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Investigation of Vibration Isolation for Different Types of Engine Mounts

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Abstract

In this study, it is aimed to reduce the vibration transmitted to the chassis by using vibration dampers in the connection between the vehicle engine and chassis. A theoretical and experimental study was examined. The vibration damper is an elastic material. In the structure of this material, spring and damping are combined with the suspension system. In this study, insulation ratios between the two were compared using new and old dampers. As the engine speed changes in the vehicles, the vibration size it produces also changes. This causes severe discomfort to the driver and passengers in the vehicle. It was observed that the vibration magnitude passing from the engine to the chassis decreased by 50%. When the old and new dampers are compared, it is seen that the vibration isolation of old dampers is very weak. Therefore, it was concluded that the appropriate damper should be selected according to the mass and operating conditions of the engine. Also, it was observed that vibration amplitude increases at low engine speeds, and vibration amplitude decreases at high engine speeds. It has been found that the new vibration damper is a better insulating material than the worn damper.

Keywords: Vibration, Motor vibration, Vibration isolation, Vibration damping, Motor chassis connection.

Research Article

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1. Introduction

There are two main reasons for vibrations occurred in vehicles: Vibrations caused by the engine and vibrations caused by the ground. Vibrations caused by road roughness have low frequencies and high amplitudes. Vibrations caused by the engine have high frequencies and low amplitudes respectively. [1] Vibration is one of the most important factors that affect comfort. [2] Vibrations caused by the engine originate from three main different reasons: Firstly, gas pressure forces occur due to the load imbalance of the crankshaft in the engine. Additionally, the effect of inertial forces of parts moving on the crank causes failure to adjust the required amount of weight balance on the crank to prevent these forces. Secondly, another main reason is the effect of the inertia forces created by the piston between the bottom dead center and the top dead center on the engine block via the crankshaft. Lastly, forces originating from fluids, frictions of contacting parts, imbalance of other moving parts, and especially the movement of the cam mechanism cause vibrations as well. [1]

It is known that diesel vehicles create more vibration than gasoline vehicles. [2] The reason for that is internal pressure forces occurred in diesel engines. Transferring vibration less to the chassis and thus making the vehicle more comfortable for the passengers is the focusing point for the automotive community. For this reason, automobile manufacturers have done many studies on engine vibration.

Rubber is an elastic material and its damping ratio is adjustable. That is why the rubber is used as a damping element in vehicles. As a result of its structural feature, rubber is one of the main materials used in engine mounts as a damping element. [3,4] Thanks to the engine mounts, some amount of vibration from the engine is isolated. Thus, the amount of vibration passing from the engine to the chassis is reduced. There are various amounts and types of engine mounts. Engine mount types can be categorized as active and passive types. Almost every automobile manufacturer is working on engine mounts. Different types of mounts and mounts with different damping rates are being produced and used.

Akmal and Bharathiraja have proposed a new engine mount design and they analyzed this design with different materials in terms of vibration and noise. CATIA V5 program is used to design the engine mount and the design is exported to the ANSYS program to carry out the mechanical and vibrational analysis. From the results of the analysis, it is understood that using natural rubber instead of polyurethane resulted in suppression of deformation with the rate of 14% and suppression of displacement with the rate of 26%. [5]

Karagoz and Tuncay designed a system consisting of 4 engine mounts that are installed to an engine. MSC Adams software is used to design and analyze. Modal analysis is performed on the system. The aim is to figure out how and where the engine mounts are located. After the optimization related to the locations of the engine mounts, improvements in the rate of transmissivity, damping, and resonance regions have been achieved. [6]

Herold et al. examined an active engine mount and they proposed a topology that includes disengaging the static forces and eliminates the disadvantages of the active mount. Experiments are carried out for three different set-ups. A serial mount, uncontrolled, and controlled engine mounts are tested as close to operating conditions as possible. The results are shown in Campbell diagrams which show frequency, the rotational speed of the engine, and acceleration of the mounting point in one graph. [7]

Santosh et al. compared three different engine mount types. Engine mounts produced with natural rubber, fluorocarbon, and butyl rubber have experimented with different engine rotational speeds in the time and frequency domain. They compared the vibration isolation characteristics of these mounts in terms of damping and stiffness. [8]

Mohanachari et al. have studied an optimized engine mount to analyze its vibrational and structural characteristics in ANSYS software. Two different materials for the engine mount are examined. Obtained characteristics of the optimized engine mounts with aluminum and structural steel materials are given. [9]

Shangguan and Lu aimed to examine a hydraulic engine mount with experiments and finite element simulation. They considered the viscosity and pressure of the fluid and the effect of the temperature together. This method called fluid-structure interaction finite element analysis (FSI FEA) is used to optimize the model to enhance vibrational isolation characteristics. [10]

Wu and Shangguan investigated Hydraulic Engine mounts in terms of its frequency-dependent dynamic characteristics. Genetic and SQP algorithms are used to optimize the original HEM. The hydraulic engine mount examined in this study is considered as 2-degree of freedom system. Therefore the system has to have two modes and natural frequencies. These natural frequencies are taken into account for the optimization process. Reaction forces, dynamic stiffnesses, and displacements occurred on the body with a rubber mount, original and optimally designed HEM is compared. It is seen that the results after the optimization, vibration, and reaction forces are remarkably suppressed for HEM. [11]

Lee et al. aimed to optimize an engine mount to obtain better acoustic features. The FRF-based substructuring method is used to examine the noise which is one of the most important factors that affect comfort in vehicles. The noise sensitivity formula is derived for an engine mount and used with the FRF-based substructuring method. The aim is to find the optimum design of the engine mount. The graphs which present the interior noise values for the rotational speed of the engine are used in a non-linear optimization method. After optimization, obtained optimum design has its peaks of noise 3 dB lower than the former design, around 1800 rpm which gives the maximum noise peak values. [12]

Fakhari and Ohadi have studied the effectiveness of an active engine mount. In order to understand how effective this engine mount is, two appropriate control algorithms are used with accelerometers to determine the location of the engine mount, and the information of the control input is obtained in this way. For different revolution numbers, these two control algorithms are separately used. Time response of the displacement of the engine and force transmitted to chassis graphs are created for two control algorithms and these are compared with each other. [13]

Using different types of engine mounts, the reduction of the vibration passing from the engine to the chassis is aimed in this study. For this purpose, the vibration movements of the engine and chassis are measured simultaneously. It is concluded that the different types of engine mounts are used and graphed according to the acceleration and amplitude values and the vibration is reduced to a certain extent.

2. Material and Method

2.1 Engine Vibrations and Measurement

Vibration measurement is a topic that is addressed in all industrial applications, especially as part of maintenance work. The significance of vibration comes to the fore in many critical mechanical concepts such as engines, shaft bearings, fans, pumps, and rotating machines. One of these most significant concepts is the engine. Vibration measurement of the engine in this work is performed as a result of various researches. Consequently, a four-channel vibration meter with a suitable measurement range for the vehicle has been provided.

Fig. 1. Experimental Setup for Vibration Measurement of the Engine

The vibration meter can measure velocity, acceleration, and displacement values separately from 4 different points. It also records the measured values in its own Excel table, including the measurement interval in terms of the day, month, year, hour, second, the measurement value, and the unit of the value it has measured. Vibration meter used in this study is also in accordance with ISO norms and quality standards.

2.2 Engine Mounts

The decrease of engine vibration transferred to a chassis has been the focus of the automotive industry with the goal of increasing comfort for the driver and passengers. The hydraulic engine mounting system has been designed to reduce the transmission of engine vibration to the chassis. It is also used to balance static load originated from the engine weight. The nonlinear aspects of the model are improved to validate model response characteristics. These parameters will be modeled as a variable vector and its value will be estimated with a linearized and extended Kalman filter. This approach will help engineers reduce design time by understanding the effects of various parameters within the hydraulic engine mounting. Based on the predicted parameters, it has been verified that the passive model derived from the simulation correctly describes the dynamic behavior of the hydraulic engine mounting system. What is expected from the ideal engine suspension system is to isolate the vibrations caused by engine irregularities and to prevent excessive oscillation of the engine caused by shock drives. Vibrations caused by road roughness have low frequencies and high amplitudes. Also, engine vibrations have relatively higher frequencies and low amplitude vibrations. The engine suspension system should have an adjustable characteristic depending on the frequency. Engine vibrations are caused by the gas pressure changes during combustion and the forces and moments created by the unbalance of the rotating parts. With analytical methods, the forces and moments exciting the engine can be obtained as a function of the crank angle.

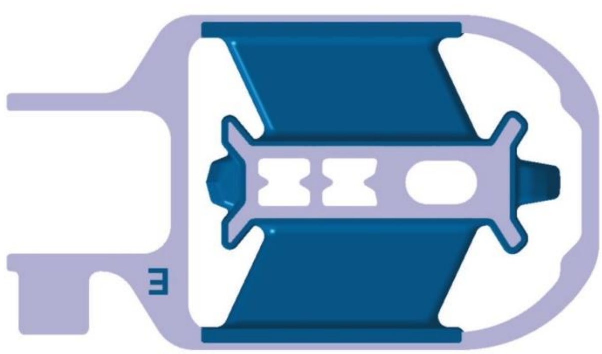

Fig. 2. Schematic view of the rubber mount. Blue parts show rubbers [14]

Conventional rubber mounts do not meet all the requirements expected from the engine mount. However, nowadays rubber mounts are commonly used due to their reasonable attributes such as having a low price, being produced more effortless, being maintenance-free, and being reliable. Semi-active hydraulic mounts have better characteristics as their parameters are easier to adjust. Active hydraulic mounts isolate vibrations by adjusting their stiffness. So they change their stiffness to soft spring stiffness in high frequencies and also they change their stiffness to hard spring stiffness in low frequencies. But active hydraulic mounts have a complex system, so the system is more expensive and less reliable.

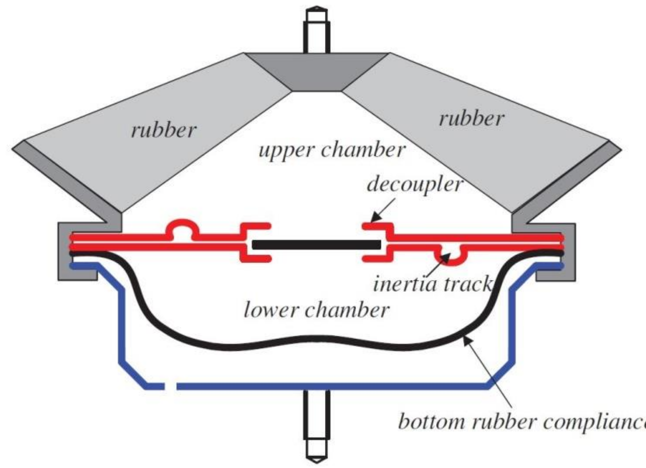

Fig. 3. Schematic view of the hydraulic mount [15]

The dynamic characteristic of an engine mount is one of the most important parameters for the engine suspension system design. There are various techniques for the measurement of dynamical characteristics. Correct placement of engine mounts is important to obtain a balanced engine suspension system. In addition, the loads on the mounts should be optimized to ensure having a long life for the mounts. Creating the mathematical model of the engine suspension system provides an important convenience in the design phase. Optimum design can be obtained by trying various mounts and placements. Computer-aided optimization techniques will facilitate the design of the engine suspension system. [1]

Table 1. Various parameters for different revolution numbers of the engine

	900 rpm	2500 rpm
Mass	127 kg	127 kg
Impact load	1240,87 N	1240,87 N
Damping coefficient	465 N.s/m	465 N.s/m
Acceleration	1,59 rad/s^2	4,37 rad/s^2
Displacement	$6{,}68x10^{-4}$ m	$1{,}08x10^{-4}$ m
Spring stiffness	$1.88x10^{6}$ N/m	$1.17x10^{7}$ N/m

Displacement, acceleration, and spring stiffness values are given in Table 1 for two separate revolution numbers of the engine. The hydraulic mount used in this study is softer and more elastic in low numbers of revolution and this mount becomes stiffer and less elastic in higher numbers of revolution.

In this study, it is intended to choose one of the most used numbers of revolutions in a vehicle. 2500 rpm is one of the numbers of revolutions that the driver and passengers are most exposed to. Also, the engine at the idling speed might affect people considerably while the engine is running but the vehicle is not moving.

3. Results

3.1 Experimental Data

Active parts of the engine are marked to place accelerometers. Also, the accelerometers are placed on the chassis to measure not only the displacement but also the acceleration data when the engine is running. These data are obtained as numerical values. Afterward, these numerical values are converted to the graphs comparatively. Graphs in the following sections show the motions of each point related to each other. Thanks to the engine mounts, the transfer of engine vibrations to the chassis decreased. This research compares the engine mount which belongs to the engine with another engine mount. The aim is to understand and compare how much each vibration absorption is going to be.

3.1.1 Graphics of the Vibration Damper Belongs to the Engine

Design and optimization of the engine mounts is a complicated process that includes a number of parameters. [16] The measurement of the engine mount which belongs to the engine is performed to analyze the vibration absorption effect of revolution numbers which are idle speed and 2500 rpm in this case. The graph of obtained data depending on time is given below.

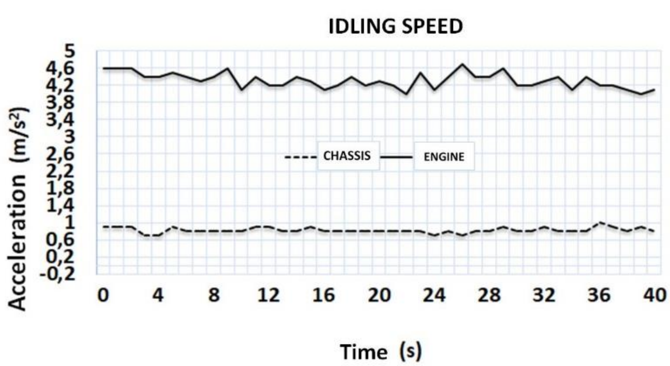

Fig. 4. Acceleration-time graph of the vibration pad used on the engine at idle speed. [17]

The original engine mount which has been used for a long time has acceleration values as shown in Fig 4. It is seen that the acceleration values are about 4.5 mm/s^2. Peek values are not encountered because of the proper acceleration of the engine. At the same time, the chassis has proper acceleration values approximately about the value of 1 mm/s^2. The vibration isolation due to the engine mount ensures fewer acceleration values on the chassis. If the engine was rigidly attached to the chassis, there would be acceleration values in the chassis close to the vibration values of the engine. Although high acceleration values are measured at the idle speed, the driver is not affected by these amounts of acceleration values and it is seen that comfort is maintained.

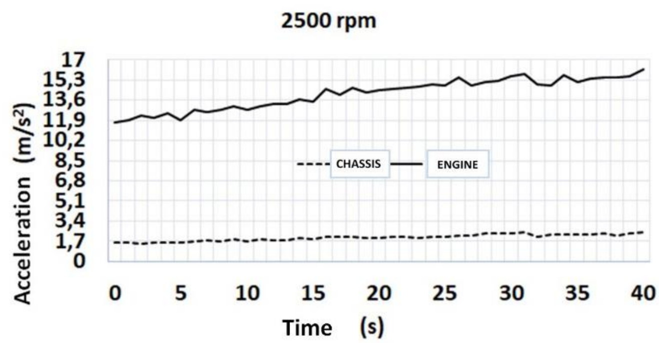

Fig. 5. Acceleration-time graph of the vibration pad used on the engine at 2500 rpm.

The acceleration-time graph of the engine and chassis at 2500 rpm is given in Fig 5. Acceleration values increase when the revolution values increase. Acceleration values in Fig 5 are 2.5 times higher than the acceleration values in Fig 4. That is because the amplitude values at the position where acceleration values occurred are low. So the displacement values are low. Low displacement values cause high acceleration values. In Fig 4, amplitude values are high and acceleration values are low. In Fig 5, amplitude values are high and acceleration values are low.

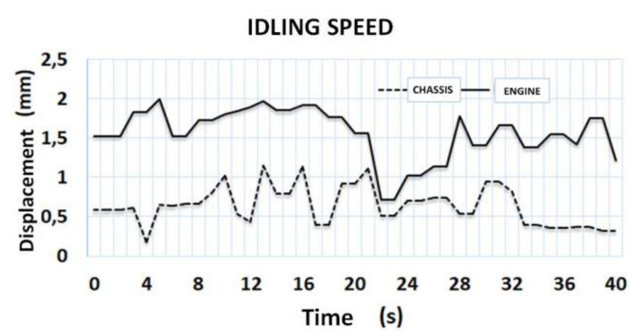

Fig. 6. Displacement-time graph of the vibration pad used on the engine at idle speed.

In Fig 6, the time-dependent displacement graph of the engine and chassis is given. Displacement values of the engine are higher than the displacement values of the chassis, so that, the engine has 3 times higher displacement values. The displacement graph of the engine is not linear. Displacement of the engine is decreased to a minimum value at a specific time interval. This specific displacement value is caused by the internal structure of the engine. On the other hand, the displacement graph of the engine is linear. It is seen that the displacement of the chassis is peaked at some specific time values. It is assumed that the motion of the engine affects the chassis negatively and the frequency values are approximated to the natural frequency value which could cause resonance. From this graph, it is understood that the engine mount used between engine and chassis is weak. This engine mount has been used for a long time, and the vibrational characteristics of the engine mount have weakened.

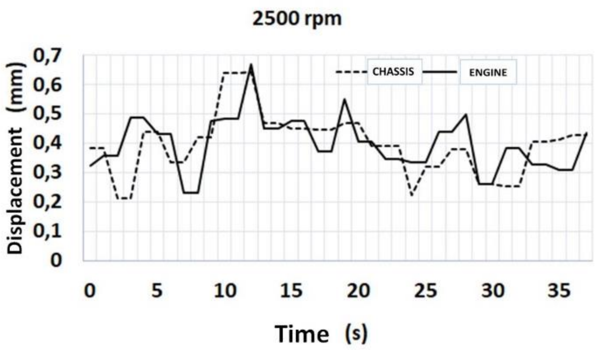

Fig. 7. Displacement-time graph of the vibration pad used on the engine at 2500 rpm

In Fig 7, amplitude values are decreased for a high number of revolutions substantially. The displacement values of the engine and chassis at the high number of revolutions are very low compared to the displacement values at the idling speed. Comfort in the high number of revolutions is slightly better than the comfort in idling speed. The driver inside the vehicle is affected less by vibration. Due to the fact that high acceleration values have little effect on a human, comfort inside the vehicle does not decrease. The human body is affected by low-frequency vibration. High-frequency vibration has not a negative influence on the human body. It is seen that the displacements that occurred at the idling speed are higher than the displacements that occurred at the high number of revolutions. In addition, the displacement differences between these two cases are very little. [17]

3.1.2 Graphics of a New Hydraulic Mount

The engine mount which belongs to the vehicle is replaced by a new hydraulic mount, the same process in the previous section is performed for this engine mount. The obtained numerical values are converted to graphs and these are shown in Figures 8-11.

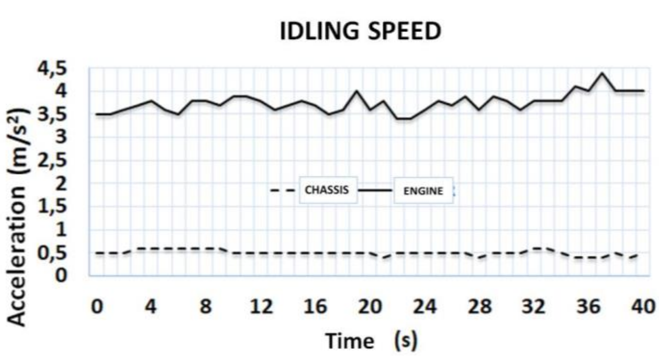

Fig. 8. Acceleration-time graph of the new vibration pad at idle speed.

The acceleration values of the new hydraulic mount at the idling speed are shown in Fig 8. For the idling speed, the new hydraulic mount has lower acceleration values compared to the old one. It is only expected to affect positively the chassis' acceleration, however, not only the acceleration of the chassis but also the acceleration of the engine is decreased. That expression leads to another statement: Adequate engine mount has been chosen and this choice assures better isolation of the vibration. Also, it will be the right decision to change the engine mounts after a certain period of time due to the functionality problems caused wear. Engine mount selection has to be made according to the mass of the engine and also the mass of the vehicle.

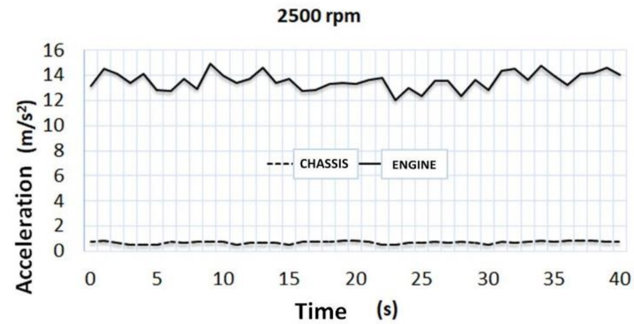

Fig. 9. Acceleration-time graph of the new vibration pad at 2500 rpm.

It is mentioned in previous sections that the performance of the hydraulic mounts is better at the high numbers of revolutions. It can be seen in Fig 9. Though nearly unchanged acceleration values of the engine, acceleration values of the chassis are declined at the high numbers of revolutions. That means the vibration the driver and the passengers are exposed to is decreased. The parts of the vehicle are affected positively so that their lives become longer as a result of the reduction of the vibrations transferred from the engine passing to the chassis. The possibility of loosening or damage to the fasteners and plastic parts of the vehicle is reduced.

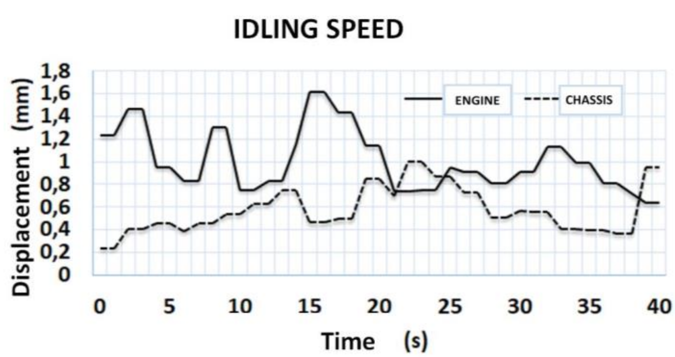

Fig. 10. Displacement-time graph of the new vibration pad at idle speed.

According to Fig 10, the average displacement of the chassis in idling speed is 0,25 mm for the new hydraulic mount, while the average displacement of the chassis is 0,5 mm for the old one. So, it is seen that the new hydraulic mount has differences from the old engine mount in terms of displacement as well as acceleration. Fig 9 also shows that the displacement of the chassis is peaked for some periods of time. These peaks are caused by the running of the engine unsteadily.

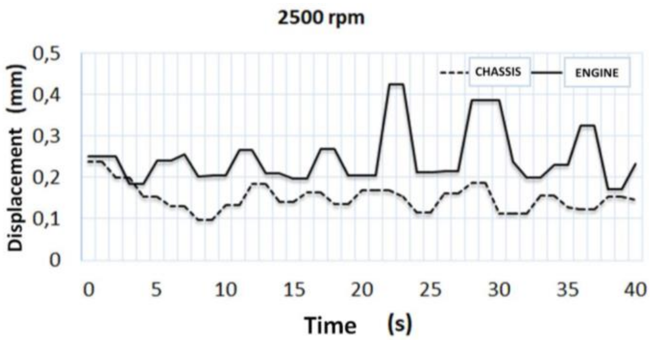

Fig. 11. Displacement-time graph of the new vibration pad at 2500 cycles. [17]

Fig 11 shows that the average displacement at 2500 rpm is 0,25 mm for the new hydraulic mount, The average displacement of the chassis is slightly lower than this displacement value. It is also noticed that amplitude is declined compared to the old engine mount. It could be considered that the declination of the amplitude values, while the acceleration values are being increased, leads to eliminating the conditions bothering driver and passengers and also provides enhanced comfort. Fig 11 shows displacement differences between chassis and engine. Displacement values of the engine peak occasionally. These peak values are decreased thanks to the new hydraulic mount. [17]

Amplitude is an important parameter in terms of the comfort of a vehicle. High amounts of amplitude and a high amount of displacement make the human body uncomfortable. Therefore the amount of displacement has to be minimized. Vibrating elements belonging to the structure have to be taken under the control with the vibration isolating elements. Engine mounts are used between engine and chassis to isolate vibration. It is understood that the engine mount is an important element of a vehicle due to the protection of the driver and passengers and the enhancement of comfort by reducing its oscillation.

3. Conclusions

The comfort of a vehicle is closely related to vibration isolation. Vibration affects the health of a human negatively. Also, vibrations have negative effects on the vehicles. Forces occurred due to the vibration may cause damage to the rotating parts and fasteners on the vehicle. When the vibration movement reaches advanced stages, it will cause damage or malfunction in the vehicles. Therefore, the connection between the vehicle engine and the chassis of the vehicle should consist of flexible elements. The flexible elements will absorb some of the engine's movement as it undergoes energy absorption. Vibration mounts between the engine and the chassis will serve this purpose. Vibration mounts have an elastic material structure. The spring coefficient of the material changes depending on the mass of the engine and the numerical size of the force that came out from the vibration. It is seen that vibration mounts wear out over time. In this research, the displacement and acceleration values of two mounts were measured. The graphs were drawn and the differences between these two mounts were examined. One of these mounts belongs to the engine, in other words, it is original and the other one is unused and replaced by the original one. It was observed that the vibration insulation of the old mount was considerably weakened and it was concluded that the appropriate mount should be selected according to the engine parameters and condition of the engine.

Thanks to the vibration mount, transfer of the vibration to the chassis from the engine are prevented to a certain extent. The imbalance of the rotating parts of the engine creates oscillating movements. That oscillation can be expressed with displacement and acceleration values. The graphs of the displacement and acceleration values over time are plotted and compared. From these graphs, it is concluded that there are certain differences between engine and chassis movement. Mostly, it is seen that the displacement and acceleration values of the chassis are lower than the values of the engine. Due to the presence of the fluid in the hydraulic mount, the spring coefficient increases proportionally to the number of engine revolutions. It is clearly understood that low numbers of revolutions make the spring coefficient lower. In addition, vibration amplitude increases at lower numbers of revolutions and decreases at higher numbers of revolutions. A new hydraulic mount prevents vibration transfer to the chassis from the engine, on a large scale. Therefore not only the driver and the passengers but also the engine parts are protected from the negative effects of the vibration.

Nomenclature

m	: mass matrix
c	: damping coefficient
k	: spring stiffness
x	: displacement
ω_d	: damped angular frequency
$\emptyset$	: phase angle
ζ	: damping ratio
ω_n	: natural frequency

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Abdurrahman Karabulut: Conceptualization, Supervision, **Hakan Şahman:** Conceptualization, Investigation, Validation, **Bahri Şamil Korkmaz:** Visualization, Writing - review & editing

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