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INTERIOR NOISE REDUCTION APPROACH FOR MONORAILSYSTEM

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ABSTRACT

This paper presents an overview on the possibilities of interior noise reduction for monorail system. It was found that the current existing noise level could further be mitigated by using passive means. Thus, nine samples out of three materials were subjected for noise test and the performance of each sample was observed. It was found that all of these samples have proved to reduce a significant amount of noise at low and high frequencies, even though the amount reduced, varies from one sample to another. It is also been noticed that this reductions were dominated by means of absorption for some samples such as those from rubber material, and it was dominated by means of reflection for some others such as those from aluminum composite and paper composite. Moreover, from the acoustic properties of each material, the whereabouts to install every material is proposed. Hence, it was suggested that, the rubber material should be installed on the upper floor of the monorail, while the paper composite should be installed under the floor, and the aluminum composite should be installed at the outer parts from the monorail such as the apron door, ceiling, etc. However, despite the promising potentials of these materials to reduce noise, there were few uncertainties with some samples at certain frequency. For example, samples from aluminum composite could not reduce noise at 1250 Hz, which denotes that it is not a good practice to use this material at that frequency. In terms of ranking, samples from rubber material reduced the largest amount followed by paper composite samples, and aluminum composite samples held the least position with an average of 26.46%, 24.69% and 16.05% respectively as for the third sample in every material.

Keywords: noise reduction, low frequency noise, absorption, reflection, rail transport.

INTRODUCTION

Rail transport perceived as one of the most efficient and environmental friendly means of transport. That is due to its potential of being safer, comfortable, environmental friendly and energy efficient form of transport. These promising characteristics have triggered stakeholders in many parts the world to rely on railways for passenger and freight transport. Despite these aforementioned potentials, noise pollution from railways is significant, for both the passengers as well as the nearby surrounding environment, as several investigations have identified noise and vibration as key factors to high comfort (Fan *et al*., 2009). Thus, railway operators and manufactures are more concerned today to optimize the railway system by increasing the quality and the ride comfort of the passengers in order to keep up their competitiveness within the transport market as well as to satisfy the authority's environmental requirement to limit the noise generated by the railways to the environment (Danneskiold-Samsoe and Thane, 1996). One way to achieve that is by mitigating the internal noise and vibration of the train (Botto, Sousa, and Costa, 2004) mentioned.

ACOUSTIC NOISE IN RAILWAYS

A proper way to solve the noise in railway trains might arise from identifying the sources that excite such noise. Such sources may differ from one system to another within the railway systems. For example, the main sources of noise in a normal train are not the same as in a monorail or in a tram. Consequently, acoustic noise in railways generally divided into two main sources, namely internal sources and external sources. The former is produced by the ventilation or air-conditioning systems. While the latter is generated by the wheel-rail interaction, the propulsion or hydraulic systems, breaks, compressor and aerodynamics (Botto, Sousa, and Costa, 2004). Thus, the wheel-rail interaction or rolling noise in general happened to be one of the main sources of noise in the normal trains (Thompson, and Jones, 2000). Whereas the gearbox and the propulsion system are the main sources of noise in monorail systems.

The variation of the noise sources may be due to the fact that, unlike the normal train the monorail does not run on a rail track but rather on an elevated beam which uses rubber tire to roll on the concrete beam in which have less noise due to this tire-beam interaction. Thus, the source is mainly coming from the gearbox and the propulsion system. However, the mechanism of the acoustic noises to reach the coach interior for almost all railway systems is through two paths. The air-borne path and the structure-borne path (Botto, Sousa, and Costa, 2004). Therefore, several studies have adopted active and massive methods to tackle such noise.

On the other hand, (Fan *et al*., 2009) further classified the noise sources as low frequency noise and high frequency noise sources. They revealed that, the propulsion and brakes systems were identified as the main noise sources responsible for the low frequency noise, while the high frequency noise is due to the wheel-rail interaction (Thompson, and Jones, 2000). The same trend was found in the monorail interior noise, which is a low

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frequency noise and the propulsion system is the found to be the main source besides the gearbox.

Several studies (Singh, Sheikh, Mitchell, 1998), (Jones and Thompson, 2000), (Fan *et al*., 2009) have adopted viscoelastic materials to mitigate the noise level in railway systems. (Fan *et al*., 2009) used passive technique using three damping materials, and the results have proved the ability of such materials to reduce a significant amount of noise.

This study was aimed to mitigate the interior noise level on a monorail system, by using passive method, which involve low frequency potential materials that possess acoustics properties such as absorption and reflection. Such characteristics would help to insulate the interior surfaces of the monorail coach, which may have a considerable noise reduction on the internal noise of the monorail coach, and eventually improve passenger comfort to a satisfactory level.

METHODOLOGY

Nowadays monorail internal noise is receiving much attention by the manufacturers as well as the operators in order to satisfy customer needs and to maintain the environmental friendly aspect of rail transport. However, a concise and comprehensive methodology will only come from a good understanding of the research scopes and the boundaries of the research. Thus, this section elaborates the method been adopted throughout this study. In order to obtain an optimal solution for the noise existing on the monorail, these two questions must to be answered clearly:

i. Where does this noise mainly come from?
ii. How could it be mitigated to a satisfactory level?

There are various sources may contribute to the overall noise level. However, this study found that, the interior noise on the monorail is mainly coming from the gearbox and the propulsion system, and the point of entry could be via the body arch. Thus, after identifying the main source, a passive method using viscoelastic material as in (Fan *et al.*, 2009) and two other materials (paper & aluminum composites) was adopted to mitigate such noise.

The details of the experimental samples

In this study, there are three different materials selected for noise reduction. Namely, viscoelastic rubber, aluminum composite and paper composite. The selection of these materials was based on either being high noise absorptive, reflective and/or good insulating material. Moreover, light weight property of the material also has been given consideration.

Furthermore, each material comprises of three samples. The difference between the samples is in their thicknesses. They are 3, 6 and 9 mm thick from each material, which make them nine samples in total, excluding the acrylic box as shown in Table 1.The acrylic box is a custom-made square box with the dimension of 150 mm.It was used to test the noise level before putting any material on it. Initial results from this box are obtained and then compared with the other results from the nine samples. Note that the box does not represent the monorail, but it is the way used to observe the difference for each material including the material that used to build the monorail itself.

Moreover, every sample has undergone several noises testing at different frequency ranging from very low to high frequency (250 - 6300Hz) at 70dB, using a typical sound level meter (SLM). This 70 dB noise was produced using the dB Generator software, with the help of two amplifiers. The results obtained from each sample were compared with that from the acrylic box. Also note that, the experiment was conducted in a fully insulated anechoic chamber (Figure-1), in order to prevent the interference of the surrounding noise.

Furthermore, the acoustic properties of every material were also been tested using the impedance tube kit, in order to observe their acoustic performance, so that an insight on where to install every material on the monorail is obtained.

Table-1. Details of the experimental samples.

No.	Sample name	Material	Thickness [mm]
1	R3	Rubber	3
2	R6	Rubber	6
3	R9	Rubber	9
4	AC3	Aluminum composite	3
5	AC6	Aluminum composite	6
6	AC9	Aluminum composite	9
7	PC3	Paper composite	3
8	PC6	Paper composite	6
9	PC9	Paper composite	9
10	Empty box	Acrylic box	0

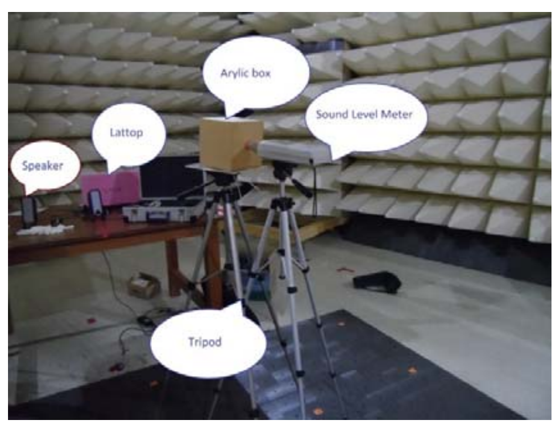

Figure-1. Experimental setup.

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RESULTS AND DISCUSSIONS

Empty box (without any material)

The empty box without being covered by any material was tested at different frequency level ranging from 250-6300Hz. The noise level was set at 70dB. The results obtained from this empty box are used as the initial starting point in this experiment. Then, this result was compared with other samples' results after covering the empty box with the potential samples.

However, it is apparent that the noise level at frequency 400 Hz is the highest, while the noise level at frequency of 1000 Hz is the lowest as seen in Figure-2.

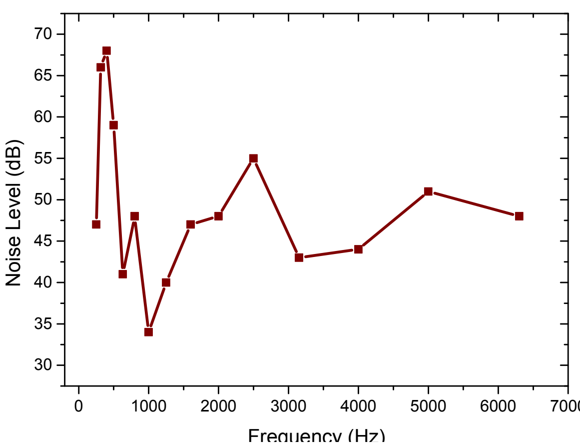

Figure-2. Noise level against the frequency for the empty box.

Comparison between R3, R6 and R9

This section presents the results of the three samples from rubber material; R3, R6 and R9 and show how much each sample from this material could reduce noise. Figure-3 shows the results of the samples R3, R6, R9 and the empty box as a function of frequency, for comparison purpose. These results proved that, all samples were able to reduce a considerable amount of noise at low and high frequencies. However, R9 could be considered as the best sample in frequencies of 1000 and below, because it reduced the highest amount. While R6 is the best option for frequency above 1000 Hz, and R3 come in the third place after R6 and R9, as illustrated in Figure-3. Consequently, this denotes that R9 could perform best at low frequency noise, while R6 for high frequency.

It is also worth to mention that, although there is a difference between R6 and R9 at low frequency, but it was not that much, therefore R6 could be considered as the optimum in overall from economical point of view. However, in terms of ranking, R9 came at the first position, while R6 held the second position and R3 came at the last position with an average of 26.46%, 25.04% and 17.83% respectively.

Based on the acoustic properties and performance of each material, a few locations to install each material was recommend. It suggested that, the rubber material should be installed at the floor of the Monorail, due to its ability to absorb a significant amount of noise at low and high frequencies in which can reach up to 26.46 % on average for certain samples, and this may increase if an air gap was used during installation. Besides, the floor is hot due to the heat coming from the motor and the propulsion system and this rubber happened to withstand a high level of temperature, which could be up to 110°C.

Furthermore, it is also recommended that the suitable thickness to be installed on the monorail is 6 mm which is R6, because it showed a wonderful performance in this thickness and it is more economical, since the difference between this sample and sample R9 is less than 2 dB, it is not economical to use a 9 mm thickness sample.

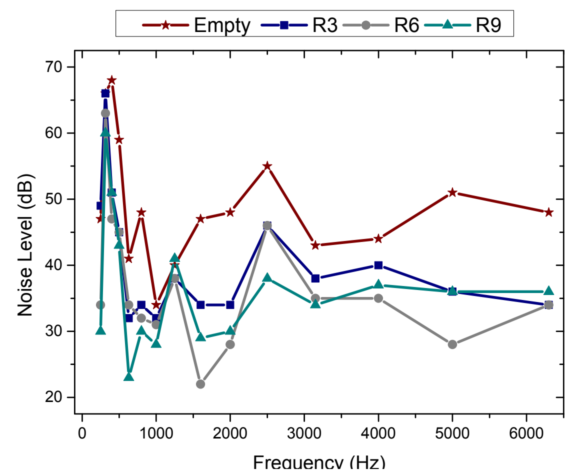

Figure-3. Noise level against frequency for R3, R6 and R9.

Comparison between AC3, AC6 and AC9

Figure-4 shows the comparison for aluminum composite samples. However, the performance of these three samples has extended to cover almost all frequency range (low and high frequencies). Comparing the three samples, AC9 has showed better performance among the three samples in individual frequencies, followed by AC6. AC3 come at the last position, which make it the least preferable. That is due to the thickness. As it is well known the relation between the thickness and noise, reduction is directly proportional which means that the thicker the sample the more noise could be reduced.

It was also observed that, these samples have something in common; they could not reduce noise at 1250 Hz. This suggests that, this material cannot reduce noise in such frequency. However, compare to other samples from the same material, AC9 show better performance in individual frequencies, while AC6 showed a bit higher results on average.

Moreover, the relation between the frequency and the noise level obtained or reduced is not proportional or linear. Which means that, the increase in the frequency will not necessarily means higher amount of noise could be reduced. However, each frequency has its own characteristics, which make it independent from the others. It is also worth to mention that, the noise reduction

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obtained from these samples is mostly by refection properties of this material.

Furthermore, there are few locations could be suggested for this aluminum composite panel. However, the best locations to install this material may include, building the car body structure with it instead of using pure aluminum, or installing it at the outer parts of the monorail car body, including the roof or the awning, apron door etc. It is intended for this location because of its ability to reflect a substantial amount of noise at low and high frequencies, thus this location suits it more compare to the other locations.

Other than that, this material is coated with Polyvinylidene fluoride, or polyvinylidene difluoride (PVDF) which has the advantage of excellent weather-resistance, anti-corrosion and anti-pollution. Therefore, installing it at the outer parts of the Monorail will be of great advantage. However, the suitable thickness for installation is 9 mm thick, which is AC9, as it is shown significant noise reduction which reached up to 16%.

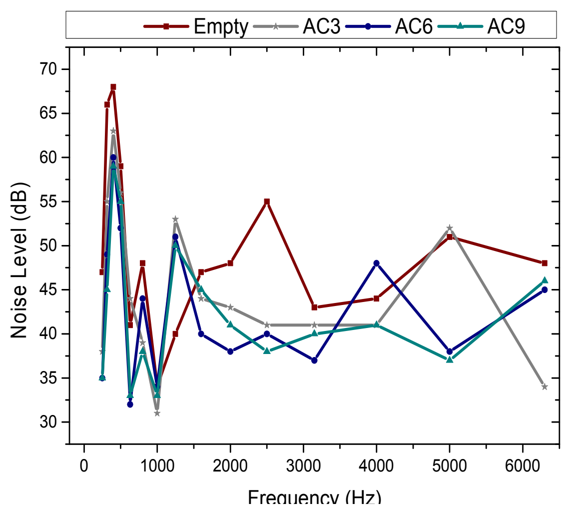

Figure-4. Noise level against frequency for AC3, AC6 and AC9.

Comparison between PC3, PC6 and PC9

In this section, samples from paper composite were compared and analyzed. As shown in Figure-5, all samples were able to reduce a substantial amount of noise at low and high frequency. In terms of ranking, PC9 would come at the first position followed by PC6 and then PC3. That is again due to the thickness, as it was mentioned earlier, noise reduction increases with the increase of the thickness. However, the surprising thing in this material is that, all of the samples (PC3, PC6 and PC9) produced a similar noise level at 1000 Hz, which was exactly the same noise level as the empty box, which means there was no occurrence of noise reduction at that frequency. The other common thing has been noticed with these samples is that; the highest noise level was occurred at 315 Hz.

In addition, there was another uncertainty in PC3; this sample produced a high noise level with respect to the empty box at 315 Hz, which denotes that, PC3 could not be used in anyway at that frequency. However, PC9 has the highest amount of noise reduced compared to the rest, which make it the best sample among the other two. It is also worth to mention that, these reductions were dominantly by means of reflection. In terms of ranking, PC9 came at the first position; PC6 held the second position and PC3 was at the last position with an average of 24.69%, 17.35% and 16.85% of noise reduction respectively.

In the case of paper composite, the suitable location to install it will be under the floor of the monorail. That is because it contains high temperature resistant mineral fiber and excellent heat resistant performance besides having very good reflective properties at low and high frequencies. In fact, its short duration maximum temperature can reach up to 180°C. However, the preferable thickness for this material to be installed on the monorail is 9 mm as well, which is PC9, since it reduced about 25% on average.

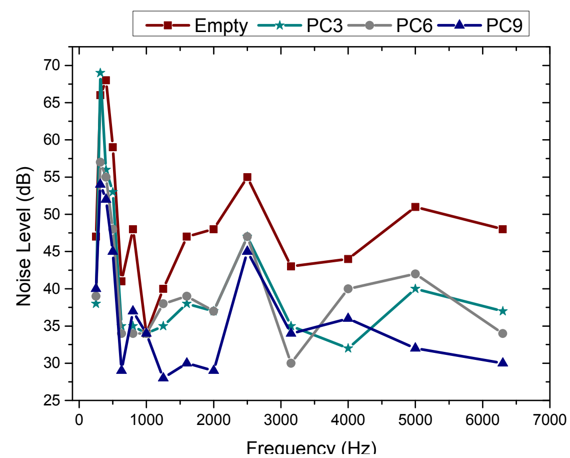

Figure-5. Noise level against frequency for PC3, PC6 and PC9.

CONCLUSIONS

This study proved that all samples were able to reduce a quite significant amount of noise at low and high frequencies. However, the amount reduced differs from sample to another, some of them showed better performance at low frequency while others at high frequency, and there were some others have shown good performance at both frequencies (low and high). Moreover, this reduction was by means of absorption for some samples, such as those from rubber material, and it was by reflection for some others, such as those from aluminum composite as well as paper composite materials. It was also realized that, softer materials tends to have absorptive properties, while hard materials possess more likely reflective properties.

The common thing been noticed with all the samples is that, the third sample in each material showed better results than the rest. That is due to the thickness, as it is well known, noise reduces with thickness. The thicker is the sample the more noise could be reduced. In addition, it was also observed that, samples from rubber material always tend to reduce larger amount of noise compared to its counterpart from aluminum and paper composites with the same thickness and that makes them the optimum in every thickness, followed by samples from paper composite and then aluminum composite samples come at the last position.

Other than that, based on the properties of each material and from the performance of each sample, the installation location of each material with appropriate thickness was recommended. Thus, the capability of these materials to reduce the interior noise of the monorail was proved.

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