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Analysis of Machine Tool Structure using RSM Approach

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ABSTRACT

Unwanted vibration in machine tools like milling, lathe, grinding machine is one of the main problem as it affects the quality of the machined parts, tool life and noise during machining operation. Hence these unwanted vibrations are needed to be suppressed or damped out while machining. Therefore the present work concentrates and aims on study of different controllable parameter that affect the responses like vibration amplitude and roughness of machined part. The part to be machined is kept on sandwich of plates made up of polymer and composite material. The sandwich along with the part to be machined ate fixed on the slotted table of horizontal milling machine. The parameters that can easily be controlled are feed, RPM of cutter, depth of cut, and number of plates that form the secondary bed material. Polymers like Polyvinyl Chloride (PVC), Polypropylene (PP) plates and composites like Glass Fiber Polyester and Glass Fiber Epoxy (GFE) plates are used in the experiments to form the sandwich (secondary bed material) on which work-piece (MS Plate) was mounted and fed to the milling cutter. Four holes are made on the specimen and the plates to ensure that the sandwich of plate including the work-piece can be bolted to the slotted table. Common up-milling operation was carried out in controlled manner. Vibration signals were recorded on the screen of phosphorous storage oscilloscope and surface roughness of machined plate was found from the talysurf. Finite element analysis (FEA) was carried out to know the resonance frequencies at which the structure should not be excited. In the course of the FEA some important facts have come up that lead to set some of the steps of precautions during the experimentation. Response surface methodology (RSM) is used to develop the model equation for each set of plate material.1.

INTRODUCTION

Vibration Problem in Machining Process

Machining of any kind is accompanied by vibrations of work-piece and tool. These vibrations occur due to the following reasons [1]

- In-homogeneities in the work piece material
- Variation of chip cross section
- Disturbances in the work piece or tool drives
- Dynamic loads generated by acceleration/deceleration of massive moving components
- Vibration transmitted from the environment
- Self-excited vibration generated by the cutting (machine-tool chatter).

Due to these vibrations the following phenomenon occurs.

- Reduction in tool life
- Improper surface quality
- Undesirable Noise
- Excessive load on machine tool

This phenomenon can be reduced when machine tools have high stiffness [2]. High stiffness in machine tools can be achieved by making them by robust structured materials through passive damping technology.

Vibration Overview

Dynamic responses of a structure can be determined by three essential parameters

- Mass
- Stiffness
- Damping

Storage of energy is associated with mass and stiffness where as damping results in the dissipation of energy by a vibration of a system. For a linear system, if the forcing frequency is the same as the natural frequency of the system, the response is very large and can easily cause dangerous consequences due to resonance effect. In the frequency domain, the response near the natural frequency is "damping controlled".

Damping Definition

Damping is a phenomenon by which mechanical energy is dissipated in dynamic systems. In other words it is also said to be any effect that tends to reduce the amplitude of vibration in an oscillatory system. Where m in (kg) is the mass of the system, k is the spring constant (in N/m), c is the damping coefficient in (Ns/m or Kg/ Sec).

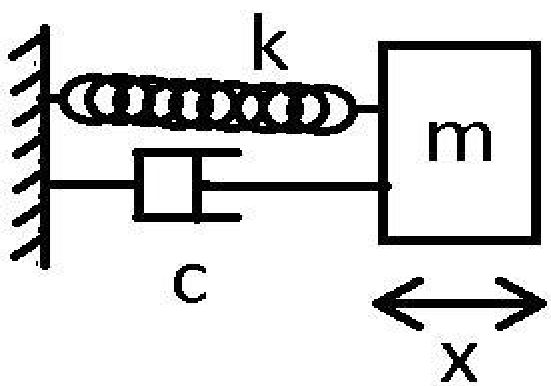

Figure 1 Spring mass damper system

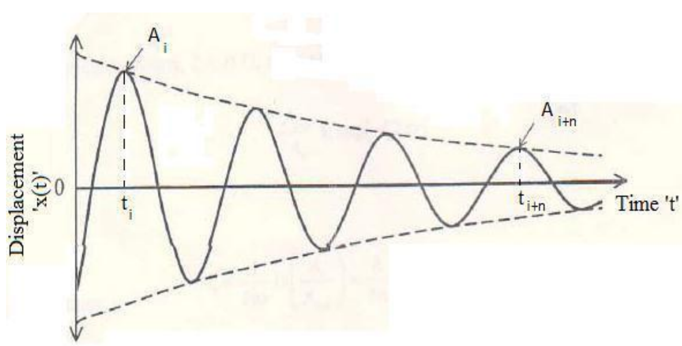

Figure 2 Vibration response of a damped system

Types of Damping

Three main types of damping are present in any mechanical system and they are: Material (Internal) damping, Structural damping, Fluid damping [3].

A. Material (Internal) Damping:

Internal damping of materials is related to the energy dissipation associated with micro-structural defects, like grain boundaries and impurities; local temperature gradients resulted from non uniform stresses distribution in vibrating beams;

eddy current effects in ferromagnetic materials; dislocation motion in metals; and chain motion in polymers. Several models have been employed to represent energy dissipation caused by internal damping. As variety of models is primarily a result of the vast range of engineering materials; there is no single model that can satisfactorily represent the internal damping characteristics of all materials.

B. Structural Damping:
Structural damping can be achieved by rubbing friction or contact among different elements in a mechanical system. Model representation of structural damping is very difficult as the dissipation of energy depends on the particular characteristics of the mechanical system which is hard to determine. The Coulomb-friction model can be used to describe energy dissipation caused by rubbing friction. As structural damping which is caused by contact or impacts at joins, energy dissipation is determined by means of the coefficient of restitution of the two components in contact.

Fluid Damping:
Relative movement of immersed material in a fluid is opposed by the fluid. This is due to drag force upon the material due to fluid. Energy dissipation happens in the due force, hence the motion is said to be damped i.e. the phenomena of fluid damping.

There are two ways damping can occur in a machine tool.

- Active damping
- Passive damping

When damping is achieved by external means for example energy dissipation by the use of controlled actuator are is called active damping whereas Passive damping refers to energy dissipation within the structure by add on damping devices such as isolator, by structural joints and supports, or by structural member's internal damping.

LITERATURE REVIEW

Lee et al. [5] have attempted and succeeded in improving the damping capacity of the column of a precision mirror surface grinding machine by designing a hybrid column made up of glass fiber reinforced epoxy composite plates adhesively bonding to a cast iron column. They have calculated the damping capacity of the newly designed column for optimizing its damping capacity. They have verified that the fiber orientation and thickness of the composite laminate plate plays important affects the damping capacity. After experiments they have found out that the damping capacity of the hybrid column was 1.35 times than the cast iron column. For machine tools having massive slides generally do not permit rapid acceleration and deceleration during the frequent starts/stops encountered in machining. Kegg et al. [6] have used composites for the huge slides for CNC milling machine. They have constructed the vertical and horizontal slides by bonding high modulus carbon-fiber epoxy composite sandwiches to welded steel structures using adhesives for a large CNC machine. These composites structures reduced the weight of slides by 34% and 26%, respectively and increased damping by 50% to 570% without decreasing the stiffness.

Rahman et al. [7] attempted to review the some important developmental research in the area of non-conventional materials for machine tool structures. They have compared many beneficial properties of some materials for machine tool structure with the cast iron. The work suggested alternative to cast iron as material for machine tool structure so that high surface finish can be achieved with high cost effective production rate. As per the results of their studies they composite materials may be a better choice to replace conventional materials of machine tool structure.

Okuba et al. [8] have succeeded in improving the dynamic rigidity of machine tool structures. This was achieved by employing modal analysis. This technique was successfully applied machines e.g. machining cell, an arm of automatic assembling machine and a conventional cylindrical grinder. By this they have successfully reduced chatter and achieved improved surface finish of a vertical milling machine, an NC lathe and a surface grinder.

It was established experimentally by Haranath et al. [10] that applied damping treatment using viscoelastic layers can effectively increase the damping of machine.

Theoretical study on the vibrations of machine tool structures with applied damping treatment by using a conventional beam element have reveled the same. Models of milling machine, radial drilling machine and lathe have been analyzed to find their natural frequency and loss factors. They have found that there is influence of layering treatment on the natural frequencies and loss factors.

LITERATURE REVIEW ON RESEARCH DONE IN DAMPING OF COMPOSITE AND VISCOELASTIC MATERIALS

Almost for 2000 materials Lazan [12] conducted comprehensive studies and experimentation to know general nature of material damping. Lazan's results show that the logarithmic decrement value is proportional with dynamic stress.

Survey by Bert [13] and Nashif et al. [14] have revealed that the damping capacity of fibre reinforced composites and materials generally exhibit higher damping than structural metallic materials.

Viscoelasticity was used to describe the behavior of material damping of composites by Gibson et al. [15] and Sun et al. [16, 17]. Adams and his co workers [18-20], Morison [21] and Kinra et al [22] used the concept of specific damping capacity (SDC) in the damped vibration analysis. Lin et al [23] used SDC in composites under flexural vibration using finite element method based on modal strain energy (MSE) method considering only two interlaminar stresses and neglecting transverse stress.

Ungar et.al [24] introduced the concept of damping in terms of strain energy and later was later Johnson et.al [25] applied this theory in combination with finite element analysis.

The effects of transverse shear deformation on the modal loss factors as well as the natural frequencies of composite laminated plates by using the finite element method based on the shear deformable plate theory was studied by Koo KN et al. [26].

Chandra et al. [27] has done research on damping in fiber-reinforced composite materials which involve theory behind composite damping mechanisms such as macro mechanical, micromechanical and Viscoelastic approaches.

METHODOLOGY

Calculations Of Excitation Frequencies That Can Be Offer My Milling Machine.
As per availability, a cuter (Side and Face Milling Cutter B 100 x 25, IS: 6308) was selected. The figure of the cutter is given below. Here B represents “straight tool”. 100 stands for outer diameter of 100mm, 25 stand for the width of 25mm and finally IS: 6308 stands for the Indian Standard that the cutter conform to (i.e. Specification for side and face milling cutters).

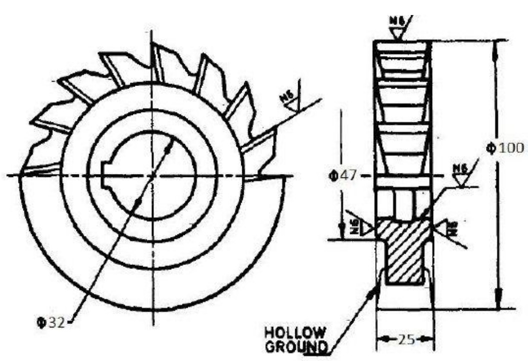

Figure 3 Geometry of cutting tool

The cutter has 26 numbers of teeth. The settings of the available RPM in the milling machine are given in the table below.

The frequency (“cutting cycle per second” or “number of hits per second”) is calculated based on the mentioned RPM setting and the total number of teeth of cutter.

Calculations of Resonance Frequencies for Five Pvc As Secondary Bed Material And Ms Plate As Workpiece (By Fem Based Modal And Prestressed Modal Analysis)
Finite element based modal analysis helped to determine the proper cutter parameter and an indication of the precautions to be taken during the metal cutting operation. ANSYS APDL used for this purpose. A typical method of solution to the system is the Lanczos algorithm had been chosen. After computation by ANSYS, 10 modes are extracted which is represented in the images below.

The fine element model discritization is done by “SOLID285” element. The element is defined by four nodes having four degrees of freedom at each node; three translations in the nodal x, y, and z directions, and one hydrostatic pressure (HDSP) for all materials except nearly incompressible hyperelastic materials. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It is also capable of simulating deformations of nearly incompressible elastoplastic materials, nearly incompressible hyperelastic materials, and fully incompressible hyperelastic materials [29].

The dicsritised models are given in the below mentioned figure. The material property of PVC.

Precautionary Conclusion Found From Modal Analysis

During experimentation one of the cutters was broken unexpectedly. This phenomenon encouraged for application of modal analysis PVC (Secondary bed material) and MS Plate sandwich. As resonance frequency was not achieved during cutting, it can be concluded that the failure was catastrophic failure. But modal analysis leads to deduce following precautionary steps.

From the table it can be said that with increase in pressure the resonant frequency increases and further increase in pressure cause in reduction of natural frequency. Hence in pressure plays in important role as it changes vibration characteristics. Therefore in experiment the pressure is kept at constant level by tightening the bolts by torque wrench. Resonance frequencies found from this analysis are much higher than the excitation

CONCLUSIONS

a) In the present work, 3types of secondary bed materials are stacked together below the workpiece to form the sandwich and the main effect plot shows the variation of response parameter with respect to controllable parameter.
b) Finite Element Analysis based modal analysis helped in deducing the precautionary steps while doing the experiment
c) RSM is utilized to develop model equation which shows the variation of response parameter with respect to controllable parameter.
d) The decrease of vibration amplitude has been observed with increase of number of layers interposed between table and work piece for PP and PVC but for GFE vibration increases of the experimental setting.
e) It can be concluded that for of the decided level setting PP and PVC are the useful secondary bed material than GFE.

REFERENCES

[1]. S. C. Sen and A. Bhattacharyya, Principles of Machine Tools, 2nd ed., 2009
[2]. S. K. Basu and D. K. Pall Design of Machine Tool, 5th ed, 2008
[3]. K. N. Koo, I. Lee “Vibration and damping analysis of composite laminates using deformable finite element”, AIAA J, Vol 31 (4), pp. 728-35, 1993.
[4]. B. C. Routara & A. Bandyopadhyay and P. Sahoo, “Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation”, Int J Adv Manuf Technol, Vol 40, PP. 1166–1180, March 2008
[5]. Lee, D.G., Chang, S.H. and Kim, H.S. “Damping improvement of machine tool columns with polymer matrix fiber composite materials”. Compos. Struct., 43,155–163, (1998).
[6]. Suh, J.D., Lee, D.G. and Kegg, R. “Composite machine tool structures for high speed milling machines”. Annals CIRP, 51(1), 285–288, (2002).
[7]. Rahman, M., Mansur, A. and Karim, B. “Non-conventional material for machine tool structures [J]”. JISM International Journal, Series C, 44 (1), 1–11, (2001).
[8]. Okubo, N., Yoshida, Y. and Hoshi, T. “Application of Modal Analysis to Machine Tool Structures”. Annals CIRP, 31(1), 243-246, (1982)
[9]. J. Vantomme “A parametric study of material damping in fiber - reinforced plastics”, Department of Civil Engineering, Royal Military Academy , Avenue da le Renaissance 30, 1994.
[10]. Haranath, S., Ganesan, N. and Rao, BVA. “Dynamic analysis of machine tool structures with applied damping treatment‖”. Int J Mach Tools Manuf, 27(1), 43-55, (1987),
[11]. Wakasawa, Y., Masatoshi, H. and Etsuo, M. “The damping capacity improvement of machine tool structures by balls packing‖”. Int J Mach Tools Manuf, 44(14), 1527-1536, (2004).
[12]. B. J. Lazan, “Damping of Materials and Members in Structural Mechanics”, Pergamon Press London, 1968
[13]. Bert, C.W., “Composite materials: A survey or the damping capacity of fiber reinforced composites in damping applications for vibration control”, AMD-Vol. 38. (1980).

[14]. Nashif, A.D, Jones, D.I.G and Henderson, J.P. Vibration Damping, Wiley, New York, (1985).
[15]. Gibson, R.F., Chaturvedi, S.K. and Sun, C.T., "Complex moduli of aligned discontinuous fiber-reinforced polymer composites", J. Mater Sci., Vol. 17. pp. 3499-3509 (1982).
[16]. Tilwani K., Patel A., Parikh H., Thakker D. J., & Dave G. (2022), "Investigation on anti-Corona viral potential of Yarrow tea", Journal of Biomolecular Structure and Dynamics, 1-13.
[17]. Parikh, H., Prajapati, B., Patel, M., & Dave, G. (2023), "A quick FT-IR method for estimation of α-amylase resistant starch from banana flour and the bread making process", Journal of Food Measurement and Characterization, 1-11.
[18]. Gibson, R.F., Chaturvedi, S.K. and Sun, C.T., "Internal damping of short-fiber reinforced polymer matrix composites", Comput. Struct 20, pp. 391—401, (1985).
[19]. Sun, C.T, Wu, J.K. and Gibson, R.F., "Prediction of material damping of laminated polymer matrix composites". J. Mater. Sci. 22, pp. 1006-1012, (1987).
[20]. Adams, R.D. and Bacon, D.G.C, "Effect of fiber orientation and laminate geometry on the dynamic properties of CFRP", J Compos.Mater. 7, pp. 402-428, (1973).
[21]. Lin D.X, Ni R.G and Adams R.D, "Prediction and measurement of the vibration damping parameters of carbon and glass fibre-reinforced plastics plates", J. Composite. Materials. 18, pp. 132 -152 (1984).
[22]. Ni R.G and Adams R.D., "A rational method for obtaining the dynamic mechanical properties of lamina for predicting the stiffness and damping of laminated plates and beams", Composites 15, pp. 193—199, (1984).