Design of Vibration Isolation Systems for Advance Metrology and Aerospace Test Laboratories in Industrial Environment

S.N. Bagchi

Design Section, Vibration & Seismic Engineering Dept., Corporate Office,
Resistoflex Group of Industries, B -103, Sec.5, Noida -201301, India
E-mail: design@resistoflex.in

Abstract—*This is an industry–academia oriented presentation highlighting the Physics, Mathematics and Engineering practices used for the design and selection of Vibration & Shock isolation systems for industrial applications. The applications are widespread from Power plant machineries to quantum metrology & Laser Holography Laboratory. Even a surgeon any in super specialty hospital requires vibration isolation of the operation table to perform a delicate brain surgery. The micro-seismic structural disturbances of the building are isolated by using Air springs.*

Air springs are also used in High speed Rail coaches, metro railways and deluxe buses for a comfortable journey. The mathematical design optimization using spring mass model of a human body and low Eigen-frequency Air springs (~ 2 Hz) will be explained. The earthquake protection of buildings and infrastructural machineries also requires Seismic isolators and snubbers in high seismic zones.

The mathematical modeling and modalities will be having an Engineering and Industrial Physics orientation. In view of the inter-disciplinary nature of the subject and wide spectrum of coverage from Molecular vibration to Machine Vibration, the presentation will contain more slides from real life applications & installations from industrial sector.

Glimpses of Applications in Aerospace Engineering will be focused in the concluding slide.

1. INTRODUCTION- HISTORY OF DEVELOPMENT

1.1 -Starting from pendulum clock to Atomic clock –

Perhaps the basic concept of correlating the oscillation frequency and time measurement started with the discovery of pendulum by Galileo. Later on the concept was used for the 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. Later on vibration or transition in quantum level had been used as a standard in Atomic clock. Later on the same concept was used for development of mechanical pendulum clock.

2. HIGH SPEED MACHINES & HIGH RESOLUTION INSTRUMENTS FOR ADVANCE METROLOGY-

With the evolution of High speed machineries and the requirement of precision motion control the vibration Isolation systems became more and more relevant. The subject areas like kineto-elasto dynamics became more important in mechanical engineering. Co-ordinate Measuring Machines (CMM) and Laser based instruments are now an essential requirement of a QC Metrology lab attached to any mechanical workshop. These high resolution instruments are affected by the building & structural vibrations of micro-seismic. The air spring supported tables are used for the isolation of micro-seismic disturbances.

3. EARTHQUAKE PROTECTION OF BUILDINGS & INFRA-STRUCTRUAL MACHINERIES IN HIGH SEISMIC ZONES -

Seismic Bearings are designed to provide base isolation by decoupling the building with the ground motion during any earthquake event in High Seismic Zones. For vibration isolation on upper floors and roof top spring isolators are used the infrastructural machineries like cooling fans, cooling towers, chillers, pumps and compressors etc.are supported on spring systems. and Seismic Snubbers are are required to limit the effective displacement of the structure for the earthquake protection.

4. MATHEMATICS AS A SUBJECT OF UNIFICATION –FROM STRUCTURAL DYNAMICS TO MACHINE DYNAMICS.

Based on spring-mass model of a system the eigen-frequency is calculated which is the solution of a differential equation. The response of the spring supported system due to any exciting force of dynamic nature depends on the unique value of eigen-frequency in x, y and z direction. An optimized design calculation of a rotating machine will be presented. The seismic isolators used for the Earthquake protection of buildings will be briefed. Wave Mechanics to Quantum Mechanics are correlated and connected through spectral parameters e.g. frequency, wavelength and velocity. Velocity (dx/dt) requires precise position and time measurement which is extremely elaborate as it approaches the 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). 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.

5. INDUSTRIAL APPLICATIONS–LINEAR AND NON LINEAR

Isolation Systems- The selection is focused on the Amplitude and frequency of the input dynamic force. Mathematically vibration is of quasi static nature and has a sense of continuity. Further it may be periodic or of random nature. But the shock is due to an impact force and is described as a pulse of short duration. Examples are travel by car or flying by an aircraft. The engine under normal operating condition produces vibrations which are isolated by engine mount. The spring damper suspension systems isolates the vehicle from road vibration & shock both. So when a vehicle crosses a road bump the shock effect is reduced by the damper system. Similarly the landing of an aircraft is a shock. For high shock isolation spring-damper systems are used. For naval ships and submarine applications both Vibration & shock isolators Non-Linear Systems are used.

5.1 Application of Air Springs-

Fig. 1: AIR SPRING MOUNT FOR A MACHINE LEG

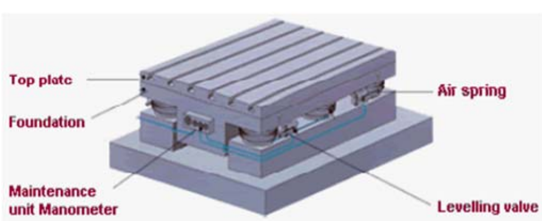

Fig. 2: AIR SPRING SUPPORTED PLATFORM

(Photo Courtesy- Conti-Tech, Germany)

5.2 Application of non- linear wire rope isolators-

Fig. 3: THE OPTO–ELECTRONIC SYSTEM MOUNTED ON A HELICOPTER REQUIRES VIBRATION ISOLATION.

Fig. 4: JET ENGINE ON A WIRE ROPE ISOLATED TROLLEY

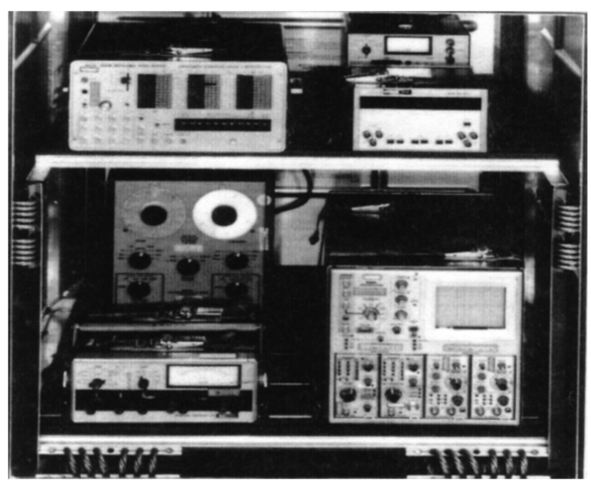

Fig. 5: TRANSPORTATION OF ELECTRONIC SYSTEMS

(Photo Courtesy–Socitec, France)

6. SYSTEM OPTIMIZATION BASED ON EIGEN-FREQUENCY CONSIDERATION

Second order 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 parameters respectively. $F_o \sin wt$ 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.

6.1 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 and 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 formulae or by using dedicated computer program.

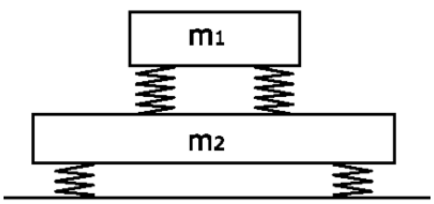

Fig. 5: Two Stage Spring-Mass Model

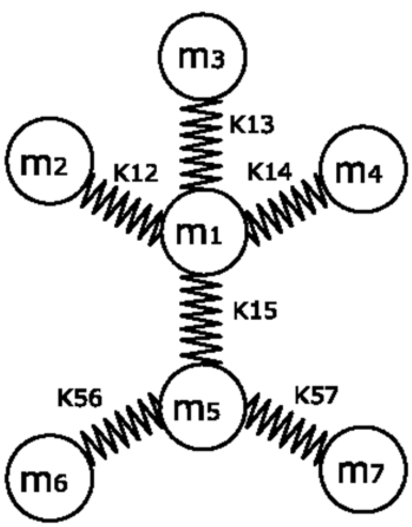

Fig. 6: A Polyatomic molecule

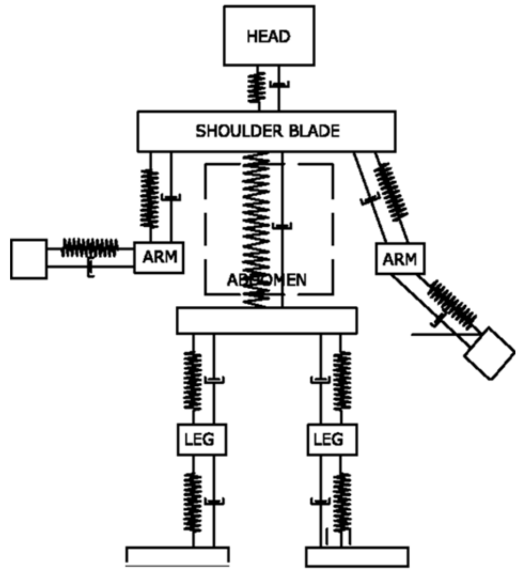

Fig. 7: Flexibility of a Human Body

6.2 Concept of Symmetry in System Design-

For an effective vibration control of heavy plant machineries high deflection springs are used. The locations of the springs are optimized with respect to the location of Centre of Gravity (CG) such that all the springs are almost uniformly loaded well within +/- 5% load variation. Heavy machines like coal crushers are installed over RCC foundations and Spring-Damper combinations are used below the foundation. The load optimization and spring selection of a typical coal crusher of a thermal plant will be detailed. The isolators are distributed symmetrically about the centre line of the machine.

6.3 An analogy of Molecular Vibration with Machine Vibration

The Molecular Vibration of a polyatomic molecule are in the Infrared(IR) frequency band of the electromagnetic radiation. The spring-mass model using bond stiffness and the atomic mass of the linked components are used to calculate the specified group vibration using quantum –mechanical model.

Similarly for a mechanical systems like turbo-engines or a reciprocating engine of a car or a ship the FFT spectrum indicates the vibration peaks at operating speed and the harmonics which are used for condition monitoring of the mechanical system.

7. TYPES OF ISOLATORS FOR INDUSTRIES–

7.1 Elastomer Material and 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.

7.2 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.

Slowest Operating speed of the machine = 1500 rpm,

Deflection at static loading = 10 mm.

Vertical isolation efficiency > 95 %,

System natural frequency = 5 Hz.

7.3 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. [Fig. 1 & 2]

7.4 Wire Rope and twisted Cable type 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 submarines

8. VALIDATION OF MATHEMATICAL RESULTS

Design optimization is based on Fuzzy and Generic logic based concepts. The calculation results are validated by actual measurement after installation and the efficiency results are found to be well within a tolerance of +/- 10 % of the mathematically predicted value.

9. ACKNOWLEDGEMENTS

The author thanks the management of Resistoflex, India for the support and encouragement of Industry-Academia oriented work with the backup of manufacturing and test facilities. Interactive design work with Conti-Tech, Germany and Socitec, France is duly acknowledged.

Dedicated to my teachers and guides at Allahabad, BHU and IIT’s for the continued guidance on Industry –Academia oriented work involving Physics & Engineering.

REFERENCES

[1] *Bhujanga Rao V* (1998) NSTL-SVM **-98**, Visakapatanam–Intro.to Shock and Vibration Isolators.

[2] *Bagchi S.N. and Jain Ratish*–(2013),Resistoflex,Noida,-Anechoic est Facility- Proceedings.of Indo-French Conf. ‘Acoustics2013’ at NPL India Nov 2013 pp 131.

[3] *Bagchi S.N.*- K:SolidMechanics, FluidMechanics, Geophysics and Relativity–Mathemetical design –80th.Conf of Indian Mathematical Society (Estd 1907) at Dhanbad.Dec 2014 Ref.IMS Newsletter No.33 March /April 2015

[4] *Bagchi S.N*.– “Application … systems design” J. Acoustic Soc.of India, **28** No. 1-4, 2000, pp 87.

[5] *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.

[6] *Bagchi S..N* (1971).–Design of Moire Fringe Refractometer - M.Tech. Final dissertation submitted to Instrument Design and Development Centre, IIT Delhi –1971.

[7] *Bagchi S.N.(*2003) - “Mathematical concepts in industrial design analogy with molecular vibrations “ Proceedings of National Conference on Optics and Photonics in Engineering at NSIT Delhi, pp. 126.

[8] *Bagchi S.N and Jain Ratish (2004)* - “Vibration isolation systems for optical and laser instruments Proc.of Intl.Conf. on Surface Engineering at I.S.R.O. Satellite Centre, Bangalore Aug. 2004 pp 355–358

[9] *Bagchi S.N. and Jain Ratish (2007)* - “ Vibration isolation system…optimization…high frequency band “ Proc.of National Symposium on Acoustics NSA -2007 Macmillan advance research series Dec.2007 pp 1053 .

[10] *Contitech, Germany*–Air Springs for commercial vehicles.

[11] *Conti Air Spring Technology*–Complete systems for vibration isolation and support machinery.

[12] *Hawking Stephen* (1996) - Space and Time- A brief history of time–pp 26

[13] *Irretier H(1999)*–Experimentelle Modalanalyse II,Institute of Mechanics, University of Kassel,e 7, Kassel,Germany, Monchebergstra 1999 pp 5-8.

[14] *Jain D.K., Bagchi S.N.and. Kumar U.V*, CEL, Sahibabad (1982)–Low Light … detection … S/N using photon counting systems (OSI Symp. Abs. Jan’82 I IT, Madras)

[15] *Jain Ratish and Bagchi S.N* (2001).–“Design Trends…Electro-Mechanical Sys.”Modern Perspectives in Machines and Mechanisms, Proc. Mech. Engg. Dept. I.I.T. Kharagpur, pp 481

[16] *Govardhan, D.K.Paul*, Earthquake Engineering Department.IIT Roorkee, India and *S.N.Bagchi, Ratish Jain,* Vibration Engineering Dept..Resistoflex, Noida India,- “Design of base isolation system for seismic protection of buildings. Proc.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

Flow chart of vibration isolation systems (in pdf) is attached separately as Annexure - A.