ACTIVE TOOL VIBRATION ISOLATION SYSTEM DESIGN FOR MICROMACHINING APPLICATIONS

Dheeraj Poojary[1], Divijesh P[2], Muralidhara[3]
[1]PG Student, Department of Mechanical Engineering, NMAMIT, Nitte, Udupi, Karnataka, India
[2]Assistant Professor, Department of Mechanical Engineering, NMAMIT, Nitte, Udupi, Karnataka, India
[3]Professor, Department of Mechanical Engineering, NMAMIT, Nitte, Udupi, Karnataka, India
[1]dheer23a@gmail.com, [2]divijesh@nitte.edu.in, [3]drmuralidhara@nitte.edu.in

Abstract
Vibration isolation is a very effective method to eliminate the unwanted vibrations in mechanical and any other systems. Isolating the ultra-precision machine from vibrating base is importance in engineering fields. This is a process of reducing transmission of vibrations into the mechanical components of the system. Two possible methods of isolating vibrations in a system are passive isolation method and active isolation method. Active vibration isolation system has capacity of isolating vibrations at all frequencies and is better when compared to passive vibration isolation systems. The active vibration isolation system consists of two amplified piezoelectric actuators. Piezoelectric actuators have advantages such as fast response, low power consumption and no wear and tear. But it has a disadvantage of limited stroke displacement. A new vibration isolation system has been developed using two actuators which are made to move only in Y- direction. In this setup, the source actuator is used to generate the vibrations and the isolator actuator is used to provide counter vibrations to the vibration generated by the first actuator, in order to nullify the vibrations in the system. The design is robust and the analysis is performed on the vibration isolation system in order to study the static, Dynamic and harmonic response of the system. This paper focuses on the design and analysis of the vibration isolation system. The future scope of the work is fabrication of the active vibration isolation system, testing the system for various parameters and implementing on tool based micromachining applications such as turning, milling etc.

Keywords: Vibration isolation, piezoelectric actuators, flexible plate, analysis, micromachining.

I. INTRODUCTION

Vibrations are the periodic motion of the particles from the equilibrium, when that equilibrium is disturbed. Mechanical vibrations degrade the fabrication and also degrades the quality of the products. Hence control of these vibrations is necessary in every fields. The vibrations in any components will reduce the component life. In human application it reduces the comfort. During machining operations, the vibration reduces product life, and has a poor surface finish. Many types of methods have been applied to isolate these vibrations in the engineering field. Vibration can result from a numerous condition, acting in combination or alone. So these vibrations need to be reduced.

A) Vibration isolation

Vibration isolation is a process of preventing or reducing transmissibility of vibration from source of vibration to the isolated region. The problem of undesired vibrations arises from an intrinsic problem in flexible structures that these systems are easily vibrated due to the task that they are assigned for, or due to severe ambient conditions. Two main types of vibration isolation systems are active vibration isolation and passive vibration isolation systems.

1) Passive vibration isolation

The passive isolators are used to attenuate vibrations in mechanical structures using passive dampers. The most common methods used for isolating vibrations in industrial equipment include Reduction of Force, Addition of mass, Tuning, Isolation, and Damping. Passive isolations methods cannot be used for all systems because it has mechanical components which in turn has vibrations. Passive vibration isolation is not favorable resonant frequency excitation.

2) Active Vibration Isolation

Active vibration isolation are the systems that dynamically react to incoming random vibrations. They sense incoming vibrations and react to them with a quick response, rather than passively reducing their effect by virtue of their mechanical structure. Active vibration control has been used for rejecting the undesired vibrations in different systems for many years. The problem of undesired vibrations arises from an intrinsic problem in flexible structures that these systems are easily vibrated due to the task that they are assigned for, or due to severe ambient conditions. This problem is not limited to one system or one design, and a wide variety of systems have suffered from this issue. An active vibration cancellation system is developed in order to reduce these vibrations.

B) The components of Active vibration isolation system

1) *Vibration sensors:*

Vibration sensors are categorized based on the type of signal being measured, i.e. displacement, velocity or the acceleration values of vibration. Types of vibration sensors are velocity sensors, displacement sensors and accelerometers.

2) *Actuators:*

Actuators are an important part of any active vibration isolation system. They generate counter signals that are necessary for isolation. Depending upon the type of actuation the actuators are classified as electromechanical, electromagnetic, fluidic or piezoelectric devices.

3) *Signal processing:*

The signal processing systems acquire data from the sensors using a data acquisition system. The sensed data gets modified into digital form for further processing. The processed data is again transformed back into analogue voltage output to actuate the amplifier with required amplification. These systems are embedded in a computer and work with the help of software systems like Lab VIEW, MATLAB etc.

4) *Piezo-electric stacks:*

Piezo electricity is the property exhibited by some materials which produce electricity on applying mechanical displacement. It is also a reversible phenomenon i.e. when the voltage is applied to the piezoelectric stack it gives the displacement by developing the force. These piezoelectric stacks are made of ceramic materials of many thin piezo ceramic layers which are parallel connected electrically. The main characteristics of the stack are: efficiency of high energy conversion, low voltage operation, large force, fast response, and no electromagnetic induction. Energy density of the stacks are very high in a small package. Due to its higher compressive strength, it provides a high load bearing capability. But, it is comparatively weak in tension. The actuator is the driving the source for the experiments. The dimensions of the actuator is of 10*10*10 by its dimensions.

II. IMPORTANCE OF THE PROPOSED WORK

The proposed design of active vibration cancellation system is used for tool vibration isolation in micromachining. The design consists of various components like the main block, bracket, flexible structure, rigid support, piezo electric stack, stiffener and the mounting plates. The main block supports all the components and has an isolated table where the tool or the work piece can be held. The stiffeners are used to absorb vibrations. The source actuator is used to generate the vibrations. These vibrations are transmitted by the flexible plate to the isolator actuator. The flexible plate is rigid in X and Z directions and it has flexible movements in Y direction. The system is designed in such a way that for the vibrations generated by the source actuator, the isolator actuator itself generates vibration in out of phase. The generated vibrations get nullified. By this way the control of the vibration is done. The developed system is compact. The designed active vibration isolation system can be used for active vibration isolation of the cutting tool/work piece in micromachining applications.

III. LITERATURE SURVEY

X. Luo et.al (2009) done investigations on vibration control by elimination of hysteresis non linearity between applied voltage and the resulting displacements. Bouc-wen model is used. Stacked piezo actuators are used. Parameters are estimated from the experimental using 'Trust-region nonlinear least square method' in MATLAB Simulink. Comparison between the displacements by the model to desired displacement is found by inverse of Bouc-wen model. This method incorporates open loop displacement control for piezo actuator. Tracking or control is done by using inverse Bouc-wen model. The error found was only 0.6% which ensured 80% of vibration isolation [1].

Miaoxian Guo et.al (2015) proposed vibration isolation system is to reduce the transmission of vibration from the machine to the base or foumdation. Provides high performance. Vibration isolation is done on the vibration that is transmitted to the sensitive equipment. A Z- direction isolation is employed by using PID controller and piezoelectric element. It over hook the passive isolation technique by using Active isolation technique. Active isolation system cancels vibration in real time. For a particular excitation signals of a significant vibration reduction is obtained [2].

Shunli Xiao et.al (2014) demonstrates the nonlinear-rate-dependent hysteresis characteristics. This nonlinear hysteresis with the inverse Bouc-wen model to control the hysteresis by identification of various parameters by particle swarm optimization method. The model handled nonlinear online rate of the PZT hysteresis. Consistently compensated rate- dependent hysteresis. Improved PZT marking accuracy and open loop hysteresis cancellation [3].

A. Harms et.al (2004) designed a tool holder which actively damps the vibration and stabilize the turning process. The designed tool holder can be used for CNC-lathes and can reduce frequent usage of tools. A multilayer piezoelectric actuator which is in collocation with a piezoelectric force sensor is used for designing. An integral force feedback control method is used for active damping [4].

Niju Rajan et.al (2013) proposed the use of Piezoelectric Actuator in active vibration isolation on CNC Lathe. The d-space 1104 controller was used. The controller is developed such a way that, the disturbing vibration and to generate the output which nullifies the existing disturbing vibration. Second set of actuators as used. First one to generate vibration second used for generating 180 out of phase vibration which produces and ensures the vibration isolation. 64% of the vibrations were found to be controlled. This is employed for the use for active vibration isolation of cutting tool in making process [5].

IV. MOTIVATION

Vibration of machining process and excessive floor has detrimental effects on part quality, tool life, and productivity, so the machine needs to be isolated from the disturbing mechanisms which disturb the metrology loop besides exciting structural resonances on the machine. Isolation of tool vibration is importance in engineering fields. The active vibration isolation system is helpful in reducing the transmission of vibratory forces to the machine or the foundation. The proposed work involves in design, analysis and development of active vibration isolation system, which can be employed for vibration isolation of the machine tool/work piece that is caused during micromachining process. By the development of this setup high quality of machining can be performed on the work piece and the tool wear due to the vibration can be reduced.

V. OBJECTIVES

a) To design fabricate and analyze piezo actuator based active vibration isolation system using single stacks.

b) To perform dynamic analysis on the parts and the system.

c) To implement the active vibration isolation setup for micromachining applications.

d)

VI. METHODOLOGY

A brief methodology of the proposed work is presented by using the block diagram.

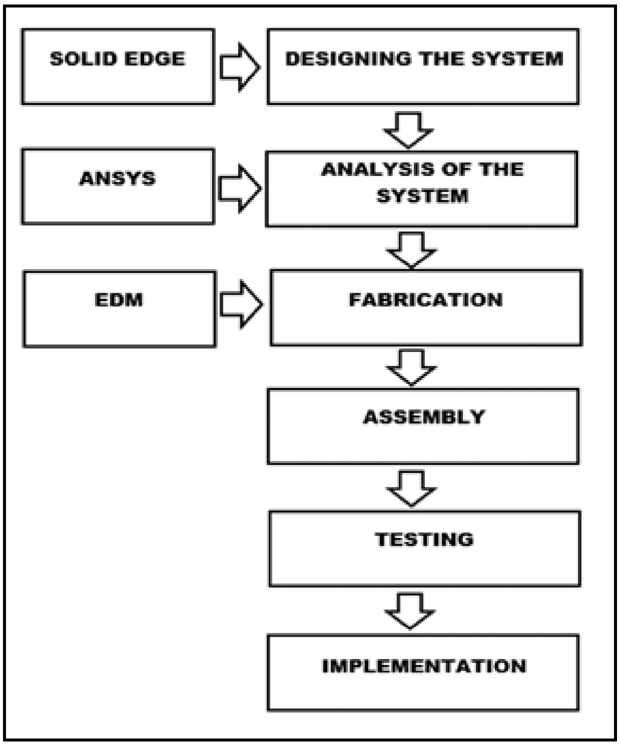

Fig 1. Block diagram of the methodology.

VII. DESIGN OFACTIVE VIBRATION ISOLATION SYSTEM

An active vibration isolation system was designed using Solid Edge V19 software. Fig 2 shows the complete assembled setup model of the active vibration isolation system. The model is named for its different parts. First the individual parts was modelled using the software. The designing of the model is done as robust as possible.

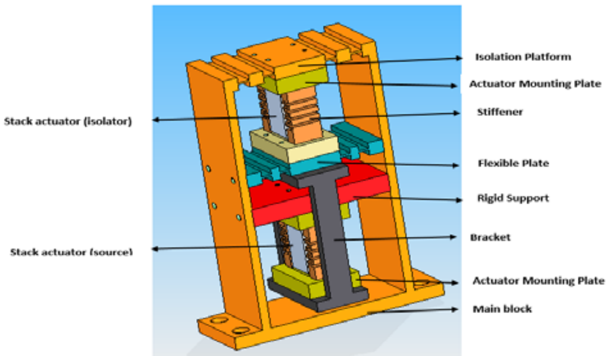

Fig 2. Assembly of active vibration isolation setup.

The proposed active vibration isolation system made up of Structural steel consists of two actuators, where source actuator is used to generate vibration and isolator actuator to nullify the transmitted vibrations. Piezoelctric actuators used are Multi Layer Actuator MLA 10×10×20. The basic principle of operation are narreted as follows, When voltage is given to the source actuator its gives the displacement in downard Y- direction pulling the isolation table in the downward Y- direction. Similarly when voltage is given to the isolator actuator it gets displacement in upward Y- direction to the same extent to when its pulled down in downward Y- direction. Hence the net displacement on the isolation table will be nill. This is how the conceptualisation is done.

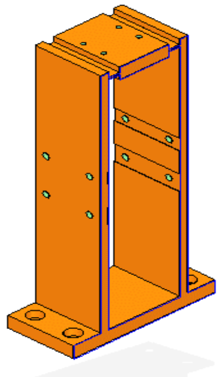

Fig 3. Model of main block.

a) Main Block: Main block is the structure that holds all the parts of the Vibration isolation system. This part is fixed to the base plate rigidly. Model is shown in the Fig 3.

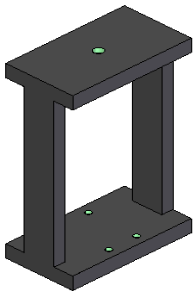

Fig 4. Model of the bracket.

b) Bracket: The actuatoris mounted on the actuator mounting plate. Hence the bracket holds the actuator assembly in turn it holds the actuator. The bracket enhance the Y- direction movement of the actuator. The model of the bracket is shown in the Fig 4.

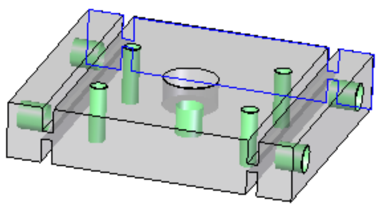

Fig 8. Model of flexible plate.

c) Flexible stucture: This structure is used to support the actuator, bracket and also it responds to the displacement generated. The model of the flexible plate is shown in the Fig 5.

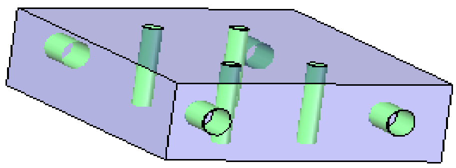

Fig 9. Model of rigid support.

d) Rigid support: This is used to support the source actuator assembly. This rigid support is constrained in all the directions . Model is shown in the fig 6.

Fig 7. Model of piezoelectric stacks.

e) Piezoelectric stacks: Piezoelectric stacks are the driving blocks of the whole vibration isolation system. They contain multiple layers of Piezo ceramic wafers piled together to form a stack. The dimension of the stack is 10*10*20 mm. Model of a Piezo electric stack is shown in fig 7.

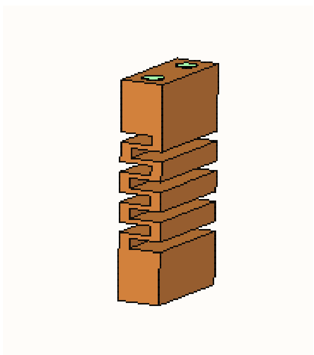

Fig 8. Model of stiffener.

f) Stiffener: These are used to absorb the vibrations. The model of the stiffenere is shown in the Fig 8.

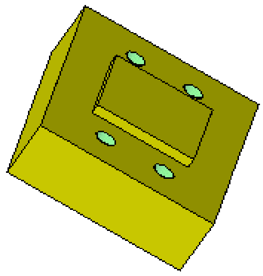

Fig 9. Model of actuator mounting plate.

g) Actuator mounting plate: These plates are used to support the actuators on both sides. Between two plates the actuators are mounted. The model of the actuator mounting plate is shown in the fig 9.

VIII. ANALYSIS OF THE ACTIVE VIBRATION ISOLATION SYSTEM

The analysis of active vibrations system was performed in order to know the displacement characteristics of the system. The analysis was performed using ANSYS 18.1 WORKBENCH. Static, modal and harmonic analysis were performed on the system. Also the analysis on the flexible plate and isolation platform was performed to know the stiffness of the parts. The material selected during the analysis is Structural steel. After the analysis was done the results data is interpreted.

A) Analysis of the isolation platform.

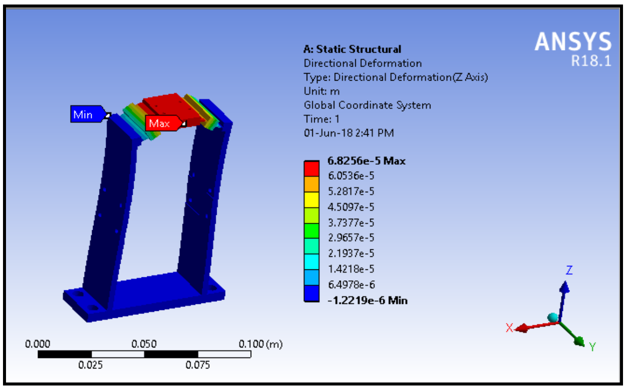

Fig 10. Analysis of the isolation platform.

Fig 10 shows the static analysis of the isolation table which is an integral part of the main block. It shows the Z- direction displacement of the isolation table. The static analysis is done by keeping the base of main block fixed and applying 100 N force on the bottom face of the isolation table in Z- direction. Solution of displacement along z- direction are shown in the figure. From the results it was found that the maximum displacement along Z- direction is 68.256µm. The stiffness is calculated using the formula,

$$\text{Stiffness along z direction} = \frac{\text{Load along Z direction}}{\text{Disp along z direction}}$$

The stiffness of the isolation table was found to be 1.46 N/µm. Dynamic analysis was performed to find the natural frequency at each mode of vibration. The results are tabulated in the Table 1.

TABLE 1. STIFFNES AND NATURAL FREQUENCIES OF THE ISOLATION PLATFORM.

	Stiffness along Z-direction (N/µm)	Natural frequency at each mode in Hz					
		Mode1	*Mode2*	*Mode3*	*Mode4*	*Mode5*	*Mode6*
Isolation platform	1.46	186.84	1032.5	1230.9	1261.1	1507.3	1604.3

B) Analysis of the flexible plate.

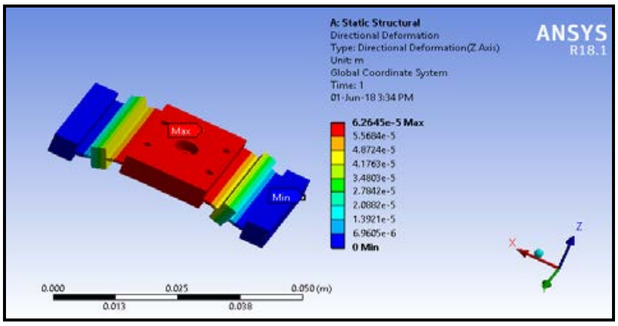

Fig 11. Analysis of the flexible table.

Fig 11 shows the static analysis of the flexible plate. Structural steel is used as the material for the analysis. The flexible pate is constrained such that it has movement in Z- direction only. The static analysis is done by fixing the part in X- direction, and applying load of 100N in Z-direction. The solution obtained for displacement is shown in the figure. The maximum displacement was found to be 62.645µm. By calculation the stiffness was found to be 1.59N/µm. Harmonic analysis is performed on the part model to know natural frequency at each mode of vibration. The result data are tabulated in the Table 2.

TABLE 2. STIFFNES AND NATURAL FREQUENCIES OF THE FLEXIBLE PLATE.

	Stiffness along Z-direction (N/µm)	Natural frequency at each mode in Hz					
		Mode1	*Mode2*	*Mode3*	*Mode4*	*Mode5*	*Mode6*
Flexible plate	1.59	2147.2	4884.1	5247.	16708	20056	23422

C) Analysis of the Stiffener

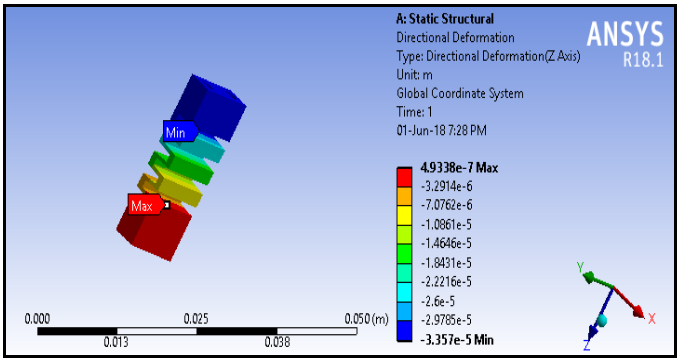

Fig 12. Analysis of the stiffener.

The analysis performed on the stiffener is shown in the figure. Structural steel is used as the material. Static and harmonic analysis was performed on the stiffener. The static analysis was performed by loading the stiffener in Z-direction and stiffness is calculated. The maximum displacement was found to be 33.57µm. The stiffness found by calculation is 2.97N/µm. The harmonic analysis was performed on the part model in order to know the harmonic behaviour of the part and to know the naural frequency at each modes. The results are tabulated in the Table 3.

TABLE 3. STIFFNES AND NATURAL FREQUENCIES OF THE STIFFENER.

	Stiffness along Z-direction (N/µm)	Natural frequency at each mode in Hz					
		Mode1	*Mode2*	*Mode3*	*Mode4*	*Mode5*	*Mode6*
Stiffener	2.97	519.75	1994.6	3882.4	5995.5	6053.7	10460

D) Analysis on the Active vibration isolation assembly setup

The analysis of the active vibration isolation is done using ANSYS WORKBENCH18.1 software. Structural steel is the material used during analysis. The analysis performed is shown in the Fig 13.

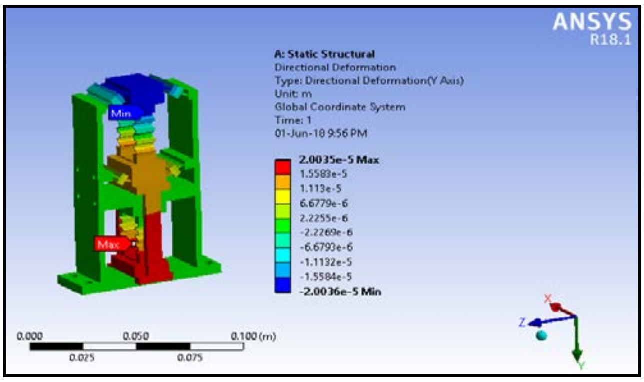

Fig 13. Analysis of the active vibration isolation setup.

The analysis is done on the system by importing the active vibraion isolation system by itscompatibility mode to ansys by converting the system to parasolid format.

Static structural modal and harmonic analysis was performed on the system. Static analysis was performed on the system in order to determine the displacement characteristics of the system. The proposed active vibration isolation system is used to reduce the vibration generated from the source to a maximum extent. So in order to underststnd this phenomenon static analysis is done.

The analysis is carried out by fixing its base first. After the base is fixed the force of 696.85 N is applied in the downward Y- direction on the actuator mounting plate(bottom assembly). Again force of 457 N was applied on the bottom of the actuator mounting plate(top assembly) in upward Y- direction. Once the force application and fixing of the base is done , it is solved for results. The directional solution is obtained in Y- direction. Now by the solution it is observed that the maximum displacement in downward Y- direction was found to be 20.035μm and in upward Y-direction is found to be 20.036μm. From this it is observed that the vibration that is generated by the source can be reduce to a maximum extent, hence the net vibrtion at the isolation platoform will be nullified .

Similarly modal and harmonic analysis was performed on the active vibration isolation system. The modal analysis is performed in order to find the natural frequency at different modes of vibration. Fig 14 shows the modal analysis for mode 1.

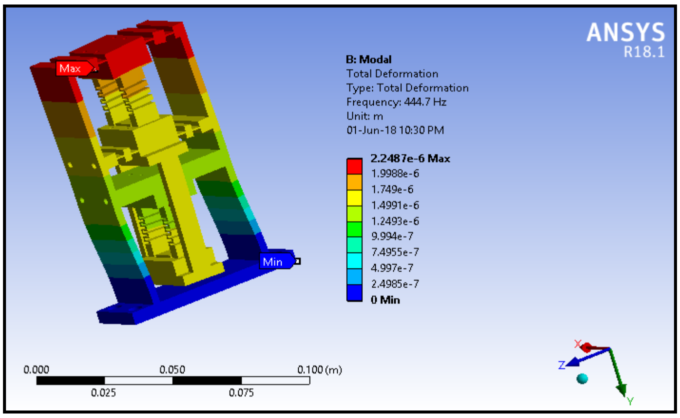

Fig 14. Modal analysis of the Active vibration isolation system setup.

The natural frequency in the first mode ofvibration was found to be 444.7Hz. Similarly the analysis is done for other modes also. The results are tabulated in Table 4.

TABLE 4. MODAL FREQUENCIES OF THE SETUP.

Natural frequency in Hz					
Mode 1	***Mode 2***	***Mode 3***	***Mode 4***	***Mode5***	***Mode6***
444.7	666.91	897.37	943.45	1418.5	1553.3

To know the frequency response of the system Harmonic analysis was carried out .The frequency response for different intervals are plotted as shown in the Fig15.

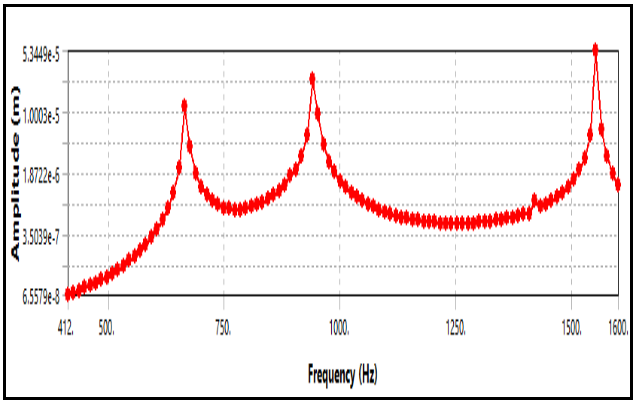

Fig 15. Frequency response active vibration isolation system.

In the plot the amplitudes are plotted in Yaxis and the frequencies are plotted in X axis. The fruqencies ranging from 400 Hz to 1600 Hz are plotted and the amplitude for each frequency is also plotted in the same graph. The ranging frequencies are taken for 100 intervals. The peak in the plot shows the highest amplitude for a particular frequency. This is the resonant frequency of the system. For the system this resonant frequency was found to be 1552 Hz.

IX. CONCLUSION

The static analysis was done in order to know the displacement characteristics of the system. The force analysis was done on the system for find the displacement of the system. The stiffness was found out for different parts such as isolation platform, flexible plate, stiffener and the stiffener assembly. The analysis is performed and the results are interpreted. From the results it is evident that vibration isolation can be achieved to a maximum extent.

Similarly, modal and harmonic analysis was performed on the system and for the parts. The modal analysis helps us to know natural frequency at different modes of vibration. In the analysis the natural frequency was found for 6 modes of vibration and the results are tabulated.

The harmonic analysis was done on the active vibration isolation system to know the frequency response of the system. This analysis gives the amplitude variation for different frequencies taken for 100 intervals. The results are interpreted by the plot of Amplitude v/s Frequency. This resonant frequency was able to find with the harmonic analysis.

X. REFERENCES

[1] Luo, H. Pu, X. Chen, Y. Hu, Z. Zhou and X. Bao, “ Investigations on piezoactuator based active vibration isolation for tool based micromachining applications” in *IEEE*, Wuhan, 2009.

[2] Miaoxian Guo, Beizhi Li, Jianguo Yang, Wei Li and Steven Y. Liang, “Active Piezoelectric Vibration Isolation System of Machine Tools” International Conference on Electrical, Electronics and Mechatronics, Shanghai, China, 2015.169-172.

[3] Shunli Xiao a, YanggminLi, “Dynamic compensation and H1 control for piezoelectric actuators based on the inverse Bouc–Wen model”, Robotics and Computer-Integrated Manufacturing 30(2014)47–54

[4] A. Harms, B. Denkena, N. Lhermet, “Tool Adaptor For Active Vibration Control In Turning Operations”, 9th International Conference on New Actuators, 14 – 16 June 2004, Bremen, Germany.

[5] Niju Rajan, Rathnamala Rao, Muralidhara,” Experimental Investigations on Active Vibration Isolation Using Piezoelectric actuators”, 2013 International Conference on Advanced Computing and Communication Systems (*ICACCS* -2013), Dec. 19 – 21, 2013, Coimbatore, INDIA.

[6] NIU Jun-chuan, ZHAO Guo-qun, HU Xia, “Active control of structural vibration by piezoelectric stack actuators” Journal of Zhejiang University Science, ISSN1009-3095 Sci 2005 6a (9):974-979.

[7] Wei Zhu∗, Xiao-Ting Rui, “Hysteresis modelling and displacement control of piezoelectric actuators with the frequency-dependent behaviour using a generalized Bouc–Wen model”, Institute of Launch Dynamics, Nanjing University of Science and Technology, Nanjing 210094, China.

[8] Li Sui, Xin Xiong Gengchen Shi, “Piezoelectric Actuator Design and Application on Active Vibration Control”, 2012 International Conference on Solid State Devices and Materials Science.

[9] Jiří Tůma and Jaromír Škuta, “Active vibration control of journal bearings with the use of piezo actuators”, TECHLAB Ltd., Prague, Sokolovská 207, CZ 190 00, Praha 9, Czech Republic, j.simek@techlab.cz.

[10] Royson D. D’Souza a, Bineesh Benny b, Anil Sequeira c, Navin Karanth P, ” Hysteresis Modeling of Amplified Piezoelectric Stack Actuator for the Control of the Microgripper”, American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS) ISSN (Print) 2313-4410, ISSN (Online) 2313-4402