Investigation of Vibration Isolation Behaviour of Spacer Fabrics with Elastic Inlay

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Abstract

The 3-dimensional (3D) structured spacer fabrics can provide good air-permeability and cushioning effect. It is deformable and has damping capacity can enable vibration isolation. This study aims to investigate the effect of an elastic inlay on the ability of spacer fabrics to isolate vibration. Seven weft-knitted spacer fabric samples consisting of three different spacer structures were constructed by using a v-bed flat knitting machine. Three of the samples were inlaid with spandex yarn on the surface layers and compare with the other three samples without the inlay. One more sample with the spandex yarn knitted together with the surface yarns of the spacer fabric was also produced to investigate the effect of the elastic yarn application method. The vibration transmissibility and compression behaviours of the samples were tested. The results showed that thicker spacer structure with a longer linking distance of the monofilament yarn can provide a higher degree and range of vibration isolation. The application of elastic yarn increases the fabric thickness. However, spacer fabric made by elastic inlay showed a lower compression stiffness than that made by elastic yarn knitted with the surface yarns. The spacer fabrics with elastic inlay showed better vibration isolation ability having a lower natural frequency and isolated vibration in a wider frequency range.

Key Words: Weft-knitted spacer fabric, Vibration transmissibility, Inlay knitting, Compression properties, Wide-band random signal

1. Introduction

Spacer fabrics are three-dimensional (3D) knitted fabrics that consist of two surface layers connected by a connective layer made of filament yarns. As fabricated by interlooping of yarns during knitting, the knitted loops of spacer fabrics allow air to pass through providing the fabric with good air-permeability. Spacer fabrics have good energy absorption capacity and are widely used to replace foam materials for cushioning purposes [1]. It is commonly applied as mattress, shoes, seats, backpacks and protective padding. The 3D structure of spacer fabric also enables vibrations to be isolated [2] owing to its deformability and damping capacity. The degree and range of vibration isolation are found to be related to the spacer structure and fabric thickness [3]. This opens up an opportunity to develop protection garments such as anti-vibration work gloves with better breathability and wearing comfort by using spacer fabrics.

Inlay knitting is a technique that applies extra yarns into a knitted structure to provide additional reinforcement or enhance the mechanical behaviour of the fabric. Inlay method can be used in the fabrication of knitting reinforced composites [4, 5]. The application of elastic yarn inlay can be found in compression garments for controlling pressure delivery [6]. Our previous study showed that the thickness and compression behaviours of spacer fabrics can be changed by incorporating elastic yarn into the surface layer of weft-knitted spacer fabric using inlay method [7]. Significant differences in the physical properties, air-permeability and compression behaviour between the spacer fabrics made of elastic inlay and that made with elastic yarn knitted with the surface yarns can be observed. The use of elastic inlay on certain spacer structures showed a negative stiffness effect which could be useful in vibration isolation. Chen et al. had investigated the negative stiffness effect [8] and the vibration isolation performance [3] of weft-knitted spacer fabrics with spandex yarn knitted together with surface yarns. However, the vibration isolation behaviour of spacer fabrics fabricated with elastic inlay has never been studied. The aim of this study is to therefore investigate the effect of an elastic inlay on the ability of spacer fabrics to isolate vibration. Spacer fabrics made of three different spacer structures with and without elastic inlay were evaluated and compared. A comparison between the spacer fabrics
made by the two elastic yarn application methods, knitting together with surface yarn and inlay methods, would be also carried out. The findings can be used as a reference for the development of anti-vibration protective garments.

2. Methodology

2.1 Materials

7 spacer fabric samples were constructed by using a 10-gauge v-bed flat knitting machine (SWG091N210G, Shima Seiki, Japan) and their details are provided in Table 1. The thickness of the samples was taken under the pressure of 0.1 N/cm². All of the samples have a single jersey surface structure, with the connective structure made with 0.08 mm polyester monofilament yarn. The connecting layer of the samples was knitted with three different spacer structures with varying linking distance. A 140D spandex yarn was used in the inlay with tuck stitches in every 2 needles (Fig. 1). In order to allow a constant tension of the elastic yarns throughout the knitting, a yarn feeding device was used to control the feeding of the elastic yarn at a constant rate of 50 % of the knitting width. All of the samples were allowed to relax for 1 week after released from the knitting machine and stored in a standard environment (20±2°C, 65±2% relative humidity) for at least 24 hours before testing.

2.2 Properties evaluation

The vibration isolation and compression behaviours of the fabric samples were evaluated. Three circular specimens with a diameter of 9 cm were prepared for each sample to carry out the vibration and compression tests. The vibration transmissibility was tested in

| Sample | Surface yarn | Structure of connective layer | Inlay (Yes/No) | Fabric weight (g/m²) | Thickness (mm) |
|--------|--------------|------------------------------|---------------|---------------------|---------------|
| A1     | 450D PET DTY |                               | No            | 500.70± 4.80        | 4.04± 0.15    |
| A2     | 450D PET DTY |                               | Yes           | 600.57± 2.73        | 5.15± 0.11    |
| A3     | 450D PET DTY + 140D spandex | linking distance of 6 needles | No            | 737.75± 3.96        | 4.55± 0.25    |
| B1     | 450D PET DTY |                               | No            | 518.73± 4.72        | 5.16± 0.21    |
| B2     | 450D PET DTY | linking distance of 8 needles | Yes           | 611.99± 3.63        | 7.23± 0.22    |
| C1     | 450D PET DTY |                               | No            | 521.35± 0.91        | 3.00± 0.20    |
| C2     | 450D PET DTY | linking distance of 4 needles | Yes           | 587.89± 2.72        | 3.75± 0.35    |

Notes: PET DTY denotes polyester drawn textured yarn.
accordance with ISO13753, Method for measuring the vibration transmissibility of resilient materials when loaded by the hand-arm system. The set-up is presented in Fig. 2. The samples were placed onto a shaker excited by using a wide-band random signal with a power spectral density between 5-1000 Hz. A piece of cylindrical steel which is 2.5 kg in weight and 9 cm in diameter was placed on top of the sample as the loading mass. The loading mass is equivalent to that found when materials are gripped the hand as specified in the standard ISO13753. The accelerations on the shaker, $a_1$, and top of the mass, $a_2$, were measured by using accelerometers. The vibration transmissibility $T$ (dB) is expressed as $T = 20 \log_{10} \left| \frac{A_2}{A_1} \right|$, where $A_1$ and $A_2$ are the Fourier transforms of $a_1$ and $a_2$ respectively. The compression behaviour of the fabric samples was tested by using a compression tester (MCT-2750, A and D company, Japan) with a flat circular indenter which is also 9 cm in diameter at a rate of 12 mm/min and compressed up to 500 N (Fig. 3).

3. Results and discussions

The vibration transmissibility of the spacer fabric samples is presented in Fig. 4. When the magnitude of the frequency response at the input frequency is less than 0 dB, the fabric samples have reduced the vibration and vice versa. The larger negative value of the frequency response magnitude indicated better the vibration isolation of the fabric. The frequency at which the highest peak appears is the natural frequency of the dynamical system consisting of the fabric and the loading mass. The compression behaviour of the spacer fabric samples is shown in Fig. 5. The pressure given by the mass of the vibration test set-up at static is 0.3854 N/cm$^2$. Therefore, the compression stress-strain curves up to the stress of 1 N/cm$^2$ are also presented (Fig. 5c to 5e).

![Fig. 4 Effect of elastic inlay on vibration transmissibility of the samples made of three spacer structures: (a) Sample A1, A2 and A3, (b) Sample B1 and B2 and (c) Samples C1 and C2.](image-url)
3.1 Effect of spacer structures

With the presence of elastic inlay, the fabric wales are held tighter together and thus the thicknesses of the spacer fabrics increase. The thickness increment on fabric made of Structure B is the largest with 39.3% while that of fabrics made of Structures A and C are 29.2% and 27% respectively. Structure B has a relatively longer linking distance of monofilament yarns which allows the two surface layers holding further apart giving a thicker fabric. It also provides more room for further increase in thickness when the elastic inlay holds the fabric wales tighter together. On the other hand, in Structure C, the linking distance is shorter and hold the two surface layers tightly, hence, the thickness increment caused by elastic inlay is relatively smaller. Moreover, it can be observed that the vibration transmissibility and compression behaviours of the three different spacer structures are largely different. Samples made with Structure B have a relatively lower natural Frequency and have vibration transmissibility less than 0 dB starting from 44.4 Hz and 28.8 Hz respectively. Structure B can provide a higher magnitude of vibration isolation at a wider input frequency range than Structures A and C. Apart from the peak at the natural frequency, 3 more apparent peaks with valleys at the frequency response magnitude below 0 dB are observed in the transmission curve of the Structure B samples. This suggests that this fabric structure itself is dynamic, with properties such as resonance and anti-resonance frequencies in this frequency range. Structure B consists of 8 courses of monofilament yarn in one repeat of the spacer structure to support the structure. The long linking distance of the monofilament yarn helps to condense the fabric wales and give the thickest fabric samples. On the other hand, Structure B samples are relatively easier to compress and enter the plateau stage at less than 1 N/cm². Plateau stage refers to the compression situation that the increment of stress slows down over a certain range of strain due to the buckle or shear of the monofilament yarns and the collapse of the spacer structure. Structure B spacer fabric samples exhibit enough strength to withstand the loading mass and at the same time have a relatively lower stiffness to reduce the natural frequency and facilitate the vibration isolation in a wider frequency range. A thin, compact structure with a short linking distance such as Structure C does not favour for vibration isolation at a low frequency range of 0-200 Hz. In Fig. 5d, a negative stiffness effect where compression stress shows a decrease with the further increase of compression strain.
appears in both Structure B samples under the compression stress below 1 N/cm². This could be a reason for the dynamic behaviour and promoting the vibration isolation capacity of Structure B.

3.2 Effect of elastic inlay

With the presence of the elastic inlay, the Young’s modulus and the compression stiffness before reaching the plateau stage are increased. The natural frequency of the samples with elastic inlay is lower than those without the inlay. Structure C has a relatively compact, stiff and thin structure. The compression stress-strain curve up to 1 N/cm² of Samples C1 and C2 are very similar. The influence of the elastic inlay on the vibration isolation is also relatively small that the transmissibility curves of C1 and C2 are similar. The difference in the vibration transmissibility curves between the samples with and without an elastic inlay is more significant in Structures A and B. Sample A3 has much higher compression stiffness and the compression strength to withstand larger stress than Samples A1 and A2. Sample A3 also has a higher peak in the natural frequency which means a lower level of damping. The degree of vibration isolation is the lowest amongst the samples constructed with Structure A. The natural frequency of Sample A2 appears in a higher magnitude and at a lower frequency of 65 Hz than that of Sample A1 with a natural frequency at 92.5 Hz. The range and degree of vibration isolation found with Sample A2 are also larger than Sample A1. Sample B2 also has a lower natural frequency and a wider range and degree of vibration isolation than Sample B1. These could be explained as the inertial effect of the inlay. The elastic inlay in Sample A2 can withstand slightly higher compression stress than Sample A1 at strains of 0-30 %. When the elastic yarns are knitted together with the surface yarns (Sample A3), this not only increases the fabric thickness but also the compression strength and stiffness which do not contribute to vibration isolation. Both methods of incorporating elastic yarn into the surface layers of spacer fabric can increase the fabric thickness. However, the elastic inlay can help to maintain the softness for compression of the spacer fabrics and thus enhances vibration isolation. Sample A3 is thicker than Sample A1 but does not show better vibration isolation. This revealed that the thickness of the spacer fabric does not directly affect its ability to isolate vibration.

4. Conclusions

The structure in the connective layer of spacer fabric can significantly affect the vibration isolation behaviour under wide-band random signal vibration with power spectral density between 5-1000 Hz. The spacer structure that has longer linking distance of monofilament yarn can provide a higher degree and range of vibration isolation. The elastic inlay can improve the vibration isolation ability of spacer fabric with a lower natural frequency and provide vibration isolation for a wider frequency range. The impact of elastic inlay is more significant in Spacer Structure A used in this study. The effect of the inlay on vibration isolation is very small in the thin and compact samples made of Spacer Structure C. Using inlay method to apply elastic yarns can have a better improvement on the vibration isolation ability than knitting the elastic yarns together with the surface yarns. The use of an elastic inlay can increase the thickness of the spacer fabric but does not result in a large increment of the compression stiffness which would therefore allow a spacer fabric with enhanced vibration isolation properties.

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