Investigation of vibration transmission properties of compressor grommets in domestic refrigerators

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ABSTRACT

As household appliances become more and more quiet every day, even the smallest contributions to product sound power levels are gaining importance. Vibration transmission through compressor grommets is such a contributor for domestic refrigerators. The vibration that originates from the reciprocating compressor is isolated from the refrigerator body by the rubber-based grommets that are placed between the compressor and the base-plate. However, this isolation is not enough in many cases that the refrigerator body is observed to be vibrating with the same characteristics as the compressor. Also in the acoustic measurements of the refrigerator, some of the frequency contributions in the product noise are seen to be in relation with this vibration. Within this study, the transmission path of this vibration and some parameters in grommet design are investigated in detail. An evaluation methodology for the compressor grommets is developed that allows minimum vibration transmission and hence the least sound power level for the refrigerator.

Keywords: Vibration, Isolation, Noise, Refrigerator, Compressor
I-INCE Classification of Subjects Number(s): 12.4.6 - 46.2 - 43.2

1. INTRODUCTION

Household refrigerators are one of the most commonly used home appliances that are expectedly seen in modern kitchens. Although the expectations of customers vary, it could be said that everybody would want a silent refrigerator in their homes. Especially in small apartments, refrigerator noise can disturb people anywhere in the house.

Several studies are being carried out focusing on refrigerator noise. These studies include design of low-noise fans (1), noise reduction of compressors (2) and investigation of refrigerant popping noise (3). The noise control studies on each individual refrigerator component have now reached a quite advanced level. However, interaction between components and refrigerator body is not such a popular topic in this area. Compressor, which is usually the main source of noise in household refrigerators utilizing vapor compression cycle, is also a major source of vibration. Compressor vibration should be isolated from the refrigerator body in order not to excite large surface-area components and generate noise.

Compressor vibration is investigated by Silveira along with the noise (4). The vibration transferred to the refrigerator through the suspension inside the compressor shell is mentioned as a factor in noise generation and improvement in this transmission path is obtained by a new design. More than 30% reduction in vibration levels is obtained.

In the study by Marshall (5), system interactions are considered while reducing the compressor noise. The structural transmission paths are listed as:

- Energy flow through the mounting feet into the base pan
- Flow along the intake and discharge tubing
- Flow through the electric cables

A long with the main design goal in selecting grommets, which is an isolation frequency well below compressor rotation frequency, two other design criteria are mentioned:

- The preloading on the grommets, caused by the weight of the compressor
- The vibration components in directions other than the vertical direction

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Coil springs are chosen to be the most effective vibration isolators.

Compressor grommets, whose function is to isolate compressor vibrations from the rest of the system, are designed to dissipate energy using the mechanism known as "hysteretic damping" (6). The isolation efficiency is known to increase by increasing crossover frequency, which is defined as the ratio of driving frequency over natural frequency.

Another study which focuses on compressor grommets is carried out by Ki et al (7). The supporting location of the grommets, the supporting plate and the rubber grommet geometry are designed using topology optimization.

In this study, the vibration transmission through the compressor grommets is investigated. The effect of the vibration on the sound power level of a refrigerator is shown and alternative grommets are tested to decrease the amount of transmitted vibration.

2. EXPERIMENTAL WORK

2.1 Phenomena

In household refrigerators, the compressor is usually placed inside a cavity referred to as "machine room", which is situated on the back side of the refrigerator and at the bottom. A base plate, usually made of formed metal holds the compressor. Between the base plate and the compressor, grommets are placed in order to provide vibration isolation (Figure 1).

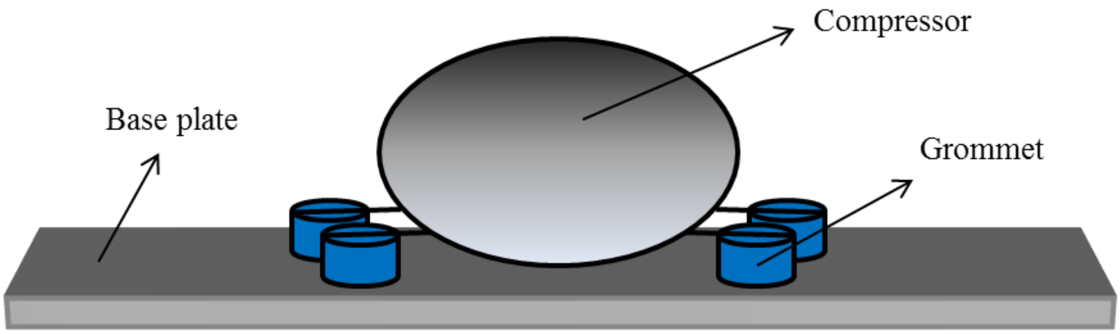

Figure 1 – The placement of compressor upon the base plate

The grommets may transmit some vibration to the base plate when they are not sufficient. The vibration also passes from the base plate to the rest of the refrigerator body and hence excites it. Vibrating refrigerator body causes increased noise levels in related frequencies.

2.2 Preliminary Measuements

Acoustic measurements are conducted on the refrigerator to define the sound power level of the product, and to derive 1/3 octave band spectrum (Figure 2). The sound power level measurement was conducted according to the relevant standards (8, 9) using a microphone array in a semi-anechoic measurement chamber. The chosen refrigerator to be measured is a bottom-freezer type free-standing appliance.

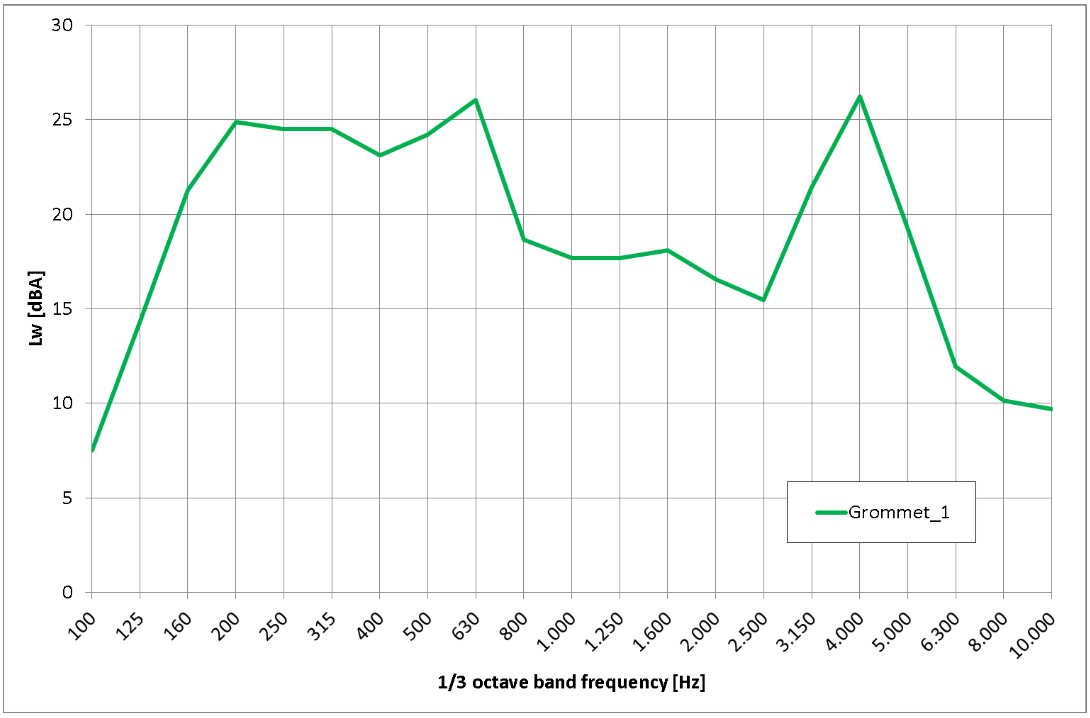

Figure 2 – 1/3 octave band sound power level spectrum of refrigerator with compressor grommet #1

The frequency band components of the acoustical noise can be assessed when the 1/3 octave band spectrum is investigated. A tonal component is detected at 4000 Hz frequency band which has a strong contribution to the total sound power level of product. It can be deducted that a decrease in this frequency band will decrease the total sound power level of the product, and hence should be worked on.

2.3 Experimental Setup

A vibration measurement setup is designed and used in order to determine the vibration caused by the compressor and its effect on the refrigerator body. A bottom-freezer type refrigerator was used in the experimental setup. The compressor is chosen to be a variable speed compressor, so that the vibration isolation properties could be assessed at different compressor speeds. Single axis accelerometers were placed at the compressor foot, which is the part of the compressor just above the grommet, and on the base plate just next to the compressor grommet (Figure 3). Using the vibration measurements from these points, the vibration transmissibility of the grommet is to be determined.

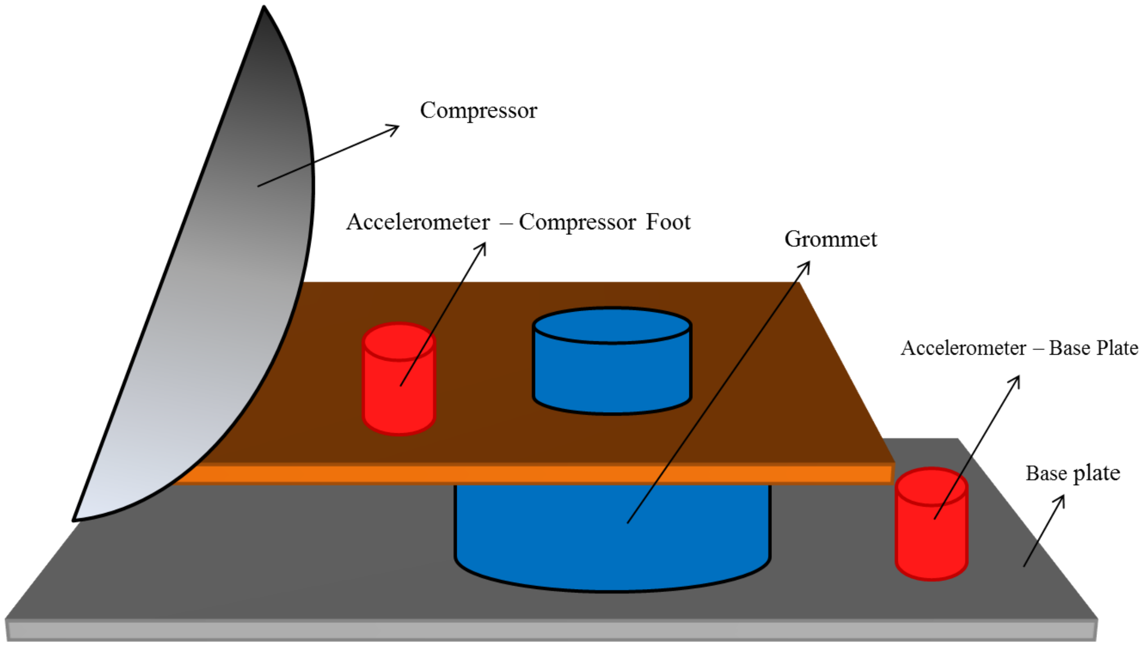

Figure 3 – Accelerometer positions on the experimental setup

As seen in the figure, the grommets act as a vibration isolator between the compressor foot, which can be defined as the input for this case, and the base plate, which can be defined as the output. The amount of vibration transferred from the compressor foot to the base plate gives the undesirable vibration transmission.

Three different grommets belonging to different producers were tested using the experimental setup. All tests were conducted on the same refrigerator and with the same compressor, so the experimental conditions can be said to be equivalent.

2.4 Experimental Results

In order to make the interpretation of the test results easier, "transmission ratio" is defined as a performance indicator. The transmission ratio is the ratio of vibration acceleration measured in the input over the vibration acceleration measured in the output (Eq. 1).

$$TransmissionRatio = \frac{a_{compressorfoot}}{a_{baseplate}} \tag{1}$$

where $a_{compressorfoot}$ is the vibration acceleration amplitude measured at the compressor foot and $a_{baseplate}$ is the vibration acceleration measured at the base plate. The FFT spectra of vibration acceleration measurements were calculated and the amplitudes at each frequency were divided in order to obtain a Transmission Ratio spectrum.

The Transmission Ratio spectra of the three grommets were obtained using the experimental setup (Figure 4). While the geometries of the three grommets are the same, the materials are different. These measurements were made while the compressor was running at 3000 rpm.

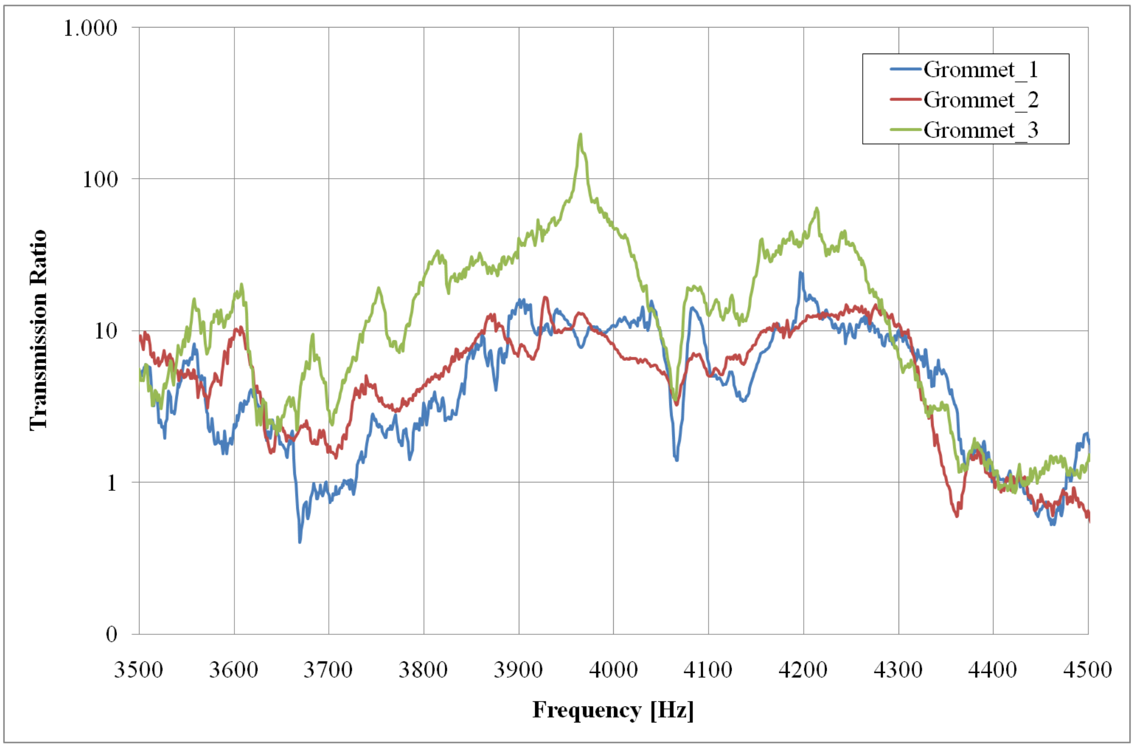

Figure 4 – Transmission ratio spectra obtained by using different grommets

Grommet 3 can be seen to have higher transmission ratio than the other 2 grommets around 4000 Hz. Thus, the vibration isolation properties of grommet 3 are better and should be preferred to be used on the refrigerator to obtain lower noise.

However, among the 3 grommets provided from different manufacturers, the material cost of grommet 3 is the highest. In order to examine an opportunity of cost reduction on grommet 3, a modified version was prototyped. The modified grommet 3 is lower in height, and weighs much less. Less material usage would make it possible to manufacture a cheaper version of grommet 3, so the Transmission Ratio of the modified grommet 3 (Grommet 3m) was tested (Figure 5).

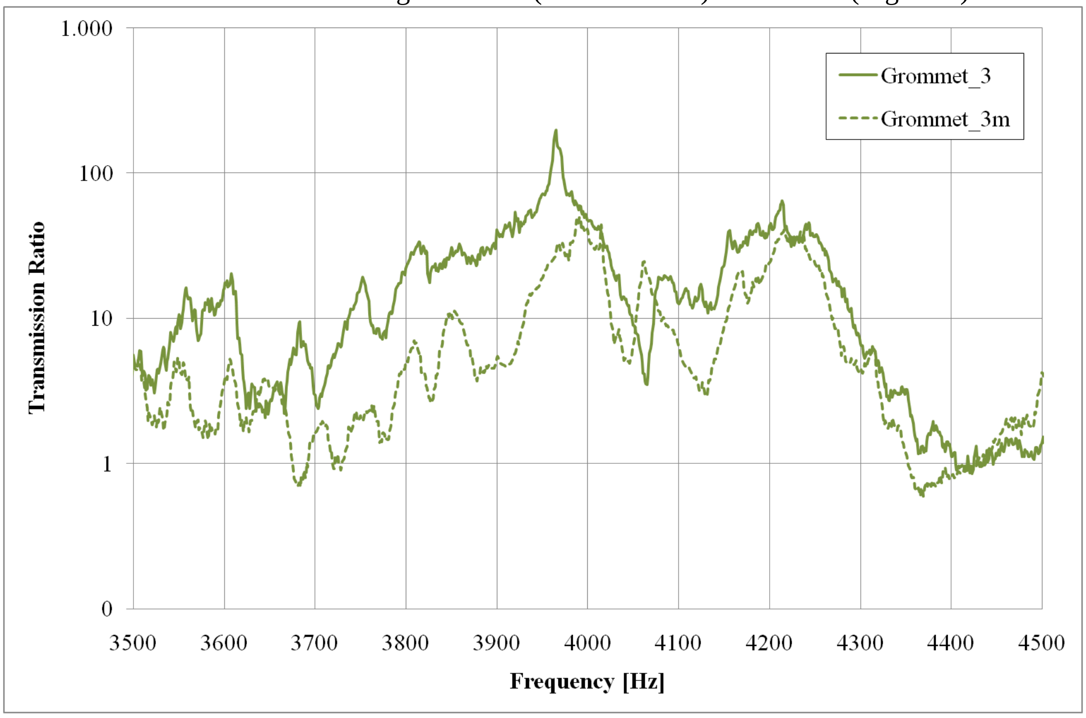

Figure 5 – Transmission ratio obtained by using modified version of grommet #3

Looking at the Transmission Ratio spectrum of grommet 3m, it is seen that its vibration isolation capability is less than grommet 3. Hence, the original version of grommet 3 should be preferred if the major concern is to reduce vibration transmission at 4000 Hz.

Another concern about grommet 3 was that if the same vibration isolation properties could be obtained at lower rotational speeds of the compressor. An experiment was conducted while the compressor was running on 2000 rpm, and the transmission ratio spectrum of grommet 3 was calculated (Figure 6).

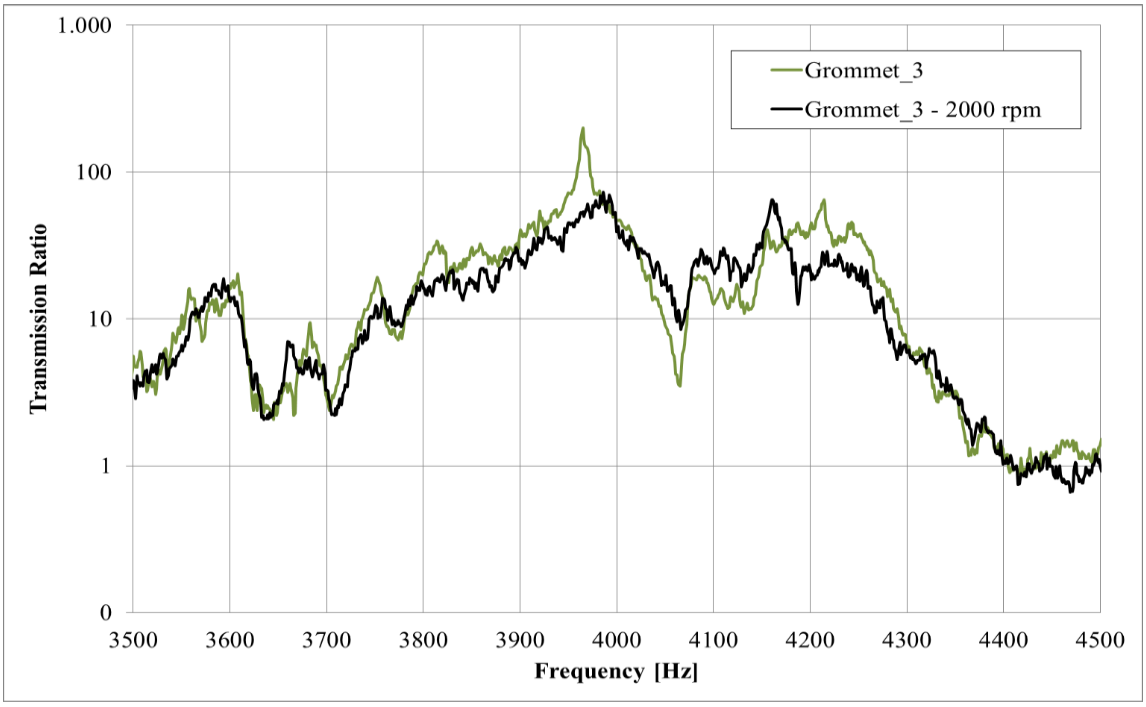

Figure 6 – Transmission ratio obtained by using modified grommet #3 at different compressor rotational speeds

Comparing the transmission ratio at compressor rotational speed of 2000 rpm to the transmission ratio at 3000 rpm, the same properties could not be observed. The best vibration transmission properties are obtained in 3000 rpm compressor running speed with the original version of grommet 3.

2.5 Validation Measurements

Acoustic measurements were conducted again on the refrigerator, so as to prove that a grommet with better vibration isolation properties can not only improve the amount of transmitted vibration but also reduce the sound power level of the refrigerator. 1/3 octave band spectra of the refrigerator with the original grommets (grommet 1) and the refrigerator with grommet 3 are compared (Figure 7).

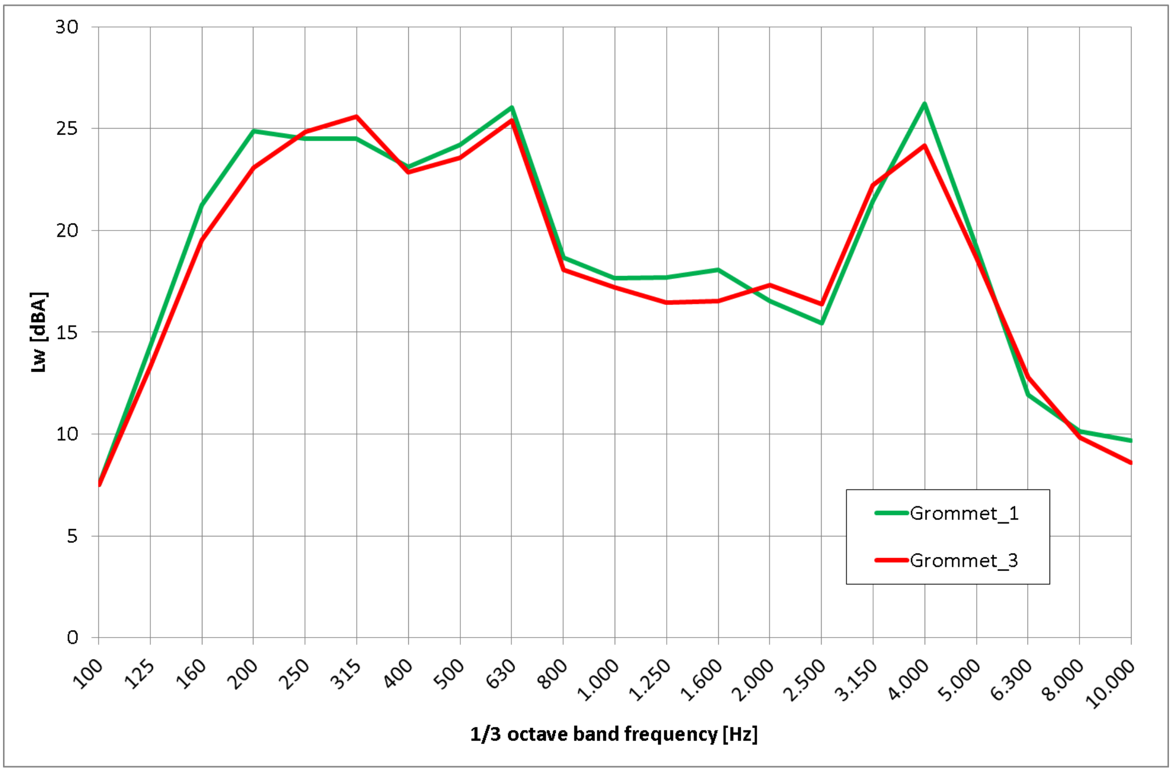

Figure 7 – 1/3 octave band sound power level spectra showing reduction on refrigerator noise

When sound power levels at 4000 Hz frequency band are compared, a 2 dBA decrease is seen to be obtained by using grommet 3 on the same refrigerator. Thus, it can be said that an improvement in vibration isolation provided by the grommets can lead to reduction in refrigerator noise.

3. CONCLUSIONS

A methodology of testing vibration isolation efficiency was developed and 3 different compressor grommets were tested in the experimental setup. The grommet showing the best vibration isolation effectiveness is replaced with the original grommets on a reference refrigerator and a decrease in sound power level is observed in the related frequency. The opportunity of reducing domestic refrigerator noise by choosing better vibration isolating grommets is shown in this study.

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