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A Review on Vibration Isolation of an Air Compressor by using Sandwich Mount Isolators

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Abstract - As per the recent trends in designing a light weight and more power output equipment's like compressor, automobile engines, aircrafts etc. are required which leads to excessive vibration on the system it can be a serious problem if resonance is occurs. The paper is intended to study and analyze the performance of composite isolators to minimize the vibration of air compressor. The composites of rubber, felt and cork are studied and analyzed. Rubber shows a least transmissibility whereas cork shows highest. From analysis it is seen that it is possible to enhance vibration characteristics by combining rubber with cork or felt.

Key Words: Composite isolator, isolation transmissibility

1.INTRODUCTION

The unwanted motions of the system are always a nuisance. One of the simplest means to reduce the vibration is to use the pads of rubber felt, cork and other vibration absorbing material. These materials are widely used for this purpose. However, this study proposes the sandwich (composite) use of these materials to combine the advantage of the materials that can be obtained if they have been used separately.

2. PROBLEM STATEMENT AND OBJECTIVE

The purpose of this project is to determine the vibration caused by a compressor and then applying passive composite vibration isolators to reduce the transmissibility i.e., vibration transmitted to the base. The combinations of rubber, felt and cork have been used as isolators to reduce the vibration transmitted to the base of compressor. The vibration without isolation is measured and then again measured by using isolator. The ratio gives transmissibility theoretically. For theoretical analysis the value of stiffness, damping ratio and mass plays a major role while the acceleration is determined experimentally by using FFT analyzer with and without isolator. In numerical simulation the amplitude ratios are compared and the transmissibility is determined.

3. LITERATURE REVIEW

R.A.Ibrahim, et. al.[1], presented a paper on "Recent advances in nonlinear passive vibration isolators". In their work, they showed that, a comprehensive assessment of recent developments of nonlinear isolators in the absence of active control means. It does not deal with other means of linear or nonlinear vibration absorbers. It begins with the basic concept and features of nonlinear isolators and inherent nonlinear phenomena. Specific types of nonlinear isolators are then discussed, including ultra-low-frequency isolators. For vertical vibration isolation, the treatment of the Euler spring isolator is based on the post-buckling dynamic characteristics of the column elastic and axial stiffness. Exact and approximate analyses of axial stiffness of the post-buckled Euler beam are outlined. Nonlinear visco-elastic and composite material springs, and smart material elements are described in terms of material mechanical characteristics and the dependence of their transmissibility on temperature and excitation amplitude. The article is closed by conclusions, which highlight resolved and unresolved problems and recommendations for future research directions.

Chen Yang, et. al.[2], presented a paper on "Study of Whole-spacecraft Vibration Isolators Based on Reliability Method". In their work, they showed that, a method for whole-spacecraft vibration isolator design is studied by the author. The WSVI stiffness problem and response problems are discussed. On the basis of the results computed with reliability theory and the data obtained from experiment, the control method of WSVI stiffness and the coupling problem are studied. The VIE problem is also discussed. From the reliability aspect, the NF of WSVI can be controlled over a large domain to avoid the possibility of spacecraft being resonant with the launch vehicle. The effect of NFC and the reliability of vibration isolation can satisfy different launching requirements. In the first part, the stiffness feature of the WSVI is studied with reliability analysis and experimental data. In the second part, the problems induced by stiffness feature are discussed. The simulated and experimental data show that the transmissibility, which is coupled with stiffness, can be reduced by attaching the vibration isolator between the spacecraft and the launch vehicle.

N.F. du Plooy, et. al.[3], presented a paper on "the development of a tunable vibration absorbing isolator". In their work, they showed that, the author describes a tunable vibration absorbing isolator. The device is based on the liquid inertia vibration eliminator, which is modified so that the frequency at which maximum isolation occurs can be changed in real time. This is achieved by using adjustable pneumatic springs. A theoretical model describing the device is derived using Lagrange's equations. The model is used to design a practical device and experimental results confirm the validity of the model. With the experimental device the results were achieved.

S.M. Megahed, et. al.[4], presented a paper on "Vibration control of two degrees of freedom system using variable inertia vibration absorbers: Modeling and simulation". In their work, they showed that, the dynamic modeling and simulation of a proposed modified design of such VIVA's for the vibration control of two d.o.f. primary systems. Lagrange formulation is used to obtain its dynamic model in an analytical form. This model, which is highly nonlinear, is used to develop a computational algorithm to study the absorber performance characteristics. This algorithm is programmed and simulated in Matlab. The obtained results are numerically verified using SAMS2000 software. The effect of mass and stiffness of the proposed VIVA on its performance and tuning is discussed. An optimization algorithm is developed to select the best absorber parameters for vibration suppression of a specific primary system. The obtained results show a good agreement with those obtained using similar techniques. In addition, a linearized model of VIVA dynamics is developed, tested and simulated for the same data used in its nonlinear model. The relative deviation between results of the linear and nonlinear models is less than 1%, which confirms the realistic use of this linearized model.

Y. Du, et. al[5]**,** presented a paper on “Effects of isolators internal resonances on force transmissibility and radiated noise”. In their work, they showed that, the internal dynamics of the isolator, which are also known as internal resonances (IRs) or wave effects, can significantly affect the isolator performance at high frequencies. To study the IR problem, a model of a primary mass connected to a flexible foundation through three isolators is used. In this model, the isolator is represented as a one-dimensional continuous rod that accounts for its internal dynamics. The primary mass is modeled as a rigid body with three d.o.f.’s the effects of the IRs on the force transmissibility and the radiated sound powers from the foundation are examined. It is shown that the IRs significantly increase the force transmissibility and the noise radiation level at some frequencies. These effects cannot be predicted using a traditional model that neglects the inertia of the isolator. The influence of the foundation flexibility on the IRs is also investigated. It is shown that the foundation flexibility greatly affects the noise radiation level but it affects only slightly the force transmissibility, especially at high frequencies where the IRs occurs.

4. THEORY OF VIBRATION ISOLATION

4.1. TYPES OF ISOLATORS

A) Active Vibration Isolation or Electronic Force Cancellation:

As shown in below fig, it is the isolation system employing electric power, sensors, actuators, and control systems Active vibration isolation systems contain, along with the spring, a feedback circuit which consists of a piezoelectric accelerometer, a controller, and an electromagnetic transducer. The acceleration (vibration) signal is processed by a control circuit and amplifier. Then it feeds the electromagnetic actuator, which amplifies the signal. As a result of such a feedback system, a considerably stronger suppression of vibrations is achieved compared to ordinary damping.

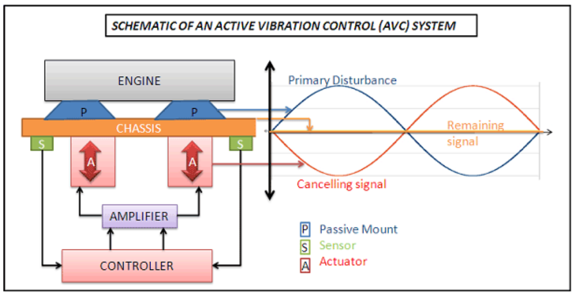

Fig.1. Active Vibration Isolation Systems

B) Passive vibration isolation:

Vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, Passive vibration isolation is a vast subject, since there are many types of passive vibration isolators used for many different applications. A few of these applications are for industrial equipment such as pumps, motors, HVAC systems, or washing machines; isolation of civil engineering structures from earthquakes (base isolation), sensitive laboratory equipment, valuable statuary, and high-end audio. The ideal vibration isolator has high static stiffness to support the isolated structure and low dynamic stiffness to ensure low transmission of dynamic forces. Isolation is achieved at frequencies greater than the square root of two times the mounted resonance frequency. Suppression of unwanted vibrations is an important goal in many applications such as machines, tall buildings, bridges, offshore platforms, pipelines and aircraft cabins. A significant amount of work has been devoted to search for a suitable means to reduce the vibration level in these applications.

Common passive isolation systems:

1. Pneumatic or air isolators -These are bladders or canisters of compressed air. A source of compressed air is required to maintain them. Air springs are rubber bladders which provide damping at the same time as isolation and are used in large trucks. Some pneumatic isolators can attain low resonant frequencies and are used for isolating large industrial equipment. Air tables consist of a working surface or optical surface mounted on air legs. These tables provide enough isolation for laboratory instrument under some conditions. Air systems may leak under vacuum conditions. The air container can interfere with isolation of low-amplitude vibration.

2. Mechanical springs and spring-dampers- These are heavy-duty isolators used for building systems and industry. Sometimes they serve as mounts for a concrete block, which provides further isolation.

3. Pads or sheets of flexible materials such as elastomers, rubber, cork, etc. Cork and/or elastomer pads are often used under heavy machinery or even under audio systems.

4. Molded and bonded rubber and elastomeric isolators and mounts- These are often used as machinery mounts or in vehicles. They absorb shock and attenuate some vibration.

5. Negative-stiffness isolators -Negative-stiffness isolators are less common than other types and have generally been developed for high-level research applications such as gravity wave detection. Lee, Goverdovskiy, and Temnikov (2007) proposed a negative-stiffness system for isolating vehicle seats. The focus on negative stiffness isolators has been on developing systems with Very low resonant frequencies (below 1 Hz), so that low frequencies can be adequately isolated, which is critical for sensitive instrumentation. In addition, all higher frequencies are also isolated. Negative stiffness systems can be made with low stiction, so that they are effective in isolating low-amplitude vibrations. Negative-stiffness mechanisms are purely mechanical and typically involve the configuration and loading of components such as beams or inverted

pendulums. Greater loading of the negative-stiffness mechanism, within the range of its operability, decreases the natural frequency.

6. Wire rope isolators-These isolators are durable and can withstand extreme environments. They are often used in military applications.

7. Bungee cord isolators and tennis balls Bungee cords can be used as a cheap isolation system which may be effective enough for some applications. The item to be isolated is suspended from the bungee cords. This is difficult to implement without a danger of the isolated item falling. Tennis balls cut in half have been used under washing machines and other items with some success.

8. Base isolators for seismic isolation of buildings, bridges, etc. Base isolators made of layers of neoprene and steel with a low horizontal stiffness are used to lower the natural frequency of the building. Some other base isolators are designed to slide, preventing the transfer of energy from the ground to the building.

9. Tuned mass dampers Tuned mass dampers reduce the effects of harmonic vibration in buildings or other structures. A relatively small mass is attached in such a way that it can dampen out a very narrow band of vibration of the structure.

4.2. WORKING OF PASSIVE ISOLATION SYSTEM:

A passive isolation system in general contains mass, spring, and damping elements and moves as a harmonic oscillator. The mass and spring stiffness dictate a natural frequency of the system. Damping causes energy dissipation and has a secondary effect on natural frequency.

Every object on a flexible support has a fundamental natural frequency. When vibration is applied, energy is transferred most efficiently at the natural frequency, somewhat efficiently below the natural frequency, and with increasing inefficiency (decreasing efficiency) above the natural frequency. This can be seen in the transmissibility curve, which is a plot of transmissibility vs. frequency.

Here is an example of a transmissibility curve. Transmissibility is the ratio of vibration of the isolated surface to that of the source. Vibrations are never completely eliminated, but they can be greatly reduced. The curve below shows the typical performance of a passive, negative-stiffness isolation system with a natural frequency of 0.5 Hz. The general shape of the curve is typical for passive systems. Below the natural frequency, transmissibility hovers near 1.A value of 1 means that vibration is going through the system without being amplified or reduced. At the resonant frequency, energy is transmitted efficiently, and the incoming vibration is amplified. Damping in the system limits the level of amplification. Above the resonant frequency, little energy can be transmitted, and the curve rolls off to a low value. A passive isolator can be seen as a mechanical low-pass filter for vibrations.

In general, for any given frequency above the natural frequency, an isolator with a lower natural frequency will show greater isolation than one with a higher natural frequency. The best isolation system for a given situation depends on the frequency, direction, and magnitude of vibrations present and the desired level of attenuation of those frequencies.

All mechanical systems in the real world contain some amount of damping. Damping dissipates energy in the system, which reduces the vibration level which is transmitted at the natural frequency. The fluid in automotive shock absorbers is a kind of damper, as is the inherent damping in elastomeric (rubber) engine mounts.

Damping is used in passive isolators to reduce the amount of amplification at the natural frequency. However, increasing damping tends to reduce isolation at the higher frequencies. As damping is increased, transmissibility roll-off decreases. This can be seen in the chart below.

Passive isolation operates in both directions, isolating the payload from vibrations originating in the support, and also isolating the support from vibrations originating in the payload. Large machines such as washers, pumps, and generators, which would cause vibrations in the building or room, are often isolated from the floor. However, there are a multitude of sources of vibration in buildings, and it is often not possible to isolate each source. In many cases, it is most efficient to isolate each sensitive instrument from the floor. Sometimes it is necessary to implement both approaches.

4.3. FACTORS INFLUENCING THE SELECTION OF PASSIVE VIBRATION ISOLATORS

4.3.1. Characteristics of item to be isolated

a). Size: The dimensions of the item to be isolated help determine the type of isolation which is available and appropriate. Small objects may use only one isolator, while larger items might use a multiple-isolator system.

b). Weight: The weight of the object to be isolated is an important factor in choosing the correct passive isolation product. Individual passive isolators are designed to be used with a specific range of loading.

c). Movement: Machines or instruments with moving parts may affect isolation systems. It is important to know the mass, speed, and distance traveled of the moving parts.

4.3.2. Operating Environment

a). Industrial: This generally entails strong vibrations over a wide band of frequencies and some amount of dust.

b). Laboratory: Labs are sometimes troubled by specific building vibrations from adjacent machinery, foot traffic, or HVAC airflow.

c). Indoor or outdoor: Isolators are generally designed for one environment or the other.

d). Corrosive/non-corrosive: Some indoor environments may present a corrosive danger to isolator components due to the presence of corrosive chemicals. Outdoors, water and salt environments need to be considered.

e). Clean room: Some isolators can be made appropriate for clean room.

f). Temperature: In general, isolators are designed to be used in the range of temperatures normal for human environments. If a larger range of temperatures is required, the isolator design may need to be modified.

g). Vacuum: Some isolators can be used in a vacuum environment. Air isolators may have leakage problems. Vacuum requirements typically include some level of clean room requirement and may also have a large temperature range.

h). Magnetism: Some experimentation which requires vibration isolation also requires a low-magnetism environment. Some isolators can be designed with low-magnetism components.

j). Acoustic noise: Some instruments are sensitive to acoustic vibration. In addition, some isolation systems can be excited by acoustic noise. It may be necessary to use an acoustic shield. Air compressors can create problematic acoustic noise, heat, and airflow.

k). Static or dynamic loads: This distinction is quite important as isolators are designed for a certain type and level of loading.

4.3.3. Cost:

a). Cost of Providing Isolation: Costs include the isolation system itself, whether it is a standard or custom product; a compressed air source if required; shipping from manufacturer to destination; installation; maintenance; and an initial vibration site survey to determine the need for isolation.

b). Relative Costs of Different Isolation Systems: Inexpensive shock mounts may need to be replaced due to dynamic loading cycles. A higher level of isolation which is effective at lower vibration frequencies and magnitudes generally costs more. Prices can range from a few dollars for bungee cords to millions of dollars for some space applications.

4.3.4. Adjustment:

Some isolation systems require manual adjustment to compensate for changes in weight load, weight distribution, temperature, and air pressure, whereas other systems are designed to automatically compensate for some or all of these factors.

4.3.5. Maintenance:

Some isolation systems are quite durable and require little or no maintenance. Others may require periodic replacement due to mechanical fatigue of parts or aging of materials.

4.3.6. Size Constraints:

The isolation system may have to fit in a restricted space in a laboratory or vacuum chamber, or within machine housing.

4.3.7. Nature of Vibrations to be Isolated or mitigated:

a). Frequencies: If possible, it is important to know the frequencies of ambient vibrations. This can be determined with a site survey or accelerometer data processed through FFT analysis. Design Curves for the Transmissibility vs. the frequency ratio is shown in graph 3.1.

b). Amplitudes: The amplitudes of the vibration frequencies present can be compared with required levels to determine whether isolation is needed. In addition, isolators are designed for ranges of vibration amplitudes. Some isolators are not effective for very small amplitudes.

c). Direction: Knowing whether vibrations are horizontal or vertical can help to target isolation where it is needed and save money.

4.3.8. Vibration Specifications of Item to be Isolated:

Many instruments or machines have manufacturer-specified levels of vibration for the operating environment. The manufacturer may not guarantee the proper operation of the instrument if vibration exceeds the spec.

4.4. OBJECTIVES OF WORK

1. To review of literature and research work done in passive isolation systems.
2. To reduce the vibration transmitted to the base produced by an air compressor.
3. To develop composite vibration isolation mounts to isolate their vibrations produced by an air compressor.
4. To test the composite mounts made by the combination of isolating material like spring, rubber, felt and cork.
5. To compare the performance of conventional and composite mounts of isolators.
6. To determine the best suited mount for the tested air compressor system.
7. To obtain performance curve of composite isolators.

4.5. PASSIVE VIBRATION ISOLATOR

4.5.1. Synthetic Rubbers:

Synthetic rubber, invariably a polymer, is any type of artificial elastomer mainly synthesized from petroleum byproducts. An elastomer is a material with the mechanical (or material) property that it can undergo much more elastic deformation under stress than most materials and still return to its previous size without permanent deformation.

Although Natural Rubber, with the benefit of modern compounding, is very satisfactory for many applications, it is also a strategically important material, a natural crop only produced in tropical countries and has relatively poor ageing properties. Therefore, synthetic materials have been developed to replace Natural Rubber in a wide range of applications. There is now a wide range of synthetics available able to cope with high and low temperatures, contact with fluids of various types (including at high pressures), and aggressive or corrosive environments.

The main Synthetic Rubbers are outlined below:

- Styrene Butadiene Rubber (SBR)

A general-purpose rubber, which, when compounded with carbon black, behaves similarly to NR (Tg is higher at about -55°C).

- Butadiene Rubber (BR)

A non-polar rubber like NR and SBR, with a very low Tg (approximately -80°C). Very high resilience (very low loss) rubber used in 'superballs', but also commonly used in combination with NR and SBR in long life rubber tyre treads. Difficult to process unless blended with another elastomer.

- Chloroprene Rubber (CR)

A polar polymer with improved resistance to attack by non-polar oils and solvents. It has high toughness, good fire resistance, good weather ability, and is easily bonded to metals.

- (Acrylo) Nitrile Butadiene Rubber (NBR)

A variation of the Acrylonitrile (ACN) content from 18 to 50% controls polarity and other properties. High resistance to non-polar oils and fuels (e.g., used in seals, fuel lines, hydraulic pipes) but high Tg. Improved versions of this much used polymer are becoming available.

- Iso Butylene Isoprene (Butyl) Rubber (IIR)

This material has a low Tg but has very little 'bounce'. It has excellent ageing properties and has a very low permeability to gases, so it is often used as a tubeless tyre liner, as well as for reservoir linings and other membranes. Chemically modified forms are frequently used.

- Ethylene Propylene Rubber (EPDM or EPR)

This is a commonly used non-polar rubber in applications that require good ageing properties, such as in heater and radiator hoses, car door water and draught seals. The structure of the polymer can be altered to give a fairly wide range of properties and uses.

- Silicone Rubber

Silicone rubber is unique in not having a carbon backbone, being –Si-O-Si-O-, and this extends the useful temperature range noticeably. It has a Tg as low as -127°C depending on type, and can be used in service at temperatures of 200°C or more for several years. Further modification with fluorine will give even better performance. Several other special purpose rubbers are available, including polyurethanes.

- Chloroprene Rubber, an early synthetic rubber, has been used in many outdoor applications due to its superior weathering properties and oil resistance. It performs well compared with Natural Rubber in many ways but can suffer from long term stiffening (change in properties) and its low temperature performance is not as good as Natural rubber.

Fig.2. Rubber

4.5.2. Felt:

Felt is a non-woven cloth that is produced by matting, condensing and pressing woolen fibers. While some types of felt are very soft, some are tough enough to form construction materials. Felt can be of any colour, and made into any shape or size.

Many cultures have legends as to the origins of felt making. Sumerian legend claims that the secret of felt making was discovered by Urnamman of Lagash. The story of Saint Clement and Saint Christopher relates that while fleeing from persecution, the men packed their sandals with wool to prevent blisters. At the end of their journey, the movement and sweat had turned the wool into felt socks.

Felt making is still practiced by nomadic peoples (Altaic people) in Central Asia and northern parts of East Asia (Mongols), where rugs, tents and clothing are regularly made. Some of these are traditional items, such as the classic yurt (Gers), while others are designed for the tourist market, such as decorated slippers. In the Western world, felt is widely used as a medium for expression in textile art as well as design, where it has significance as an ecological textile.

Applications-

- Felt is used everywhere from the automotive industry to musical instruments and home construction.
- It is often used as a damper. In the automotive industry, for example, it damps the vibrations between interior panels and also stops dirt entering into some ball/cup joints.
- Felt is used on the underside of a car bra to protect the body.
- Bearing seals, ink roll, polishing, printing pads, lubricator wicks, and precision uses where high grade felt with good appearance and durability is required.
- Vibration mounts precision channels, oil seals, bumpers, gaskets, and lubricator wicks.
- Automotive, aircraft, machine components: Similar to 16R1 and 16R2, where lower quality is acceptable. Machinery pads and steel wiping applications.
- Gaskets, liners, bearing seals, where precision tolerances, life and quality are not as exacting.
- Dryer drum seals, impregnated packing, insoles, insulation; oil, dust and mud shields. Chassis strips, spacers, dash liners, anti squeak strips and pads, sound deadening and acoustic uses.

Fig.3. Felt

4.5.3. Cork:

Cork is an impermeable, buoyant material, a prime-subset of bark tissue that is harvested for commercial use primarily from Quercus suber (the Cork Oak), which is endemic to southwest Europe and northwest Africa. Cork is composed of suberin, a hydrophobic substance, and because of its impermeability, buoyancy, elasticity, and fire resistance, it is used in a variety of products, the most common of which is for wine stoppers. The montado landscape of Portugal produces approximately 50% of cork harvested annually worldwide, with Corticeira Amorim being the leading company in the industry. Cork was examined microscopically by Robert Hooke, which led to his discovery and naming of the cell.

Applications:-

- Cork's elasticity combined with its near-impermeability makes it suitable as a material for bottle stoppers, especially for wine bottles.
- Cork is also an essential element in the production of shuttlecocks & used instead of wood or aluminium in automotive interiors.
- Cork's bubble-form structure and natural fire resistance make it suitable for acoustic and thermal insulation in house walls, floors, ceilings and facades.
- Sheets of cork, also often the by-product of more lucrative stopper production, are used to make bulletin boards as well as floor and wall tiles.
- Cork's low density makes it a suitable material for fishing floats and buoys, as well as handles for fishing rods (as an alternative to neoprene).
- Granules of cork can also be mixed into concrete. The composites made by mixing cork granules and cement have lower thermal conductivity, lower density and good energy absorption.
- Natural cork closures are used for about 80% of the 20 billion bottles of wine produced each year. After a decline in use as wine-stoppers due to the increase in the use of cheaper synthetic alternatives, cork wine-stoppers are making a comeback and currently represent approximately 60% of wine-stoppers today
- Cork is used in musical instruments, particularly woodwind instruments, where it is used to fasten together segments of the instrument, making the seams airtight. Conducting baton handles are also often made out of cork.
- It is also used in shoes, especially those using Goodyear Welt Construction Cork is also used inside footwear to improve climate control and comfort.
- Cork is used as the core of both baseballs and cricket balls.
- Cork is often used, in various forms, in spacecraft heat shields. Mechanisms in inkjet and laser printers.
- Cork has been used as a core material in sandwich composite construction .Cork can be used as the friction lining material of an automatic transmission clutch, as designed in certain mopeds.

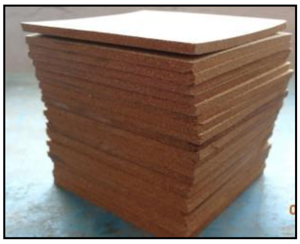

Fig.4. Cork

5. THEORETICAL ANALYSIS

Vibration isolation of a system means to reduce the vibration of the system by using suitable means of isolators between the system to be isolated and the exciter or the source of vibration. If we consider only the vertical motion, it can be described mathematically by a single degree of freedom.

$$mx + cx + kx = F(t) \quad (1)$$

Where:

m = mass of system
k = stiffness
c = viscous damping
x (t) = vertical displacement
F (t) = excitation force

If we are neglect damping, the vertical motion of the system, x(t) can express to be:

$$x(t) = \frac{F_O/_K}{(1 - r^2)} \sin(\omega t)$$

$$\text{Where: } r = \frac{\omega}{\omega_n} \quad \omega_n = \sqrt{\frac{k}{m}} \quad (2)$$

The system has a natural or resonant frequency, at which it will exhibit large amplitude of motion, for a small input force. In units of Hz, this frequency, *f*n is:

$$f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (3)$$

In units of RPM (revolutions per minute), the critical frequency is:

$$RPM_{CRITICAL} = 60\, f_n = \frac{60}{2\pi}\sqrt{\frac{k}{m}} \quad (4)$$

The force transmitted to the floor is: $F = kx$

The ratio of transmitted force to the input force is called transmissibility, T

$$T = \left|\frac{F_T}{F_O}\right| \quad (5)$$

Where:
F_T = Force Transmitted to the base
F_O = Excitation Force.

This same equation can be used to calculate the response of a machine **X** to displacement of the foundation, **Y**.

The effectiveness of the isolator, expressed in dB is:

$$E = 10 \log_{10} \frac{1}{T} \quad (6)$$

The effectiveness of the isolator, expressed in percent is:

% Isolation = (1-T) *100

A. Calculation of Stiffness (K):

For Single layer of Rubber:

Displacement for 5 Kg is 0.62 mm.

K_R = 5/0.62 = 8.06 Kg/mm

∴ K_R = 8.06 x 9.81 =79.1129 N/mm.

∴ K_R = 79.1129 x 1000 = 79112.9 N/m.

For Single layer of Felt:

Displacement for 5 Kg is 0.6 mm.

K_F =81.750 x 1000 = 81750 N/m.

For Single layer of Cork:

Displacement for 5 Kg is 0.47 mm.

K_C =104.3617 x 1000 = 104361.7 N/m.

Using the above calculation, the values of stiffness are calculated.

1. Rubber- Rubber- Rubber (RRR)

$$\frac{1}{K_{RRR}} = \frac{1}{K_R} + \frac{1}{K_R} + \frac{1}{K_R} = \frac{3}{K_R} = \frac{3}{79112.9} = \frac{1}{26370.96}$$

$$\therefore K_{RRR} = 26370.96 \text{N/mm}$$

2. Felt- Felt- Felt (FFF)

$$\frac{1}{K_{FFF}} = \frac{1}{K_F} + \frac{1}{K_F} + \frac{1}{K_F} = \frac{3}{K_F} = \frac{3}{81750} = \frac{1}{27250}$$

$$\therefore K_{FFF} = 27250 \text{ N/mm}$$

3. Cork- Cork- Cork (CCC)

$$\frac{1}{K_{CCC}} = \frac{1}{K_C} + \frac{1}{K_C} + \frac{1}{K_C} = \frac{3}{K_C} = \frac{3}{104361.7} = \frac{1}{34787.23}$$

$$\therefore K_{CCC} = 34787.23 \text{ N/mm}$$

4. Rubber - Felt - Rubber (RFR)

$$\frac{1}{K_{RFR}} = \frac{1}{K_R} + \frac{1}{K_F} + \frac{1}{K_R} = \frac{2}{K_R} + \frac{1}{K_F} = \frac{2}{79112.9} + \frac{1}{81750} = \frac{1}{26657.60}$$

$$\therefore K_{RFR} = 26657.60 \text{ N/mm}$$

5. Rubber - Cork - Rubber (RCR)

$$\frac{1}{K_{RCR}} = \frac{1}{K_R} + \frac{1}{K_C} + \frac{1}{K_R} = \frac{2}{K_R} + \frac{1}{K_C} = \frac{2}{79112.9} + \frac{1}{104361.7} = \frac{1}{28684.2}$$

$$\therefore K_{RCR} = 28684.2 \text{ N/mm}$$

B. Calculation of Damping Co-Efficient (C):

Damping ratio (Ɛ) of materials is:

Rubber - 0.075; Felt – 0.06; Cork – 0.06

Ɛ = C/C_C

$C_C = 2\sqrt{Km}$

C = Ɛ x C_C

For Rubber

C_R = $Ɛ_R$ x C_{CR}

$C_R = 0.075 \text{ x } 2\sqrt{79112.9x40}$

C_R = 266.83 Ns/m.

For Felt

C_F = $Ɛ_F$ x C_{CF}

$C_R = 0.06 \text{ x } 2\sqrt{81750x40}$

C_R = 216.99 ≈ 217Ns/m.

For Cork

C_C = $Ɛ_C$ x C_{CC}

$C_C = 0.06 \text{ x } 2\sqrt{104367.1x40}$

C_C = 245.17Ns/m.

1. Rubber- Rubber- Rubber (RRR)

$$\frac{1}{C_{RRR}} = \frac{1}{C_R} + \frac{1}{C_R} + \frac{1}{C_R} = \frac{3}{C_R} = \frac{3}{266.83} = \frac{1}{88.94}$$

$$\therefore C_{RRR} = 88.94 \text{ Ns/m}$$

2. Felt- Felt- Felt (FFF)

$$\frac{1}{C_{FFF}} = \frac{1}{C_F} + \frac{1}{C_F} + \frac{1}{C_F} = \frac{3}{C_F} = \frac{3}{217} = \frac{1}{72.33}$$

$$\therefore C_{FFF} = 72.33 \text{ Ns/m}$$

3. Cork- Cork- Cork (CCC)

$$\frac{1}{C_{CCC}} = \frac{1}{C_C} + \frac{1}{C_C} + \frac{1}{C_C} = \frac{3}{C_C} = \frac{3}{245.17} = \frac{1}{81.72}$$

$$\therefore C_{CCC} = 81.72 \text{ Ns/m}$$

4. Rubber - Felt - Rubber (RFR)

$$\frac{1}{C_{RFR}} = \frac{1}{C_R} + \frac{1}{C_F} + \frac{1}{C_R} = \frac{2}{C_R} + \frac{1}{C_F} = \frac{2}{266.83} + \frac{1}{217} = \frac{1}{82.62}$$

$$\therefore C_{RFR} = 82.62 \text{ Ns/m}$$

5. Rubber - Cork - Rubber (RCR)

$$\frac{1}{C_{RCR}} = \frac{1}{C_R} + \frac{1}{C_C} + \frac{1}{C_R} = \frac{2}{C_R} + \frac{1}{C_C} = \frac{2}{266.83} + \frac{1}{245.17} = \frac{1}{86.39}$$

$$\therefore C_{RCR} = 86.39 \text{ Ns/m}$$

C. Calculation of Transmissibility without Damping Effect:

The transmissibility of a system without damping effect is given by the equation:

$$T_r = \frac{1}{|r^2 - 1|} \tag{7}$$

Where r = ω/ω_n

ω = 2πN/60 = 2πx480/60 = 50.26 rad/s

$\omega_n = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{40}}$ (m=40 Kg = mass of test rig)

$$\therefore T_r = \frac{1}{\left(\frac{\omega}{\omega n}\right)^2 - 1} = \frac{1}{\left(\frac{50.26x\sqrt{40}}{\sqrt{K}}\right)^2 - 1} = \frac{1}{\frac{101042.7}{K} - 1} = \frac{K}{101042.7 - K}$$

1. Rubber- Rubber- Rubber (RRR)

$$T_r = \frac{K}{101042.7 - K}$$

K = 26370.96 N/m

$$\therefore T_r = \frac{26370.96}{101042.7 - 26370.96}$$

$\therefore T_r$ = 0.3531

2. Felt- Felt- Felt (FFF)

$$T_r = \frac{K}{101042.7 - K}$$

K = 27250 N/m

$$\therefore T_r = \frac{27250}{101042.7 - 27250}$$

$\therefore T_r$ = 0.3692

3. Cork- Cork- Cork (CCC)

$$T_r = \frac{K}{101042.7 - K}$$

K = 34787.23 N/m

$$\therefore T_r = \frac{34787.23}{101042.7 - 34787.23}$$

$\therefore T_r$ = 0.5250

4. Rubber - Felt - Rubber (RFR)

$$T_r = \frac{K}{101042.7 - K}$$

K = 26657.60 N/m

$$\therefore T_r = \frac{26657.60}{101042.7 - 26657.60}$$

$\therefore T_r$ = 0.3583

5. Rubber - Cork - Rubber (RCR)

$$T_r = \frac{K}{101042.7 - K}$$

K = 28684.2 N/m

$$\therefore T_r = \frac{28684.2}{101042.7 - 28684.2}$$

$\therefore T_r$ = 0.3964

D. Calculation of Transmissibility with Damping Effect:

The transmissibility of a system without damping effect is given by the equation:

$$T_r = \frac{\sqrt{1 + (2\varepsilon r)^2}}{\sqrt{((1 - r^2)^2 + (2\varepsilon r)^2)}} \tag{8}$$

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K} - 1\right)^2 + \left(\frac{50.26C}{K}\right)^2}}$$

1. Rubber- Rubber- Rubber (RRR)

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K} - 1\right)^2 + \left(\frac{50.26C}{K}\right)^2}}$$

K = 26370.96 N/m, C= 88.94 Ns/m

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26 \text{ x } 88.94}{26370.96}\right)^2}}{\sqrt{\left(\frac{101042.7}{26370.96} - 1\right)^2 + \left(\frac{50.26 \text{ x } 88.94}{26370.96}\right)^2}}$$

$$T_r = \frac{\sqrt{1 + 0.028}}{\sqrt{8.018 + 0.028}}$$

T_r = 0.3574

2. Felt- Felt- Felt (FFF)

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K} - 1\right)^2 + \left(\frac{50.26C}{K}\right)^2}}$$

K = 27250 N/m, C= 72.33 Ns/m

$$T_r = \frac{\sqrt{1 + \left(\frac{50.26 \text{ x } 72.33}{27250}\right)^2}}{\sqrt{\left(\frac{101042.7}{27250} - 1\right)^2 + \left(\frac{50.26 \text{ x } 72.33}{27250}\right)^2}}$$

$$T_r = \frac{\sqrt{1 + 0.0177}}{\sqrt{7.333.018 + 0.0177}}$$

T_r = 0.3720

3. Cork- Cork- Cork (CCC)

$$T_r = \frac{\sqrt{1+\left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K}-1\right)^2+\left(\frac{50.26C}{K}\right)^2}}$$

K = 34787.23 N/m, C= 81.72 Ns/m

$$T_r = \frac{\sqrt{1+\left(\frac{50.26 \times 81.72}{34787.23}\right)^2}}{\sqrt{\left(\frac{101042.7}{34787.23}-1\right)^2+\left(\frac{50.26 \times 81.72}{34787.23}\right)^2}}$$

$$T_r = \frac{\sqrt{1+0.01393}}{\sqrt{3.6274+0.01393}}$$

$$T_r = 0.5276$$

4. Rubber - Felt - Rubber (RFR)

$$T_r = \frac{\sqrt{1+\left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K}-1\right)^2+\left(\frac{50.26C}{K}\right)^2}}$$

K = 26657.60 N/m, C= 82.64 Ns/m

$$T_r = \frac{\sqrt{1+\left(\frac{50.26 \times 82.64}{26657.60}\right)^2}}{\sqrt{\left(\frac{101042.7}{26657.60}-1\right)^2+\left(\frac{50.26 \times 82.64}{26657.60}\right)^2}}$$

$$T_r = \frac{\sqrt{1+0.0242}}{\sqrt{7.7862+0.0242}}$$

$$T_r = 0.3621$$

5. Rubber - Cork - Rubber (RCR)

$$T_r = \frac{\sqrt{1+\left(\frac{50.26C}{K}\right)^2}}{\sqrt{\left(\frac{101042.7}{K}-1\right)^2+\left(\frac{50.26C}{K}\right)^2}}$$

K = 28684.2 N/m, C= 86.39 Ns/m

$$T_r = \frac{\sqrt{1+\left(\frac{50.26 \times 86.39}{28684.2}\right)^2}}{\sqrt{\left(\frac{101042.7}{28684.2}-1\right)^2+\left(\frac{50.26 \times 86.39}{28684.2}\right)^2}}$$

$$T_r = \frac{\sqrt{1+0.0229}}{\sqrt{6.3634+0.0229}}$$

$$T_r = 0.4002$$

E. Calculation of Effectiveness and Isolation:

The effectiveness of the isolator, expressed in dB is:

$$\mathrm{E} = 10 \log_{10} \frac{1}{\mathrm{T}}$$

The effectiveness of the isolator, expressed in percent is:

% Isolation = (1-T)*100.

6. CONCLUSION

The performance of rubber is found to be better than other isolators for the air compressor followed by felt and cork. However, the application of the isolators depends upon the variables like weight of system, frequency of excitation, damping co-efficient and other factors. It is advisable to use rubber with felt, cork or other material to enhance the vibration characteristics. The performance characteristics of isolators can be enhanced by using layers (composites) of these isolators.

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