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DESIGN OPTIMIZATION OF VIBRATION ISOLATION SYSTEMS FOR EQUIPMENTS AND MACHINERIES FOCUSING THE APPLICATIONS IN HIGHER SEISMIC ZONES

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ABSTRACT

This is an industry oriented presentation of inter-disciplinary nature covering the design aspects and concepts for the optimized selection of Vibration & Shock isolation systems focusing the application of Seismic snubbers for the earthquake protection in higher seismic zones.

The historical development aspects starting from the study of motion of a pendulum by Italian Physicist Galileo Galilei and later the study of vibration of musical instruments and membranes etc may be considered as the beginning of mathematical formulation and correlation of various parameters like frequency, amplitude and energy etc. With the development of atomic & molecular spectroscopy and Quantum concepts, the Planck's Quantum formula in 1900 connected the Energy and vibration frequency of Electro-Magnetic waves. On the other hand perhaps te engineering aspects of development of efficient vibration isolation systems may be attributed to the development of comfortable suspension systems for automobiles leading to the development of Air Spring systems for luxury buses.[9, 10].The vibration isolation concept is based on the selection of natural frequency (fn) of the isolator depending on the disturbing frequency (fd). But shock is an event in space and so it requires a fourth dimension of time to define a shock event in space. For shock response calculation the input is taken as equivalent of Half sine or Triangular pulse of specified time duration. Shock isolators are Non linear systems.

The selection of different types of industrial mounts like multilayered pads, elastomer mounts, spring damper Systems and Air spring systems for the industrial applications will be highlighted. The combination of spring mounts and seismic snubbers to restrict the excessive movement of machines during earthquake will be explained [18, 20]. Earthquake protection of pipe lines in high rise building will be covered.The mathematical optimization techniques will be detailed. The calculated results are validated by actual measurement after installation.The Vibration isolation efficiency results are found to be within +/-5% for defined mechanical systems.

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INTRODUCTION

History of development - from pendulum clock to Atomic clock

The basic concept of correlating the oscillation frequency and time measurement of a simple pendulum was introduced by great philosopher and scientist Galilei Galileo.He described the dependency of time period on the length of a simple pendulum.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 $E = h\nu$ where h is Planck's constant and ν is the frequency.[12, 14]. Later on vibration or transition in quantum level had been used as a standard in Atomic clock.

Mathematics as a subject of unification

Wave Mechanics to Quantum Mechanics are correlated and connected through spectral parameters e.g. frequency, wavelength and velocity.[12, 14] 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 the time history may be converted to frequency domain by using Fast Fourier Transform(FFT).Hence it is a convenient parameter to cover Seismic waves (Infrasonics) to Electromagnetic Waves. The energy and momentum correlates the wave and particle nature. The selection of isolators for any mechanical system or structure is primarily based on Eigen frequency or natural frequency (fn) calculation and optimization of the system with the standardized isolators. [16, 17]

SELECTION OF 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. [2] 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 Beds etc. (c) All metal wire rope isolator – preferred for high temp applications in Aerospace.[7, 8] (d) Air springs – Low natural frequency – Application in deluxe buses, railways and isolated tables for Holography and interferometery experiments in laboratories. [17, 18]

OPTIMIZATION BASED ON EIGEN-FREQUENCY CONSIDERATION

Second order Differential equation (ODE)

Second order Differential equation (ODE) are used for the analysis of a dynamic system in single degree of freedom (SDOF) using a orthogonal set of co-ordinates x, y and z direction. M

$(d^2x/dt^2) + C\ (dx\ /\ dt\ ) + Kx = F_0 \sin \omega t$, where M, C and K is the mass, damping and stiffness values e system, C is the damping coefficient, K is the spring stiffness, $F_0 \sin \omega t$ 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.

The Frequency spectrum

It is interesting to glance through the wide ranging frequencies involved in various types of vibrations. The atomic and molecular vibration frequencies are in optical and infrared frequency band in the frequency range of 10^{12} to 10^{14} Hz and the forces involved are of electro-magnetic nature.[Ref.1, 6, 12, 14] Acoustic vibrations in audible band is in the frequency range from 20 Hz. to 20 KHz order.[3] The aerodynamic noise generated by a high speed jet aircraft is higher than 600 Hz. The frequencies of machine vibration are limited to 150 Hz or so. The effective frequencies involved in building vibration are considered from 1 to 80 Hz. The resonance frequencies related to human body organs are in the range from a few hertz to 30 Hz order. Infrasonic waves generated by earthquake is less than 20 Hz frequency . Micro-seismic vibrations generated by road traffic or rail movement near any laboratory building are considered in the lower range of 5 Hz or so. Vibration isolated tables with low natural frequency of less than 2 Hz. are used for the isolation of sensitive instruments in a micro- tech laboratory. [4, 9, 10, 19] .The new negative stiffness (-K technology) a natural frequency of 0.5 Hz is achievable.

Shock as an Event

Shock is mathematically defined as an event in space. So in addition to 3 D space coordinates it requires a fourth dimension of time for defining a shock event Shock is an impulsive force of higher order which causes disturbance or chaotic condition leading to catastrophic failure of the system. Examples are Earthquake, collision of planets and asteroids, collision of vehicles, underwater explosion near a naval ship or submarine, [2, 3], landing of an aircraft and stage separation of spacecraft etc. In industrial environment input shock is specified in the form of half sine wave pulse for preliminary selection and response analysis. Non linear systems are used for attenuation high amplitude shocks. In quantum mechanics and electronics this is termed as perturbation.[14] The collision of highly accelerated particles, tunneling of electron through a potential barrier, the latest being the Large proton collision accelerator.

MATHEMATICAL APPROACH FOR SELECTION OF ISOLATORS

Vibration and shock analysis and response studies are of interdisciplinary nature and involves Newtonian mechanics, matrix mechanics. Wave mechanics, Aerodynamics, Lattice dynamics or Quantum mechanics depending on the nature of excitation and inertia mass, dimension and speed involved. Here we will describe the selection of springs using a spring mass model.

Spring mass model

The rigid body dynamics applied to a spring mass model in single degree of freedom (SDOF) are used for selection. In a two stage or multistage arrangement the isolators are used in stages. The design is critical and the resonance condition must be checked. Applications are categorized as per load rating deflection. For vibration isolation the linear springs are used whereas for shock non linear systems are preferred. [17, 18].] The vibration isolation efficiency is calculated using standard formula or by using dedicated computer program. [Fig. 1, 2, 5 & 6]

Input data required for calculation

For industrial machines the primary selection calculation requires the following input data. (1) The Total weight of the system including operating fluid & job weight (2) Centre of gravity of the system. (3) Lowest operating speed of the system. (4) The General assembly drawing of the system. (5) Location of the system - Ground floor / upper floor / roof top & Seismic zone number for earthquake protection. [Fig 2] (Seismic snubbers are used with spring systems to limit the excessive movement during earthquake)[18, 20] (6) Overall dimension of the equipment (7) Base frame details for isolator fixing arrangement.

TYPES OF ISOLATORS FOR INDUSTRIAL APPLICATIONS

Elastomeric - Metal Bonded Isolators & Multilayered bearings

For slowest operating speed = 1500 rpm, Deflection under actual load = 3 mm

Vertical isolation efficiency > 80% System natural frequency (f_n) = 9 Hz.

Springs and Viscous Dampers

Spring Viscous dampers with high viscosity fluid are used to provide damping of 5 to 20% example Spring damper systems are suitable for machines generating high dynamic loading.

Slowest Operating speed = 1500 rpm,

Deflection at static loading = 10 mm. Vertical isolation efficiency > 95 %,

System natural frequency = 5 Hz. Spring system [Fig.1 & 3]

Air Springs

Low frequency vibration isolated tables using air spring systems are used for such application. [9, 10, 15] For slowest Operating speed = 500 rpm, Vertical isolation efficiency > 98% System natural frequency = 1.8 Hz. The natural frequency of an air spring system can lowered by using additional air reservoirs attached to the air spring system. However the applications are limited to laboratories and ground testing of aerospace systems & components response studies for exciting forces of μg order [Fig.4]

Wire Rope and Cable Isolators

a. The all-metal & multidirectional configuration

b. Temperature from – 180 deg.C to + 300 deg.C.

c. The damping provided are high in the range of 15 to 20%

d. Applications in aerospace, naval ships and transportation.

SPRING MASS MODELS

(CONCEPTUAL DRAWING - NOT TO SCALE)

VIBRATION ENGG, APPLICATION DRAWING
DRG. NO. APP-0106020F (NOT TO SCALE)
DRN. AKS **CHKD.** SNB , DESIGN SEC, RPL

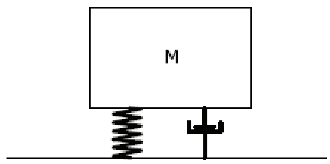


FIG.1-MODEL OF SPRING DAMPER SYSTEM

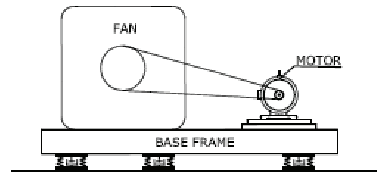
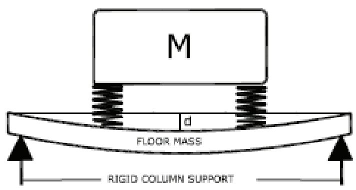


FIG.3 -SPRING DAMPER SYSTEM



d= DEFLECTION OF THE SUPPORTING FLOOR/ROOF TOP DUE TO LOADING

FIG.2 - HEAVY MACHINE ON ROOF TOP

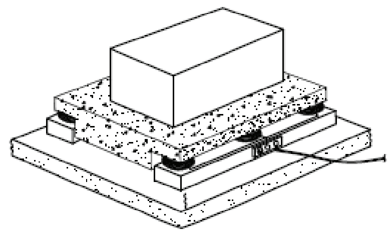


FIG.4 - AIR SPRING SYSTEM

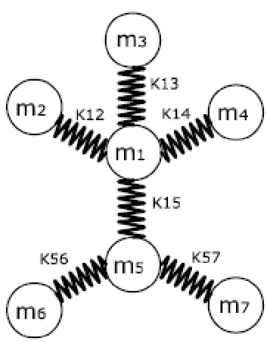


FIG.5- A POLY-ATOMIC MOLECULE
(MOLECULAR VIBRATION)

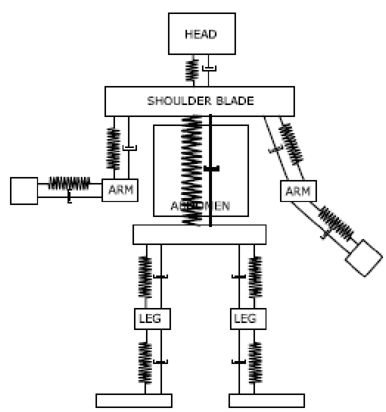


FIG.6 - A FUZZY MODEL OF HUMAN BODY

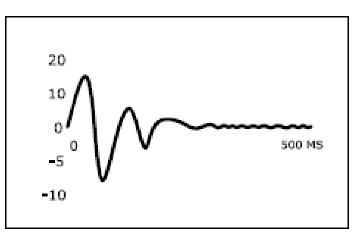


Fig. 7 ;- SHOCK RESPONSE -ACCELERATION
SUPPORTED MASS 70 Kg ON ISOLATOR fn = 7 Hz

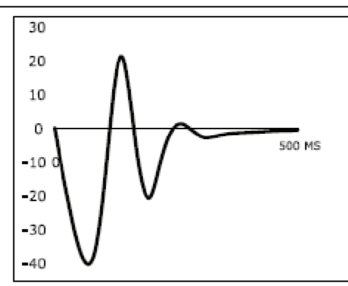


Fig. 8 ;- SHOCK RESPONSE DISPLACEMENT
SUPPORTED MASS 70 Kg ON ISOLATOR fn = 7 Hz

ISOLATION EFFICIENCY RESULTS & VALIDATION

The design practices and methodology are well established. The calculated results were validated by actual measurement and were found to be well within +/- 5 % for precisely defined mechanical systems .Standard computer programs may also be used for design validation.

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