Theoretical Analysis of Machine Tool Vibrations

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Abstract: Machine tools play vital role in the metal working sector. Predictions of vibrations in machine tools are necessary for improving the operational efficiency, product quality and safety in the machining processes. During the operation, machines generate vibrations which result in deterioration of machine tools eventually causing failure of some subsystems or the machine itself. Vibrations in the machine-tool system are a well known fact for causing a number of machining problems including tool wear, tool breakage, machine spindle bearings wear, poor surface finish, inferior product quality and higher energy consumption. The present paper deals with the study of various types, sources and effects of vibrations in machine tools that how the different types of vibrations affect the machine-tool-workpiece. Various methods to minimise and control the vibrations during machining are also discussed.

***Keywords*: Cutting, damping, machine tool, vibration, workpiece**.

1. Introduction

A machine tool is designed to achieve desired orientation of the cutting tool with respect to the workpiece and imparting desired cutting and feed motions to the workpiece. Machine tools vibrate more or less during operation. The vibration causes rapid wear of machine parts and unwanted vibrations may cause loosening of parts from the machine (Singh 2007). Excessive vibration may cause operational inefficiency, product-quality problems, and increase the cost of manufacturing. Therefore, predictions of cutting vibrations are important for reducing machine downtime and work piece failure costs. Mostly in machine tools during the cutting process, time-dependent (dynamic) forces also come into play and produce fairly rapidly varying deflections in the machine-work-tool system. These dynamic deflections (vibrations) not only produce dimensional, shape and finish imperfections but also endanger life of both the cutting tool and the machine on account of impact and fatigue (Chen et al. 2016). To achieve higher accuracy and productivity vibration in machine tool must be controlled. For analysis of dynamic behaviour of machine tool rigidity and stability are two important characteristics (Kovacic 1998).

2. Types of Machine Tool Vibrations

Machine tool vibrations may be classified as free, forced and self –excited (self-induced).

2.1 Free Vibration

Free (Random or transient) vibration is caused by shock (or impulsive) loading of the machine tool, e.g. when the tool strikes a hard grain in the work-piece, suddenly enters into the work-piece or when a certain impulse gets transmitted through the machine foundation. In such cases, a relatively large force acts for a relatively small time on the elastic structure of the machine tool. As a consequence, it starts vibrating.

2.2 Forced Vibration

During the operation of the machine tool, periodic forces are brought into play by such forcing factors as unbalanced rotating members, bearing imperfections, mountings defects or misalignments in machine members. Also external vibration may be transmitted to the machine tool via foundation. In all such cases, the machine itself starts vibrating at the frequency of the forcing factors. Still another reason of forced vibration is the fact that under certain conditions, the cutting process become periodic in character, e.g. during discontinuous chip formation, inhomogeneous chip formation and chip formation with a built-up edge. The cutting force under such conditions is fluctuating in character with a frequency corresponding to that of chip segmentation, shear angle variation or make and break frequency of the built-up edge(Juneja and Sekhon 2008).

2.3 Self-Induced Vibration

Such vibration is caused, built up and sustained by the interaction or coupling inherent between the cutting process and vibratory system comprising the machine, tool and work-piece form a closed loop (Figure 1).

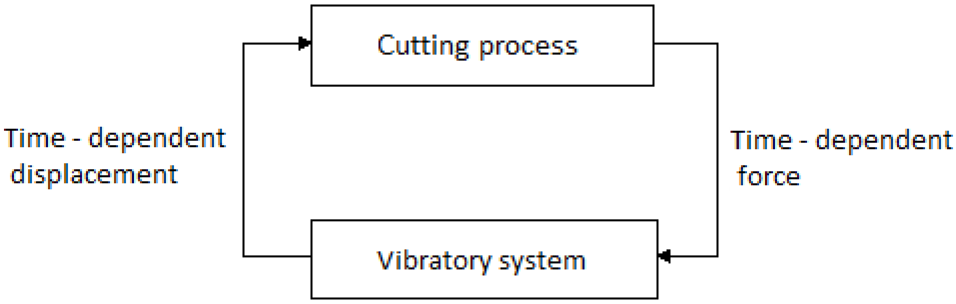

Figure 1: Interaction between the cutting process and the vibratory system (Mei et al. 2009)

The motion of the vibratory system produces a time-dependent (fluctuating) relative displacement between the work piece and the tool. The cutting process, as a result, is affected and the cutting force also starts fluctuating. The interaction (coupling) between the cutting process and the vibratory system depends upon the instantaneous mutual orientation of the cutting force and the direction of the relative motion between the tool and work piece (Rao 2003). If the mutual orientation between the two is somehow altered, their mutual influence or coupling also gets changed. Under some conditions, the coupling between the vibratory system and the cutting process becomes such that the vibration once started due to any random cause does not die down; it may even build up into a severe vibration called chatter.

2.3.1 Chatter relevance in machining

Chatter is a highly complex phenomenon due to the diversity of elements that can compose the dynamic system and its behaviour: the cutting tool, the tool holder, the workpiece material, the machine tool structure and the cutting parameters. Predicting its occurrence is still the subject of much research, even though the regenerative effect, the main cause of chatter, was identified and studied very early (Goyal and Pabla 2015). Moreover, chatter can occur in different metal removal processes: milling, turning, drilling, boring, broaching and grinding. Chatter occurrence has several negative effects like:

- Poor surface quality
- Unacceptable inaccuracy
- Excessive noise
- Disproportionate tool wear
- Machine tool damage
- Reduced material removal rate (MRR)
- Increased costs in terms of production time
- Waste of materials and energy
- Environmental impact in terms of materials and energy
- Costs of recycling, reprocessing or dumping non-acceptable final parts to recycling points

For these reasons, chatter occurence is a serious issue. In workshops, machine tool operators often select conservative cutting parameters to avoid chatter and, in some cases, additional manual operations are required to clean chatter marks left on the part surface. This common practise usually results in a decrease in productivity (Quintana and Ciurana 2011).

3. Sources of vibrations

3.1 Inhomogeneous work piece material

- Hard spots or a crust in work piece leads to free vibrations.
- Discontinuous chip removal results in fluctuation of the cutting thrust.
- The breaking away of a built-up edge from the tool face also imparts impulses to the cutting tool.

3.2 Variation in chip cross section

- Variation in the cross-sectional area of chip is due to the shape of the machined surface or due to the configuration of tool.
- Pulses imparted to the tool and job.
- Pulses have shallow fronts for turning of eccentric parts and steep fronts for slotted parts and for milling/broaching.
- Bouncing of the cutting tool on machined surface can be minimized by closing the recess with a plug or with filler

3.3 Disturbances in the work piece and tool drives

- Forced vibration induced by rotation of unbalanced member affects the surface finish & tool life. This can be eliminated by careful balancing or by self centering.
- Rotating components should be placed in position where effect of unbalance is less.
- Electric motors produce both rectilinear and torsional vibration.
- Rectilinear vibrations are due to a non-uniform air gap between the stator & rotor, asymmetry of windings, unbalance, bearing irregularities, misalignment with driven shaft
- Torsional vibration is due to various electrical irregularities.

3.4 Vibration transmitted from the environment

- Shock and vibration generated in presses, machine tools, internal-combustion engines, compressors etc., are transmitted through the foundation to other machines, which they may set into forced vibration.
- Vibration transmitted through the floor may be reduced by vibration isolation (Rao 2003).

4. Effect of Vibrations:

- Variation in chip thickness, penetration rate and cutting speed.
- The major effect is poor surface finish.
- Dimensional accuracy of job is also affected.
- Vibrations also effects tool life.

5. Vibration control in machine tool

The vibration behaviour of a machine tool can be improved by a reduction of the Intensity of the sources of vibration by

(i) Enhancement of the effective static stiffness and damping.

(ii) Appropriate choice of cutting regimes, tool design and work-piece design.

(iii) Both parameters are critical for accuracy of machine tools, stiffness by reducing structural deformations from the cutting forces and damping by accelerating the decay of transient vibrations.

(iv) Changing the cutting conditions e.g. by decreasing the feed rate and depth of cut and increasing the rake angle.

(v) Changing the tool geometry and the method of clamping the work piece.

(vi) By changing the characteristics of the vibratory system (Singh 2007). This can be done as follows:

Employing tuned undamped vibration absorbers to counteract forced vibrations where the frequency of the exciting force remains strictly constant, e.g. in the case of electromagnetic unbalance of motors used in precision machine tools.

(a) Increasing the stiffness of the offending mode, e.g. by using a stiffener between the table and overarm of a horizontal milling machine, employing tighter clamping and supporting methods and reducing overhang of the tool in a lathe.

(b) Introducing additional damping in the vibratory system especially in the form of damped, vibration absorbers. Successful use of such devices has been reported in boring, milling and turning operations as shown in figures 2, 3 and 4.

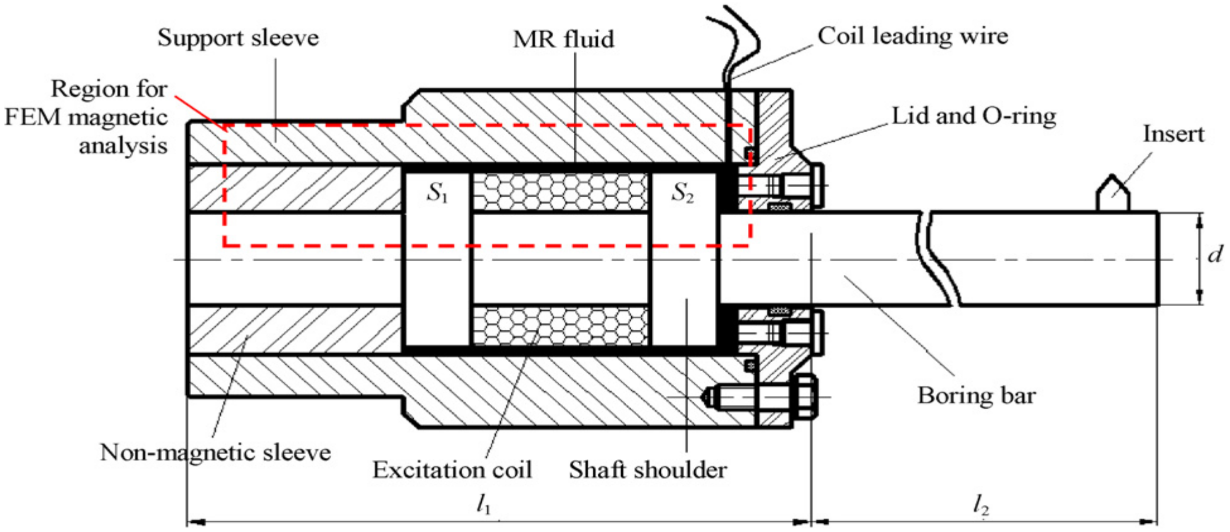

Figure 2. MR fluid-controlled boring bar with chatter suppression (Mei et al. 2009)

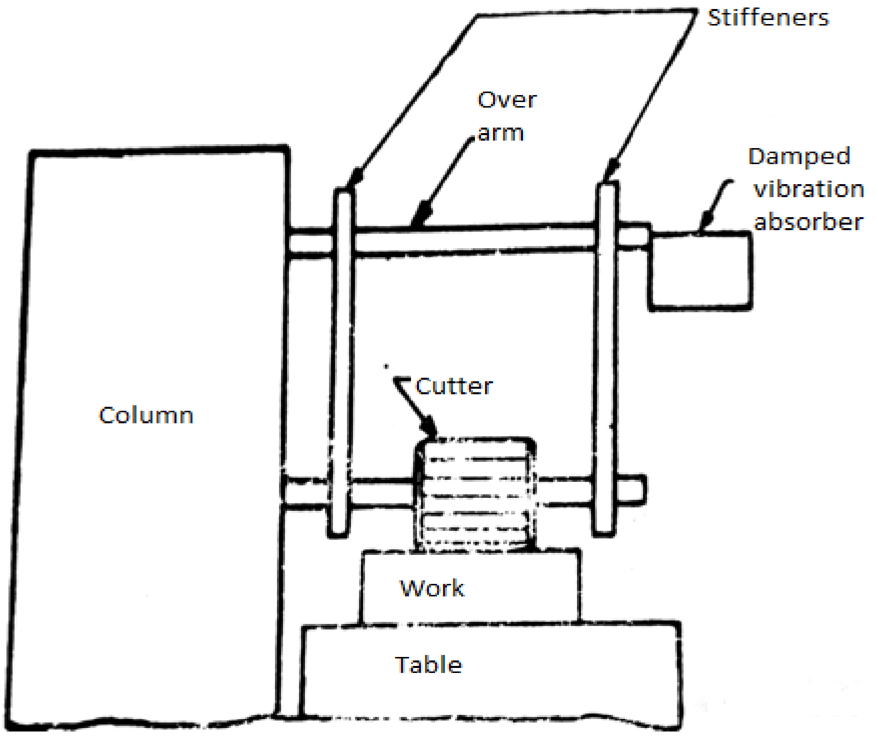

Figure 3. Damped vibration absorber on a horizontal milling machine (Juneja and Sekhon 2008)

While designing a new machine or redesigning an existing machine, existing models are thoroughly tested for their chatter behaviour. The offending modes and their frequencies are identified. Changes considered beneficial(mass redistribution, strengthening of particular structural members by changing their size and shape, incorporation of viscous damping at proper places like spindles etc. and frictional damping at the various structural joints) are proposed and their possible effects carefully predicted(Tobias and Fishwick 1958).

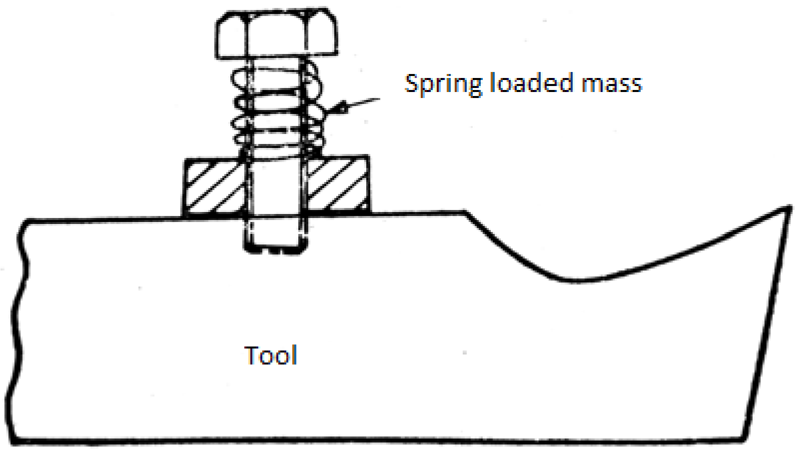

Figure 4. Damping of turning tool (Juneja and Sekhon 2008)

6. Conclusion

Vibrations in machining result from the lack of dynamic stiffness of some component of the machine tool-tool holder- cutting tool-workpiece system. Therefore, to prevent damage, the vibration level must be controlled. The most common self-excited vibration is regenerative chatter. It is concluded the machine tools are crucially affected by the vibrations. The vibration behaviour of a machine tool can be improved by a reduction of the intensity of the sources of vibration by enhancement of the effective static stiffness and damping. By appropriate choice of cutting regimes, tool design and work-piece can be designed properly. Abatement of the sources is important mainly for forced vibrations. Stiffness and damping are important for both forced and self excited (chatter) vibrations. Both parameters are critical for accuracy of machine tools.

7. References

1. Chen JF, Lo SK and Do QH (2016). An approach to the classification of cutting vibration on machine tools. An article by MDPI.
2. Goyal D and Pabla BS (2015).Condition based maintenance of machine tools—A review. CIRP Journal of Manufacturing Science and Technology;321:12
3. Hanna NH, Tobias SA (1974). Theory of nonlinear regenerative chatter. Journal of Engineering for Industry, Transactions of the ASME 96 Ser B (1):247–255.
4. Juneja BL and Sekhon GS (2008). Fundamental of metal cutting and machine tool .New Age International Private Limited Publishers.
5. Kovacic J (1998). The chatter vibrations in metal cutting-Theoretical approach. Mechanical Engineering ;1(5):581-593.
6. Mei D, Konga T, Shihb AJ and Chen Z (2009). Magnetorheological fluid-controlled boring bar for chatter suppression. Journal of materials processing technology;209:1861–1870.
7. Quintana G and Ciurana J (2011). Chatter in machining processes: A review. International Journal of Machine Tools & Manufacture;51:363–376.
8. Rao SS (2003). Mechanical Vibrations (Prentice Hall, New Jersey, USA).
9. Singh VP (2007). Mechanical Vibrations. Dhanpat Rai & Co.(P) Ltd.
10.Tobias SA, Fishwick W.(1958) Theory of regenerative machine tool chatter, The engineer.