# DESIGN OF VIBRATION ISOLATION SYSTEMS WITH SEISMIC SNUBBERS FOR THE PROTECTION OF MACHINES & EQUIPMENTS IN HIGHER SEISMIC ZONES.

**Bagchi S. N. and Jain Ratish**
Design section ,Vibration & Seismic Engineering Dept.,
Corporate Office ,Resistoflex Group, B -103 ,Sec.5,Noida -201301. India
e-mail design@resistoflex.in ; website- www.resistoflex.in

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**ABSTRACT**

[This is an industry oriented presentation describing the design and selection of vibration isolators for industrial application. For heavy machineries like Chillers , cooling towers, blowers, pumps and generators, spring systems are used for vibration isolation. When such systems are installed in higher seismic zones seismic snubbers are required to protect the spring system during seismic event. The Horizontal Forces are pre dominant in case of an earthquake which may lead to the failure of spring system. To limit the spring movement to a safe level Seismic snubbers are used. The mathematical design aspects and isolation efficiency results will be focused.

In introduction the Physics of Forces and Energy involved in oscillations in Large scale universe to vibration in atoms and molecules will be briefed. Infra-gravity waves, Acoustic waves and seismic wave propagation involving wide frequency range and different types of layered medium will be touched upon. An analogy of Machine vibration & Molecular Vibration spectrum will be presented.

The other application area where vibration & Seismic isolator selection is critical will include the installation of infrastructural machineries on the roof top or elevated structures in higher seismic zone will be covered.

## INTRODUCTION

The Vibrations and Oscillations from the infinite dimensional Large Scale Universe to the Quantum Universe of Atoms & Molecules and even further infinitesimal sub atomic particles all are governed by the Four Fundamental Forces of Nature (Gravitational, Electro-Magnetic (E.M), Strong Nuclear and Weak Interaction. Out of which gravitational force is the weakest force, but it is a long ranging force and is always attractive. The other field of forces are comparatively short ranging. The particle and wave nature duality exists. The energy of E.M.waves are calculated by using Quantum Theory conceptualized by Max Planck in the year 1900. The seismic waves are low frequency Shock wave are stress waves propagated through the soil & rocks which interacts at the base of the building foundation.

All the planetary movements in its respective orbits are primarily governed by the interaction of mass dependent gravitational force. The steady state universe after the big bang more or less represents the vibratory and oscillatory state of Universe. But any stray or rare event of collision of planets or massive explosion like big bang is termed as a Shock event in space. Shock is analyzed in 4D-Space –Time Dimension.

### 1.1 Frequency spectrum – From Earthquake to Electro Magnetic waves

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. Acoustic vibrations in audible band is in the frequency range from 20 Hz. to 20 KHz order. 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

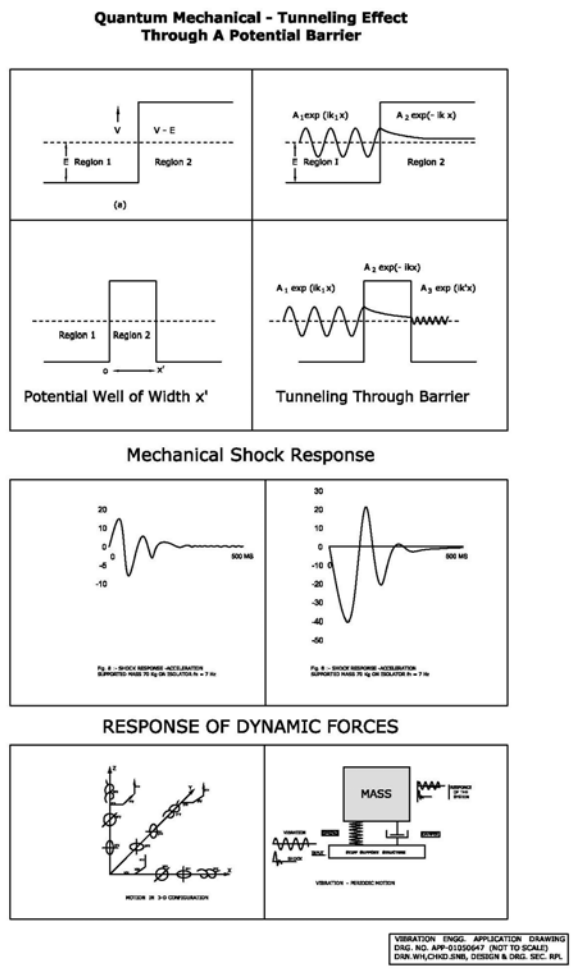
sensitive instruments in a micro- tech laboratory. The new negative stiffness
(-K technology) a natural frequency of 0.5 Hz is achievable.

**2.VIBRATION AND SHOCK DEFINITIONS –**
Vibration is periodic or random in nature and implies a sense of continuity .Example - An automobile engine , turbo machines or any rotating machine vibrates till it is in operating condition . Vibration isolators are used to bring down effective transmission of forces to the supporting structure. For mathematical analysis and selection of isolators 3 Dimensional orthogonal set of coordinates are used . Vibration in general create disturbance in the form of mechanical displacement and noise which may lead to fatigue failure after prolonged exposure

**2.1 Shock event** – Shock is mathematically defined as an event in space . 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, landing of
an aircraft and stage separation of spacecraft etc. In industrial environment
the input shock is specified in the form of half sine wave pulse for the 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. The collision of highly accelerated particles, tunneling of electron through a potential barrier, the latest being the Large proton collision accelerator.

**3. 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.

**3.1 Spring mass model -**
The rigid body dynamics applied to a spring mass model in single degree of freedom (SDOF) are used for preliminary selection. In a two stage or multistage arrangement the isolators are used in stages.(Fig 1 & 2) The design is critical and the resonance condition is avoided. Applications are categorized as per load rating deflection . For vibration isolation the linear springs are used whereas for shock non linear systems are preferred. The vibration isolation efficiency is calculated using standard formula or by using dedicated computer program. For mathematical analysis spring systems are defined in terms of stiffness.




**Selection Methodology& System Optimization-Non-Structural Components :-**
**Differential equation ( ODE)** 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 , Fo Sin wt represents the dynamic force. Eigen frequency 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

**3.2 Sensitive Equipments – Isolation from micro-seismic vibration of quasi static nature - microseisms**

In general the sensitive equipments or electronic instruments do not generate vibration of their own but requires isolation from the disturbances from the ground or supporting structure. The stiffness of the supporting structure is very important. The supporting structure stiffness should be at least ten times higher than the isolator stiffness for achieving optimum isolation result in industrial environment. Examples are Co-ordinate Measuring Machines(CMM), Laser Holographic set ups, Interferometers , High power microscopes and Atomic Force Microscopes etc.

**3.3 Input data required for calculation- (Rotating Machine)**

For industrial machines the primary selection 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 no.

6. Overall dimension of the equipment.

7. Base frame details for isolator fixing arrangement. The base frame & supporting structure stiffness should be at least Ten times ( X 10 ) higher than the spring stiffness for optimum result.

Depending on the Centre of gravity ( CG ) position the mounting locations are planned .For asymmetrical systems the load distribution on isolators are optimized by using computer program. Location of the isolator are balanced by using iterative method so that the load variation on isolators are minimized within +/- 15 % of the nominal value .

**3.4 Roof top installations in seismic zones -**

For rooftop isolation are critical , where high deflection spring mounting systems are used to achieve at least 90 % vibration isolation. During the earthquake the roof top acceleration in horizontal direction is magnified and may create a resonance or near resonance situation which may cause large displacement of the system and resulting the damage of the spring system. Seismic snubbers are attached to the system which restricts the movement of the spring within a permissible limit The free movement allowance for vibrations of quasi- static nature is incorporated in the design of

snubber system. Thus the vibration isolation efficiency is not adversely affected by using the snubber. But during the seismic shock disturbances the displacement is restricted and there is a higher shock transmission. As a typical example the shock transmission during seismic activity may be of the order of 4g .However the mechanical systems like chillers etc are rugged enough to tolerate a shock of 5 g order. These equipments are designed to tolerate the road transportation shock of similar order and hence the equipment and the mounting systems are protected against seismic shock.

**4. TYPES OF ISOLATORS FOR INDUSTRIAL APPLICATIONS**

**4.1 Elastomeric - Metal Bonded Isolators : -**

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

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

The energy is due to the coiling of long chain compound. The internal damping is small. Due to cost effectiveness and easy availability multilayered pads are widely used in industries . For mechanical systems the square cell pads are available in the nominal load range from 2.5 Kg / cm^ (2) to 14 Kg / cm^ (2) . These multilayered bearings are stacked upto 6 layers for general applications in mechanical systems. The building bearings for seismic isolation are designed for horizontal displacement and typically consists of 12- 14 layers. The aspect ratio and stability is an important consideration while designing a seismic bearing.

**4.2 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. The tuned dampers are used to reduce the effective force magnification at resonance point. However for higher seismic zones only spring systems are used. Example of a rotating machine like DG set, The rated load of spring is decided depending the total weight of the system.

Slowest Operating speed of the machine = 1500 rpm,

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

System natural frequency = 5 Hz.

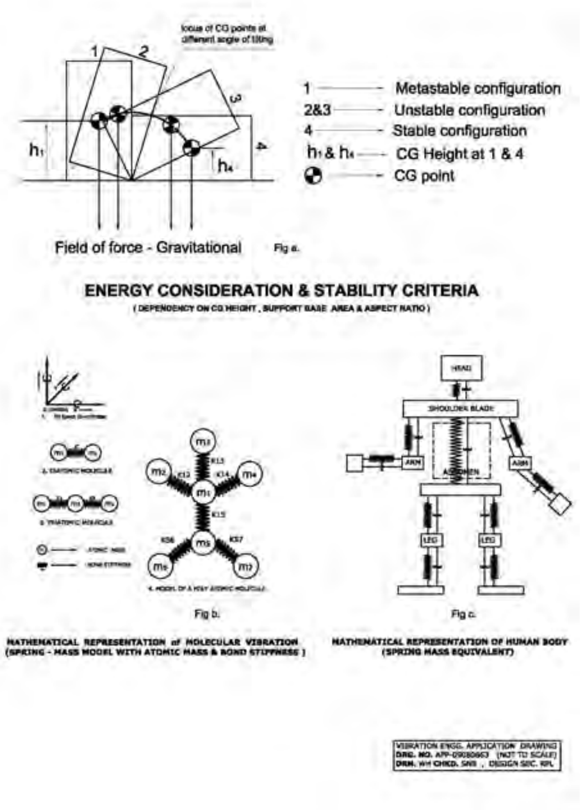
### 4.3 Air Springs :

Low frequency vibration isolated tables using air spring systems are used for such application. 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 The air springs are used in railways and transportation.

### 4.4 Wire Rope and Cable Isolators :

a. The all-metal & multidirectional configuration.
b.Temperature .range - – 180to + 300 deg.C.
c The damping provided are high in the range of 15 to 20%
Applications in aerospace, naval ships and transportation.




## 5.ISOLATION FFICIENCY CALCULATION RESULTS

As an example the vibration isolation efficiency of a typical Fan – motor system with asymmetric load distribution is shown here

Total Mass of the Fan + Motor + Accessories = 590 Kg.
No.of Spring isolators = 8 Nos.,
Load after optimization = 74 Kg each (+/- 5%)
Operating speed of the fan = 880 RPM.,
Motor speed = 1440 RPM.
Stiffness of spring isolator = 39.24 N /mm each
Static deflection (vertical ) Nominal = 18 mm
Vertical Natural frequency = 3.7 Hz.
Ratio of Exciting frequency/system nat. freq. = 3.9
Calculated Vibration isolation efficiency > 90 %

## 6. CONCLUSION

The design practices and methodology are well established. The calculated results were validated by actual measurement and was found to be well within +/- 5 % .In view of the deviation and dimensional variation of the system an empirical tolerance of + 5 / - 10 % may be considered in system design

**REFERENCES-**

1. BorisV.Derjaguin(1960)–The forces between molecules,ScientificAmerican, **203** No.1 pp 47
2. BhujangaRaoV(1998)NSTL-SVM-**98**,Visakapatanam–Intro.toShock and Vibration Isolators.
3. Bagchi S.N.– "Application of vibration and shock techniques in industrial systems design" .Journal of Acoustic Society Of India, **28** No. 1-4, 2000, pp 87.
4. Bagchi S.N.and Harsh Vardhan, IDDC, IIT Delhi (1974 )– Moire Fringe Refractometer (abs. Symp.Optics and Electro Optical technology at MNR Engg. College,Allahabad,March 1974.
5. Bagchi S..N (1971).–Design of Moire Fringe Refractometer - M.Tech. Final dissertation submitted to Instrument Design and Development Centre, IIT Delhi –1971.
6. Bagchi S.N.(2003 ) - "Mathematical concepts in industrial design of vibration isolation systems and an analogy with molecular vibrations " Proceedings of National Conference on Optics and Photonics in Engineering at NSIT Delhi, pp. 126.
7. Bagchi S.N and Jain Ratish (2004) - "Vibration isolation systems for optical and laser instruments & experiments related to surface engineering and metrology" Proceedings of International Convention on Surface Engineering at I.S.R.O. Satellite Centre, Bangalore Aug. 2004 pp 355 – 358
8. Bagchi S.N. and Jain Ratish (2007) - " Vibration isolation system selection and optimization calculation results extended to high frequency band " Proceedings of National Symposium on Acoustics NSA -2007 Macmillan advance research series Dec.2007 pp 1053 .
9. Contitech,Luftedersysteme,Hannover,Germany – Air Springs for industrial applications..
10. Socitec International,Sartrouville,Cedex, France – La protection contre les chocs et vibrations - Selection Guide for Wire Rope Isolators Standard line Helical and Polycal.
11. Hawking Stephen ( 1996) - Space and Time- A brief history of time – pp 26
12. Herzberg .G.– Molecular Spectra and Molecular Structure

13. Irretier H(1999) – Experimentelle Modalanalyse II,Institute of Mechanics, University of Kassel,e 7 ,Kassel,Germany ,Monchebergstra 1999 pp 5-8.
14. Irretier H ( 1997 ) – Schwingungen in Roteierendedn Maschinen Universitat GH Kassel
15. Jain D.K., Bagchi S.N.and. Kumar U.V, CEL, Sahibabad (1982)–Low Light level detection with improved S/N using photon counting systems ( Abs. Jan'82 I IT, Madras)
16. Jain Ratish and. Bagchi S.N.(1998 )– Vibration Isolation techniques for CMM and sensitive instruments in Hi-tech area – Journal of Metrology Society of India. **XIII**, pp 43
17. Jain Ratish and Bagchi S.N ( 2001). – "Design Trends and Application of Vibration Isolation Techniques for Electro- Mechanical Systems in Dynamic Environment" Modern Perspectives in Machines and Mechanisms, Proceedings NaCoMM , Mechanical Engineering Department . I.I.T. Kharagpur, pp 481
18. Jain Ratish and Bagchi S.N.(2002) – "Design considerations for vibration isolation of sensitive instruments and systems from micro seismic disturbances"- Proceedings of 12th Symposium on Earthquake Engineering at I I T Roorkee , **2** , pp 1543
19. Jain Ratish and Bagchi S.N.(2003) "Design of vibration isolation systems for metrological laboratories in industrial environment" Proceedings of 4th International Conference on Advance in Metrology: Equivalence of Standards and Global Recognition (Admet 2003) at N P L New Delhi Journal of Metrology Society of India, **18** pp 211
20. A.K.Mallik, Dept.of Mechanical Engineering,IIT Kanpur -Evolution of theory of Machines–From steam Engines to Mechatronics– Modern Perspectives in Machines and Mechanisms –. Proc.NaCoMM – 2001 at IIT Kharagpur Dec 2001 pp45
21. S.N.Bagchi,Design, RPL,Noida and Bishakh Bhattacharya,Mech Engg.Dept, IIT Kanpur – Design Analysis and Attenuation characteristics of Elastomer isolators in a large freq. band-Proceedings of Indo-French Conferance 'Acoustics2013' at NPL Nov 2013 pp 1412
22. S.N.Bagchi and Ratish Jain –(2013) Design section,Vibration Engg.Dept.Resistoflex,Noida,-Design & Application of Multi-layered Structural Bearings focusing Anechoic Test Facility- Building & Environmental Acousics session -Proceedings of Indo-French Conferance 'Acoustics2013' at NPL India Nov 2013 pp 131
23. S.N.Bagchi- Design RPL, Noida,-The Mathematical and Physical Science concepts involved in Design of Advance Vibration & Shock isolation Systems focusing Automobile & Aerospace Applications,- Proc. of Conf on Advance Techniques & Devices in Mathematics & Physical Sciences [ An International Meet ] CATDMP-2015 at Dept of Mathematics & Physics,SRM University,Delhi-NCR campus Jan. 2015 ( ISBN -978-93-84935-11-5)
24. S.N.Bagchi- K:Solid Mechanics,Fluid Mechanics,Geophysics and Relativity – Mathemetical design of Vibration & Shock isolation Systems focusing Automobile and Aerospace applications – 80th.IMS Conf.of Indian Mathematical Society ( Estd 1907) at Indian School of Mines ,Dhanbad.Dec 2014 Ref.IMS Newsletter No.33 March /April 2015
25. White H.E (1934) - Introduction to Atomic Spectra, International Series in Pure and Applied Physics,Mc-Graw Hill Book Company, Kogakushu Company Ltd. Tokyo, Japan
26. Govardhan,D.K.Paul,Earthquake Engg. Dept., IIT Roorkee, India and S.N.Bagchi , Ratish Jain, Vibration Engineering Dept..Resistoflex, Noida India,- "Design & Development of the base isolation system for seismic protection of buildings. Proceedings of 7th.World Congress on Joints, Bearings and Seismic systems for Structures at Green Valley, Las Vegas,Neveda, U.S.A. Oct 2-6,2011, pp 957-971

**Annexure-A**