Predicting the Dynamic Stiffness of a Glove Material using Mechanical Impedance Model

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Abstract. Anti-vibration glove has been developed to be able to attenuate vibration transmitted to the hand. However, the performance depends on lots of factors such as the contact area and contact force. In addition, the materials used in gloves are commonly made of foam and gel, which produce complex response when these factors are changed. This study aimed to predict the dynamic stiffness of a glove based on the measured transmissibility and apparent mass, using mechanical impedance model. This is used so that the dynamic response of the material can be well understood when parameters such as contact area and contact force are changed. The mechanical impedance model has previously been used to predict transmissibility and showed prediction that is comparable to the measured transmissibility. Measured transmissibilities and apparent masses of the hand of five subjects were used in the model to predict the dynamic stiffness of the glove material. The predicted dynamic stiffness was then compared to the dynamic stiffness measured experimentally. The results showed that the predicted dynamic stiffnesses were similar to the measured dynamic stiffness. In conclusion, the mechanical impedance model is able to predict dynamic stiffness of the glove material.

1. Introduction

A glove shall have transmissibility of less than 0.9 at frequencies less than 200 Hz and less than 0.6 at frequencies greater than 200 Hz, before it can be considered as an anti-vibration glove, as required in the International Standard ISO10819:2013 [1]. There are many gloves passed the requirement in the standard but the performance of the glove in attenuating vibration transmitted to the hand is still unclear. A glove that can attenuate vibration, can also amplify vibration (i.e., at resonance). Coupling with the dynamic response of the hand and the dynamic response of the glove material, the performance of the glove could not well be understood. Both parameters (i.e., dynamic response of the hand and the dynamic response of the glove material) depends on factors such as the contact area [2], contact force [3, 8], location of measurement [4], vibration magnitude [5], posture of the hand and the arm [6], as well as the frequency of vibration [2-6]. It has been suggested that the contact area and the contact force are two prominent factors influencing the transmissibility of vibration through glove to the hand [7]. Changing the contact area, or the contact force, will change the dynamic characteristics of the material in attenuating vibration [2-3]. Hence, in order to understand the glove performance in various conditions, it is important to be able to quantify the material dynamic stiffness so that how the material response during vibration exposure in different situation can be well understood.
The dynamic stiffness of the glove material can be measured using an indenter rig [8]. An indenter rig contains a force cell fixed at one direction measuring the output force, a shaker placed opposite to the force cell that generates vibration exposure to the material, and an accelerometer attached to the table of the vibrator, measuring the input acceleration. The dynamic stiffness is the ratio of the cross spectral densities of the input acceleration and output force, to the power spectral density of the input acceleration. An indenter rig was used to measure the effects of contact area, and contact force on glove material dynamic stiffness, and found that the dynamic stiffness increases with increasing the contact force or contact area [2-3, 8].

Glove transmissibility can be predicted based on the method specified in the International Standard ISO13753:2008 [9]. The material proposed to be used in an anti-vibration glove, is placed on a shaker, with mass placed on top of the material, before vibration is exposed to the material and mass system. The input acceleration and output acceleration are used to predict glove transmissibility. The glove transmissibility is used to analyse whether the proposed material is able to be used in an anti-vibration glove. A study conducted previously based on the ISO13753 and ISO10819 has found discrepancies in terms of glove effectiveness in reducing vibration [10].

Mechanical impedance model was first used in 1986 by Fairley and Griffin, to predict the transmissibility of seat to the body [11]. In 2004, the mechanical impedance model was able to predict the effects of material dynamic stiffness on the glove transmissibility [8]. Later, Rezali and Griffin in 2016, 2017, and 2018 showed a good comparison between predicted transmissibility and measured transmissibility of glove material to the hand when material thickness, contact area and contact force were changed [2-4]. In all experiments conducted previously, measured dynamic stiffnesses and measured apparent masses of the hand were used in the model to predict glove transmissibility.

In this study, the dynamic stiffness of the glove material, apparent mass of the hand, and glove transmissibility were previously measured [2] and the glove dynamic stiffness was predicted using the measured apparent mass of the hand, and the measured glove transmissibility. It is expected that the predicted glove dynamic stiffness was similar to the dynamic stiffness measured experimentally.

2. Methods and Procedures

2.1. Measured glove transmissibility, apparent mass of the hand, and the dynamic stiffness of the glove material

The apparent mass and glove transmissibility were acquired from a referred paper previously published [2]. The palm of the hand was placed on a wooden palm adapter containing an accelerometer measuring acceleration at the palm. An impedance head with a contact area of 25 mm was attached on the table of vibrator. The palm adapter was then placed on top of a contact area with diameter of 25 mm. The input acceleration and output force were measured by the impedance head. A 10-s random vibration with frequency ranging from 5 to 500 Hz was generated with a magnitude of 2 m/s². In the measurement of glove transmissibility, the glove material was placed between the palm adapter and the contact area.

This study only covered 5 subjects of 10 subjects from the referred paper. The subjects were required to place their hand on the palm adapter with a preload force of 20 N. They had to maintain the force during the vibration exposure.

The dynamic stiffness of the glove material on the other hand was acquired from a referred paper previously published [2]. The dynamic stiffness was measured using an indenter rig. An impedance head was used to measure the output force due to the input acceleration from vibration generated by a shaker placed opposite to the fixed force cell.

2.2. Mechanical Impedance Model

The mechanical impedance model was used to predict glove transmissibility to the palm [4] and given by:

\[ T(f) = \frac{\omega^2 S(f)}{\omega^2 S(f) - M_{\text{inv}}(f)} \]
Where $S(f)$ is the dynamic stiffness of the material, $M_{hp}(f)$ is the apparent mass of the hand, $T(f)$ is the transmissibility of the glove material to the hand.

By rearranging the equation, the dynamic stiffness of the glove material can be predicted when the apparent mass of the hand and the glove transmissibility were acquired.

3. Results and Discussion

3.1. Measured apparent mass of the hand and the measured glove transmissibility

The apparent mass of the palm of the hand used in the prediction of dynamic stiffness is shown in Figure 1 for all 5 subjects from 20 to 200 Hz. The apparent mass decreased with increasing frequency of vibration. There were two resonances observed, one at frequency about 20 Hz and another at frequency about 50 Hz. Previous studies have shown that the resonances in the apparent mass of the hand are expected to be at around 15 Hz and 50 Hz. The apparent mass was much less than the apparent mass measured in some studies [12].

![Figure 1](image_url)

**Figure 1.** Apparent mass of the palm of the hand measured experimentally used for the prediction of material dynamic stiffness, from the referred published paper. Individual data.

Figure 2 shows the glove transmissibility to the palm of the hand used in the prediction of material dynamic stiffness for all 5 subjects from 20 to 200 Hz. The glove transmissibility increased before decreased at frequencies greater than the resonances. The resonance was found to occur at frequency about 50 Hz depending on subjects.
3.2. Predicted and measured dynamic stiffness of the glove material
The dynamic stiffnesses of glove material measured experimentally and predicted using the mechanical impedance model are shown in Figure 3. The measured material dynamic stiffness was lower than the predicted material dynamic stiffness at frequencies greater than about 100 Hz. At frequencies less than 100 Hz, the measured material dynamic stiffness was similar to the predicted material dynamic stiffness with an exception to two subjects at frequencies less than about 40 Hz.

3.3. General discussion
The material dynamic stiffness was predicted by using the mechanical impedance model and compares well with the measured dynamic stiffness. The limitation of the indenter rig is that it can only measure dynamic stiffness in flat condition whilst in real situation, anti-vibration gloves are used in various situation, with vibration exposure from different axis. It is expected that with this finding, researchers
can predict dynamic stiffness of glove material in a condition that is difficult to be represented by using an indenter rig.

4. Conclusions
The predicted dynamic stiffness of the glove material was similar to the dynamic stiffness experimentally measured at frequencies less than 100 Hz but was overestimated at frequencies greater than about 100 Hz. This shows that the mechanical impedance model is capable of predicting the material dynamic stiffness.

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