Investigation of Sound Transmission Loss of an Automotive Door Sealing System by Using FEA

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Introduction

Seals are elastomer elements used in automotive doors to prevent heat, water or noise intrusion from outdoor to car interior. When full sealing is obtained to ensure that no aspiration noise is presented, sound transmission loss through seals becomes important.

Sound transmission loss analysis of a seal is a twofold procedure (Fig. 1). In the first phase, nonlinear, high strain deformation analyses should be performed to obtain deformed seal geometry in its working condition. Then, deformed geometry should be transferred to acoustic analyses in which the sound transmission loss characteristic of the seal structure is obtained.

Elastomers show both hyperelastic and viscoelastic characteristics. Hyperelastic material characterization is important when deformation analyses are performed while the frequency dependent viscoelastic material behavior is essential in the acoustic analyses.

Within the scope of this work, mostly second step, acoustic analyses are going to be on the focus, and the effect of frequency dependent viscoelastic material characterization is going to be analyzed. Main aim of this work is to understand if it is essential to take the viscoelastic frequency dependent material characterization into account during acoustic analyses phase.

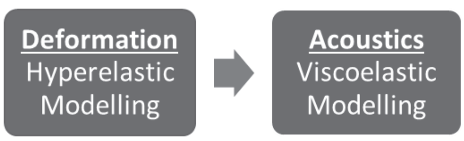


Figure 1: Analyses of a seal system as a two-step procedure

Motivation

When compared the whole car body, seals are quite small. Yet it is important to analyze seal structures and importance can be categorized into two main groups. Firstly, analyze of the seals are important structurally, because all the seal designs are supposed to work under full sealing. If the full sealing is not obtained, aspiration noise might occur especially in high driving speeds. Also, it is important to understand the door closure force, for the automotive companies in the recent years, which is directly connected to the seal structure. Secondly, acoustic analyses of the seals are important, since, seals might constitute a weak link in sound transmission chain depending on the frequency contribution of the noise outside. Hence vibro-acoustical analyses of the seal sound transmission phenomena are essential.

Common practice in automotive industry is to use two seals in door structure such that one seal is attached to the car body while the other one is presented in the door structure. For that reason, a simplified, representative two seal system with a channel is considered in this study.

Different aspects of this problem have been covered in the literature so far [1-5]. Within the scope of this work, effect of frequency dependent viscoelastic material characterization is evaluated and the results are given for a simple representative two seal structure.

Viscoelasticity

Viscoelastic damping mechanism is strongly displayed in many polymeric, elastomeric and amorphous glassy materials. This damping mechanism is caused by the relaxation and recovery of the molecular chains after deformation.

Viscoelastic materials have time dependent relationship between stress and strain, unlike the elastic materials, described in terms of relaxation and creep. This can also be described as a behavior between pure elastic and pure viscous cases.

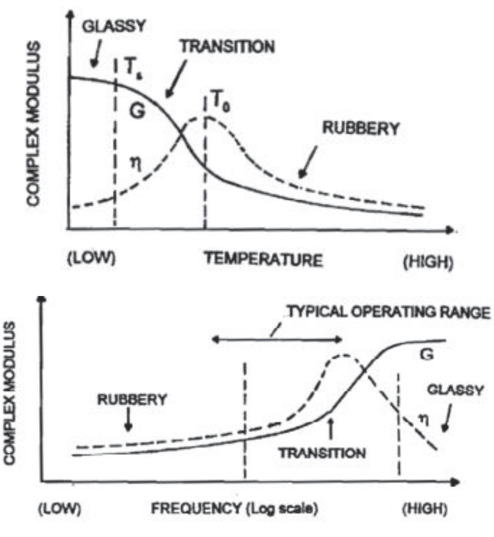


Figure 2: Viscoelastic behavior, temperature (upper) and frequency (lower) dependent material characteristics [6]

Typical viscoelastic material behavior is that the modulus and loss factor of the material is a function of frequency and temperature. Figure 2 explains these phenomena. Upper graph shows the variation of the real part of the complex modulus and loss factor with temperature for constant frequency, and the lower graph explains the variation of the real part of the complex modulus and loss factor with frequency, for constant temperature.

The main aim of this work is to understand the necessity of using frequency dependent viscoelastic material characteristics in sound transmission loss analyses. For that purpose, material tests are performed to obtain modulus and loss factor of the material for different frequencies while keeping the temperature as constant at 20°C.

Material Tests

Material used in this study is an EPDM rubber with hardness value of 65 ShA. Both for deformation analyses and acoustic analyses, hyperelastic and viscoelastic material tests are performed. Mostly viscoelastic tests are going to be in the focus.

5 cm long thin material samples are obtained for material testing. Tests are performed by Perkin Elmer SII DMA equipment. Preloading conditions are ignored and small deformation magnitudes are taken into account, hence linear viscoelastic behavior is obtained.

Tests are performed according to the standards ISO 18347 Mechanical vibration and shock - Characterization of the dynamic mechanical properties of visco-elastic materials - Part 4: Dynamic stiffness method, ASTM D 5992 - Standard Guide for Dynamic Testing of Vulcanized Rubber and Rubber-Like Materials Using Vibratory Methods, ISO 10112 - Damping materials - Graphical presentation of the complex modulus and ISO 6721-1:2011 Plastics - Determination of dynamic mechanical properties - Part 1: General principles

Test frequencies are 1, 2, 4, 10 and 20 Hz, and test temperatures are between -80^{o}C and 60^{o}C. 15 parameter Arhenius model is fit onto the obtained values. Figures 3 and 4 show the results obtained from material tests.

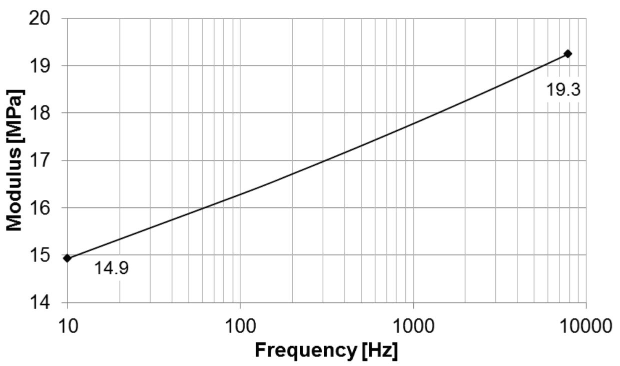


Figure 3: Modulus value of elastomer sample versus frequency

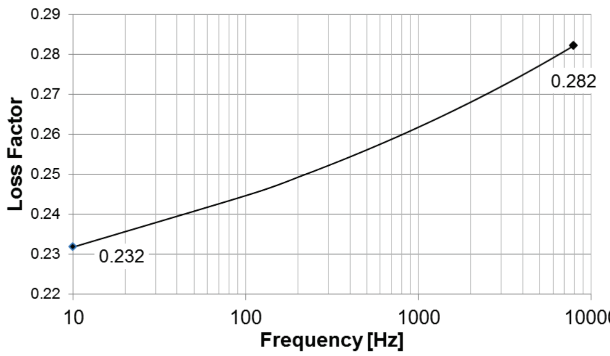
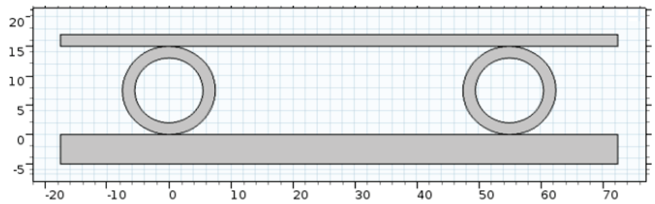


Figure 4: Loss factor value of elastomer sample versus frequency

Simplified Two Seal – Channel Structure

Figure 5 shows the representative two seal geometry in undeformed and deformed phases. For simplicity, seal structure is considered as circular and the channel in which the seals are presented is taken as rectangular. Plane wave input is defined as the left side of the structure and the sound transmission loss values are obtained by integrating the acoustic variables on the seal surfaces.



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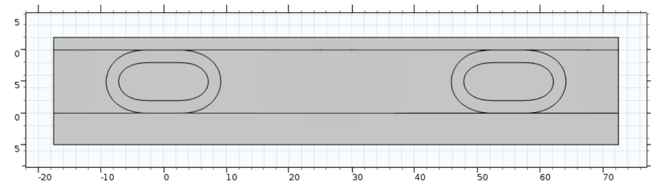


(b)

Figure 5: Representative two seal geometry: (a) undeformed, (b) deformed and air parts added

Verification

In order to verify the finite element model, results obtained from finite element analyses are compared with the results from transfer function matrix method. For this comparison, simplified one seal geometry, described in Park's work is used. [1] One seal can be approximated with two membranes separated each other with a distance.

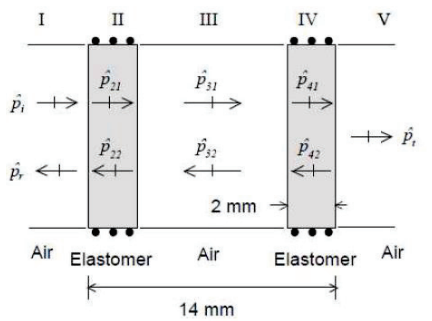


Figure 6: Approximate seal geometry – dual membrane [1]

Figure 6 shows the representative single seal geometry used in comparison. Same geometry is modeled in finite element environment and the results are compared with the transfer function matrix calculations described in Park's work. Results are given in Figure 7. Even though results between 100 – 1000 Hz show discrepancies amplitude wise, both models are capable of obtaining the mass-air-mass resonance frequency of the two membrane model.

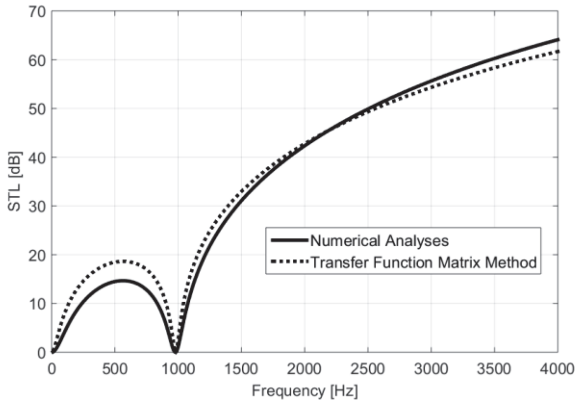


Figure 7: Verification results, FEA versus transfer function/ matrix method

Results

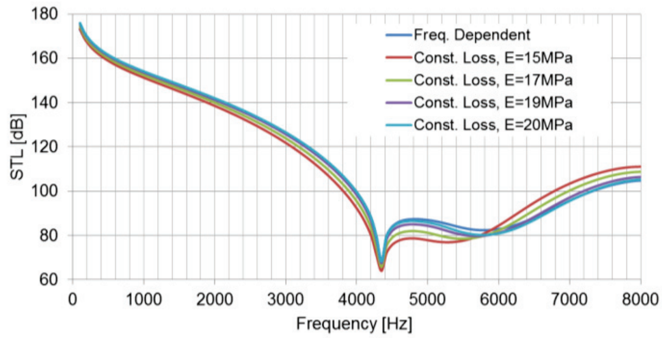
Same loadings and boundary conditions are applied to the two seal model. Frequency range is determined as between 100 Hz and 8000 Hz. Air parts are modeled as fluid acoustic domains with density and sound speed definition. Mesh resolution is high enough to solve 8000 Hz case. Two scenarios, with five different cases are defined. Within the first scenario, results obtained by considering the frequency dependent loss factor and modulus values are compared with four different cases where the loss factor is kept constant but the modulus values are altered. Within the second scenario, modulus value is kept constant but the loss factor is altered. Table 1 shows the definitions of cases considered in this work. Table 2 shows the numerical values used for modulus and loss factor values. Variable numerical values are selected within the range that material testing indicated. Density of the material is taken as 1.1g/cm^3 and Poisson's ratio is as 0.499 throughout the study. Results are given in figures 8 and 9.

Table 1. Definitions of cases

	Case 1	Case 2	Case 3	Case 4	Case 5
Scenario 1	Frequency dependent loss factor and modulus	For constant loss factor, modulus changes			
Scenario 2	Frequency dependent loss factor and modulus	For constant modulus, loss factor changes			

Table 2. Definitions of cases with numerical values

	Case2	Case3	Case 4	Case5
Scenario 1	η: 0.257 E:15MPa	η: 0.257 E:17MPa	η: 0.257 E:19MPa	η: 0.257 E:20MPa
Scenario 2	η: 0.23 E:17MPa	η: 0.25 E:17MPa	η: 0.27 E:17MPa	η: 0.28 E:17MPa



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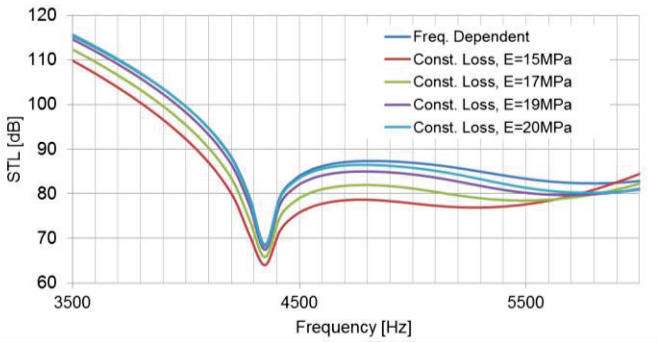

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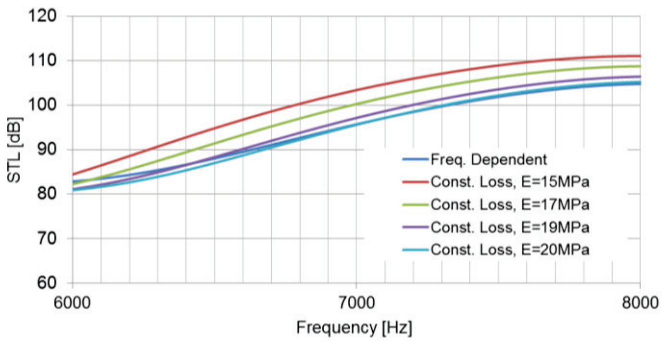
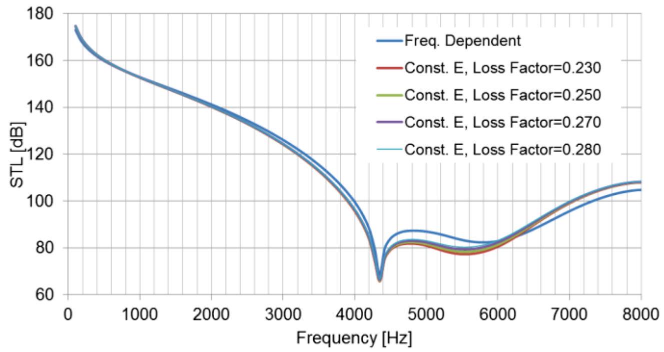


(c)

Figure 8: Results of scenario 1 for different frequency ranges for convenience. (a): broad band results; (b): Results around resonance; (c): Results for high frequencies. In this scenario, frequency dependent material characterization is compared with constant loss factor and variable Young's modulus.



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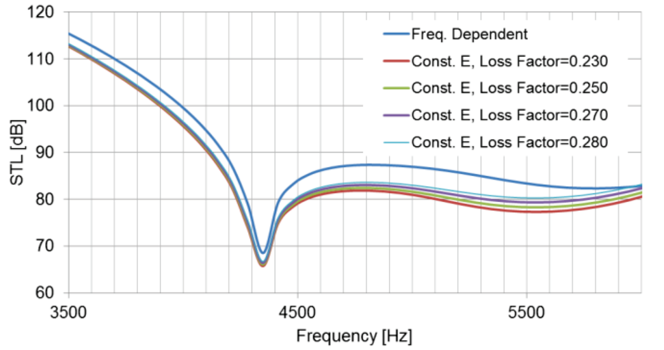

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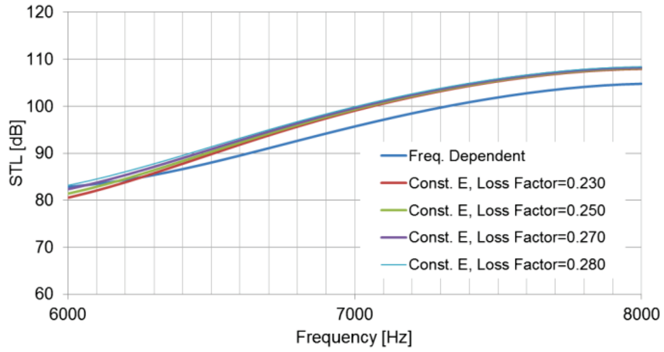

(c)

Figure 9: Results of scenario 2 for different frequency ranges for convenience. (a): broad band results; (b): Results around resonance; (c): Results for high frequencies. In this scenario, frequency dependent material characterization is compared with constant Young's modulus and variable loss factor.

Discussions

Sound transmission loss values of a representative two seal system is obtained both with and without the frequency dependent viscoelastic material characterization. Results show that considering the frequency dependent effects does not change the transmission loss of the whole system in all frequency bands not more than 10 dB. (Figures 8 a & 9 a) For the low frequency range, frequency dependent effects are negligible. Around resonance and high frequencies, however, the effect is much more visible. (Figures 8 b/c & 9 b/c)

Results suggest that, when considering a real geometry of a door seal system, frequency dependent characters become crucial especially around resonance. This results should be extended for real seal systems with more complex geometry and more complex materials, since the real sealing systems usually consists of elastomer parts with different compositions, hence different mechanical properties. It should be noted that, elastomer mechanical properties strongly depend on the composition of the sample, such that this approach might be applied again for different compositions. Different mechanical behavior of the elastomers might show higher variations in modulus and loss factor characterization.

This work gives a basic insight of viscoelastic material characterization of the elastomer samples using a simple geometry and material. The results obtained here strongly suggest that the viscoelastic material characterization is important. The other essential parameter that effects elastomer behavior temperature is taken as constant in this work. Normally, in outdoor driving conditions, temperature changes might be observed which can affect the seal stiffness significantly. For lower temperatures, elastomer might shift out of its designed operating range and both structural and acoustical results might differ significantly.

References

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