knitted fabric can be adjusted by the position of the stitch cam (NP). The higher the NP value, the higher the stitch length, the looser the fabric. Under these circumstances, the data show that the natural frequency decreases with a higher NP, which is reflected in a lower stiffness of the fabric. In the case of PP (figure 5) and Acrylic fabrics (figure 6), all tested structures follow this tendency in the perpendicular direction. The exceptions are single jersey from PES (figure 3) and SW1-SW2 from CO (figure 7), which do not follow this rule.

Fabric thickness influence on fabric's natural frequencies

Fabric thickness can be a control parameter for fabrics where this parameter is evenly distributed on the surface. Fabrics with higher thickness and lower stiffness are recommended for vibration isolation [15]. In the diagram shown in figure 8, it can be seen that SW2 made of PES and PP is such a structure where the natural frequencies decrease with increasing thickness. The same is available for interlock from

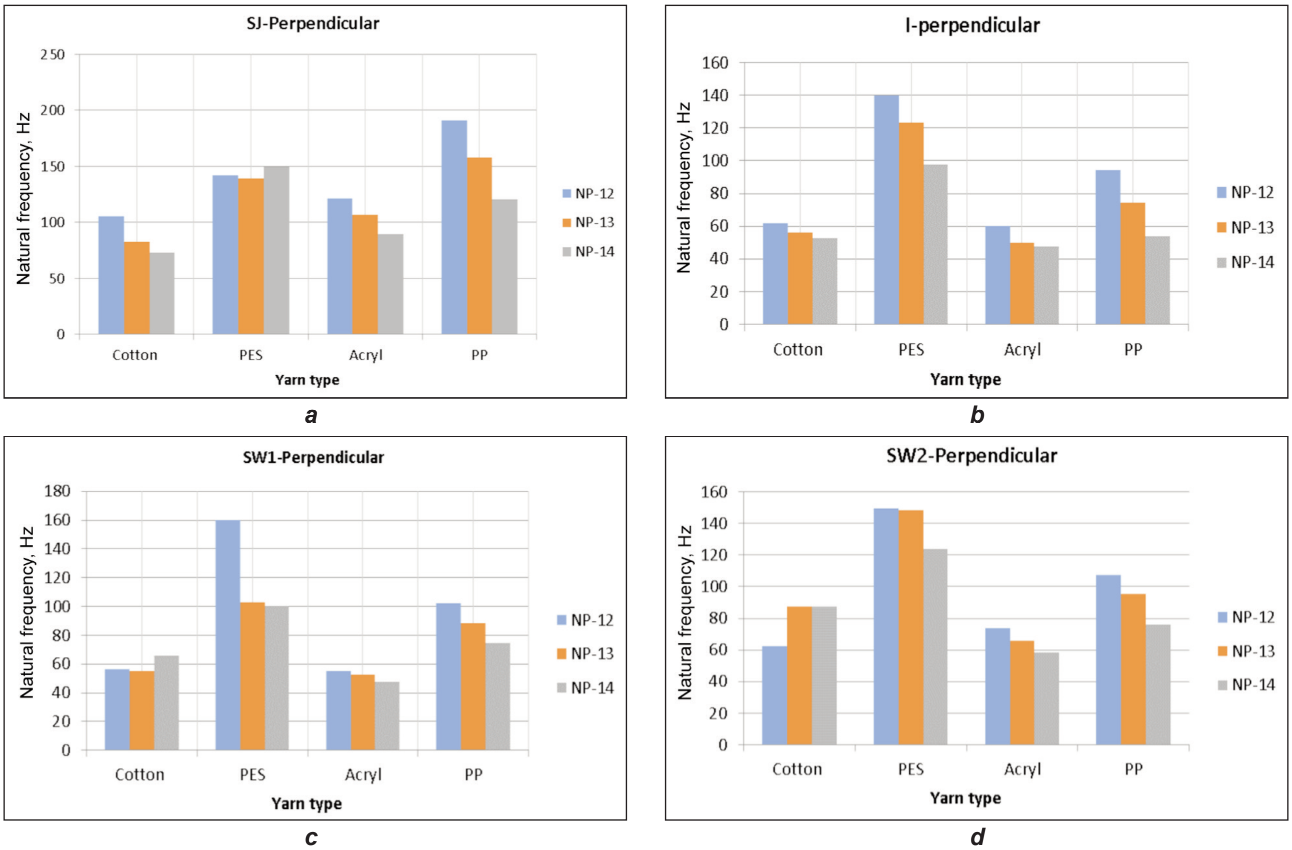


Fig. 4. Natural frequencies of knitted structures: *a* – Single jersey; *b* – Interlock; *c* – Sandwich 1; *d* – Sandwich 2

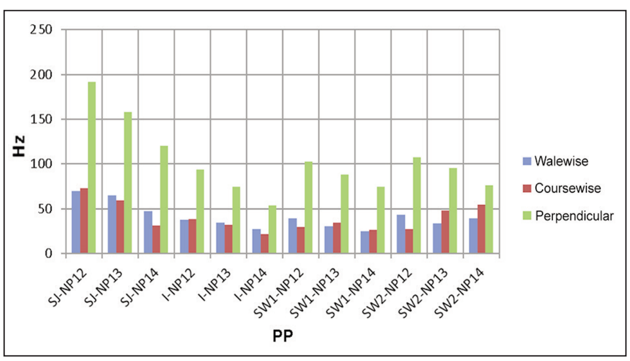


Fig. 5. Natural frequencies of PP fabrics

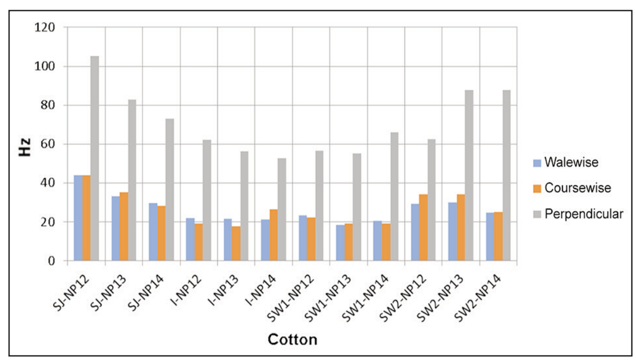


Fig. 7. Natural frequencies of CO fabrics

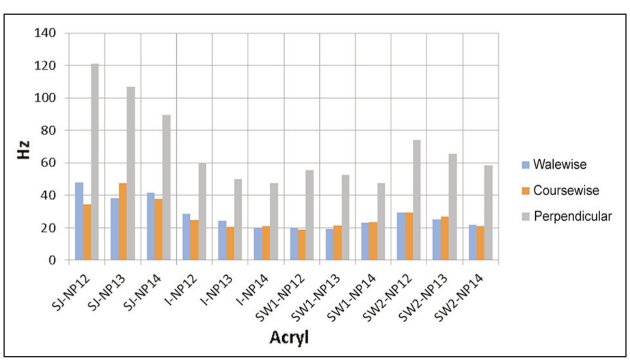


Fig. 6. Natural frequencies of Acryl fabrics

PES and Acrylic yarns and SJ from all yarns. SW1 shows a different behaviour due to its non-uniform thickness resulting from the structural connection of the two layers, creating thus a channelled structure.

CONCLUSIONS

Humans are exposed to vibrations in their activities from a variety of sources, whether from power tools or while riding in vehicles. The energy absorbed from these sources is emitted in the form of vibrations, some of which are transmitted to humans and can cause permanent occupational diseases, having also a negative influence on the worker's effectiveness and productivity [27].

The free vibration method, known in the field of mechanical engineering, was transferred by the authors to the textile field in order to test and characterize textile materials for potential vibration isolation applications.

Knowledge of the natural frequencies of textiles is necessary when designing a material to protect against vibration. Otherwise, resonance, a dangerous

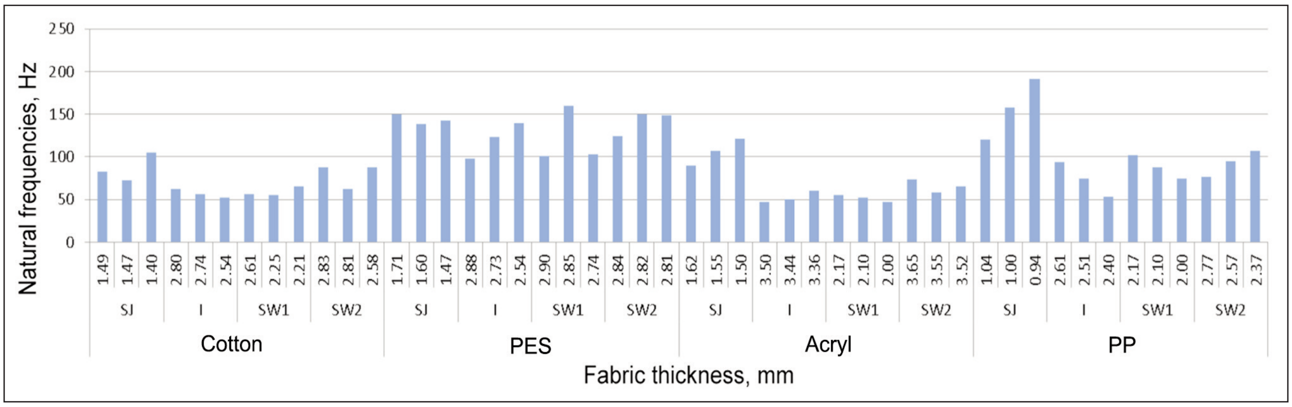


Fig. 8. Natural frequencies of various fabric's thickness

phenomenon that occurs during the use phase, may occur when the excitation frequency of an external force overlaps with the natural frequency of the system. This is the case, for example, with collapsed buildings during an earthquake, because the earthquake force overlaps with the natural frequencies of the building.

This study reports on an investigation of the natural frequencies of weft knitted fabrics made of different yarns determined by the free vibration method. The behaviour of four typical knitted fabrics, single layer and two layers, made of natural and synthetic yarns was experimentally investigated using a vibration test system that measures the frequency of a metallic mass attached to the fabric and excited by shock.

The results discuss the two main factors affecting the natural frequencies of knitted fabrics, namely the yarn type and the tightness of the fabric. The experimental data confirm that the selection of raw material is significant for the development of fabrics with controlled natural frequencies. Fabric tightness is a technological parameter that influences many properties of the produced structures, including the natural frequencies, as confirmed by this analysis.

In future research, the authors will present the design and fabrication of knitted fabrics tailored for a specific vibration isolation application. The particular requirements of the fabric's end use will determine what level of natural frequencies is desired. For example, the knitted fabric should have a different frequency range than the external system generating the vibrations to prevent their transmission. Thus, in the design phase, the structural and technological parameters to control the material properties must be defined.

The development of breathable and recyclable materials with good insulation performance is highly desirable as an alternative to polymer foams, rubbers, gels and air bladders. It was demonstrated that a thicker fabric with a lower stiffness has better vibration isolation performance due to its lower isolation frequencies [15].

As a design principle, a knitted fabric developed for antivibration purposes should be able to absorb energy efficiently while having sufficient stiffness to avoid collapse and an acceptable thickness to preserve the sense of touch and dexterity while performing tasks [18].

REFERENCES

[1] ISO-International Organization for Standardization, *ISO/WD 2631-1 Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration – Part 1: General requirements,* 2001

[2] Canadian Centre for Occupational Health and Safety, Government of Canada, *Vibration,* 2021

[3] Eurofound, *Sixth European Working Conditions Survey – Overview report,* 2017

[4] Andrejiova, M., Pinosova, M., Badida, M., *Occupational Disease as the Bane of Workers' Lives: A Study of Its Incidence in Slovakia. Part 2,* In: International Journal of Environmental Research and Public Health, 2021, 18, 12990, 1–21, https://doi.org/10.3390/ijerph182412990

[5] Evich, K.O., Olegovna, S.M., *Russia Patent No. RU244337. Glove for protection hands from vibration,* 2012

[6] Gerhard, K., Joel, B., Romain, B., *France Patent No. WO2020094966. Vibration portection glove,* 2020

[7] Hughes, G., Hughes, J.C., *United States of America Patent No. US2015/0181955. Ambidextrous anti-vibration glove with impact and pinch point protection,* 2015

[8] Ok, K.J., *Korea Patent No. KR100487752. Glove for absorbing vibration, having vibration isolation structure contained within,* 2005

[9] Wei, C., *China Patent No. CN206565350. Vibration-absorbing mitten,* 2017

[10] Seghedin, N.E., Blaga, M., Ciobanu, R., *Weft knitted fabrics behaviour under dynamic testing*, In: Book of Proceedings of the 12th AUTEX World Textile Conference, 2012, ISBN 978-953-7105-44-0

[11] Blaga, M., Seghedin, N.E., Buhai, C., Chitariu, D., *Dinamic testing of the warp knitted spacer fabrics*, In: Proceedings of the 13th AUTEX World Textile Conference, 2013, ISBN 9783867803434 3867803439

[12] Blaga, M., Seghedin, N.E., *Knitted Spacer Fabrics Behaviour at Vibrations*, In: Journal of Textile Engineering & Fashion Technology, 2017, 3, 2, 602–608, https://doi.org/10.15406/jteft.2017.03.00092

[13] Liu, Y., Hu, H., *Vibration Isolation Performance of Warp-knitted Spacer Fabrics*, In: Proceeding of The Fiber Society 2011 Conference, 2011, 63–64, ISBN: 978-1-63266-644-4

[14] Liu, Y., Hu, H., *An Experimental Study of Compression Behavior of Warp-knitted Spacer Fabric*, In: Journal of Engineered Fibers and Fabrics, 2014, 9, 2, 61–69, https://doi.org/10.1177/155892501400900207

[15] Liu, Y., Hu, H., *Vibration isolation behaviour of 3D polymeric knitted spacer fabrics under harmonic vibration testing conditions*, In: Polymer Testing, 2015, 120–129, https://doi.org/10.1016/j.polymertesting.2015.09.003

[16] Sum, N.W., *Development of anti-vibration glove with weft knitted spacer fabrics,* BA Thesis, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, 2013

[17] Chen, F., *A study of vibration behavior of weft-knitted spacer fabrics*, Doctoral Thesis, Institute of Textiles and Clothing, The Hong Kong Polytechnic University, 2015

[18] Chen, F., Liu, Y., Hu, H., *An experimental study on vibration isolation performance of weft-knitted spacer fabrics*, In: Textile Research Journal, 2016, 86, 20, 2225–2235, https://doi.org/10.1177/0040517515622149

[19] Yu, A., Sukigara, S., Masuda, A., *Investigation of Vibration Isolation Behaviour of Spacer Fabrics with Elastic Inlay*, In: Journal of Textile Engineering, 2020, 66, 5, 65–69. https://doi.org/10.4188/jte.66.65

[20] Palicska, K.L., Augusztinovicz, F., Szemeredy, A., Szucs, L., *Development and test of new knits of anti-vibration*, At: AUTEX2019 – 19th World Textile Conference on Textiles at the Crossroads, 2019

[21] Chainsaw Journal, *Anti-Vibration Glove Reviews – Worth Every Penny*, 2019, Available at: https://www.chainsawjournal.com/ [Accesed on September 2021]

[22] Riley, T.H., Dias, T., *The development of acoustic and vibration sensing yarns for health surveilliance*, In: Proceedings of the 25th International Congress on Sound and Vivration, 2018, 327–333

[23] Rahemtulla, Z., Riley, T.H., Dias, T., *Developing a Vibration-Sensing Yarn for Monitoring Hand-Transmitted Vibrations,* In: Proceedings, 2019, 32, 6, 1–4, https://doi.org/10.3390/proceedings2019032006

[24] Rahemtulla, Z., Riley, T.H., Dias, T., *Vibration-Sensing Electronic Yarns for the Monitoring of Hand Transmitted Vibration,* In: Sensors, 2021, 21, 8, https://doi.org/10.3390/s21082780

[25] Rades M., *Vibratii mecanice (Mechanical vibrations)*, Printech Publishing House, Bucharest, 2008

[26] Blaga, M., Harpa, R., Seghedin N.E., Marmarali, A., Ertekin, G., *Evaluation of the knitted fabrics stiffness through dynamic testing*, In: IOP Conf. Series: Materials Science and Engineering, 2018, 459, 012033, IOP Publishing, https://doi.org/10.1088/1757-899X/459/1/012033

[27] Mansfield, N.J, *Human response to vibration*, CRC Press, London, 2005

Authors:

MIRELA BLAGA[1], NECULAI EUGEN SEGHEDIN[1], CRISTINA GROSU[1,2]

[1]"Gheorghe Asachi" Technical University of Iasi,
56 D. Mangeron Street, 700050, Iasi, Romania

[2]National Research Development Institute for Textiles and Leather,
16 Lucretiu Patrascanu Street, 030508, Sector 3, Bucharest, Romania

Corresponding author:

MIRELA BLAGA
e-mail: mblaga@tex.tuiasi.ro