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Vibration Suppression System for a Real Petrol Engine Exploiting Optimum Shaker Position

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Abstract

Reducing vibration of the engine with minimum changes to the engine mounts remains as one of the main challenges in automotive industry. Several researchers and giant car companies have presented valuable effort in these areas however there is still room for improvement of the control system. In an attempt to reduce an automobile engine's vibration, the authors have designed and implemented an engine mounting control system which have experimentally tested on a real single-cylinder engine. The system comprises an electromagnetic shaker and incorporates a control strategies based on the PID controller and inversing method, Application of these control systems on the engine resulted in %10-%12 vibration reduction. To improve the controlling system and increase the amount of reduction, new shaker position is chosen and implemented. Relocating the shaker to its optimum position contributes to the vibration reduction of about %20 which shows a significant progress comparing to the conventional shaker 's position.

1. Introduction

The vibration of a single cylinder engine (4-stroke) comes from three sources, which the most significant one is generated through the change in momentum of the piston. For reducing this vibration, balancing weights are incorporated in most of the single-cylinder crankshafts; however, these weights are not able to balance the motion of the piston completely.

The second source of vibration is created by the change in speed of the piston or its kinetic energy. The frequency of this vibration is double of the vibration caused by the change in the piston momentum. The third vibration is produced due to the power generated by the engine during the power stroke. In a four-stroke engine, the cylinder fires once every two revolutions, which result in the lower vibration frequency (half of the main source of vibration frequency) [1]. Flywheel can be used to absorb the second and third vibration.

To accomplish a superior result for vibration decrease, one of the most important components in a car chassis is the engine mount. The vehicle engine mounting system, generally, consists of an engine, which is the main vibration source and a number of mounts associated with the car structure.

The engine mounting system has been utilized to isolate the driver and passenger from the vibration created by the engine. Different types of mount systems are available from passive to active and elastomeric to hydraulic which have been used for different applications to improve the engine mounting system performance. Mounting of an engine has basically three purposes, namely, 1) to prevent the engine from bouncing off the chassis due to the driving turbulences, 2) to support the engine weight statically, and 3) to isolate the engine vibration from the chassis [2]. To attain the second and third purposes, the engine mount needs to have two conflicting characteristics. To prevent the engine from bouncing off the chassis at low frequency (f < 20Hz) the engine mount must be very stiff, which requires huge damping. On the other hand, at high frequency level (20–40 Hz), the engine mount should be able to isolate the engine vibration from the chassis [2]. This requires using low stiffness characteristic, which may cause awkward vibration in the car's cabin [3]. Moreover, modern car designs tend to have lighter structures beside power-intensive engines. Which both requirements deteriorate the vibration and causing it to increase significantly. These features are frequently clashing significant improvement in the performance of mounting systems.

Low elastic stiffness is essential to decrease the vibration of unbalanced engine disturbances, (the forces transmitted to the structure are proportional to the stiffness and damping of the mounts) [1] . Fig. 1 illustrates the influence of frequency and damping on the force transmissibility via the typical two elements of Voigt mount model with the aim of achieving a low transmissibility, the engine disturbance frequency (at idle speed) should be higher than the engine mount resonance frequency in a certain direction. This can prevent the mounting system excitation.

Low elastic stiffness of the mount can cause delay on the transient response of the engine mount while the shock excitation happened (by sudden braking or acceleration). The shock excitations may trigger the engine resonance mode at lower frequencies to be excited. Low value of stiffness can also damage the engine by enlarging static and quasi-static engine displacement. As a result, vibration reduction of engine is obtainable if only high stiffness and high damping mount exists.

Based on the above discussion, the rubber mounts can only be effective on none-resonance vibration. Their behavior in resonance frequencies is not faultless and sometimes amplify the vibration signal coming from the engine [6]. To attain better vibration cancelation of the engine, active vibration control system can be used to generate the opposite force and reduce the vibration specifically in resonance frequency, in which the rubber mounts are not effective.

There have been different researches on active engine mounts but most of the represented methods are only applied to the simulated engine or an electric motor using Matlab or ADAMS simulation [5,7,8,10,11]. A lack of experimental work on real engines was evident from previous researches. Tian-ye et al [10]. applied a fuzzy controller on the unbalanced electric motor and put the shaker underneath the system. Lee et al. [8] tried an experimental approach on hydraulic exciter using Feedforward method. Their results showed a total vibration reduction of 20-50%, but their controller has not been tested on a real engine.

Mahil et al. [7] tested the PID controller on a mathematical engine model using Matlab Simulink. This test was carried out on 4DOF and 6DOF engine model. They represented the comparison between PID controller and LQR method and noted that PID controller had better performance for the 6DOF engine on the front side of the system. They gave the system a sinusoidal disturbance whereby frequency changed linearly over time from 0.5 to 50 Hz in 100 s. However, those controllers were applied to the realistic engine model via Matlab software, which is completely different from an actual engine.

Darsivanit et al. [11] represented the comparison between PID controller tuned with Ziegle-Nichols method and neural network controller while applying them on an engine within the simulated Matlab model. In their model only the sinusoidal force disturbance was considered with the frequency of 1 Hz and 18 Hz (their engine model was a two degree of freedom system). The first disturbance was a sinusoidal disturbance at 1 Hz frequency; they measured the transmitted force variations after applying the disturbance to the system, once without controller (open Loop) and once with PID controller. Their result showed that a 60% transmitted force reduction can be achieved using controller compared to the open loop system. The second test was based on a sinusoidal disturbance at 18 Hz frequency; this time a 75% reduction of transmitted force occurred. Their results showed better performance for the neural network controller, however high controller overshoot and phase shift is the problem of neural network method, which causes the stability issue.

In another experimental approach by Kowalczyk [5] an active vibration control system was applied on the chassis (the shaker placed on the transmission cross member). The control signal was generated by inertial-mass shaker and FxLMS controller was used.

2. Configuration of the control system

To gain the best result in vibration isolation, an active system should implement on the engine mount or the chassis of the car.

In this paper, author presented three different sets of experiments for having Active vibration reduction using electromagnetic shaker, controller system, filter and amplifier. The control methods used are Inversing method and PID controller through Zeigler-Nichols tuning method. Two sets of experiments have been done while the shaker was placed on the chassis. The third experiment is utilizing inversing method by placing the shaker on an innovative place which results in the maximum vibration reduction.

Most of the previous active engine vibration cancelation researches used hydraulic shakers although the hydraulic shakers are more powerful but electromagnetic shakers have faster response, therefore in this experiment electromagnetic shaker has been used. The shaker generates the opposite force to reduce the vibration. Place of the shaker is playing important role in an active vibration control. In all of the researches done so far, the shaker was placed on the chassis to reduce the vibration transmitted from the engine to the chassis. As an example, Kowalczyk [5] applied his control system on the chassis (the shaker placed on the transmission cross member).

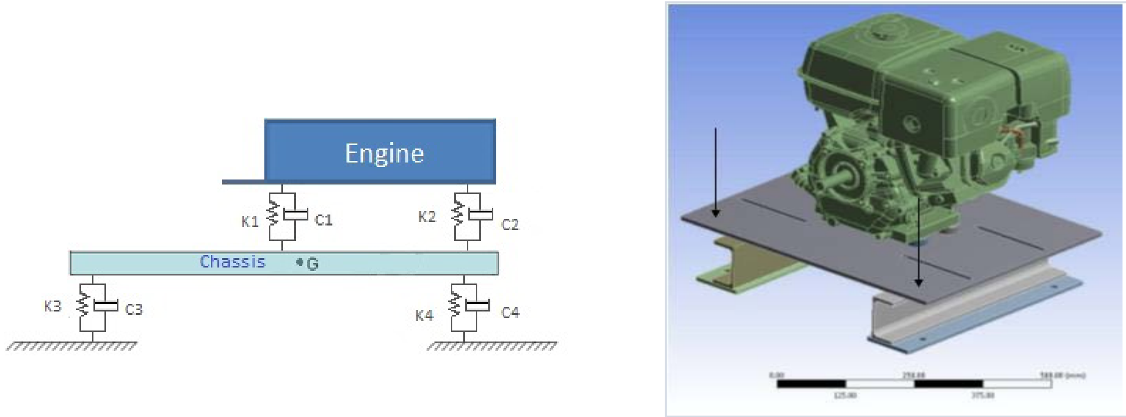
This paper presents the experiment which in, placing the shaker on the chassis and on the engine have been compared to find the best location.

In developing an Active control system, there are two important practical considerations: The experiment should be done near the engine resonance frequency because the biggest excitation of the engine happens in these frequencies. The second important point is the mode shape on that frequency. In the experiments presented in this paper, the engine resonance frequency was near 40 Hz and the mode shape was vertical at this frequency.

The purpose of designing engine mounts is to suppress the noise and vibration at high frequencies. Conversely, at lower frequency range, and near resonance frequencies, choosing soft rubber mounts might magnify the unwanted vibration. To solve this issue and to reduce the low frequency excitation and specially excitation at resonance frequencies, active mounts can be used. Therefore, to design an effective controller for a system, identifying the resonance frequency and mode shape of a system is mandatory.

For simulating the vehicle chassis and the road, two plates are connected to each other by four rubber mounts and the engine is located on the top plate via the rubber mounts. These two plates are representing the road and the chassis of the car (Fig. 4). The experimental setup is shown in Figure 2.

In this test, the vibration signal of the engine captured by accelerometer and sent to the Compact Rio to control the output signal going to the shaker. Two piezoelectric accelerometers are used for reading the vibration generated by the engine. These accelerometers are mounted at different locations on the rig representing vehicle chassis. The input signal from the accelerometers is then analysed by the LabVIEW software and the output signal is generated accordingly and sent to the shaker via CompactRIO (cRIO) to cancel vibration.



(a) (b)

Figure 1: Engine platform (a) mechanical model of the engine and chassis, (b) engine platform; two arrows indicate the optimal places of the shaker on the Chassis, which are on the two corners of the plate, (according to the center of gravity of the engine on the mount and also the geometry of the plate). Six different position has been examined for finding these points.

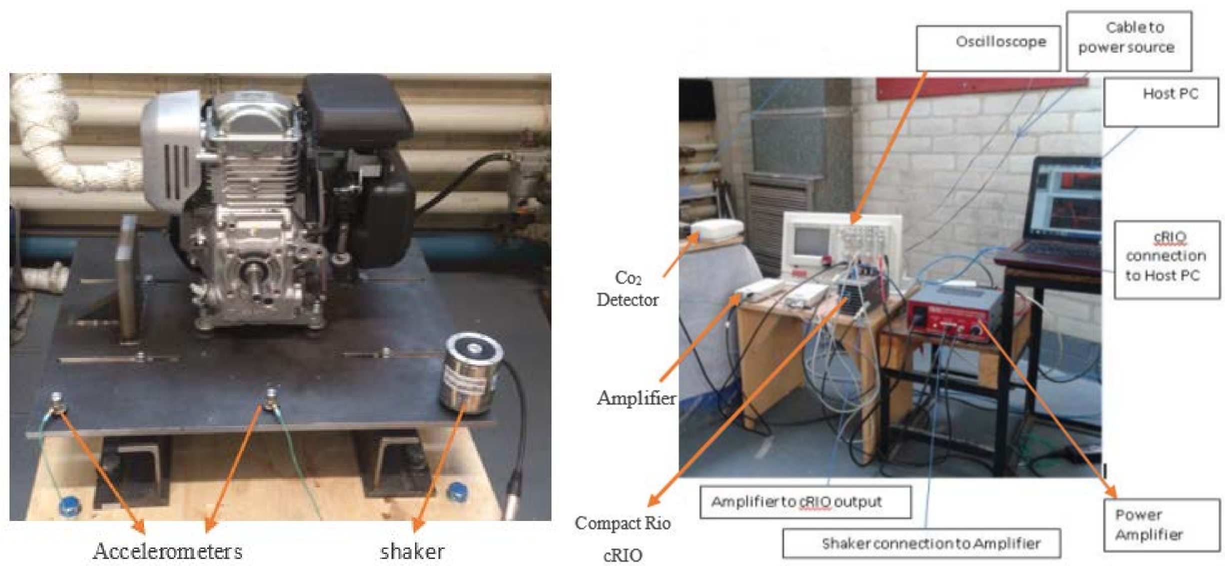


Figure 2: Experimental setup

2.1 Inversing signal method

In inversing strategy, the active control system applies a force to the system against the vibration of the engine. The petrol engine runs at the resonance frequency of 40Hz. In this test the vibration signal was coming from the accelerometer to CRio which connects to the computer for controlling purposes. The control program (Figure 3), which designed for this experiment includes a Butterworth filter to eliminate the unwanted high frequency noise from the engine.

The signal goes to the controller from the filter and in the controller the signal is inversed to produce the opposite signal. Modified signal goes from the CRio to the electromagnetic shaker to create opposite force. The results indicate the vibration reduction of 10% in comparison with the system without active controller, while the shaker is placed on the chassis.

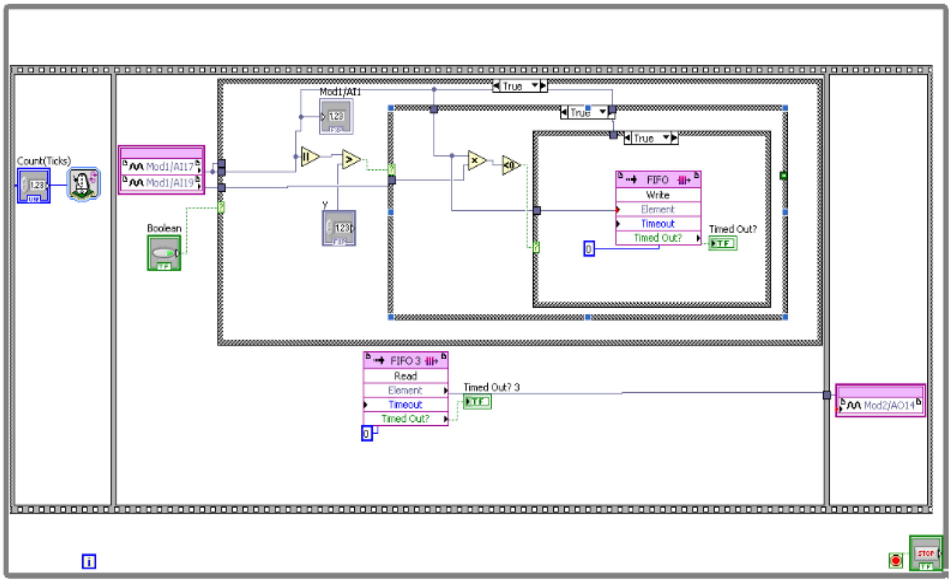


Figure 3: Inversing controller designed through LabVIEW Software

2.2 PID controller

In another experiment, a PID controller is implemented in the system (Fig. 4) while the shaker was on the chassis and different gains have been examined. A controller program was written using FPGA and real time to apply the PID controller tuned with the Zeigler Nichols method.

With the optimum gains at the 40Hz frequency, 12.5% vibration reduction is achieved (Fig. 5). Using PID controller couldn't significantly improve the vibration reduction of the engine comparing to the inversing method. The author has examined different tuning methods with PID as well, and similar results were achieved.

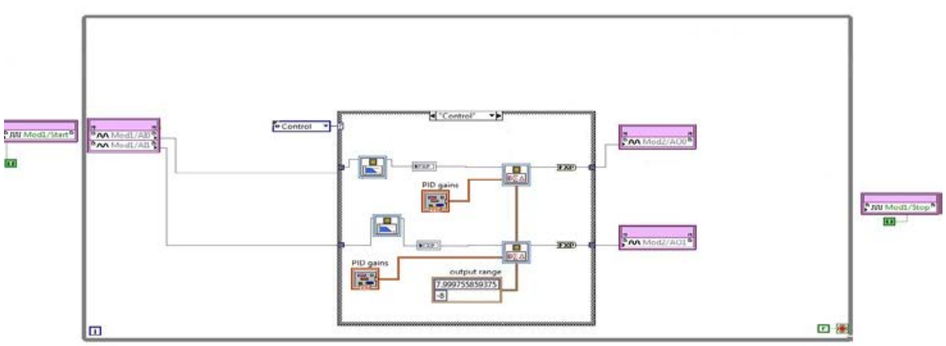


Figure 4: PID Controller

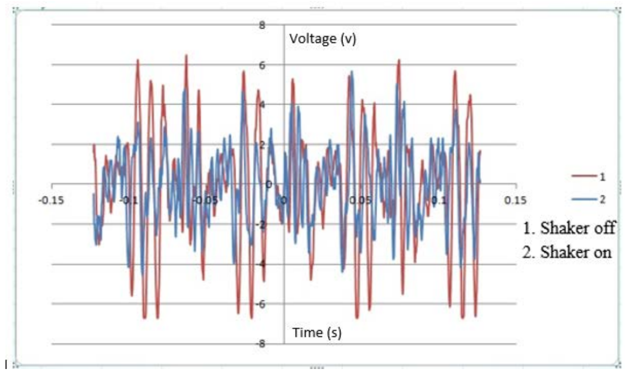


Figure 5, Active engine mount vibration graph using PID controller

3. Optimization

To improve the vibration performance, the author tries to find the influence of the shaker position in the vibration reduction, based on the ineffectual behavior of the rubber mount at resonance frequencies (explained in section 1). By choosing the place of the shaker on the chassis like other conventional researches, the maximum reduction that achieved was almost 10% using two different control methods. Therefore, the new position has been carefully chosen on the engine to reduce the vibration of the engine at its source, before it transmitted to the rubber mounts and to prevent the vibration magnification by the mounts. The new plate is designed and attached to the engine itself and the shaker is located on the plate (Fig. 6). This test was run in 40Hz frequency. The result was significantly improved compared to the previous position, and a 20% reduction was achieved, while the shaker was placed on the external plate. This reduction was achieved by using the inversing control method. As illustrated in Figure 7, 20% reduction in RMS value of acceleration accrued while the shaker was on the engine.

Figure 6: New shaker place

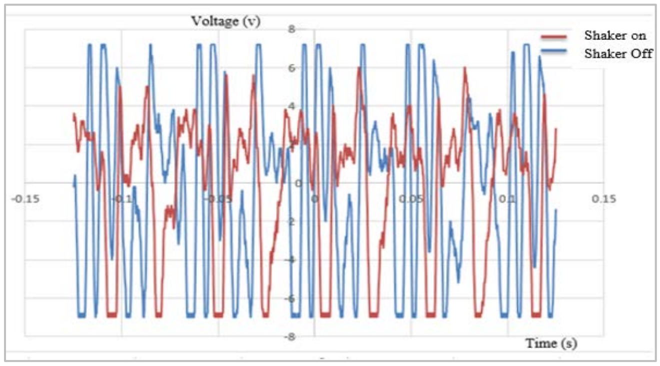


Figure 7: Accelerometer output when the controller is active and not active

4. Conclusion

This paper presents three experimental tests on the real petrol engine. All the controllers have been designed by the LabVIEW software via FPGA module and the signal has been transmitted to the engine by CompactRio. Two tests have been done using the Inversing control method with different shaker positions (on the chassis and on the engine). Another experiment was conducted using PID controller with Zigler-Nicholas tuning method while the shaker placed on the chassis. Both controllers contributed to the similar vibration reduction around %10, While the shaker was located on the chassis,

However, the results revealed that placing the shaker on the engine (vibration source) causes better vibration reduction comparing to the situation where it is placed on the chassis. The reason can be due to the different parameters, although the most important one is that the rubber mount are not effective in resonance frequencies. Therefore, the paper suggestion is to reduce the vibration force on the engine (at the vibration source), before it transmitted to the chassis by applying active vibration control on the engine.

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