Investigation of Vibration Damping in the Passenger Seat Constructions

Lütfiye DAHİL[1]
Abdurrahman KARABULUT[2]
Osman Nuri UÇAN[3]

Abstract
Under the lights of scientific studies, it is known that the vibration has significant effects on living creatures and non-living things. Human body faces with many different vibrations daily. The aim of this study is to provide comfortable and healthy travel by decreasing the vibration coming from the chassis of the intercity buses and to protect the feet of the passengers from vibration-based threats by producing the amortization in footboards of the seats in harmony with developing technology. In existing vehicles, the leg constructions of the seats are in rigid structure. For this purpose, the experimental modal analysis has been carried out by utilizing impact test method. These measurements were firstly taken as a whole once the legs were mounted on the seat. Then the measurements were carried out only on the legs. As a result of experimental modal analysis, for both of the legs, the FRF (Frequency Response Function) graphics in X, Y and Z directions and the damping rates were obtained. By comparing these graphics and damping rates for both of the legs, the result was obtained. As a result of the experimental studies, it has been observed that the casting legs have decreased the vibration on passenger by damping it more than original legs do.

Keywords: *vibration, modal analysis, damping, car seat*

1. Introduction

It is known that the vehicles are exposed to vibration because of roughness of the roads and design of the chassis together with engine components. As a result of these negativities affecting the vibration, significant damages occur in human body and mental health. The vibration isolation is of great importance for the vehicles. Depending on the material used in vehicle and seat design, the vibration forces reach at the passengers. Despite of the utilization of on-vehicle damping systems in order to decrease these forces, the amount of vibration cannot be decreased to desired levels. A study on vibration and movement has been carried out. In that study, the vibration has been classified as whole-body vibration and hand-arm vibration [1]. A detailed study emphasizing the effects of certain model parameters related to vibration response characteristics of the seat-dummy system has been carried out, and that study has been carried out on model parameters ranging within natural frequencies, mode types in frequency response ranges, and resonance

[1] *Istanbul Aydın University, Mühendislik Fakültesi, Makine Mühendisliği, lutfiyedahil@aydin.edu.tr*
[2] *Afyon Kocatepe University, Teknoloji Fakültesi, Makine Mühendisliği, akarabulut@aku.edu.tr*
[3] *Istanbul Aydın University, Mühendislik Fakültesi, Makine Mühendisliği, uosman@aydin.edu.tr*

locations [2]. From the aspect of ergonomics, the factors affecting the driver of the vehicle (truck, tractor, car, and etc.) are noise, dust, exhaust gas, temperature (coldness or heat), allocation of control organs, and in-vehicle vibrations, respectively. The most important one among them is observed to be the in-vehicle vibrations [3].

Via many studies, it has been determined that the reason of the spinal defects is the vibrations transmitted from the vehicle to the driver. For example; in a clinic study on a driver spending more than his working hours on driving vehicle, it has been revealed that he complained about back pains more than other pains [4, 5, 6]. The medical and biological effect of the vibration depends mostly on the amplitude and the duration of exposure. The frequency of the vibration having significant effect on human body is between 1 Hz and 100 Hz [7]. Vibration leads to increase in deformation of some tissues in body, increase in respiration rate, higher energy consumption, increase in oxygen consumption, higher heart rates, increase in blood pressure, decrease in performance, and it also affects the central nervous system. When exposed to low-frequency vibrations, people feel concussion. But, on the other hand, they feel tingling and even burning when exposed to high-frequency vibrations [8].

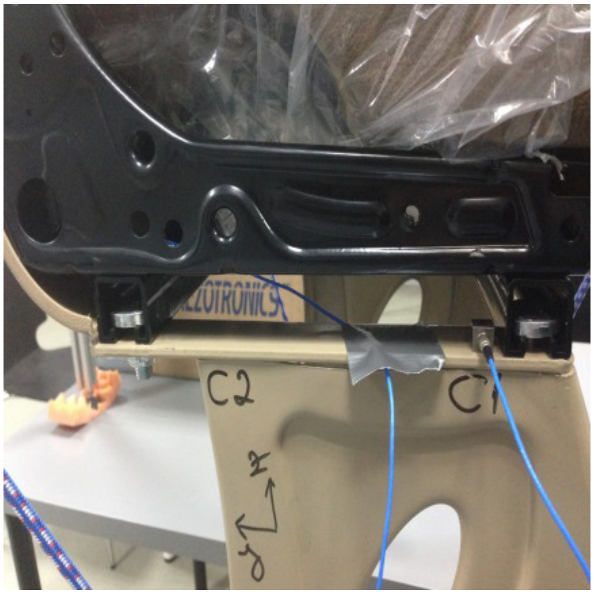
The isolation systems of the tractor seats were examined, and it has been concluded that the damped natural frequencies of the seats were high, that the damping rates were not adequate, and that it is required to eliminate the dry fiction occurring between the plaque of the driver seat connected to tractor and the mobile part during vertical movement [9]. The damping coefficient in porous material depends on the pores. The more the number of pores is, the more damping there is [10]. The aim of this study is to ensure the comfortable and healthy journeys of passengers. In order to do it, the seat legs made of porous material have been manufactured via vacuum method. These legs have improved the damping, and decreased the vibration reaching to the feet of passengers.

Since this material will act as a damping element because of its properties, it will filtrate some of the forces coming to the material gap. It would protect the passenger from the vibration in this way.

2. Material and Method

The measurements were executed via FRF measurements at the junction points of the legs with floor and the connection points of the legs with seat structure. In order to obtain the FRF, utilization of “Impact Test” method was found to be appropriate. In Impact Test method, the input (stimulation) is applied on the structure via the impact hammer, and the response is measure via accelerometer. The FRF obtained in this way indicates to what extend the input will transform into vibration within the structure. Almost every peak in FRF graphics corresponds to the resonance frequency (natural frequency). By comparing the obtained FRF, the information about the dynamic behaviors between the leg types was obtained. Since the stimulation effects to come to the seat will occur at the point of connection of the seat with floor, these points were selected to be the points where the stimulation will be implemented during measurement. The points where the vibrations coming from the floor will be transmitted directly to the passenger (connection points between the legs and seat structure) were determined to be the response points. The free-free conditions were ensures as well as possible before the tests.

The data was gathered from the seat via 2 accelerometers having 3 axes. The stimulation is provided from the bolt holes where the legs are mounted on the floor.



***a)** response points*

***b)** shot points with a hammer*

***Figure 1.** The stimulation and acceleration measurement points on the legs*

The points where the accelerometers are connected to and the locations of stimulation points are demonstrated in Figure 1. “C” points are the points where the accelerometers are connected, and the “T” points are the points where the stimulation is applied. In modal test, more than 2 points must be measured. The accelerometers were connected to the mentioned points tightly via adhesives. The Cartesian coordinates were established.

3. Discussion and Results

The changes in stimulation and response points lead to changes in frequencies and amplitude values in FRF graphics. From the change in amplitude values, it is seen that the actual mode frequency overstrains the part.The force has been applied on points remarked with T for each foot, and then the acceleration has been measured at the points remarked with C corresponding to that force.

In order to obtain a FRF graphic, 5 hammer impacts have been applied on each of stimulation points, and the mean of these 5 FRF graphics were taken.

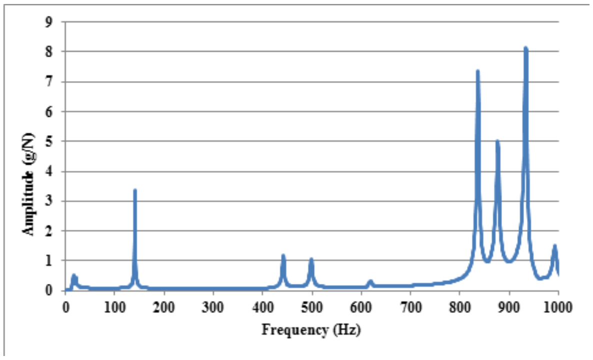


***Figure 2.** FRF graphic of seat-original leg in 0-1000 Hz range*

In Figure 2, the resonance frequencies of the original leg are presented. The leg resonated for 9 times in 0-1000 Hz frequency range. It has no effect on seat damping in high frequencies. In Table 1, the damping points of each of the resonance frequencies are presented. The damping rate of each of the mods is different.

Table 1. *Original leg mode frequencies and damping rates*

Mode	Mode Frequency [Hz]	Damping Rate
1	139.755 ±0.0102	0.25 ±0.006
2	440.508 ±0.0158	0.34 ±0.003
3	497.374 ±0.0149	0.35 ±0.003
4	617.276 ±0.0106	0.57 ±0.002
5	835.665 ±0.0196	0.20 ±0.002

The damping rate in Mode 1 is shown to be 0.25. While the first mode ends the movement of the object, the damping rate of 0.25 tries to stop the movement of the object. Different damping rates were determined for each of resonance frequency values.

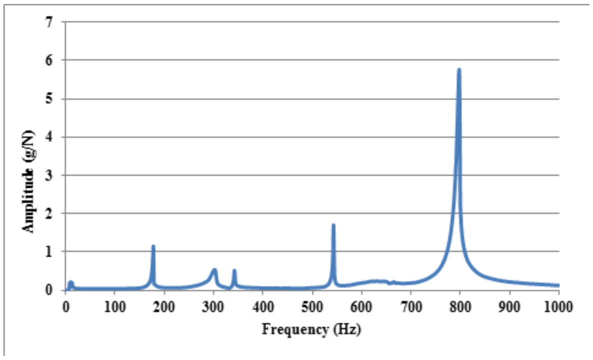


Figure 3. *FRF graphic of seat-casting leg in 0-1000 Hz range*

The casting legs manufactured from aluminum material via vacuum casting method show dynamic properties different from others. In Figure 3, the FRF graphic of casting leg is presented. It resonates at 175 Hz, 299 Hz, 340 Hz, 540 Hz and 795 Hz. The resonance-mode frequencies are at the peak points of the graphic. First mode is seen at 175 Hz. The first peak couldn't be evaluated to be a resonance since it is very close to zero. The peak at the frequency values close to zero occurs in dynamic of the part. The first peak is not seen when mounted. The damping rates of resonance-mode frequencies of casting leg are presented in Table 2.

Table 2. *Casting leg mode frequencies and damping rates*

Mode	Mode Frequency [Hz]	Damping Rate
1	175.301 ±0.0337	0.68 ±0.018
2	299.684 ±0.0630	1.10 ±0.019
3	340.677 ±0.0944	0.30 ±0.027
4	540.774 ±0.0536	0.30 ±0.009
5	795.436 ±0.0253	0.42 ±0.003

Considering the damping rates, it is seen that the damping in first 2 modes is much better than that in marginal leg. While there are very close values in third mode, the original leg's damping is better in fourth mode, and casting leg show better damping property in fifth mode. Particularly the natural frequencies of the casting leg are lower than natural frequencies of original leg.

It will be tried to control the vibration damping in most important direction throughout the shifting of the seat, "z" direction, and the shift of the seat. The most effective amplitude of the vibration disturbing people in vehicles occurs in vertical direction. Despite that, there is a certain amount of shifting in "x" and "y" axes. These values are utilized in general design of the cars. The separate examinations were executed for each of 3 axes. Since the frequency range, in which the human body feels discomfort, is up to 100 Hz, the examinations were executed in 0-100 Hz range. Since the legs' dynamic behaviors show difference in FRF graphics, the examinations were executed within certain frequency ranges.

20-45 Hz range 1st Band
45-100 Hz range 2nd Band

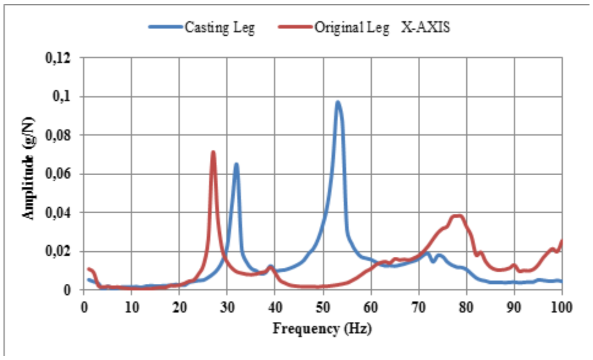


Figure 4. *FRF graphic in direction of x-axis in 0-100 range*

It is seen in Figure 4 that it has postponed the 1st mode of original leg to higher frequencies, that it has increased the damping rates for 1st mode, and that it has led to improvement from this aspect. It has also been observed that it hasn't led to any improvement useful for 2nd mode of original leg, that it has made damping worse, and that it has postponed the mode to slightly lower frequencies. It has been observed that it provided improvements in second band by increasing the rates of damping in proportion to original leg. It has been seen in original leg that the decreases occurred in modes in high frequencies (45-100 Hz range) and there occurred improvements from this aspect.

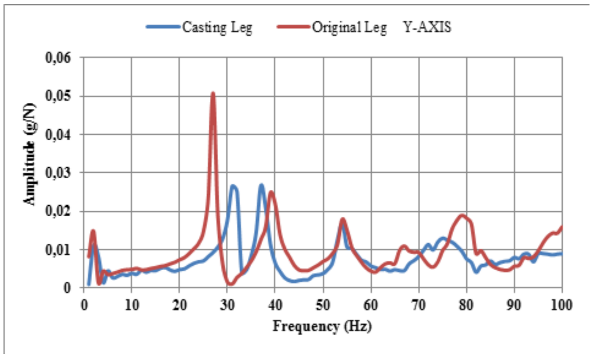


Figure 5. *FRF graphic in direction of y-axis in 0-100 range*

As seen in Figure 5, it has been observed that it postponed the 1st mode in original band to higher frequencies, and that it led to a little increase in damping rates for 1st mode.

Within 45-100 Hz range, it has been seen that it created dominant modes at 74 and 78 Hz in proportion to original leg. In proportion to original leg, the improvements were observed in damping rates, and there occurred the improvements from this aspect.

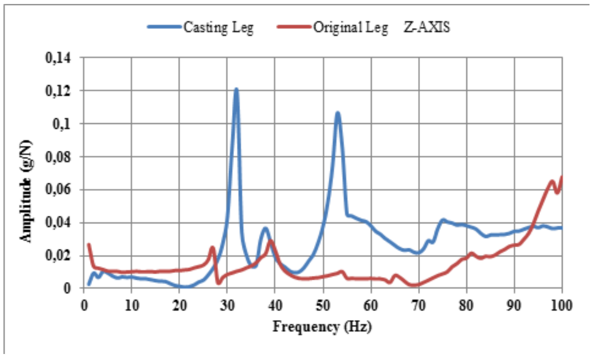


Figure 6. *FRF graphic in direction of z-axis in 0-100 range*

As seen in Figure 6, it has led to an improvement by postponing the 1st mode in the original leg at 1st band to higher frequencies, but it hasn't created any improvement for 2nd mode but made the damping worse. It has been observed that it largely decreased the damping rates within 45-100 Hz range, and it hasn't led to an improvement from this aspect. It has been seen that it decreased the modes which occurred in original leg at high frequencies, and so it has led to improvement from this aspect.

4. Conclusion

As seen in FRF graphics; while the amplitude levels are low in certain frequencies, they reach very high amplitudes (peak points) at certain frequencies. The force implemented at these special frequency points, where the amplitudes peak, transforms more into vibration within the structure. The special frequency values, where the structure exhibit higher reactions against the implemented force, correspond to natural frequencies of the structure. Considering the lower frequencies, it is seen in the graphics that the casting leg would work better, while it is seen that the original leg would work better while considering the higher frequencies. Particularly considering the damping rates obtained, it can be concluded that casting leg showed better damping in first 2 modes in proportion to original leg, and that it would offer more comfortable and healthier journey by decreasing the vibration coming to passenger seat.

REFERENCES

[1] Griffin M. J., Vibration and Motion. Handbook of human factors and ergonomics. A.Willey-Interscience Publication John Willey & Sons Inc., New York, 1997.

[2] Kim S. K., White S.W., Bajaj A.K., Davies P. Simplified models of the vibration of mannequins in car seats. Journal of Sound and Vibration, Vol 264, 2003, p. 49-90.

[3] Hampel G.A., Chang W.R. Body height change from motor vehicle vibration. Industrial Ergonomics, 1997, p. 489-498.

[4] Bovenzi M., Zadini A. Self reported low back symptoms in urban bus drivers exposed to whole body vibration. Spine, Vol. 17, 1992, p. 1048-1059.

[5] Dupuis H., Zerlett G. Whole body vibration and disorders of the spine. International Archives of Occupational and Environmental Health, Vol. 59, 1987, p. 323-336.

[6] Troup J.D.G. Clinical effects of shock and vibration on the spine. Clinical Biomechanics, Vol. 3, 1988, p. 227-231.

[7] www.fmo.org.tr/wp-content/uploads/2012/02/6Titreşim-Mahmut-Candır.pdf [8]https://www.facebook.com/permalink.php?story_fbid=241708382576628&id=241684699245663 (Occupational healt hand safety expert)

[9] Karabulut A. Tractor driver seats research on insulation system. Gazi University. Ph.D. Thesis. 1995, p.34.

[10] Dahil L., Karabulut A., Baspınar M.S. Damping effect of porous materials. AKU- Journal of Science, Vol. 11, 2011, p. 1-7.