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Design and Development of Hydraulic Engine Mount Isolation for Improved Vibration Damping

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Abstract— Hydraulic engine mount is basically used to damp the vibrations so that the applications, for which it is used, can run safely. For Agricultural applications such as 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. The incorporation of solenoid actuator makes the passive mount to active engine mount. The experimentation of hydraulic engine mount is done on designed test rig by using FFT analyzer. The performance of neoprene rubber mount as compared to hydraulic mount is not adequate. The results of passive and solenoid actuated mount are compared by measuring vibration parameters. All values of acceleration are safe when compared with maximum theoretical value of acceleration. 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.

Index Terms— Hydraulic engine mount; Hand arm vibrations; Solenoid actuator; FFT analyzer; Vibration

I. INTRODUCTION

NVH is directly relates to chassis condition. 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 equipment. Long term vibrations are the cause of adverse effects on the body.

An engine mount is an application component that attaches the engine bracket to the chassis. The engine is connected to the application body by several mounts, which are important for smooth operation of the application. An engine mount should isolate the passenger cabin from engine generated noise and vibration. The engine mount must also hold the engine in place and restrict it from moving. Engine vibrations have two major sources: (1) intermittent pulsing due to ignition in the engine cylinders, and (2) inherent unbalances in the reciprocating components of the engine.[1]

Vibration isolation can be simply defined as isolating an object from the source of vibration. In order to achieve this objective, isolators must be used. There are two major types of isolation. The first type is the passive isolation in which passive techniques such as rubber pads or mechanical springs are used. This is done by using a mechanical connection which dissipates or redirects the energy of vibration before it gets into the structure to be isolated. The second type of isolation is active isolation which contains along with the spring, a feedback circuit which consists of a sensor such as a piezoelectric accelerometer, a controller and an electromagnetic transducer. [5]

Hand-arm vibration (HAV) level is one of the safety aspects which must be controlled to prevent long term health problems. It is also found that the handheld agricultural machineries, like power weeder, grass trimmer; lawn mower the operator is continuously suffering from these hand arm vibrations. So, to avoid the health problems and for better comfort to the operator during his working hours, proper vibration isolation is necessary. [4],[12]

Dynamic forces, inertia forces could cause rapid fatigue of vehicle components and discomfort for the occupant. The conventional elastomeric mounts do not meet all the requirements and can only offer a trade-off between static deflection and vibration isolation. The isolating characteristic of the rubber mount is not good because the transmitted force increases in higher frequencies due to the constant damping. Passive hydraulic mounts can provide better performance than elastomeric mounts, especially in the low frequency range, but they cannot solve all the inherent problems that arise during vehicle operations. In agricultural low-cost machinery applications, by introducing a new design of hydraulic engine mount the vibration isolation can be done. By using solenoid actuator, the mount will become active. So, in variable frequencies, it will give better damping. The designed mount will be beneficial for agricultural equipments.

II. LITERATURE REVIEW

T. Ramchandran and K. P. Padmanaban [1], studied the sources of vibration in internal combustion engines and discussed on different mountings required for vibration isolation.

Yunhe Yu et al. [2], 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 engine speed range and prevent engine bounce from shock

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excitation. So, the development of engine mounting systems has mostly concentrated on the improvement of frequency- and amplitude dependent properties.

A. S. Sathawane and A. V. Patil [3], presented the analytical study of the engine mount to suit the requirements of the engine. In this paper, maximum literature is regarding rubber mounts. This paper covers the brief study of rubber and elastomer. Theoretical modeling of engine mount subjected to vertical, lateral, transverse loads are considered and static stiffness of the engine mount is calculated by using standard formulation.

Ko Ying Hao et al. [4], 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 is discussed that the current design of grass trimmer does not have any device to reduce the vibration which is directly transmitted from the engine to the handle grip and hand arm causing fatigue and numbness.

Ali Masih Hosseini [5], focused on Design, simulation, identification and verification of a low-cost solenoid based active hydraulic engine mount. To build an active engine mount, a commercial On-Off solenoid is modified to be used as an actuator and it is embedded inside a hydraulic engine mount. In this thesis, HEM is modeled and tested, solenoid actuator is modeled and identified and finally the models were integrated to obtain the analytical model of the active hydraulic mount.

X. Wang and Dr. D. Denker [6], discussed the conception and design strategies for engine mount system based upon calculation and experimental methods. In this paper the performance, design and dynamic response of the hydraulic engine mount are studied in the frequency range 0-250 Hz.

J. Christopherson et al. [7], discussed on how the suspended decoupler is essential in design of Hydraulic engine mount. The study of this paper deals with the design of suspended decoupler.

Doug Taylor [8], discussed a brief review of fluid damping technology with specific case studies being provided from pedestrian bridges now equipped with viscous dampers.

III. DESIGN OF NEW HYDRAULIC ENGINE MOUNT

3.1 Theoretical background of the vibration isolation

Vibration isolation is a procedure by which the undesirable effects of vibration are reduced. Basically, it involves the insertion of a resilient member (or isolator) 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 specified conditions of vibration excitation. An isolation system is said to be active or passive depending on whether external power is required for the isolator to perform its function. Vibration isolation can be used in two types of situations. In the first type, the foundation or base of a vibrating machine is protected against large, unbalanced forces. In the second type, the system is protected against the motion of its foundation or base. This project of hydraulic engine mount comes in first situation.

Vibration control is the design or modification of a system to suppress unwanted vibration or to reduce the force or motion transmission. The design parameters include inertia properties, stiffness properties, damping properties and even the system configuration, including the number of degrees of freedom. Vibration control can be done best by vibration isolation where in the vibration isolators are used either to protect a foundation from large forces developed during an operation of a machine or to protect a machine from accelerations induced by the motion of its base.

3.2 Construction and working of New Hydraulic engine mount (HEM)

The new configuration of designed hydraulic engine mount is as shown in Fig. 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 there is not any external power source, then mount will act as passive. When it is solenoid actuated by ON-OFF switch, then it becomes active. The mount is simple in construction. It consists of i) Piston and Cylinder, ii) Reservoir, iii) Spring, iv) Hydraulic Oil and v) DC solenoid.

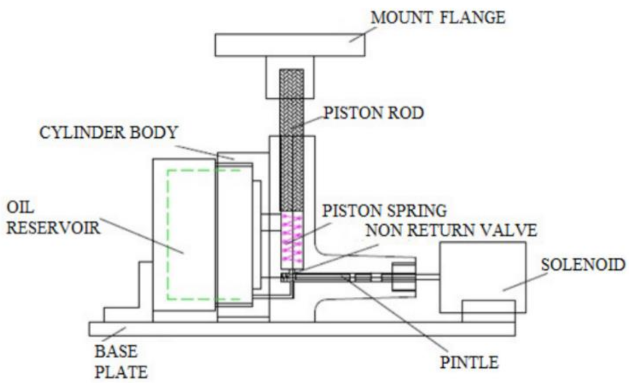

Fig.3.2 Assembly of Active-Passive Hydraulic mounts

As shown in Fig., there is an open passage for the transfer of fluid from the piston cylinder to the reservoir. The loads from the engine are transmitted through the piston to spring. Along with this, there is presence of hydraulic oil to absorb the vibrations. So, it improves damping. Spring will compress little due to loads and small displacement of the system due to oil. Now, as loads are transmitted through the piston to fluid, the pressure of oil is increased in the chamber. Due to this pressure, the fluid is forced or pumped into the reservoir through fluid gate provided here. So, this piston chamber is also called as pumping chamber. The reservoir is already having some fluid inside with little air. The pressure in the reservoir is less than pumping chamber pressure, but obviously more than atmospheric pressure. During this moment, the fluid and spring offer resistance to the downward movement of the piston and hence vibrations are

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isolated. This System is a passive hydraulic mount system. The mount exhibits an amplitude dependent characteristic with hard state in response to high amplitude vibrations (shock and resonance) and soft state in response to the low amplitude vibrations (engine high frequency vibration). The performance of this system is always better than rubber mount.

As shown in the Fig., ON-OFF DC solenoid actuator is provided in this passive mount. This is a new modification in systems to make mount tunable for changing frequencies. It makes the system active state. This solenoid actuated active system is introduced in order to improve the performance flexibility of passive hydraulic mounts. When solenoid actuator is actuated by means of external source, it forces the rod against the spring force. This inside movement of actuator rod presses the ball in left direction against small balancing spring. The principle of non-return valve is achieved by using a solenoid actuator. As soon as spherical ball displaces from its mean position towards the left, there is free opening for hydraulic oil through the orifice. The oil starts flowing downwards through orifice slowly to the bottom of the cylinder body. A small cavity is provided below the orifice. In solenoid actuation condition, when engine is running at different rpm then all dynamic forces are taken by the piston as discussed earlier. The loads are transmitted to piston spring and oil and hence energy is dissipated here. Spring and fluid offer resistance to piston travel. Now there are two passages for the flow of fluid due to high pressure which is created in pumping chamber. 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. This means that the damping is superior as compared to passive hydraulic mount. 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 Analysis of Piston Design

Material: EN9 [19]

Table 3.3.1 Selection of material for Piston

Part Name	Ultimate tensile strength, N/mm^2	Yield strength N/mm^2
Piston	600	380

σ_{all} = Sut / FOS

Considering FOS = 4,

$\sigma_{all} = 600/4 = 150\ N/mm^2$ for piston and reservoir.

Diameter of Piston = 8 mm

Area of piston, $R = \pi d^2 = 50.26\ N/mm^2$

Axial load on Piston (P) = 18.63 N

Stress due to load of engine, $\sigma_{th} = P / A = 0.3706\ N/mm^2$

FEA analysis of Piston

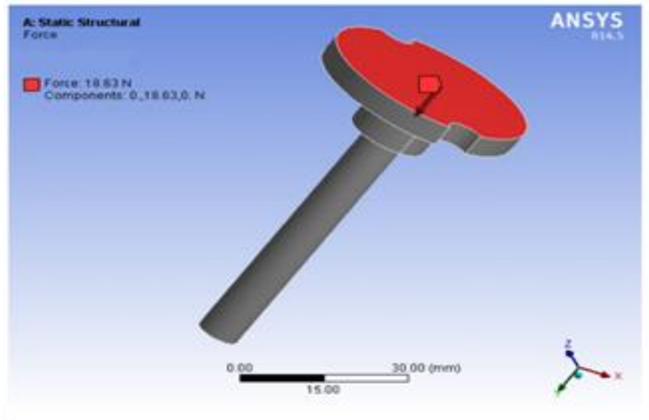

Fig.3.3.1 Loads given to the piston

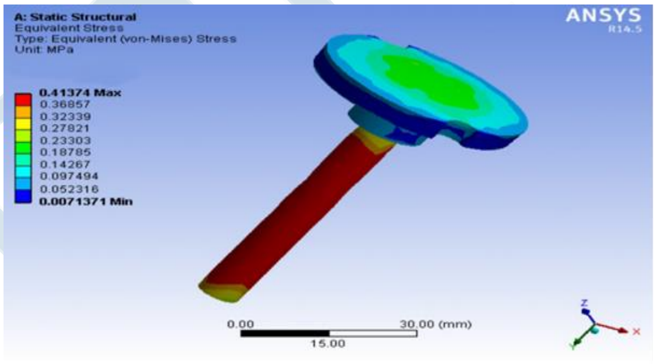

Fig.3.3.2 Solution for equivalent (Von-Mises) stress

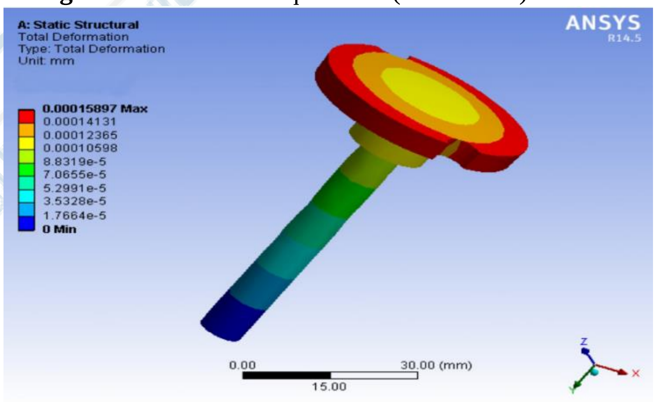

Fig.3.3.3 Deformation after loading.

Table 3.3.2 Result analysis of Piston

Part Name	Theoretical Stress, N/mm2	Von-Misses stress, N/mm2	Deformation, mm	Result
Piston	0.37	0.415	0.00015	safe

1. Maximum stress by theoretical method and Von-Mises's stress is well below the allowable limit, hence the piston is safe

2. Piston shows negligible deformation under the action of forces.

So, the designed piston which is critical component of HEM is safe and can be implemented in actual use.

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3.4 Analysis of reservoir Design

Material: EN9 [19]

Table 3.4.1 Selection of material for Reservoir

Part Name	Ultimate tensile strength, N/mm^2	Yield strength N/mm^2
Reservoir	600	380

It is considered that the pressure inside the reservoir is one-third than the pressure in the cylinder. So, pressure inside the reservoir = 0.125 MPa. This is nothing but maximum theoretical stress developed in the reservoir.

FEA analysis of reservoir

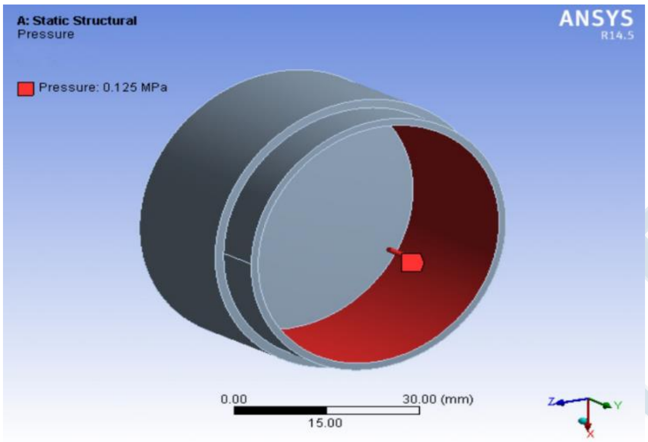

Fig.3.4.1 Pressure given to the reservoir

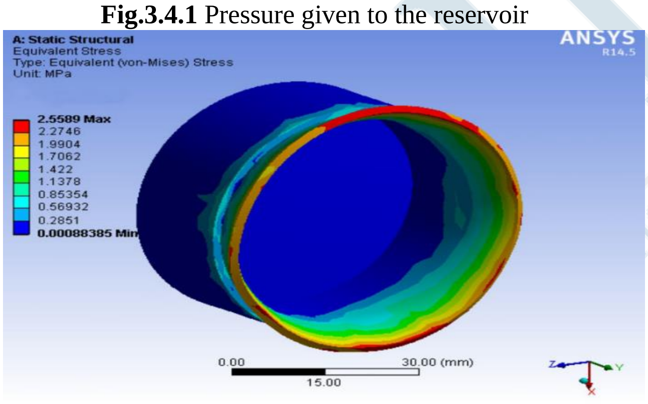

Fig.3.4.2 Solution for equivalent von mises stress

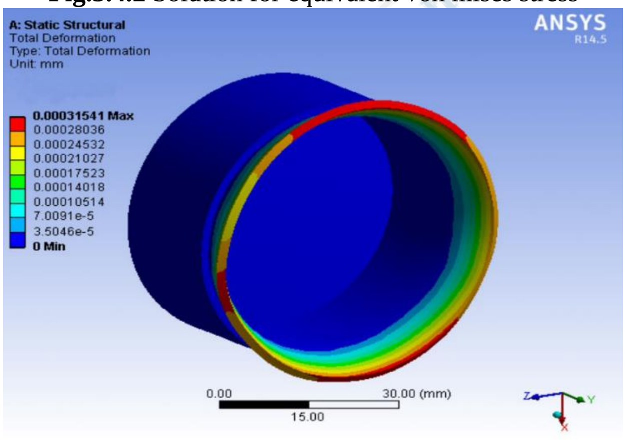

Fig.3.4.3 Deformation in reservoir

Table 3.4.2 Results analysis of Reservoir

Part Name	Theoretical Stress, N/mm^2	Von-Misses stress, N/mm^2	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

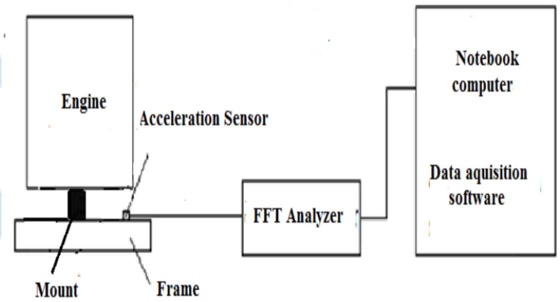

Fig.4.1 Schematic of experimental Set-up

The general arrangement of experimental analysis for set-up is as illustrated in Fig. The frequency response of the machine frame subjected to engine vibrations at different rotational speed of the engine is tested by using FFT analyzer. First of all, the engine was allowed to stable or run at constant rpm. Then analyzer was set to particular frequency. After this reading was taken one by one. All this data is entered into the computer by using data acquisition software. The SKF FFT analyzer is used for testing purposes of hydraulic engine mounts as well as neoprene rubber mounts. Acceleration values are found at different rotational frequencies by using FFT analyzer. These readings are available in graphical form of acceleration verses frequency. According to readings, performances are analyzed.

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V. RESULTS AND ANALYSIS

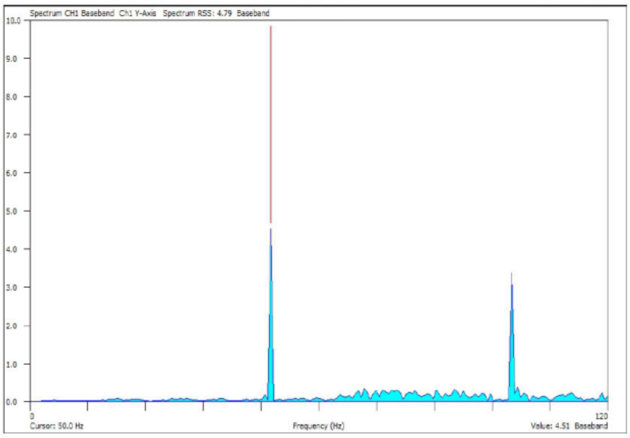

Fig.5.1 Acceleration verses frequency graph at 50 HZ for passive HEM

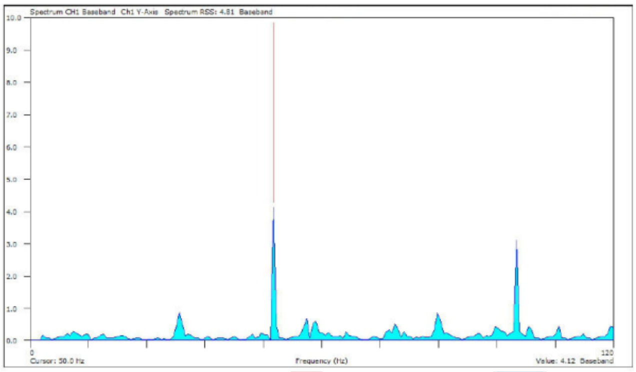

Fig. 5.2 Acceleration verses frequency graph at 50 HZ for solenoid actuated HEM

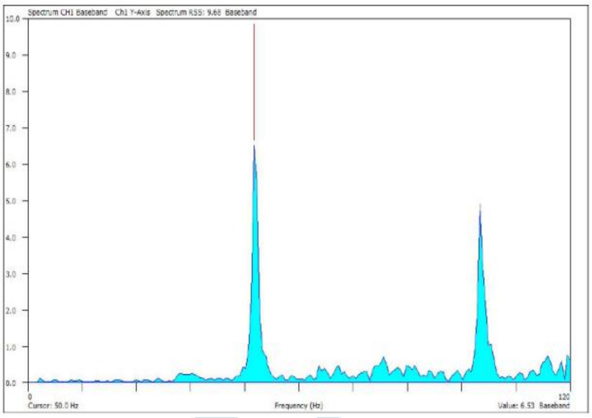

Fig.5.3 Acceleration versus frequency graph at 50 HZ for Neoprene rubber mount

Table5.1 Results of FFT readings

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	2000	33.33	2.34	1.96	4.46
3	2500	41.66	3.72	3.31	5.34
4	2600	43.33	3.91	3.68	5.73
5	3000	50	4.51	4.12	6.51

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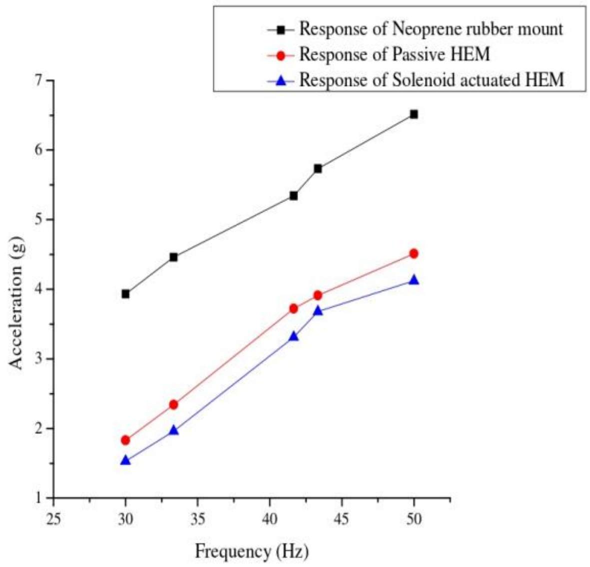

Fig.5.4 Comparison between tested mounts

From the performances of above three mounts, it comes to know that at the excitation frequency of 50 Hz when last reading was collected, the vibration acceleration of rubber mount is very high. Passive hydraulic mount shows a considerable reduction in vibrations to about 30.93% when evaluated with rubber mount. After actuating solenoid, vibrations are further reduced to 36.75% compared to rubber mount. At 50 Hz, solenoid actuation reduced the vibrations to 9% when evaluated with the passive hydraulic engine mount. This introduction of the solenoid actuator in passive hydraulic mount gives better results in terms of isolation. As per the will of the operator, the solenoid is actuated by switching on-off. When the solenoid is off position, mount becomes passive. Both passive and active features are included in same mount which gives better performance, which is cleared through above experimentation. Thus, to meet the comfort requirement of operator by reducing hand arm vibrations, it is clear that isolation should be better [12].

VI. CONCLUSION

A new configuration of hydraulic engine mount is designed for agricultural applications; critical components like the piston and reservoir are designed and validated by using FEA. These components of the passive hydraulic mount are safe.

Advancement in a designed passive hydraulic engine mount is done by incorporating DC solenoid actuator to make the mount active for better.

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.

Theoretical calculation shows that vibration acceleration transmitted to frame at 50 Hz frequency is 4.63g for passive hydraulic mount. The experimental value of a passive hydraulic mount i.e., 4.51g at 50 Hz deviates from the theoretical value by 2.8% because of working and environmental conditions.

When passive hydraulic mount is evaluated with solenoid actuated hydraulic mount at 50 Hz, the vibrations are reduced to 9% by solenoid actuated mount.

To meet the comfort level of the operator while working on handheld machinery, it is clear that solenoid actuated hydraulic engine mount isolation is better.

VII. FUTURE SCOPE

The hydraulic mount is designed for low-cost handheld agricultural machinery. It is tested on 35 cc petrol engine. So, in the future work, the same approach can be used for designing vibration control system in high-cost machinery to reduce vibrations.

In this research, ON- OFF solenoid is selected to make the passive mount into an active state. This solenoid actuation can be done automatically by employing closed loop system. The solenoid will be actuated as per vibrations of the frame.

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