Reducing the impact and operating conditional Mechanical vibrations on Hydraulic valves: Experimentally and Theoretically

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Abstract - *Vibrational behavior of fluid power systems is a very important aspect regarding life-time of the components and especially noise problems within hydraulic circuits. Vibration emitting and noise generating elements in hydraulic systems are valves. The impact of mechanical vibrations on the environment, particularly on hydraulic valves is one major problem in industry. Two ways of reducing the impact of mechanical vibrations on the valve are proposed and a theoretical analysis, constituting the basis for selecting a material for an effective vibration isolator for the valve, is carried out. The objective of this study is to minimize a vibration in hydraulic system especially in hydraulic valve using various isolators like rubber pads of different thickness, washer, damper etc. and analyses the system by using FFT analyzer, MATLAB and ANSYS software. MATLAB analysis is done to find the anti-vibrating materials which have minimum vibration at same force applied on it and have three forces different operating condition. ANSYS analyses are for comparing same anti-vibrating materials with different size and shape as well as choose appropriate anti-vibrating materials among all. To find anti-vibrating materials which have minimum vibration at same force applied on it by using FFT analyzer, experimentation done. Finally, comparing all the results which obtain by software analysis and experimentally selection of one appropriate anti-vibrating material is done.*

***Key Words*: Hydraulic Valve, Vibration, Isolator, MATLAB Analysis, Finite Element Analysis, FFT Analyzer, Anti-vibrating Material**

1. INTRODUCTION *(Size 11 , cambria font)*

Vibrational behavior of fluid power systems is a very important aspect regarding life-time of the components and especially noise problems within hydraulic circuits. Vibration emitting and noise generating elements in hydraulic systems are valves.

The impact of mechanical vibrations on the environment, particularly on hydraulic valves is one major problem in industry. Two ways of reducing the impact of mechanical vibrations on the valve are proposed and a theoretical analysis, constituting the basis for selecting a material for an effective vibration isolator for the valve, is carried out.

A running engineering machine is a source of mechanical vibrations with a wide spectrum of frequencies, including low frequencies. The vibrations act on the operator inside the machine, on all the machine subassemblies and subsystems and indirectly, on the surrounding environment. For the sake of the health of the machine's valves, it is essential to identify the mechanical vibrations to which they are subjected. Such vibrations often may disturb the operation of the entire hydraulic system of a mobile machine. A disturbance in the operation of such a system is reflected in a change in the pressure fluctuation spectrum. The disturbance may lead to deterioration in the accuracy of positioning the actuators, to uneven operation, shortening of the machine's life and sometimes to a higher level of low-frequency noise emitted. Low-frequency vibrations and noise have a particularly adverse effect on hydraulic valves and the human being. In hydraulic valves they may excite the vibration of their control elements (such as the slide and the head). This occurs when the frequency of the external mechanical vibrations is close to that of the free vibrations of the valve control element. In the case of a human being, the vibrations via the skin mechanoreceptors transmit specific information to the central nervous system, causing reflex reactions of the human body. The vibrations are accompanied by noise, also with low-frequency components. The noise is the subject of EU standard regulations. Hydraulic equipment producers, however, rather seldom specify the operating requirements concerning the resistance of their products (e.g. valves) to mechanical vibrations.

In the recent past there has been a significant increase in the use of hydraulics in our industries. The use of oil hydraulic system as a means of power transmission in modern machines evolved a few decades earlier in the western world. But its application in Indian industries is of comparatively recent choice and hence, there is great deal of urgency and importance to master the art of its application and maintenance. Hydraulic system are not extensively used in machine tools, material handling devices, transport and other mobile equipment, in aviation system, etc. At the movement there exists a big gap between the availability and requirement of trained manpower in this vital field of modern engineering in India. To bridge the gap, it is essential that our design and application engineering and maintenance personnel from the lowest to highest level are given extensive, on the job training so that operation efficiency of machineries using a hydraulic system as the prime source of power transmission can be maintained at an optimum level. Apart from fluid power system designer, a good maintenance and millwright mechanism should also have first-hand theoretical knowledge to enable him to tackle practical problems encountered during installation, operation and maintenance of hydraulic equipment.

The purpose of this test is to determine any mechanical weakness and/or degradation in the specified performance of specimens and to use this information, in conjunction with the relevant specification, to decide upon the acceptability of the specimens. In some cases, the test method may also be used to demonstrate the mechanical robustness of specimens and/or to study their dynamic behavior. Categorization of components can also be made on the basis of a selection from within the severities quoted in the test.

The objective of this study is to minimize a vibration in hydraulic system especially in hydraulic valve using various isolators like rubber pads of different thickness, washer, damper etc. and analyses the system by using FFT analyzer and MATLAB, ANSYS software.

2. Vibrating System

HV is a vibrating system which vibrations should be reduces. The hydraulic valve is mount on one platform, on same platform electric motor which sucks the hydraulic oil is mounting. Therefore the vibration on hydraulic valve is due to two reasons first is due to vibration of electric motor it means when electric motor run or doing its operation vibration is produce due to this vibration hydraulic valve also vibrates. Second is due to vibration of hydraulic valve itself it means that when valve is in working due to change in pressure of flow of hydraulic fluid vibration is occur in hydraulic valve. Due to both vibration hydraulic valve is vibrate.

Therefore, vibrating system consists:

1) Hydraulic valve
2) Hobbing machine
3) Electric motor which is mounting on same platform of HV

2.1 Direction Control Valve

To carry out such directional movement to several cylinders, the hydraulic system uses several directional control valves. The valves are mostly actuated electrically through solenoids. These valves change the direction of the flow of the hydraulic oil to the various cylinders and the control is eccentrically done by the operator in the proper sequence. It consists of spool inside a cylinder which is mechanically or electrically controlled. The movement of the spool restricts or permits the flow, thus it controls the fluid flow.

We are use the directional control valve i.e. 4/2 solenoide operating DCV. Which have two operating position and four port. Its designation is – DSG-01-2B2-A240-N1-50

Its maximum pressure is 315 kcf/cm^{2}and the operating temperature range is (-15^{0}C to 60^{0}C) i.e. temperature of oil use in valve.

Specifications of valve:

- Designation – DSG-01-2B2-A240-N1-50
- Maximum flow – 63 L\min
- Maximum operating pressure – 315 kcf/cm^2
- Maximum T- line back pressure – 160 kcf/cm^2
- Maximum changeover frequency – 300 cycle\min
- Mass – 2.2 kg

2.2 Hobbing Machine

Hobbing machine is do vertical broaching processes. Broaching is a machining operation in which the tool has a linear displacement. The tool shape is the same as the part shape and is well suited to producing complex cross sections. In broaching, each tooth progressively removes some material, to produce the final shape. All operations (roughing, semi-finishing, finishing) are achieved in a single pass. Specially recommended for large series, broaching is an alternative technology to milling, boring, turning, grinding and EDM. The broaching process is extremely accurate. The efficiency demonstrated in heavy production is unmatched by any other process. Broaching is especially suitable for automotive factories where high efficiency and a high level of accuracy is required. A surface broach is used to remove material from an external surface. Surface broaching is usually carried out on a vertical machine with a broach which is either pushed or pulled down. The entire length of the broach is usually fixed to the machine.

Hydraulic valve is providing hydraulic fluid to the hobbing machine. During the operation on hobbing machine pressure of HF is changes. By considering three conditions of operation (say starting, during and ending) pressure of HF is change and this change in pressure of HF is cause of vibration obtained in HV.

2.3 Electric Motor

An electric motor is an electrical machine that converts electrical energy into mechanical energy. Most electric motors operate through the interaction between the motor's magnetic field and winding currents to generate force. Electric motors can be powered by direct current (DC) sources, such as from batteries, motor vehicles or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters or generators.

Electric motors are one of the most commonly used pieces of equipment in industry. A basic electric motor has a magnetized stator that surrounds a rotor; the magnetic interaction between the two causes the rotor to spin. Faults in motors can develop due to resonances, imbalance, misalignment and foundation problems or improper mounting. These faults can lead to bearing failures and cause vibration.

3. Anti-vibrating Material

The common materials utilized for vibration isolation such as cork, felt, glass fiber, or elastomats, offer a wide choice to fit most requirements. The main differences between these materials are their stiffness, or natural frequency characteristics, and the amount of damping each can provide. However, the selection of the particular material is usually based on such non-vibration oriented requirements as resistance to chemicals, tear strength, abrasion resistance, cost, lateral stability, and load capacity. For example, natural rubber has good isolation. Characteristics and fair temperature dependent properties, but does not age well and does not have the resistance to chemicals possessed by some of the synthetics. Glass fiber which has been pre-stressed and compressed to high densities provides an effective vibration isolation system for floors of large buildings. Floating floor systems can be effective isolators, protecting sensitive instruments from building structural vibration, or preventing equipment vibrations from being transmitted to the building structure. Glass fiber pads are also used as unit isolators for machinery mountings. Cork pads, which consist of natural cork granules compressed and steam baked to form slabs of the desired density, have fine aging characteristics and are particularly suitable for isolating concrete foundations. Felt pads are used for applications in which an isolation material with good cementing characteristics is important. Felt has found widespread use in the textile machinery field and is generally recommended when machinery movement or rebound must be closely controlled.

3.1 Isomat

Isomat is a high quality, easy to use and economical elastomatic isolation material. It has low frequency vibration, acoustic and shock isolation. It is high quality chloro-prepen or neoprene compound.

- <u>Features:</u>
- High resilience and low damping characteristics.
- Excellent shock absorption characteristics.
- Excellent ozone, oil and general chemical resistance.
- Low level of creep.
- Long lifetime.
- Fire / flame resistance.

3.2 Synthetic Rubber

It is a high performance general purpose anti vibration material used globally in a very wide range of industrial equipment and machine mounting applications as well as in buildings and structures.

<u>Features:</u>

- Reduces noise and vibration
- Excellent chemical resistance including oil, grease, cleansing agents
- Stable under a wide range of atmospheric conditions
- Low poisons ratio
- Ability to withstand very high dynamic and static loads
- Wide temperature range (-25^{0}C to +120^{0}C)
- Easy to cut into strips and pads

3.3 Natural Rubber

It is an 'environmentally friendly', high performance, durable and economical solution to provide vibration and impact sound insulation. It is produced from the highest quality recycled rubber and foam granulate with a polyurethane bonding agent in tightly controlled, state of the art manufacturing processes.

<u>Features:</u>

- 100% recycled and 100% recyclable
- Excellent impact sound insulation and vibration absorption
- Operating Loads up to 0.11N/mm2 (110kPa)
- Simple and quick installation methods
- Excellent long-term resilience
- Resistance to moisture absorption and rot

3.4 Washers

Washers are used to isolate bolt-through connections by providing a resilient separation of the bolt and the isolated structure where there is no space available for an isolation sleeve.

<u>Features:</u>

- Used in conjunction with acoustic / anti-vibration pads to provide a degree of vibration isolation across bolt-through fixings where they are required for stability and security.
- They can be used in conjunction with other washers to increase acoustic performance by stacking together Manufactured for durability, performance and ease of onsite installation by vulcanising zinc plated washers to a Chloroprene (Neoprene) acoustic washer.
- Good oil, chemical and fire resistance.
- Operating temperature range from -10 to +90ºC

3.5 Selection of Anti-Vibration Materials

Selection of anti-vibration materials is based on parameters like range of temperature, types of failure, chemical properties, cost of material etc. Comparison done between various materials as shown below:

Table -1 Comparison of AVM's

	Chemical resistance	Temp range (°C)	Failure	Avail-ability	Other properties
Isomat	Good	-30 to +120	Low creep rate (high age)	Medium	Shock absorber and flame resistance
Rubber	Ok	-30 to +80	Low age	High	Resistance to moisture absorption and recyclable
Cork	Good	-25 to +120	Creep rate 1.7	Low	……………….
Washer	Good	-10 to +90	Deflection 0.4 to 1.0	High	Fire resistance

According to the comparison isomat is a good material, so we use isomat, synthetic rubber and washer as ant vibration materials. Availability of rubber is very high and its cost is comparatively lower than isomat, rubber materials are available in various size and shape and its properties like temperature range and failure age is suitable for valve. So rubber synthetic materials and isomat materials are selected.

3.6 Selected AVM's

Nitrile Rubber

Nitrile Rubber is synthetic rubber. It is high performance vibration and shock damping material. It has excellent chemical resistance property. It has high damping coefficient also deflation of material is less. Properties of AVM from catalogue is 1) damping coefficient = 0.09 2) dynamic frequency = 90 Hz 3) Deflection = 0.3 mm

Rubber Re-inforced with cotton

Rubber Re-inforced with cotton is synthetic rubber. It is neopropen compound which is moulded with cotton material. Properties of AVM from catalogue is 1) damping coefficient = 0.16 2) dynamic frequency = 300 Hz 3) Deflection = 0.04 mm

Isomat

Isomat is elastomeric material. It is high quality ISO6446 compliant chloroprene compound. It provides excellent low frequency vibration, acoustic and shock isolation. It has high damping coefficient also deflation of material is less. Properties of AVM from catalogue is 1) damping coefficient = 0.13 2) dynamic frequency = 22.5 Hz 3) Deflection = 0.75 mm

Washer

Material of washer is Chloroprene (Neoprene) compound, which is synthetic rubber. Properties of AVM from catalogue is 1) damping coefficient = 9.5 N-sec/mm 2) Deflection = 1.00 mm

This four AVM's are selected by comparing it's mechanical properties, availability and price's from above selecting categories; which categories are selected upon AVM's availability, there chemical properties like resistance, range of temperature, types of failure etc.

4. Matlab Software

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include:

- Math and computation
- Algorithm development
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including Graphical User Interface building

4.1 Calculations for MATLAB analysis

We known that basic mathematical equation for any vibratory system is
$m\ddot{x} + c\dot{x} + kx = F \sin \omega t$

So, Calculations for MATLAB is as follows –

Stiffness and Damping Coefficient of AVM's

To calculate theoretical value of stiffness (k) and damping coefficient (c) of anti-vibrating material

For Nitril Rubber (i.e. sample R_2 and R_3) :

I) Stiffness of rubber =>

$$k = \frac{mass\ of\ system}{deflaction\ in\ antivibating\ pad} = \frac{m}{\Delta s}$$

We know the mass of system from eq.(2)

m= 169 N and Δs =0.3 mm (apprax.)

$$k = \frac{m}{\Delta s} = \frac{169}{0.3}$$

$$\boldsymbol{k = 563.33\ N/mm}$$

II) Coefficient of rubber =>

$$c = \zeta \times 2m\omega_n$$
$$= \zeta \times 2m \times 2\pi f$$

from catalogue,

ζ = 0.09

f_{dynamic} = 90 Hz

So,

$$c = 2m \times 2\pi \times \zeta \times f$$

$$= 2 \times 169 \times 2\pi \times 0.09 \times 90$$

c = 17193.38 N-sec/mm

For Rubber re-inforced with cotton (i.e. sample R_1) :

I) Stiffness of rubber =>

$$k = \frac{mass\ of\ system}{deflaction\ in\ antivibating\ pad} = \frac{m}{\Delta s}$$

We know the mass of system from eq.(2)

m= 169 N and Δs =0.04 mm (apprax.)

$$k = \frac{m}{\Delta s} = \frac{169}{0.04}$$

$$\boldsymbol{k = 4225\ N/mm}$$

II) Coefficient of rubber =>

$$c = \zeta \times 2m\omega_n$$

$$= \zeta \times 2m \times 2\pi f$$

from catalogue,

ζ = 0.16

f_{dynamic} = 300 Hz

So,

$$.c = 2m \times 2\pi \times \zeta \times f$$

$$= 2 \times 169 \times 2\pi \times 0.16 \times 300$$

c = 17193.38 N-sec/mm

For Isomatic material (i.e. sample E_1 and E_2) :

I) Stiffness of rubber =>

$$k = \frac{mass\ of\ system}{deflaction\ in\ antivibating\ pad} = \frac{m}{\Delta s}$$

We know the mass of system from eq.(2)

m= 169 N and Δs =0.75 mm (apprax.)

$$k = \frac{m}{\Delta s} = \frac{169}{0.75}$$

$$\boldsymbol{k = 225.33\ N/mm}$$

II) Coefficient of rubber =>

$$c = \zeta \times 2m\omega_n$$

$$= \zeta \times 2m \times 2\pi f$$

from catalogue,

ζ = 0.13

f_{dynamic} = 22.5 Hz

So,

$$c = 2m \times 2\pi \times \zeta \times f$$

$$= 2 \times 169 \times 2\pi \times 0.13 \times 22.5$$

c = 6.208 N-sec/mm

For Washer material (i.e. sample W_1,W_2 and W_3) :

I) Stiffness of rubber =>

$$k = \frac{mass\ of\ system}{deflaction\ in\ antivibating\ pad} = \frac{m}{\Delta s}$$

We know the mass of system from eq.(2)

m= 169 N and Δs =1.00 mm (apprax.)

$$k = \frac{m}{\Delta s} = \frac{169}{1.00}$$

$$\boldsymbol{k = 169\ N/mm}$$

II) Coefficient of rubber =>

$$c = \zeta \times 2m\omega_n$$

$$= \zeta \times 2m \times 2\pi f$$

from catalogue,

$\boldsymbol{c = 9.5}$ **N-sec/mm**

4.2 Mass of Vibrating System

Anti-vibrating pads are inserting below the hydraulic valve, so to calculate the force on the Anti-vibrating pads we have consider load/force on hydraulic valve which is cause of vibration of hydraulic valve. Hydraulic valve and the motor which provide hydraulic fluid to valve is mounting on same platform so, the vibration in hydraulic valve is due to vibration in motor. Also vibration due to resistance or flow of hydraulic fluid is negligible. Therefore the total mass of vibrating system is a mass of electric motor and the mass of hydraulic valve.

We have to calculate mass of system,

Power of Motor = 3 hp = 2238 watt

Speed of Motor = 1440 RPM

$$power\,(in\ watt) = torque \times \frac{2\pi \times speed\,(in\ rpm)}{60}$$

$$\therefore torque = \frac{power \times 60}{2\pi \times speed}$$

$$\therefore torque = \frac{2238 \times 60}{2\pi \times 1440}$$

$$\therefore torque = 14.84\ N.m$$

We know, $torque = force \times 2\pi r$

Where, r =radius of armature of motor =14mm =14$\times 10^{-3}$m

$$\therefore force = \frac{14.84}{2\pi \times 14 \times 10^{-3}} = 168.70\ N$$

$168.70N = 17.2\ kg$ ……….(1kg = 9.81 N)

We known, the mass of hydraulic valve = 1.6 kg

So, **Total mass of vibrating system = 17.2 + 1.6 =18.8 kg (i.e.184.5N)**

4.3 Force (F) on AVM's

Also find the force on anti-vibrating pad at various operating conditions. Change in force of hydraulic valve during operation is depending upon operating condition and specification of machine.

The machine is a hobbing machine; hobbing is a machines process for making gears, splines and sprockets on a hobbing machine, which is a special type of milling machine. The teeth or splines are progressively cut in to the work piece by series of cuts made by a cutting tool called a hob. Compare to the other gear forming process it is relatively in expensive but still quite accurate, thus it is used broad range of parts and quantities. It is most widely used gear cutting process for creating spur and helical gears and more gears are cut by hobbing than any other process since it is relatively quick and in expensive. Details of machine are follows

Table -2 Specifications of Hobbing machine and tool

1.	Cutting speed of tool	: 280 mm/min = 0.28 m/min
2.	Material of tool	: carbide
3.	Maximum length of work piece	: 80 mm
4.	Pitch	: 0.5 module
5.	No. of Teeth	: 43
6.	Rack angle	: 30^0
7.	Width of work piece	: 60 mm
8.	Diameter of work piece	: 40 mm
9.	Tensile strength of tool	: 344.8 MPa
10.	Material of work piece	: Mild Steel
11.	Rise per tooth	: 0.1
12.	Cutting depth/tooth	: 0.03
13.	Specific cutting resistance	: 3 kN/mm²

We knew the table of calculation:

Table No. 5.2. Calculations for cmti data book

1.	Cutting speed	v	m/min
2.	Maximum length of work piece	ℓ_{max}	mm
3.	Pitch of broach teeth	p	mm
4.	No. of teeth cutting at a time	Z	$Z=\frac{\ell_{max}}{p}+1$
5.	Rack angle	γ	Deg.
6.	Tensile strength of work piece	σ	Kgf/mm²
7.	Rise per tooth	Sz	mm
8.	Specific cutting force	Ks	Kgf/mm²
9.	Sum of length of all teeth engaged at any instant	L*	mm
10.	Cutting force	Pz	Kgf

- $Ks = 450 + 3\sigma - 11\gamma - 2500Sz$
- $L = \pi dz$
- $Pz = Ks.L.Sz$

To calculate cutting force of tool, from above table

1) $Ks = 450 + 3\sigma - 11\gamma - 2500Sz$

$= 450 + 3 \times 344.8 - 11 \times 30 \times \frac{\pi}{360} - 2500 \times 0.1$

= 1231.52 kgf/mm²

2) $L = \pi dz$

$.z = \frac{80}{43} + 1 = 2.86$

$.L = \pi \times 40 \times 2.86 = 359.39$mm

3) $Pz = 1231.52 \times 359.39 \times 0.1 = 434.05\ kN$

To calculate load on anti-vibrating pad

$Load = width\ of\ cut \times cutting\ depth/tooth \times no.of\ eng$

For, no.of engaged cutting teeth = 1

$L_1 = 60 \times 0.03 \times 1 \times 3 = 5.4\ kN$

For, no.of engaged cutting teeth = 20

$L_2 = 60 \times 0.03 \times 20 \times 3 = 108\ kN$

For, no.of engaged cutting teeth = 43

$L_3 = 60 \times 0.03 \times 43 \times 3 = 232.2\ kN$

4.4 MATLAB Analysis

We have do MATLAB analysis to find the anti-vibrating material which have minimum vibration at same force applied on it. We have three forces at different operating condition; by applying that first we are found equations as below:-

We known the basic equation which is used in MATLAB

$$m\ddot{x} + c\dot{x} + kx = F \sin \omega t$$

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$$\therefore \ddot{x} = \frac{1}{m}[-c\dot{x} - kx + F\sin\omega t]$$

Equations in MATLAB

For nitrile rubber:-

1. $184.5\ddot{x} + 17193.3\dot{x} + 563.33x = 5400 \sin\omega t$
2. $184.5\ddot{x} + 17193.3\dot{x} + 563.33x = 108000 \sin\omega t$
3. $184.5\ddot{x} + 17193.3\dot{x} + 563.33x = 232200 \sin\omega t$

For rainforced rubber:-

1. $184.5\ddot{x} + 101.8\dot{x} + 4225x = 5400 \sin\omega t$
2. $184.5\ddot{x} + 101.8\dot{x} + 4225x = 108000 \sin\omega t$
3. $184.5\ddot{x} + 101.8\dot{x} + 4225x = 232200 \sin\omega t$

For elastomer material:-

1. $184.5\ddot{x} + 6.21\dot{x} + 225.3x = 5400 \sin\omega t$
2. $184.5\ddot{x} + 6.21\dot{x} + 225.3x = 108000 \sin\omega t$
3. $184.5\ddot{x} + 6.21\dot{x} + 225.3x = 232200 \sin\omega t$

For washer:-

1. $184.5\ddot{x} + 9.5\dot{x} + 169x = 5400 \sin\omega t$
2. $184.5\ddot{x} + 9.5\dot{x} + 169x = 108000 \sin\omega t$
3. $184.5\ddot{x} + 9.5\dot{x} + 169x = 232200 \sin\omega t$

We have speed of system is 1440 rpm, so the frequency of system is

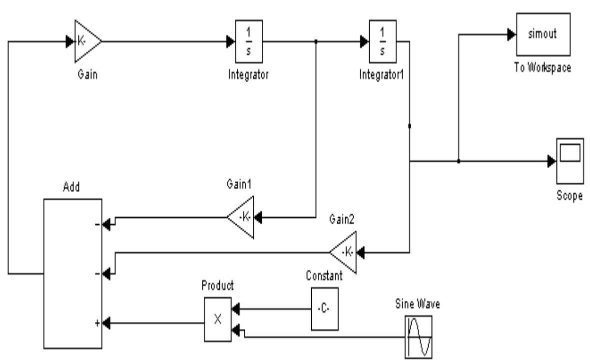
$$f = \frac{\omega}{2\pi}$$

$$\therefore f = \frac{1440}{2\pi}$$

$$= 229.183\ Hz$$

4.5 Simulink model

Simulink model for above equation –



4.6 Result of MATLAB analysis

MATLAB analysis is done for four AVM and three force F1= 5400 N, F2=108000 N and F3=232200 N. Only peak to peak analysis of vibrational amplitude is done from above graphical results and then plot result table as follow.

Table - 3 Peak to peak analysis of vibrational amplitude

Force(in N)	5400	108000	232200
anti-vibrating material amplitude (in mm)			
Nitrile rubber	0.0017	0.036	0.077
Rainforced rubber	0.025	0.50	1.05
Elastomer	0.12	2.25	5.00
Washer	0.13	2.50	5.5

From above result table we can conclude that two materials Nitrile rubber and Re-inforced rubber having minimum amplitude; so it should have minimum vibration. It means that it is good anti-vibrating material within all four materials. So theoretical and by doing MATLAB analysis we can conclude that the Nitrile rubber and Re-inforced rubber having high anti-vibration property.

5. FEA of Anti-vibrating Material

Vibational stress analysis done by using ANSYS software. Objective of this analysis is to choose best AVM from different types of material and in same material different type of shape and size, so we use different size and shape of AVM for Finite Element Analysis.

5.1 Material properties of AVM

For all the AVM some common conditions are-

1) Force exerted on AVM during operation is F2=108000N
2) AVM and Hydraulic Valve have vertical vibrations
3) Horizontal support is fixed (i.e. AVM is place on foundation)
4) Properties of all AVM required for analysis are given below

5.2 Harmonic Analysis

A harmonic analysis is used to determine the response of the structure under a steady-state sinusoidal (harmonic) loading at a given frequency. A harmonic, or frequency-response, analysis considers loading at one frequency only. Loads may be out-of-phase with one another, but the excitation is at a known frequency. This procedure is not used for an arbitrary transient load. Harmonic Analysis we have given one face as a fixed support and on other face we applied load which is taken from the experimentation loading conditions. So that we will get the total deformation from harmonic analysis.

Dimensions of AVM's

AVM are having different shapes for analyses are as follows, and details of their dimension are also mentioned.

- Size A1 of rectangular shape having length 7cm width 6cm and thickness 3cm.
- Size A2 of rectangular shape having length 7cm width 3cm and thickness 3cm.
- Size B1 of washer shape having outer diameter 4.9cm, inner diameter 1.3cm and 3cm height
- Size B2 of washer shape having outer diameter 4.9cm, inner diameter 3.3cm and 3cm height
- Size B3 of washer shape having outer diameter 4.9cm, inner diameter 2.6cm and 3 cm height

Material Properties of AVM

There are four types of the anti-vibration materials are used in the analysis. Detailed material properties are given in the following table. Different shapes are used for analysis

Table- 4 Material Properties of AVM

Properties	Re-inforced Rubber	Nitrile Rubber		Isomat		Washer		
		A1	A2	A1	A2	B1	B2	B3
Density in 10^{-4} Kg/cm^3	9.65	1.34	1.007	8.79	8.93	1.28	1.31	1.39
Poisson's Ratio	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Damping coefficient N-sec/mm	101.8	17193.38	17193.3	6.208	6.208	9.5	9.5	9.5
Elasticity in N/mm^2	5	2300	2300	6.6	6.6	5.5	5.5	5.5
Stiffness in N/mm	4225	563.33	563.33	225.3	225.3	169	169	169

Boundary conditions

Application of the force and the fixed suppot is known as the boundary condition. Fixed support is given to the bottom face of the material, which is applied on the all nodes on the bottom face so that the all nodes on the bottom face has all degree of freedoms constrained. Second boundary condition is the load in the form of force. Force is applied on the top face means on the all nodes available on the top face. Maximum value of the force is 108000N in downward direction.

Result of total deformation in the material is as shown in the table.

5.3 Results

Table -5 Result of FEA

Total deformation of material			
Sr. No.	Material	Size of Material	Deformation in Micrometer
1	Rubber reinforced cotton	A1 sheet	76151
2	Nitrile Rubber	A1 Sheet	165
3		A2 Sheet	916
4	Isomat	A1 Sheet	16830
5		A2 Sheet	31799
6	AVM	B1 Washer	1171.5
7		B2 Washer	4362.1
8		B3 Washer	7822.8

From harmonic analysis we have found the deformation of the anti-vibration material is shown in the above table. We can see that the deformation of the various materials varies as its shape varies. Material Nitrile rubber is having small deformation as compared to the other materials. Also small deformation occurs for size A1 for same material as compare to size A2. When shape wise comparison is done sheet size means cubical size is shows high isolation than hollow cylindrical size, so cubical shape is act as good isolator.

6. Experimentation

Objective of the experimental setup is to choose one appropriate anti-vibrating material from four anti-vibrating materials which is use to reduce vibrations in hydraulic valve. We already choose four anti-vibration materials on the basis of there properties and price, among those we have to select one best material.

Vibration occurs in the hydraulic valve is mainly due to vibration of the electric motor which is mount on same platform on which hydraulic valve is mount, so we have to reduce that vibration by using anti-vibrating material. Then we analyze the change in amplitude of vibration using FFT Analyzer. Details of experimental setup are as follow.

6.1 Vibrating system

As shown in figure, the hydraulic valve is mount on one platform, on same platform electric motor which sucks the hydraulic oil is mounting. Therefore the vibration on hydraulic valve is due to two reasons first is due to vibration of electric motor it means when electric motor run or doing its operation vibration is produce due to this vibration hydraulic valve also vibrates. Second is due to vibration of hydraulic valve itself it means that when valve is in working due to change in pressure of flow of hydraulic fluid vibration is occur in hydraulic valve. Due to both vibration hydraulic valve is vibrate.

Fig -1: Vibrating system

6.2 Anti-vibrating Materials (AVM)

We are choosing four anti-vibrating materials which have different mechanical properties like stiffness and damping coefficient.

R1 is the Re-inforced rubber with cotton material as shown in fig below

Fig -2: AVM1

R2 is the Nitril base rubber material as shown in fig below

Fig -3: AVM2

E1 is elastomer material as shown in fig below

Fig -4: AVM 3

W1 is washers as shown in fig below

Fig -5: AVM4

6.3 Experimental Setup

Direction control HV is regulated pressure and the direction of Hydraulic Fluid which is supply to the hobbing machine. This hydraulic fluid is use during the vertical broaching operation on hobbing machine, so pressure of HF is change during changing the condition of broaching operation. Mainly three operating condition was consider during the vertical broaching process. First is when job is mount on machine and the broaching tool just touch the job, it means just start the operation or first teeth of broaching tool are engaged with job. Second condition is during the broaching operation, means when middle part of vertical broaching is done. Third condition is when the operation is just ended or the last teeth of broaching tool are engaged with job. Therefore during these three conditions due to change in pressure of HF, so vibational force is change and amplitude of vibration on HV also change.

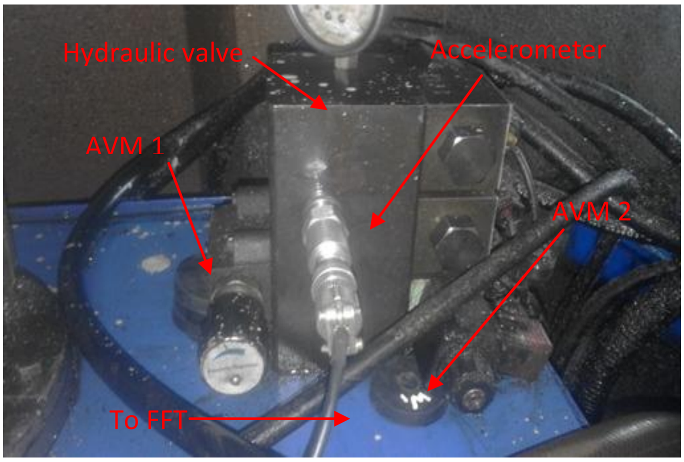


Fig -6: Experimental Setup
(Vibrating system with Accelerometer and AVM)

Hydraulic valve have vibrations; to measure that vibration with and without AVM using FFT Analyzer. FFT Analyzer is connected to the hydraulic valve by using accelerometer; which is transfer vibrational frequency to the FFT in form of electric charge which is equal to the vibrational force. So get amplitude of vibration on the FFT. Then the four different type of AVM insert below the hydraulic valve one after another and take the reading for three different condition of vibrating force. The experimental setup is show fig. 7.8.

6.4 Result of experimentation

Experimentally results of amplitude of vibration of hydraulic valve for particular condition of force and anti-vibrating material is show on FFT screen. From that result table for particular AVM is as shown below. It can be taken peak to peak analysis only i.e. peak-to-peak value of amplitude of vibration.

Table -6 Result Table of Vibration of HV at no AVM

At No AVM	
HV Condition	Amplitude (in micro meter)
Starting operation	216
In middle of operation	205
Ending operation	198

Table -7 Result Table of Vibration of HV at Nitrile Rubber as AVM

At Nitrile Rubber as AVM	
HV Condition	Amplitude (in micro meter)
Starting operation	92.1
In middle of operation	104
Ending operation	148

Table -8 Result Table of Vibration of HV at Re-inforced with cotton Rubber as AVM

At Re-inforced with cotton Rubber as AVM	
HV Condition	Amplitude (in micro meter)
Starting operation	130
In middle of operation	148
Ending operation	153

Table -9 Result Table of Vibration of HV at isomat as AVM

At isomat as AVM	
HV Condition	Amplitude (in micro meter)
Starting operation	153
In middle of operation	160
Ending operation	179

Table -10 Result Table of Vibration of HV at washer as AVM

At washer as AVM	
HV Condition	Amplitude (in micro meter)
Starting operation	160
In middle of operation	167
Ending operation	191

6.5 Conclusion

Results of No-AVM and various AVM should be compare for all condition, we get following result table:

Table -11 Results of No-AVM and various AVM should be compare for all condition

HV Condition	Various AVM amplitude in micro-meter				
	No-AVM	Nitrile Rubber	Rubber Re-inforced with cotton	Elastomer	Washer
Starting operation	216	92.1	130	153	160
In middle of operation	205	104	148	160	167
Ending operation	198	148	153	179	191

From above result table we can conclude that all four AVM has good AVM because its amplitude is less than amplitude of vibational force at No-AVM but amoung all four AVM Nitrile rubber having minimum amplitude; so it should have minimum vibration. It means that it is good anti-vibrating material within all four materials. So experimentally found that Nitrile rubber is good anti-vibrating material; because its amplitude for all the condition of operation is less than another three materials. Therefore choose the Nitrile rubber as AVM for given vibrating system.

7. Result comparison and conclusion

Following Table shows Comparison between all results obtained by MATLAB Analysis and experimentally taken through FFT Analyzer.

Table -11 Comparison between results obtained by MATLAB Analysis and Experimentally taken

Comparison between results obtained by MATLAB Analysis and Experimentally taken										
HV Condition	Various AVM amplitude in micro-meter									
	No-AVM		Nitrile Rubber		Rubber Re-inforced with cotton		Isomat		Washer	
	MATLAB	EXP.	MATLAB	EXP.	MATLAB	EXP.	MATLAB	EXP.	MATLAB	EXP.
Starting operation	0	216	1.7	92.1	2.5	130	120	153	130	160
In middle of operation	0	205	36	104	500	148	2250	160	2500	167
Ending operation	0	198	77	148	1050	153	5000	179	5500	191

we conclude that –

1) As vibrational force on AVM increase it increase amplitude of vibration. Therefore, deflection of AVM also increases. Therefore, we are say that, amplitude of vibration is low AVM has low deflection and good AVM is that which has low amplitude of vibration.
2) All four material are good anti-vibrating materials, its value of deflection is lower than no-AVM is use.
3) Two AVM has low deflation namely, Nitrile Rubber and Rubber Re-inforced with cotton. Form MATLAB analysis result, deflection of Nitrile Rubber is minimum among other materials. Experimentally results also show deflection of Nitrile Rubber is minimum than other materials.
4) The value of amplitude of vibration for Nitrile Rubber is minimum theoretically i.e. MATLAB Analysis as well as experimentally among four AVM. Also it is economically cheap material. Also have chemical resistance property so; it couldn't react with hydraulic valve in case of leakage. Therefore, Nitrile Rubber is select as a AVM for our Hydraulic valve to reduce vibration.
5) By comparing above two table we conclude that Nitrile Rubber has minimum deformation in actual i.e. by experimentation and also by analyzing in MATLAB as well as ANSYS software.
6) Size A1and A2 are cubical in shape, but A1 is large than A2 (A1 > A2), so from the table we conclude that larger size AVM has more isolation than smaller size. Also hollow cylindrical shape of washer shows second less deformation, so hollow shape AVM is act good isolators than solid AVM.
7) When shape wise comparison is done sheet size means cubical size is shows high isolation than hollow cylindrical size, so cubical shape is act as good isolator.
8) From all above discussion, we found that Nitrile Rubber of size A1 i.e. larger size, and cubical shape AVM is minimize vibration of hydraulic valve effectively, so for particular hydraulic valve we select Nitrile Rubber of size A1.

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