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DESIGN AND APPLICATION OF MULTILAYERED STRUCTURAL BEARINGS FOCUSING ANECHOIC TEST FACILITY

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Abstract -
This is an industry oriented presentation describing the design and fabrication of multilayered bearings for vibration isolation. Depending on the load requirement and column size the unit loading is calculated. The number of layers of elastomer pads in the stack depends on the natural frequency 'fn' of the required bearing. Alternate metal sheet and padare used to form the stack.Design calculation for a typical Vertical load of 20 MT is highlighted. The calculated results for high load bearing and its validation methodology will be presented.

In view of wide variety of structural bearings, an overview of different types of bearing starting from PTFE slide bearing to multilayered bearings for Earthquake protection of buildings & Hospitals, floating floor bearings for the dancing floor tapping noise isolation in a hotel , for reducing the structure borne disturbances in the reading room of a library will be briefed. Even a doctor performing a delicate brain surgery requires adequate isolation of the operation theatre. The other industrial application areas where vibration, shock & noise isolation is important will include plant machineries, sensitive electronic equipments in aircraft & aerospace vehicles, automobiles, railways, naval ships & laser holography, high resolution spectroscopy and high power microscopy related set ups in a test laboratory.The spring mass model is the starting point for preliminary design in Single Degree of Freedom (SDOF) calculation in Euclidean plane which is extended to 3 orthogonal set of co-ordinates in X,Y,Z axis for 3D response calculation. Theanalysisinvolves Fourier transform, Hilbert transform,wavelet concepts for an optimized solution.Mathematical approach is universal in nature and is unified by Eigen frequency solutions of differential equations.Higher order equations are used for non–linear systems. The calculated results are validated by actual measurement after installation. For workshop and plant machineries, the isolation systems are designed for 90 % vibration isolation efficiency and the measurements after installation were found to be well within a tolerance level of + 5/ - 10 % .

1. Introduction-

1.1 –Vibrationanalysis ranging fromAtomic & Molecular Spectroscopy to Acoustics -The vibrations&oscillations of small amplitude arethe responses of periodic dynamic forces of quasi static nature but we are able to sense and analyze only a small portion of vibration spectrum covering audio portion of acoustic band and visible portion of electromagnetic waves. In addition to ear and eye, our skin is sensitive to mechanical vibration and heat (near Infrared) up to certain perception levels. Quasi static vibration has a sense of continuity and is tolerable up to a specified level. Example-Long distancetravelling by road or railway where a better comfort level is achieved by designing the suspension system with Air springs of low natural frequency.Since our flexible body organs like knee joint, intestine, spinal & shoulder joints are excited during a long journey we feel joint pain and fatigue when the suspension systems are stiff leaf spring or metallic spring.[Fig5] Shock is due to high amplitude impulsive force. Mathematically Shock input isin the form half sine, triangular or rectangular pulse. Shock is an event in space so in addition to 3 space coordinate (x,y,z), a fourth dimension of time is required to define the shock. [1] Examples- collision of planets, asteroids, vehicles or blow of a forging hammer.The atomic and Molecular vibrations ranges fromultraviolet to infrared frequencies in Electromagnetic spectral band.[2,3] The acoustic frequency band is from20Hz to20 KHz. Infrasound < 20 Hz and ultrasounds > 20KHz extends the spectrum beyond the audible range.

1.2 –Vibrations related to plant machinery and buildings in Inertial frame of reference in Earth's Gravitational Field. Any dynamic system comprising of machines and mechanism generates complex vibration spectra due to a combination of reciprocating and rotating motion of various moving parts in the module.[Fig.1] The resultant forces are analyzed along the 3 orthogonal axis in Euclidean plane. For rotating machine like turbines, axial fans etc. the dynamic loading is specified as per balancing grade.[6] Typical machines like coal crushers of any thermal power plant requires isolation from shock loading also in addition to normal vibration. Typical shock loadings may be due to hammer broken or damaged gear tooth condition.To isolate the vibratory forces andtransient forces , heavy spring damper systems are used to isolate the crusher from supporting structure. The forging hammers require special attention since the shock waves generated spreadsthrough the ground and causes disturbances in nearby buildings. Similarly sensitive laboratory equipments like interferometers, holography set ups etc. are disturbed by trains passing through a railway track near the laboratory or heavy vehicles passing through a nearby highway. Vibration isolated Air spring fitted tables of low frequency (< 2 Hz) are used to isolate the disturbances of micro-seismic nature. [7] We will be focusing on thevarious aspects of design and application of Multilayeredbearings for turbojet engine test bed, isolation of foundation from groundand Anechoic building columns. For earthquake protection of buildings multilayered Seismic bearings are used .[Fig 6]

2.Selectionof Isolators for Industrial Applications :-

Input data required for selection are load, lowest operating speed or disturbing frequency ,Centre of gravity (CG) location and type of application. For example Isolator selection for a typical HVAC fan- motor will depend on installation location like ground floor, rooftop, mobile trailer or on board of a naval ship. [6] The industrial isolators are categorized as per load-deflection and material characteristics.(a) Elastomer / Rubber metal bonded isolators.- Due to limited load and deflection range available the application of such isolators are in general limited to small & medium size of rotating machines of operating speed of 20 Hz& above. Depending on environmental condition neoprene / nitrile rubber isolators are used. (b) Spring-Viscous Dampers are used for Diesel generating sets, coal crushers, automobile &tractor Engine Test Bedsetc. (c) All metal wire rope isolator – preferred for high temp applications in Aerospace.[8] (d) Air springs – Low natural frequency - Application indeluxe buses, railways and isolated tables for Holography and interferometery experiments in laboratories. [7]

2.1Elastomer Isolator material structureand Entropy-

Due to loading the molecular forces in the elastomer material acts as reaction. Elastomers are long chain compounds with cross linking between the chains. By vulcanization process cross links are produced. Elastomer materials posses inherent damping property. Hence for low damping requirement,separatedampers are not required. So elastomer based isolators are comparatively lighter and compact.Elastomer material based isolator show configuration based entropy change due to coiling and uncoiling of long chain compound. Bonding forces and shape factor play the major role during the displacement of quasi static nature. Long chain compounds twisted in the coiled configuration, provides the internal energy in the form of elasticity.Slow process stretching is isothermal. When external tensilestress is applied it stretches the coiled molecules. Hence the possible configuration and entropy decreases. Since the deformation in elastomer material does not involve change in the valence angles and atomic spacing of skeleton chain it responds well to small forces . Due to its inherent material damping properties , compact size and lightweight advantages it is a preferred material for lightweight electronic modules in aerospace applications. Silicone rubber based isolators have higher temp range. Elastomer isolators may be moldedin various shapes and sizes suiting the application. The rated load capacity depends on the size and shape of the isolator.However for any model the soft,medium and hard variety may be manufactured by changing the hardness of the material. Seismic bearings are multilayered bearings with high deflection capability in horizontal direction. [12]

3.Mathematical Analysis and Design Aspects –

3.1 Historyof development - from pendulum clock to Atomic clock

Perhaps the basic concept of correlating the oscillation frequency and time measurement started with the discovery of pendulumby Galileo way back in 16^{th}.century. Later on the concept was used for the development of mechanical pendulum clock. Since such clocks functioned under the influence of Earth's gravitational field so adjustment mechanism was provided to adjust the length of the pendulum for setting. Max Planck around 1900 developed the Quantum theory using the concept of Simple harmonic oscillators with energy values E = hν where h is Planck's constant andν is the frequency.[4]. Later on vibration or transition in quantum level had been used as a standard in Atomic clock.[5]

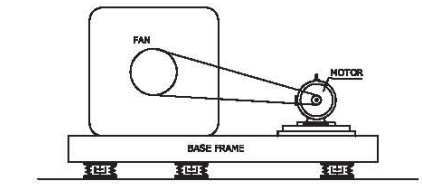
3.2-Mathematics as a subject of unification- Wave Mechanics to Quantum Mechanics are correlated and connected through spectral parameters e.g. frequency, wavelength and velocity. The velocity parameter varies from ~ mm/sec (machine vibration) to ~ 3 x 10^8 m/sec (velocity of light in vacuum).Velocity (dx/dt) requires precise position and time measurement which is extremely elaborate as it approaches velocity of light. Frequency is measurable and resolvable by electronic systems and using Fast Fourier Transform(FFT) in frequency domain. Hence it is aconvenient parameter to cover Seismic waves (Infrasonic) to Electromagnetic Waves. The energy and momentum correlates the wave and particle nature. The selectionof isolator for anymechanical system or structureis primarily based on Eigen frequency or natural frequency (fn) calculation and optimization of the system with the standardized isolators.[11]

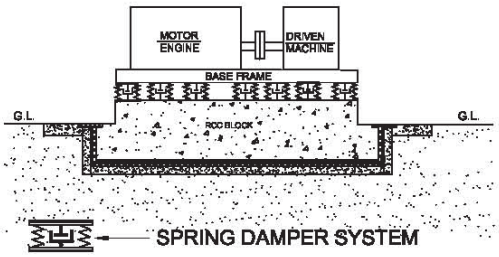
4System Optimization based on Eigen-frequency consideration.-

4.1 -Second order Differential equation (ODE) for the analysis of a dynamic system in single degreeof freedom (SDOF) using a orthogonal set of co-ordinates x, y and z direction.M (d^2x / dt^2) + C (dx / dt) + Kx = F_0 Sin ωt ,where M , C and K is the mass, damping and stiffness values e system,C is the damping coefficient , K is the spring stiffness , Fo Sin wt represents the dynamic force.Eigenfrequency of the spring mass system is calculated by using the formula fn = $\frac{1}{2\pi}\sqrt{K/M}$, K is the spring stiffness and M is the sprung mass

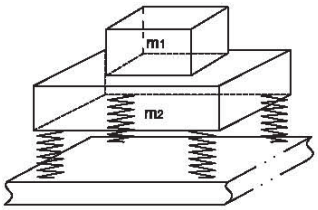
4.2 PDEs – Partial Differential Equations-

A general form of Second order Partial Differential Equation
in (x , y)domain
$A(x,y)\partial^2u/\partial x^2$ + $2B(x,y)\partial^2u/\partial x.\partial y$ + C $(x,y)\partial^2u/\partial y^2$
= f ($x, y, u, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}$) where u is the unknown state variable and A, B, C are the coefficients of the equation.

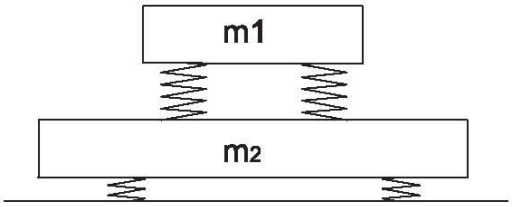




1 - MECHANICAL SYSTEM ISOLATION

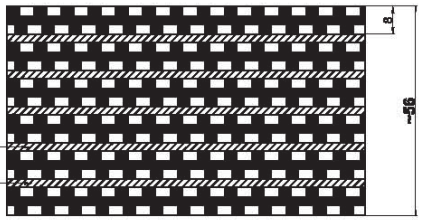


2-(a) SINGLE STAGE ISOLATION
SPRING MASS MODEL



2-(b) TWO STAGE ISOLATION
SPRING MASS MODEL

TYPE:- SC 8/50

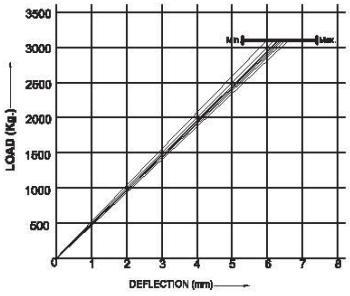


Intermetallic sheets

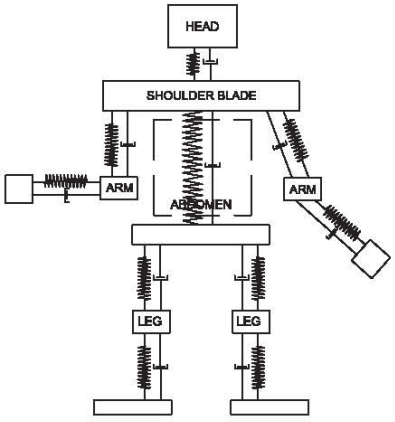
6 LAYERS STACK

3 - MULTI-LAYERED BEARING

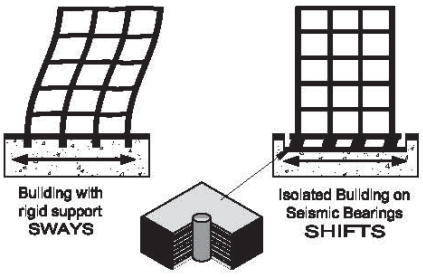
LOAD - DEFLECTION RANGE
SQUARE CELL PAD , STYLE - SC
SC 08/50 C , 300X300X08 mm , 6Layer



4 - LOAD - DEFLECTION TEST



5 - A Fuzzy & Flexible Model of Human Body



6 - BUILDING ON SEISMIC BEARINGS
in collaboration with
Dept. of Earthquake Engineering I I T Roorkee - Resistoflex

VIBRATION ENGG. APPLICATION DRAWING
DRG. NO. APP-09081259 (NOT TO SCALE)
DRN.W.H,CHKD.SNB, DESIGN & DRG. SEC. RPL

5.Multilayered elastomer pads and isolation efficiency results –

Multilayered pad stacks are designed on static loading and deflection required. The aspect ratio and shape factor limits the max. no. of layers i.e. height of the stack . Typicalloading of Square Cell pads of SC 8/50 (thickness 08 mm& hardness 50) ~ 3.5 Kg/cm^2 and SC 12/50 (thickness 12 mm and hardness 50) ~ 14 Kg/cm^{2}As pads are molded, the maximum size available for design with SC type pads are limited to 450 X 450 mm. Based on loading requirement size is calculated. The Maximum static loading of SC 8/50 ~ 7088 Kg. and for SC 12/50 ~ 28350 Kg. Example – For 20 MTLoad, SC-12/50 type size= 400x400mmunit loading = 12.5 Kg/cm^2 will be required.A typical Multilayer bearing of SC8/50 (6 layers) for 03 MT with max loading testare shown in Fig.3 & Fig.4. A blend of Natural and Synthetic rubber is used for general application. Natural Rubber pads are used for indoor application. Neoprene pads are preferred for environment resistant applications.After calculating the size of the bearing depending on the static loading on each bearing thenext step is to calculate the number of layers required for the particular application. Example–For isolating the disturbing frequency (fd) = 25 Hz.The vertical static deflection of isolator required is > 4.1 mm for isolation efficiency ~ 90% (for fd> 25 Hz.). So the number of layers of SC8/50 will be approx 6 layers stack with metal sheet in between rubber layers.

5.1Conclusion & Validation of Results -The spring-mass modeling and preliminary designs are based on fuzzy and generic logic.[Fig 2] The designs are validated by dedicated computer program. In some cases the results werevalidated by actual measurement after installations and it was found to be well within the acceptable level of + 5 / - 10 % of the calculated value.

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