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A THEORETICAL STUDY AND 3D MODELING OF NONLINEAR PASSIVE VIBRATION ISOLATOR

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Abstract:

The study of sound and vibration are closely related. Sound or "pressure waves" are generated by vibrating structures (e.g. vocal cords); these pressure waves can also induce the vibration of structures (e.g. ear drum). Hence, when trying to reduce noise it is often a problem in trying to reduce vibration. The high speed engines and machines when mounted on foundations and supports cause vibrations of excessive amplitude because of unbalance forces setup during their working. These are the disturbing forces which damage the foundation on which the machines are mounted. So the vibration transmitted to the foundation should be eliminated or reduced considerably by using some devices such as springs, dampers etc. between the foundation and machine. "Passive vibration isolation" refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, as opposed to "active vibration isolation" or "electronic force cancellation" employing electric power, sensors, actuators, and control systems. Passive vibration isolation is a vast subject, since there are many types of passive vibration isolators used for many different applications. [1-6]. The proposed isolator is divided into three portions. The upper portion is a table on which the isolated objects are placed. The upper portion consists of one horizontal top plate and two vertical hexagonal plates. The middle portion consists of two shafts connected by elements to provide a nonlinear restoring force. Constant force springs, coil springs and wires are examples of such elements. Here constant force springs are composed of rolled spring steel and have constant restoring force regardless of their stretch. At both ends of each shaft, inner and outer roller bearings are installed. In the lower portion one screw connected by two beams. The beams are connected to the cranks using pin connections. Half of the length of the screw jack is threaded by the opposite direction to that of the outer half. With such a composition the horizontal restoring force provides by the middle portion can be converted into the vertical restoring force. In conversion, the vertical resisting force can be adjusted simply by changing the angle of the inclined bars of the cranks which is the key ingredient of the present vibration isolator. All the 3 different portions are designed using CATIA V5 and assembled together [1].

Key Words: Theoretical Study, Vibration Isolator, Nonlinear, 3D Modeling, CATIA V5 & Passive Technique

1. Introduction:

Vibration Theoretical:

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road. Vibration is occasionally "desirable". For example, the motion of a tuning fork, the reed in a woodwind instrument or harmonica, or mobile or the cone of a loudspeaker is desirable vibration, necessary for the correct functioning of the various devices. More often, vibration is undesirable, wasting energy and creating unwanted sound – noise. For example, the vibration motions of engines, electric motors, or any mechanical device in operation are typically unwanted. Such vibrations can be caused by imbalances in the rotating parts, uneven friction, the meshing of gear teeth, etc. Careful designs usually minimize unwanted vibrations. [5]

Types of Vibration:

Free vibration occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its "natural frequency" and damp down to zero. Forced vibration is when a time-varying disturbance (load, displacement or velocity) is applied to a mechanical system. The disturbance can be a periodic, steady-state input, a transient input, or a random input. The periodic input can be a harmonic or a non-harmonic disturbance. Examples of these types of vibration include a shaking washing machine due to an imbalance, transportation vibration (caused by truck engine, springs, road, etc.), or the vibration of a building during an earthquake. For linear systems, the frequency of the steady-state vibration response resulting from the application of a periodic, harmonic input is equal to the frequency of the applied force or motion, with the response magnitude being dependent on the actual mechanical system. [5]

Vibration Isolation:

The high speed engines and machines when mounted on foundations and supports cause vibrations of excessive amplitude because of unbalance forces setup during their working. These are the disturbing forces which damage the foundation on which the machines are mounted. So the vibration transmitted to the foundation should be eliminated or reduced considerably by using some devices such as springs, dampers etc. between the foundation and machine. These devices isolate the vibrations by absorbing some disturbing energy themselves and allowing only a fraction of it to pass through to the foundation. Thus the amplitude of vibration is minimized and the adjoining structure or foundation is not put to heavy disturbances. The isolation is expressed in terms of force or motions. Lesser the amount of force transmitted to the foundation, greater is said the isolation. So machines are mounted on isolation mount. There are two basic requirements for an isolator.

Firstly, there should be no rigid connection between the unit and the base otherwise the undesired vibrations will be completely transmitted from the unit to the base. It may damage the supporting structure. Secondly, it should be ensured that the isolators remain together in case of damping material i.e. rubber, cork, felt, fails. It should be just to keep the machine or unit in the safe position with respect to the support. [5]

Importance of Vibration Isolators:

It is aimed at reducing the vibration level in one or several areas. This can be done by delaying the spread of vibration along the path from the source to the receiver. Vibration isolation can come in various forms. If the source is isolated from the surroundings, it is referred to as source isolation. If the receiver is isolated, it is referred to as shielding isolation. Shielding and source isolation may be combined if necessary. And if there is a demanding requirement for low vibration level, the source and the receiver should both be isolated. One form of vibration isolation is the steel spring isolator, which isolates potentially damaging low and high frequency vibration. Steel spring isolators are furnished with welded steel housings or cast iron. Mounts, on the other hand are vibration isolators that use rubber as the isolating medium and can protect objects and sensitive components from influencing each other, isolate or reduce structure-borne noise and extend the life of the equipment or structure.

Isolator is defined as a device that reflects and absorbs waves of oscillatory energy, extending from a piece of working machinery or electrical equipment, and with the desired effect being vibration insulation. The goal is to establish vibration isolation between a body transferring mechanical fluctuations and a supporting body (for example, between the machine and the foundation). The structure consists of a rubber envelope that is internally reinforced by a spring. During manufacture, the rubber and the spring are intimately and permanently connected as a result of the vulcanization process that is integral to the processing of the crude rubber material. Under action of weight loading of the machine, the rubber envelope deforms, and the spring is compressed or stretched. [5]

Benefits of Vibration Isolation:

The need to reduce the transmission of vibration and damping between two elements while maintaining mechanical support is a complicated yet important part of most areas of engineering, development and product design. With vibration isolation, payoffs are often immediate and long term – energy savings, reduced breakdowns, and reduced cost of replacement parts.

Types of Vibration Isolator:

Active Isolation: Active vibration isolation systems contain, along with the spring, a feedback circuit which consists of a sensor(piezoelectric accelerometer or a geophone), a controller, and an actuator. 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. Active isolation today is used for applications where structures smaller than a micrometer have to be produced or measured. [5]

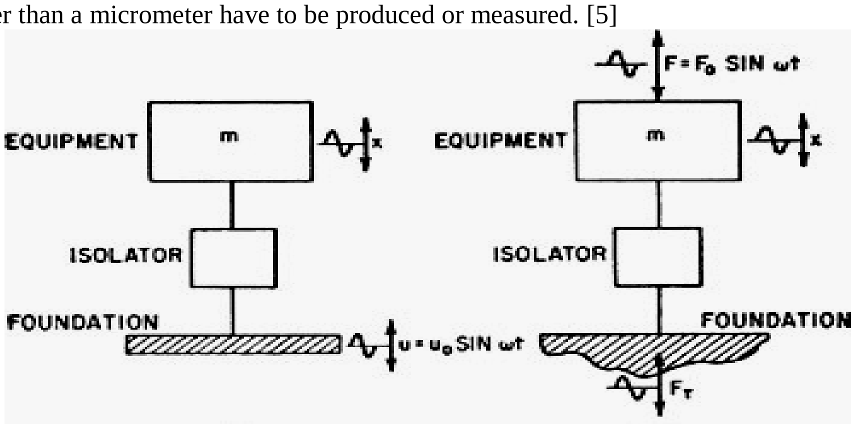

Figure 1: Active Isolation System [5]

Passive Isolation: 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. [5]

Applications:

Consider a vibrating machine, bolted to a rigid floor (Figure a). The force transmitted to the floor is equal to the force generated in the machine. The transmitted force can be decreased by adding a suspension and damping elements (often called vibration isolators) Figure b , or by adding what is called an inertia block, a large mass (usually a block of cast concrete), directly attached to the machine (Figure c). Another option is to add an additional level of mass (sometimes called a seismic mass, again a block of cast concrete) and suspension (Figure d).

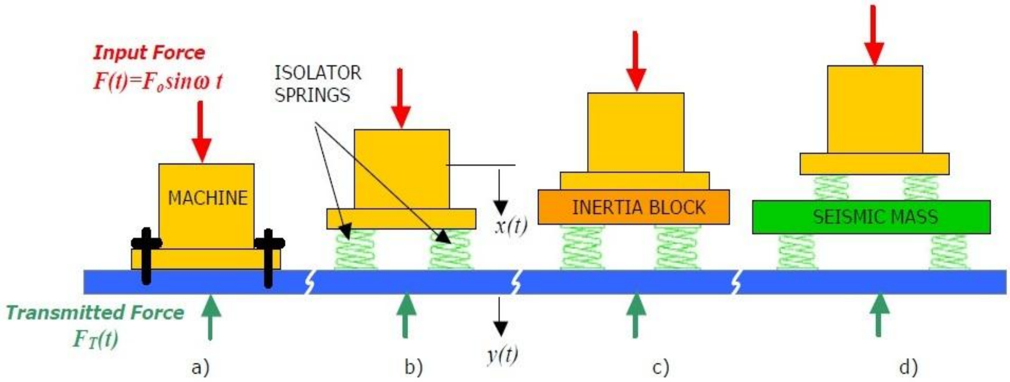

Figure 2: Vibration isolation systems: a) Machine bolted to a rigid foundation, b) Supported on isolation springs, rigid foundation, c) machine attached to an inertial block, d) Supported on isolation springs, non-rigid foundation (such as a floor); or machine on isolation springs, seismic mass and second level of isolator springs [5]

If we consider only the vertical motion, the case shown in Figure b can be described mathematically by a single degree of freedom, lumped element system. Vibration isolation (defined as T<1) occurs when the excitation frequency is > 1.4 *fn*. For minimum transmissibility (maximum isolation), the excitation frequency should be as high above the natural frequency as Possible.

Passive Isolation:

"Passive vibration isolation" refers to vibration isolation or mitigation of vibrations by passive techniques such as rubber pads or mechanical springs, as opposed to "active vibration isolation" or "electronic force cancellation" employing electric power, sensors, actuators, and control systems. 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. A basic understanding of how passive isolation works, the more common types of passive isolators, and the main factors that influence the selection of passive isolators. [5]

Common Passive Isolation Systems:

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.

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

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.

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. [5]

Wire Rope Isolators: These isolators are durable and can withstand extreme environments. They are often used in military applications.

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.

Base Isolators for Seismic Isolation of Buildings, Bridges: 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.

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.

Working of Passive Isolation:

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. [5]

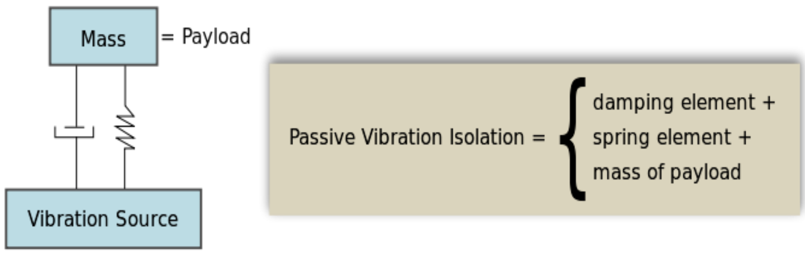

Figure 3: Working of Passive Isolation [5]

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.

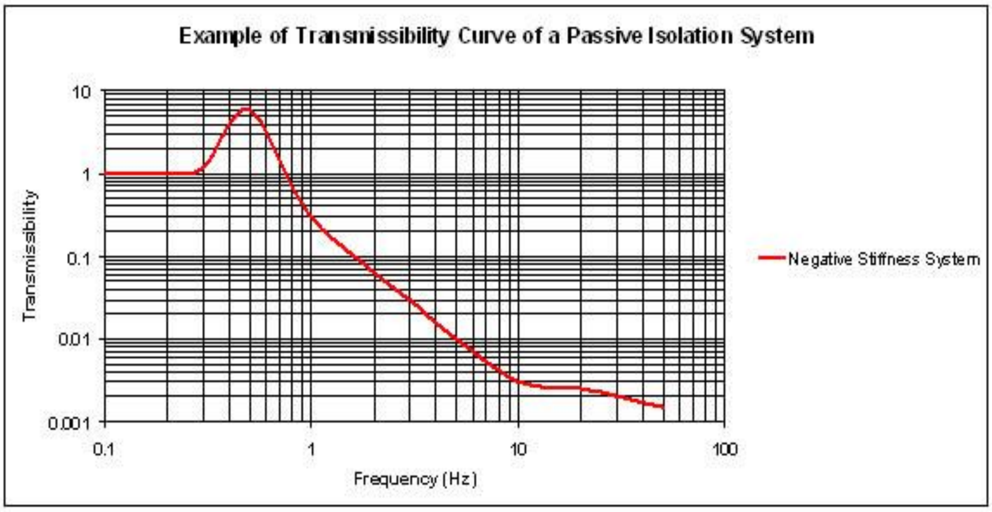

Figure 4: Transmissibility Curve of Passive Isolation System [5]

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 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.

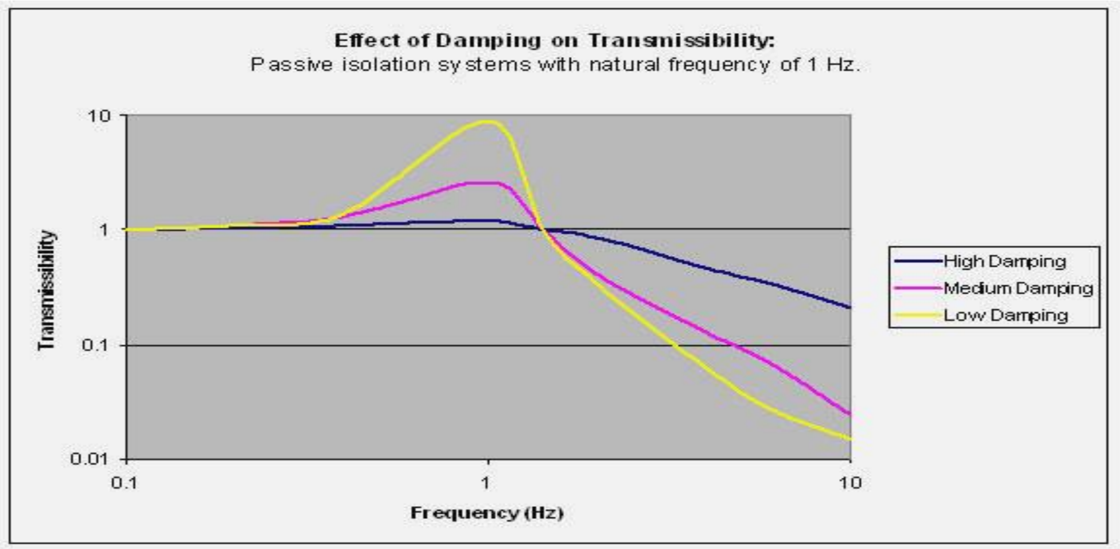

Figure 5: Effect of Damping on Transmissibility [5]

Factors Influencing the Selection of Passive Vibration Isolators:

Characteristics of item to be isolated:

- ✓ 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.
- ✓ 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.
- ✓ 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.

Operating Environment

- ✓ Industrial: This generally entails strong vibrations over a wide band of frequencies and some amount of dust.
- ✓ Laboratory: Labs are sometimes troubled by specific building vibrations from adjacent machinery, foot traffic, or HVAC airflow.
- ✓ Indoor or outdoor: Isolators are generally designed for one environment or the other.
- ✓ 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.
- ✓ Clean room: Some isolators can be made appropriate for clean room.
- ✓ 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.
- ✓ 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.

- ✓ Magnetism: Some experimentation which requires vibration isolation also requires a low-magnetism environment. Some isolators can be designed with low-magnetism components.
- ✓ 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.
- ✓ Static or dynamic loads: This distinction is quite important as isolators are designed for a certain type and level of loading.

Static loading is basically the weight of the isolated object with low-amplitude vibration input. This is the environment of apparently stationary objects such as buildings (under normal conditions) or laboratory instruments.

Dynamic loading involves accelerations and larger amplitude shock and vibration. This environment is present in vehicles, heavy machinery, and structures with significant movement.

Cost:

- ✓ 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.
- ✓ 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.

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.

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.

Size Constraints:

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

Nature of vibrations to be isolated or mitigated

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

Basic Characteristics of Nonlinear Isolators:

Need for Nonlinear Isolation: Linear vibration isolators are only useful if their natural frequencies are well below the excitation frequency. Thus, they are limited to such applications as moderate environmental disturbances. However, under severe environmental disturbances such as shocks, impact loads, or random ground motion, their spectrum will definitely contain dangerous low-frequency components. The isolator under these conditions experiences excessive deflections that can cause over-stress and even damage to the system. For this reason, it is imperative to consider effective nonlinear isolators, which can serve several applications, such as

- ✓ Reducing line spectra in the radiated acoustical signature of marine vessels.
- ✓ Isolating equipment mounted in ships navigating in extreme sea waves. Reducing the magnitude of the high launch loads across all frequency bands acting on spacecraft.
- ✓ Reducing severe vibrations due to impact loads.
- ✓ Protecting buildings, bridges, liquid storage tanks, oil pipelines, and nuclear reactor plants against the damaging effects of earthquakes.
- ✓ Isolating laser interferometers of gravitational wave detectors.
- ✓ Isolating electronic equipment, automotive vehicle front-end-cooling systems, and passengers from road roughness excitation.
- ✓ Isolating automotive power-train system, engine through proper design of rubber and hydraulic mounting systems.

- ✓ Protecting operators of hand-held machines.

Difference between Linear and Non-linear Vibrations:

In the linear systems, the cause and effect are linearly related i.e. the cause and effect change in such a manner that their relation with respect to each other is the same and is given by linear plot. In the nonlinear systems, this relationship between cause and effect is no longer proportional. The properties of nonlinear systems depend on the dependent variables.

The so called linear systems tend to become nonlinear with larger vibration amplitudes. The analysis of nonlinear systems is however comparatively difficult. Sometimes there is no exact solution available. One major difference between the linear and nonlinear systems is that the superposition principle does not hold good for nonlinear systems. [2]

A general equation of the linear systems given as

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

In which all the three terms on the LHS of the equation are linear functions of $\ddot{x}$, $\dot{x}$ and x respectively.
A general equation of nonlinear systems is given by

$$m\ddot{x} + \beta(\dot{x}) + f(x) = F(t)$$

In which the second and third term on the LHS of the equation are not linear functions of $(\dot{x})$ and (x) as used to be the case in linear systems.

Examples of Non-linear Vibration System:

The following examples of nonlinear vibration systems are given

- ✓ Simple Pendulum,
- ✓ Vibration of a String,
- ✓ Hard and Soft Spring,
- ✓ Belt Friction System,
- ✓ Variable Mass System,
- ✓ Abrupt Nonlinearity,
- ✓ Rotating Noncircular Shaft Carrying Rotors,
- ✓ Cantilever with Curved Guide,
- ✓ Pendulum of Variable Length etc.

1. Literature Review:

Nader Jalili (2002) investigated that Semi-active (SA) vibration-control systems are those which otherwise passively generated damping or spring forces are modulated according to a parameter tuning policy with only a small amount of control effort. SA units, as their name implies, fill the gap between purely passive and fully active vibration-control systems and offer the reliability of passive systems, yet maintain the versatility and adaptability of fully active devices. During recent years there has been considerable interest towards practical implementation of these systems for their low energy requirement and cost. This paper briefly reviews the basic theoretical concepts for SA vibration-control design and implementation, and surveys recent developments and control techniques for these systems. Some related practical applications in vehicle suspensions are also presented in this paper by him. [3]

R.A. Ibrahim (2008) here in this paper the theory of nonlinear vibration isolation has witnessed significant developments due to pressing demands for the protection of structural installations, nuclear reactors, mechanical components, and sensitive instruments from earthquake ground motion, shocks, and impact loads. In view of these demands, engineers and physicists have developed different types of nonlinear vibration isolators. This article presents 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 elastica and axial stiffness. Exact and approximate analyses of axial stiffness of the post-buckled Euler beam are outlined. Different techniques of reducing the resonant frequency of the isolator are described. Another group is based on the Gospodnetic–Frisch-Fay beam, which is free to slide on two supports. The restoring force of this beam resembles to a great extent the restoring roll moment of biased ships. The base isolation of buildings, bridges, and liquid storage tanks subjected to earthquake ground motion is then described. Base isolation utilizes friction elements, laminated-rubber bearings, and the friction pendulum. Nonlinear viscoelastic 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. [2]

Yoshikazu Araki, Takehiko Asai, Kosuke Kimura, Kosei Maezawa, Takeshi Masui (2013) their paper presented a vertical quasi-zero stiffness (QZS) vibration isolator with a mechanism for adjusting restoring force. QZS vibration isolators have high initial stiffness and QZS around the static equilibrium position. This way, excessive deformation due to self-weight can be avoided while having enough vibration reduction capability to dynamic excitations. One of the main issues left for QZS vibration isolators is the difficulty in keeping the vibration reduction capability when the vibration isolated object is replaced. In such a case, adjustment of its restoring force becomes necessary in accordance with the self-weight of the newly placed vibration isolated object. This paper attempts to address this issue by proposing a mechanism that enables quick and easy adjustment of the restoring force of a QZS vibration isolator. The proposed mechanism consists of cranks and a screw jack. With the present mechanism, the restoring force provided by horizontally placed springs can be converted into the vertical restoring force of the vibration isolator. In the conversion, the vertical resisting force can be adjusted simply by applying and removing torque to the screw jack to change and hold the angle of inclined bars placed in the cranks. In this study, a prototype of a class of QZS vibration isolator having the proposed mechanism is produced. Shaking table tests are performed to demonstrate the efficacy of the present mechanism, where the produced prototype is subjected to various sinusoidal and earthquake ground motions. It is demonstrated through the shaking table tests that the produced prototype can reduce the response acceleration within the same tolerance even when the mass of the vibration isolated object is changed. [1]

Daolin Xu, Qiping Yu, Jiaxi Zhou, S.R.Bishop (2013) their paper presented a nonlinear magnetic low-frequency vibration isolator designed with the characteristic of quasi-zero stiffness (QZS). An approximate expression of the magnet repulsive force is proposed and a unique analytical relationship between the stiffness of vertical spring and initial gap settings of the magnet springs is derived for the QZS system. Based on the harmonic balance (HB) method, the force transmissibility is formulated and the jumping frequencies, effect of excitation force and damping ratio are discussed for characteristic analysis. An experimental prototype is developed and tested. The performance of the QZS system is verified through a series of experimental studies showing that the new model greatly outperforms standard linear isolation systems especially in low-frequency domain. The tuning techniques for adapting to the change of loading mass and adjusting the QZS property in practice are also addressed. [4]

2. Modeling:

Mechanisms for Adjusting Restoring Force:

The proposed isolator is divided into three portions. The upper portion is a table on which the isolated objects are placed. The upper portion consists of one horizontal top plate and two vertical hexagonal plates. The middle portion consists of two shafts connected by elements to provide a nonlinear restoring force. Constant force springs, coil springs and wires are examples of such elements. Here constant force springs are composed of rolled spring steel and have constant restoring force regardless of their stretch. At both ends of each shaft, inner and outer roller bearings are installed. In the lower portion one screw connected by two beams. The beams are connected to the cranks using pin connections. Half of the length of the screw jack is threated by the opposite direction to that of the outer half. [1]

The distance between the two beams can be changed by rotating the screw jack while keeping the geometry of the mechanism symmetric. The position of the beams is automatically locked simply by removing the torque applied to the screw jack. This way the angle of the inclined bar in each crank can be changed and held simply by applying and removing the torque to the screw jack. The inclined sides of the hexagonal plates are placed on the inner bearings of the shafts and outer bearings of the shafts are placed on the inclined bars of the cranks. With such a composition the horizontal restoring force provides by the middle portion can be converted into the vertical restoring force. In conversion, the vertical resisting force can be adjusted simply by changing the angle of the inclined bars of the cranks which is the key ingredient of the present vibration isolator.

Schematic Diagram of Proposed Device Using CATIA V5:

Upper Portion:

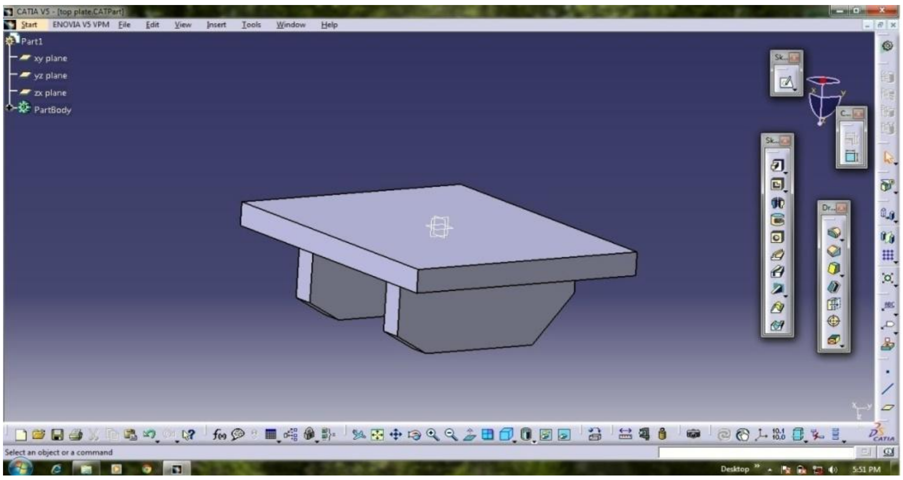

Figure 6: Upper Portion of the Isolator

The upper portion is a table on which the isolated objects are placed. It consists of one horizontal top plate and two vertical hexagonal plates.

Middle Portion:

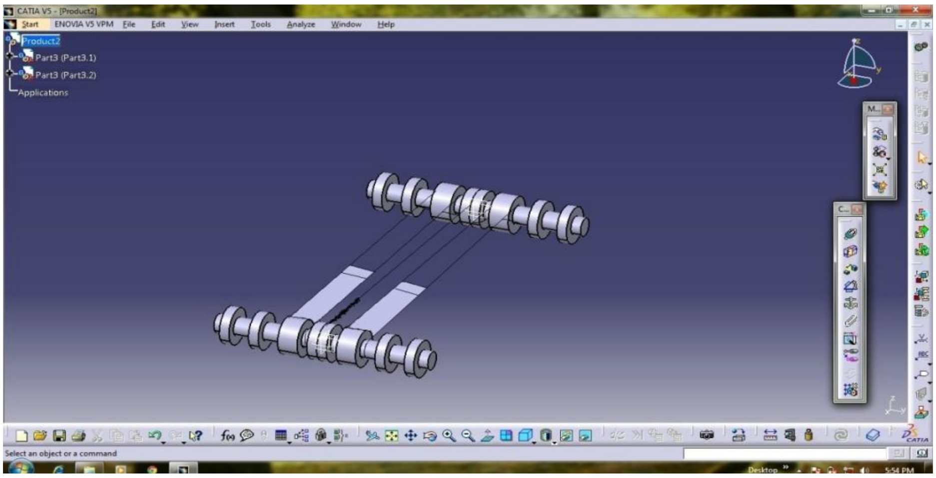

Figure 7: Middle Portion of the Isolator

It is composed of two shafts connected by elements to provide a nonlinear restoring force. Constant force springs, coils springs and wires are example of such elements. At both ends of each shaft, inner and outer roller bearings are installed.

Lower Portion:

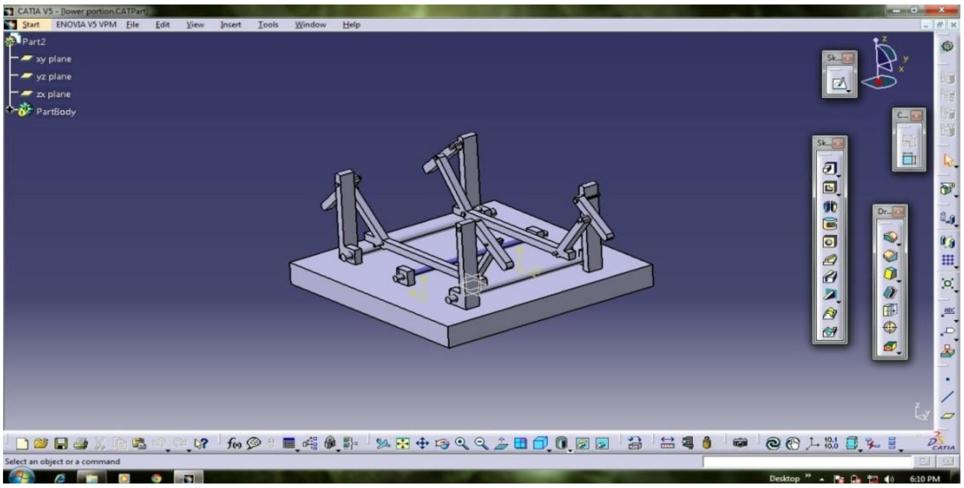

Figure 8: Lower Portion of the Assembly

Here, one screw jack, two linear bushes and four cranks are attached to the base plate. The screw jack and linear bushes are connected by two beams. The beams are connected to the cranks using pin connections. Half of the length of the screw jack is threaded in the opposite direction to the other half. The distance between the two beams can be changed by rotating the screw jack and the position of the beams are automatically locked simply.

Final Assembly:

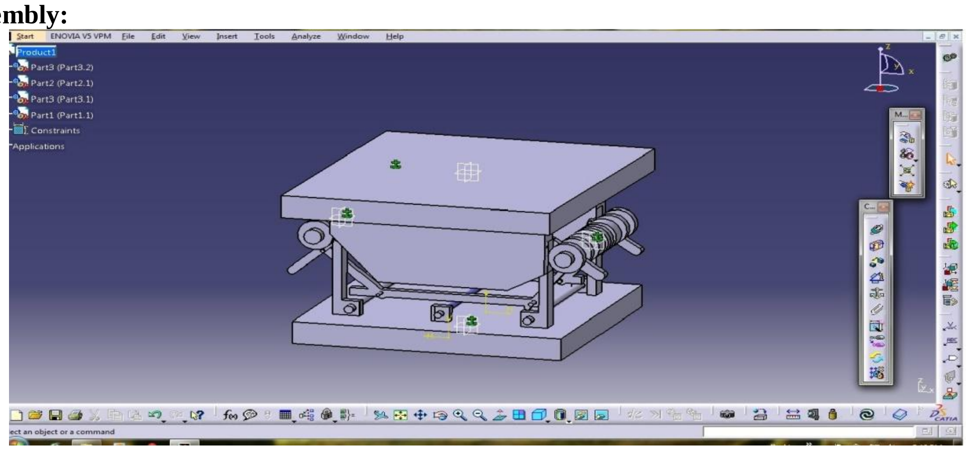

Figure 9: Final Assembly View-I

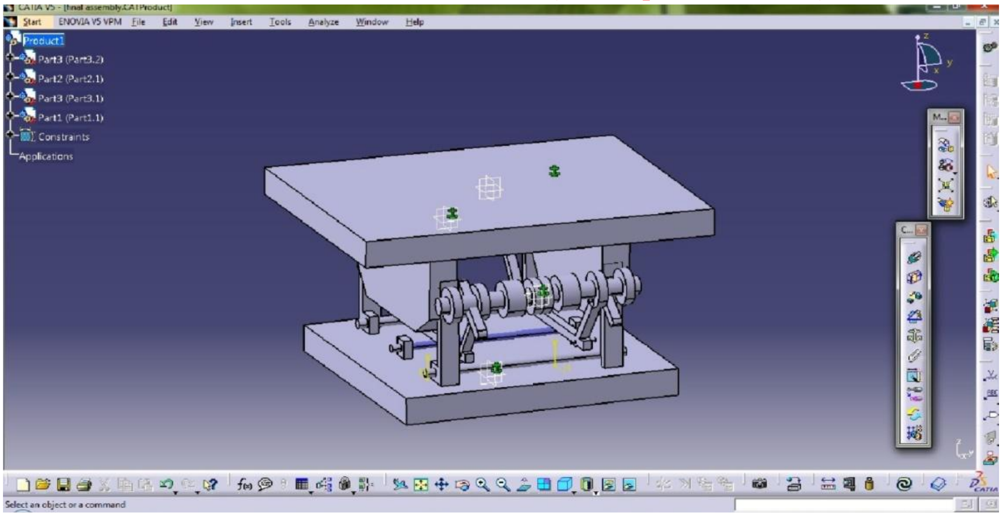

Figure 10: Final Assembly View-II

3. Conclusions:

It can be used where exact amount of vibration cannot be known or else where the amplitude of vibration is so high that active isolator cannot be used. Also where human operator cannot operates the system manually; in those cases it should be operated automatically. Load withstanding capacity is also very high in this case. So ideal situation where it can be used is like in nuclear power plants or any other kinds of power plants which is situated far from cities and cannot be operate manually. For these types of systems, they can be affected by earth quakes and tsunami, their amount of force cannot be predicted. So these types of passive nonlinear isolator are used, which can work automatically and withstand the high load and also protects the power plants by isolating them, absorbing all the vibrations.

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