

Design Development and Testing of Hydraulic Engine Mount Isolation in Agricultural Applications

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Abstract: The ideal engine mount should isolate engine vibration caused by unbalanced force in the engine speed range and prevent the engine bounce from shock excitation. For Agricultural applications like power weeder, grass trimmer Hand Arm Vibrations (HAV) are experienced by the operator continuously. It is also observed that some agricultural equipment has no any vibration isolation device to damp these excessive vibrations. Conventional mounts such as rubber mounts fail to provide better performance during damping vibrations due to some limitations. These troubles are overcome by hydraulic engine mount. In this work, a new configuration of hydraulic engine mount is designed for vibration isolation. Solenoid actuator makes this passive mount to the active engine mount. The experimentation of hydraulic engine mount is done by using FFT analyzer. The performance of neoprene rubber mount as compare to hydraulic mount is not adequate. The results of passive and solenoid actuated mount are compared by measuring vibration parameters. The result shows that designed hydraulic engine mount is beneficial for vibration isolation. The developed model can be used for designing the vibration control system for agricultural applications such as power weeder.

Keywords : Agricultural applications, FFT analyzer, Hand arm vibrations, Solenoid actuator, Vibration

I. Introduction

Noise, vibration and harshness are the indications of poor quality and improper vibration isolation system. So due to these vibrations, it feels uncomfortable to the passenger. In agricultural equipments like power weeder, lawn mower the vibrations from the engine transferred to the handle and it becomes uncomfortable for the operator to work with that particular equipment. Long term vibrations are the cause of adverse effects on the body. The power given by the engine must be transferred easily and utilized by the application without shocks and vibrations. It is necessary that the engine must be located properly in place and not move tremendously from its position due to inertial loadings. The vibrations coming from the engine should be damped. An engine mount situated in between the engine bracket and chassis. An engine mount holds the engine and damp the vibrations as far as possible. Frequency of vibration generally depends on engine rpm, load on engine, number of cylinder and stroke number. 'Low frequency, high amplitude' and 'high frequency, low amplitude' is the different conditions when vibration isolation is very necessary [1, 2]. Different types of mounts are available in market like rubber mount. A rubber mount consists of a bulk rubber, casted with a metal casing, and a mounting rod. These mounts suppress engine torque and vibrations through thermal dissipation. It is also observed that isolating characteristics of rubber mount is not up to the mark because the force which is transmitted increases in higher frequencies due to constant damping. These vibrations are not damped superiorly by the conventional mounts like rubber mount. Also, existing engine mounts are not giving too much vibration isolation. So it needs to make an active hydraulic engine mount which will perform as per changing vibration condition [3, 4]. Hand-arm vibration (HAV) level is important term which needs to be controlled to prevent adverse health problems. Such adverse effects are like secondary Raynaud's phenomena and carpal tunnel syndrome due to vibratory environment. Multiple studies have shown that continuous exposure to hand arm vibrations lead to permanent adverse health effects. Also vibration syndrome has circulatory and neural effects in the fingers. To avoid all these effects, an attempt is to minimize vibrations by using better hydraulic engine mount. It is also found that less research is done in the area of low cost machinery. Maximum work is done in vibration isolation systems for four wheeler vehicles. In this study, a new configuration of hydraulic engine mount is designed for agricultural applications. A test rig is designed for hydraulic engine mount. Two stroke petrol engine of 35 cc is selected for test rig. The designed hydraulic engine mounts is located between the engine and frame. This mount damps the vertical vibrations due to unbalance in the engine. The torque generated due to large rpm is responsible for mass imbalance. So it needs to damp these vibrations, otherwise the system will fail within short duration. Dynamic forces, inertia forces could cause rapid fatigue of vehicle components. Many of the agricultural applications like power weeder, grass trimmer does not have any device to reduce the vibration which is directly transmitted from the engine to handle. In agricultural low cost machinery applications, by introducing a new design of hydraulic engine mount the vibration isolation can be done. The mount will be beneficial for agricultural equipments [5, 6].

II. Literature Review

T. Ramchandran et al. [1], studied the sources of vibration in internal combustion engines and discussed on different mountings required for vibration isolation. The IC engine is made up of reciprocating and rotating parts. So it produces unbalanced forces during running condition and tremendous vibrations of the vehicle supporting members. In this work, an attempt is made to represent the sources of engine vibrations and its different isolations.

Ali Masih Hosseini [2], focused on design, simulation, identification and verification of a low cost solenoid based active hydraulic engine mount. To make an active engine mount, a commercial On-Off solenoid is modified to be used as an actuator and it is inserted inside a hydraulic engine mount. This thesis focused on the active hydraulic engine mount design for vibration isolation in cars.

A. S. Sathawane et al. [3], presented the analytical study of engine mount for the different requirements of the engine. In this paper, maximum literature is regarding rubber mounts. Even though the current engine mount designs are acceptable for vibration isolation, the performance improvement of the engine mounting system is still required for the tendency of light weight and higher power of the vehicle.

Yunhe Yu et al. [4], presented the review of automobile vehicle engine mounting systems. It is discussed that the ideal engine mount is the system should isolate engine vibration caused by engine disturbance force in the different engine speeds. It is observed that the optimization of engine mounting systems is quite desirable. The current work on the optimization of the engine mount systems shows some confines. Also weight reduction and increased power requirements often have adverse effects on vibratory behavior. This requirement greatly increases the vibration and noise level. These two aspects are often differing.

Ko Ying Hao et al. [5], mentioned the actual problem of vibration in petrol driven grass trimmer. The paper covers the study of the design and development of suspended handles for reducing hand arm vibrations. It was observed that the current design of grass trimmer does not have any device to reduce the vibration. So these vibrations transmitted from the engine to the handle grip and hand-arm, which is responsible for fatigue and numbness. It is also observed that the frequency-weighted rms acceleration attained the level of 23.94 m/s^2 for a 32 cc petrol engine for an unbalanced single string grass trimmer. So research in agricultural field is required to make this type of machine vibration level little for the safety purpose of an operator.

V. K. Tewari et al. [6], researched on effect of vibration in the work stress during field operation of hand tractor. The operators of the hand tractors experience high levels of vibration in the hand and arm, which cause early fatigue and result in shorter work hours. It was found that the present design of the hand tractors available in developing countries in general. But it is important to notice that in India particular does not have any device to reduce vibration. So vibrations are directly transmitted from the engine to handle grips, finger, hand-arms, and shoulders causing stress and discomfort.

III. Design Of New Hydraulic Engine Mount

3. Design of New Hydraulic Engine Mount (HEM)

3.1 Vibration Isolation Concept

Vibration isolation is a procedure by which the adverse effects of vibration are reduced. Basically, it involves the insertion of a resilient member between the vibrating mass (or equipment or payload) and the source of vibration so that a reduction in the dynamic response of the system is achieved under conditions of vibration excitation. An isolation system is said to be active or passive depending on whether or not external power is required for the isolator to perform its function. A passive isolator consists of a resilient member (stiffness) and an energy dissipater (damping). Examples of passive isolators include metal springs, cork, felt, pneumatic springs, and elastomer (rubber) springs. Vibration isolation can be used in two types of situations. In the first type, the foundation or base of a vibrating machine protects against large unbalanced forces. In the second type, the system is protected against the motion of its foundation or base. Similar to the first type, frame is protected against engine vibrations by using hydraulic engine mount. Newly designed hydraulic engine mount is located in between engine and frame. The first type of isolation is used when a mass (or a machine) is subjected to a force or excitation. These impacts are transmitted to the base of the forging or stamping machine. This impacting can damage not only the base or foundation, but also the surrounding or nearby structures and machines. The operators of these machines feel discomfort in this vibratory and noisy environment. Similarly, in the case of reciprocating and rotating machines, the inherent unbalanced forces are transmitted to the base or foundation of the machine. In such cases, the force transmitted to the base, F_T , varies harmonically, and the resulting stresses in the foundation bolts also vary harmonically, which might lead to fatigue failure. The ideal vibration isolation system should reduce this transmitted force to the greatest extent. Even if the force transmitted is not harmonic, its magnitude is to be limited to safe permissible values. So it is clear that for the best comfort of an operator, better isolation system is necessary [7].

3.2 Construction And Working Of The New Hydraulic Engine Mount

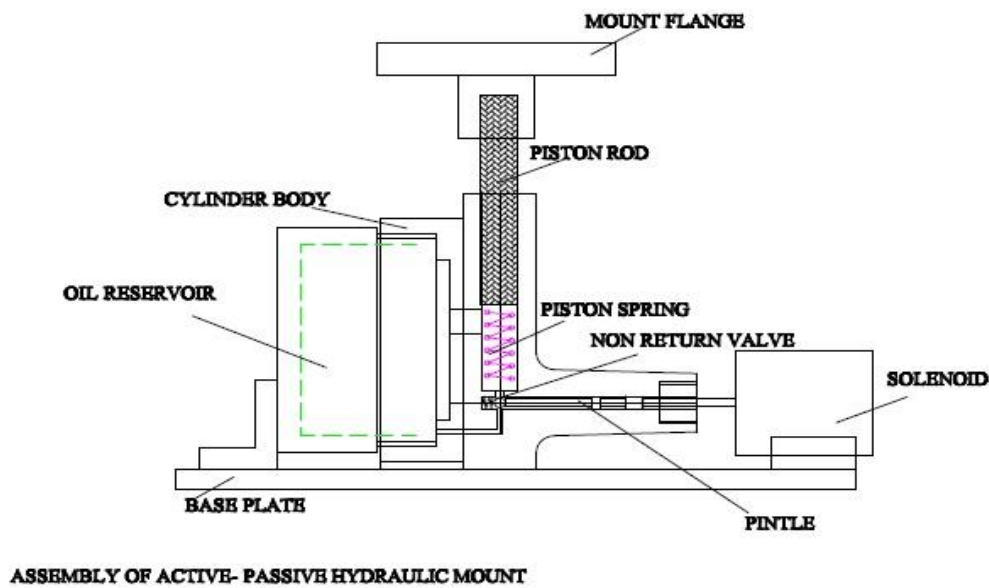


Fig. 1 Assembly of new hydraulic engine mount

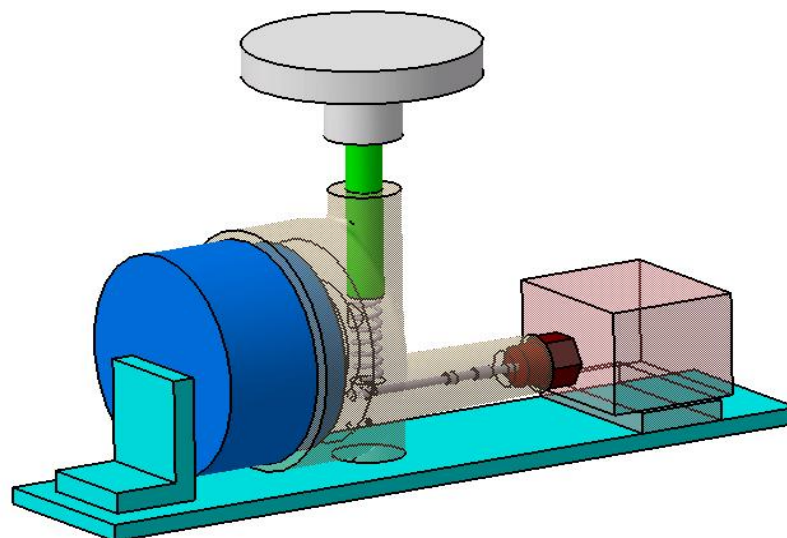


Fig. 2 Solid Modeling of HEM

The new configuration of our designed hydraulic engine mount is as shown in Fig. 1. This mount is located in between engine and frame. So it will damp the vibrations of engine in vertical direction. This hydraulic mount is having both passive and active features. When solenoid actuator activates, the mount becomes active. This mount consists of main components i) Piston and Cylinder, ii) Reservoir, iii) Spring, iv) Hydraulic Oil and v) DC solenoid. In practical applications, the engine is not totally loaded on dampers. It is bolted to a flange or plate. Similarly, in test rig, partial load is given on the mount. Now, when the engine starts running at different rpm, an imbalance is created. This rotational imbalance is responsible for producing a large number of vibrations which may lead to failure of the system. So it is necessary to reduce these vibrations by using hydraulic mount in between the engine and frame. When engine produces imbalance, then vibrations are transmitted to the frame. So if the hydraulic mount is inserted, then all static and dynamic loads, i.e., force impressed due to imbalance are taken by the piston as shown in Fig. 1. So piston is a critical component of mount which will take all static and dynamic loads without failure. So the design of the piston and analysis is one of the important aspects. In this study, piston is designed and analysis is done by using FEA. All the components like piston and cylinder, damper body, reservoir are made by using EN9 material which is having good strength enough and readily available. Spring of material spring steel is used which is below the piston having adequate stiffness and can absorb shocks and dissipate energy in a fluid. During the running of the

engine, the loads transmitted through the piston to hydraulic oil, hence pressure increases in the cylinder. As shown in Fig. 1 and Fig. 2, there is a free fluid passage for transfer of oil from the piston cylinder to the reservoir. So due to increased pressure part of the oil is passed in the reservoir. Hence this piston cylinder is nothing but the pumping chamber. The reservoir is completely filled with oil in addition of a small quantity of air inside it. Pressure in the reservoir is obviously less than pumping chamber pressure. During this moment, the fluid and spring offer resistance to the downward movement of the piston and hence vibrations are isolated. This System is a passive hydraulic mount system.

As shown in the Fig.1, ON-OFF DC solenoid actuator is provided in this passive mount. A small orifice is provided below spring or at the bottom of piston cylinder. The flow through an orifice is restricted by means of a small spherical ball of non-return valve. When the solenoid actuator is activated by means of external power source, a ball is pressed against spring and orifice opens. A part of oil goes into the reservoir and small quantity of oil travels through the orifice. While travelling through an orifice the transmitted load decreases in small amount. So solenoid actuated mounts are used in variable frequency conditions where the pattern of vibrations is not fixed. Active mounts are used to improve the low frequency features of the system like increasing damping.

3.3 Design And Analysis Of Piston

Material for piston and reservoir: EN9 [8]

Table 1 Properties of EN9

Part Name	Ultimate Tensile Strength, N/mm ²	Yield Strength, N/mm ²
Piston	600	380

Maximum allowable stress is:

$$\sigma_{allowable} = \frac{S_{ut}}{FOS} \quad (1)$$

Now for piston and reservoir, considering Factor of safety (FOS) = 4,

$$\sigma_{allowable} = \frac{600}{4} = 150 \text{ N/mm}^2$$

OR, by considering yield strength:

$$\sigma_{allowable} = \frac{S_{yt}}{FOS} \quad (2)$$

$$\sigma_{allowable} = \frac{380}{4} = 95 \text{ N/mm}^2$$

Diameter of piston = 8 mm

Area of piston = 50.26 mm²

Axial load on piston due to engine weight = 18.63 N

Theoretical Stress due to the load of the engine is:

$$\sigma_{th} = \frac{P}{A} \quad (3)$$

$$\sigma_{th} = 0.3706 \text{ N/mm}^2$$

3.3.1 FEA Analysis Of Piston

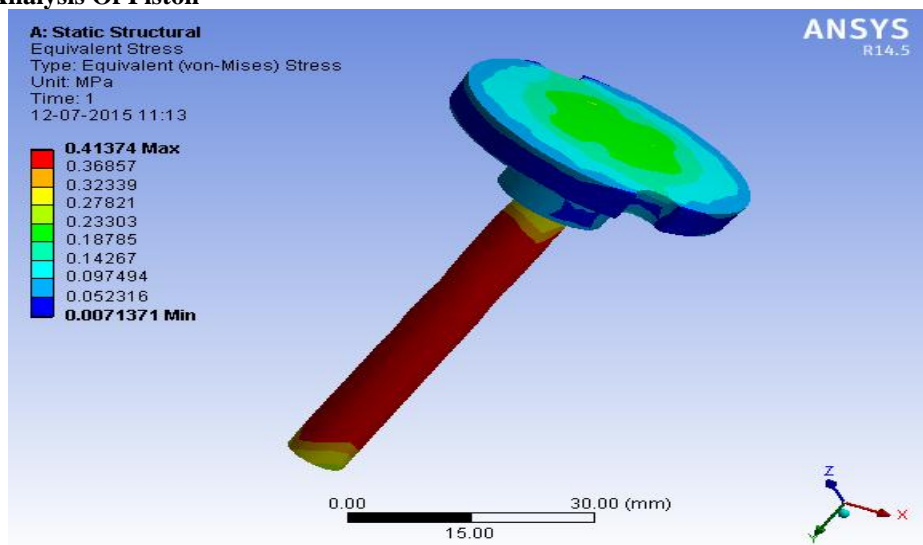


Fig. 3 Solution of equivalent stress developed due to loading in FEA

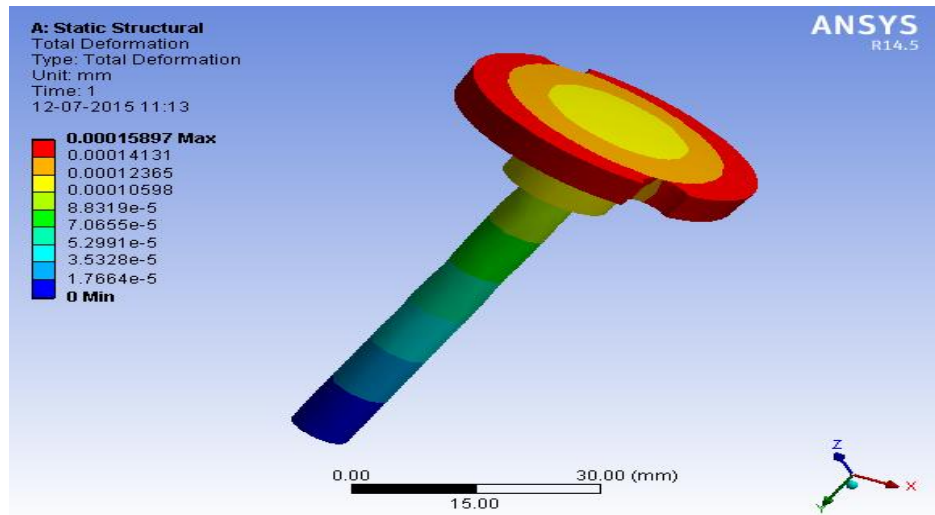


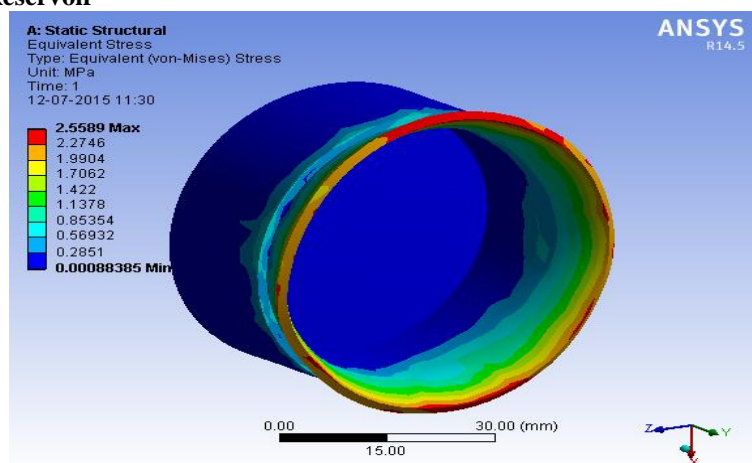
Fig. 4 Deformation after loading

Table 2 Result analysis of piston

Part Name	Theoretical Stress, N/mm ²	Von-mises stress, N/mm ²	Deformation, mm	Result
Piston	0.37	0.415	0.00015	Safe

1. Maximum stress by theoretical method and von-mises stress are well below the allowable limit, hence the piston is safe
2. Piston shows negligible deformation under the action of forces.

3.3.2 Analysis Of Reservoir



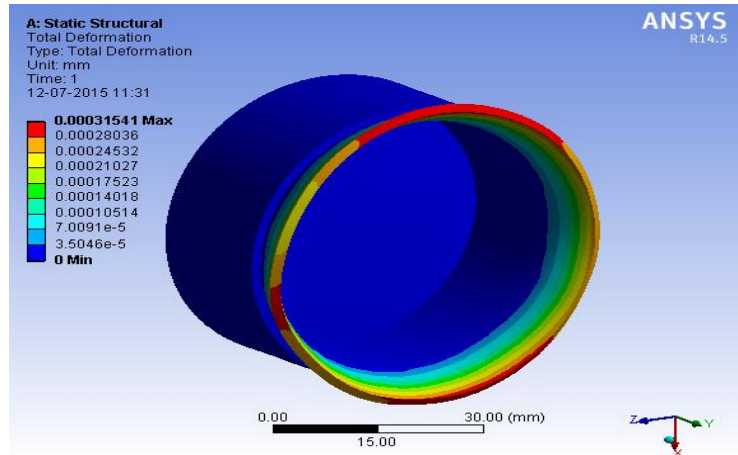


Fig. 5 Solutions for reservoir after loading in FEA

Table 3 Result analysis of reservoir

Part Name	Maximum theoretical stress or pressure, N/mm ²	Von-mises stress, N/mm ²	Maximum deformation, mm	Result
Reservoir	0.125	2.5	0.0003	Safe

1. Maximum stress by theoretical method and von-mises stress are well below the allowable limit, hence the reservoir is safe.
2. Reservoir shows negligible deformation under the action of forces.

IV. Experimentation

In this work, new hydraulic engine mount is tested by using FFT analyzer. Model: SKF Micro log Analyzer GX series CMXA 75 is used for experimentation purpose. HEM is mounted in between Engine and frame. The measurement of vibrations transferred to the frame via hydraulic mount is the area of interest here. So accelerometer of the analyzer is fixed at the bottom of the mount, i.e. on the frame. The accelerometer is magnetic in nature. Readings are taken at different rpm from 1800 to 3000 rpm. When the engine is running at different rpm, its speed is made constant by loading. The accelerometer is first set at a particular frequency and then readings are taken. So at a particular frequency, acceleration values are noted by FFT in terms of g. In this experiment, first all readings are taken on the passive hydraulic engine mount and then by actuating solenoid active hydraulic mount. After that, this hydraulic mount is replaced by neoprene rubber mount. Readings are taken on neoprene mount by using FFT analyzer at the same frequency. According to readings, performances are analyzed.

V. Results Of FFT Analyzer

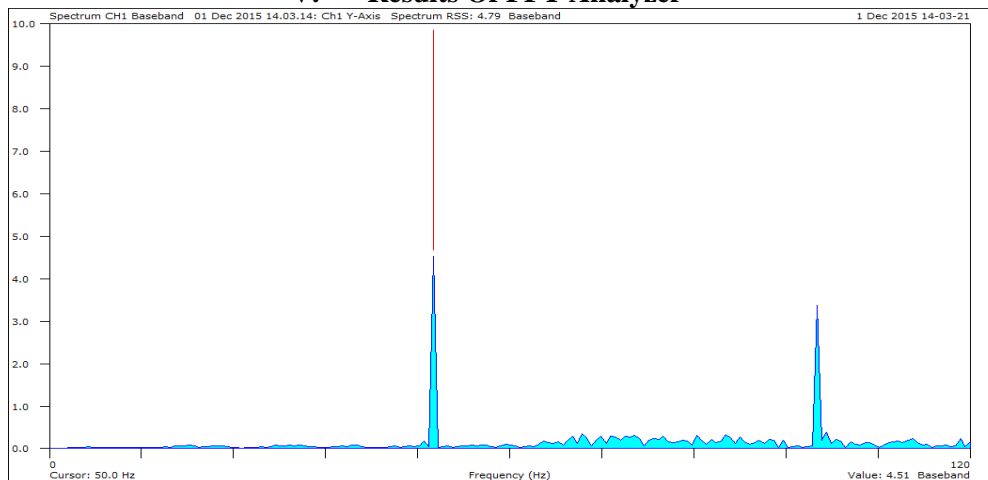


Fig. 6 FFT reading of acceleration at frequency 50 Hz for the passive hydraulic engine mount

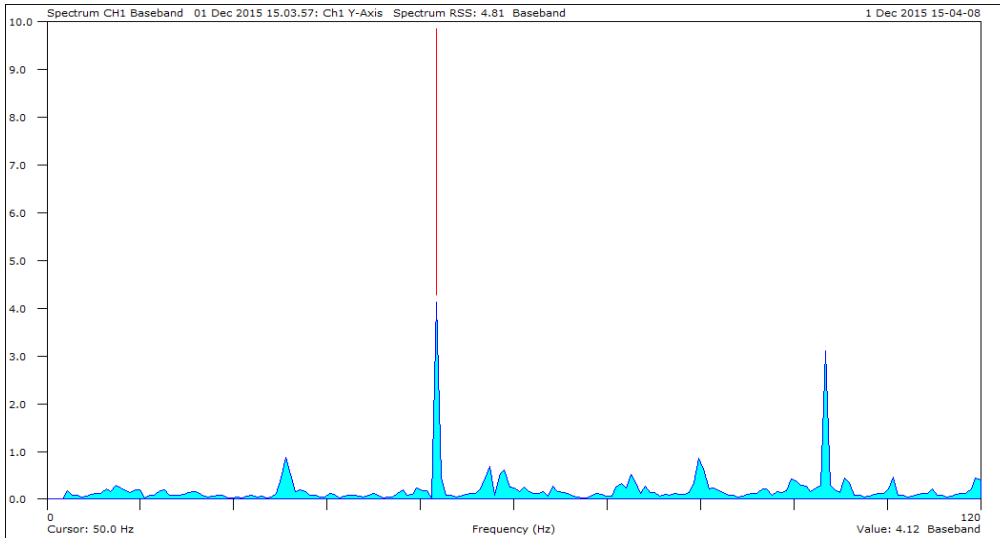


Fig. 7 FFT reading of acceleration value at 50 Hz for solenoid actuated hydraulic engine mount

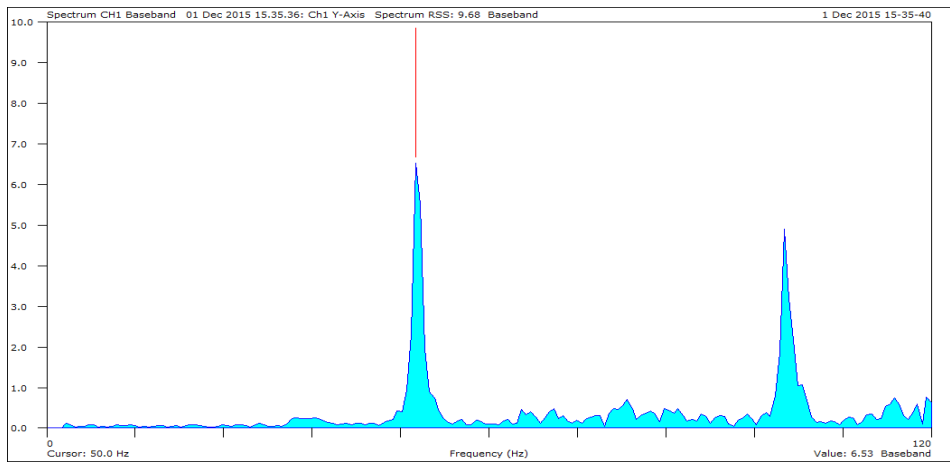


Fig. 8 FFT reading of acceleration at 50 Hz for neoprene rubber mount

Table 4 Values of acceleration from tested mounts

Sr. No.	Speed, rpm	Frequency, Hz	Acceleration of Passive HEM, g	Acceleration of Solenoid Actuation HEM, g	Acceleration of Neoprene Rubber mount, g
1	1800	30	1.83	1.53	3.93
2	2500	41.33	3.62	3.31	5.34
3	3000	50	4.51	4.13	6.53

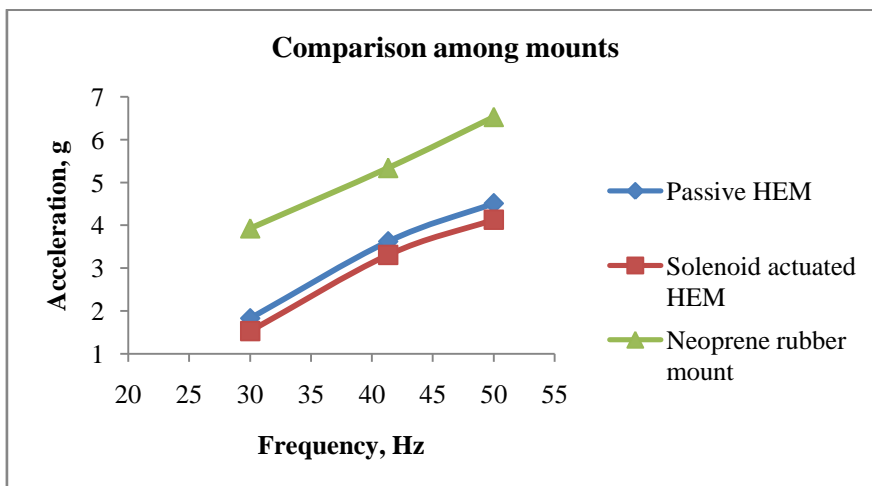


Fig. 9 Comparison between Passive HEM, Solenoid actuated HEM, Neoprene rubber mount.

It is seen that from Fig. 6, 7, 8 and 9 that the acceleration value goes on increasing significantly with the increasing engine speed, especially in the increasing speed range. Fig. 9 shows the acceleration verses frequency curve showing that, the neoprene rubber mount is having higher values of acceleration as compared to passive and solenoid actuated hydraulic engine mount. It is found that the accelerations of passive hydraulic mount show significant reduction in vibrations transmitted to the frame. Solenoid actuated hydraulic engine mount is having superior performance than rubber and passive hydraulic mount. As the engine speed starts increasing, the hydraulic mounts isolation effect was significantly superior to neoprene rubber mount. Due to severe hardening of rubber mounts high frequency stiffness, its performance is not obvious. In all three mounts comparison, it is seen that when solenoid is actuated, mount was having excellent vibration reduction capacity. Solenoid actuated hydraulic mount shows small reduction in vibration compared to passive hydraulic mount. These three mounts vibration isolation performance make a satisfactory evaluation.

VI. Conclusion

From the present work following concluding remarks can be withdraw:

1. A new configuration of hydraulic engine mount is designed for agricultural applications such as a grass trimmer; critical components like the piston and reservoir are designed and validated by using FEA.
2. These components of the passive hydraulic mount are safe. Advancement in this passive mount is done by incorporating DC solenoid actuator to make mount active for better isolation.
3. Experimentation is done with a neoprene rubber mount, passive and solenoid actuated hydraulic engine mounts by using FFT analyzer.
4. Experimentation shows that compared with the neoprene rubber mounting system, isolation effect of hydraulic engine mounting systems has obvious advantages. When evaluated with neoprene rubber mount, vibrations are reduced to 30.93% by the use of passive hydraulic mount and 36.75% by the use of solenoid actuated hydraulic engine mount at 50 Hz frequency.
5. So it is concluded that this new introduction of solenoid actuation works better than a passive hydraulic engine mount.

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