MACHINE TOOL ENGINEERING (MCE 525)

INTRODUCTION

A machine tool is a power driven device in which energy is utilized in deformation of material for shaping, sizing or processing a product to desired accuracy by removing the excess material in the form of chips. Machine tools are generally used for two purposes:

- To produce certain form
- To produce finished surface.

All machine tools serve a common purpose, to cut and form materials, and all are dependent upon certain principles. These principle govern the designs that enable the machine tools to

- produce precise results repeatedly
- apply forces and power as required
- do their work in an economical manner.

Good design and operation of a machine tool depends upon observing principles that keep errors small. Evidences of these principles are found in the structural members, the bearings and guide ways for straight and rotary motions, the micrometer scales, and the standards of construction of all good machine tools.

Elements of Machine tools

Various elements of any machine tool are

(a) Structure which is formed by bed, column and frame. The strength and rigidity of the machine tool are provided by designing the structure suitably.
(b) Slides and tool structure
(c) Spindles and spindle bearing
(d) Kinematics of machine tool drives
(e) Work holding and tool holding elements.

- **Structure (Bed, Column and Frame)**

A proper design of the bed structure is of vital importance in order to minimize slip stick phenomenon. Bed, base, column and box- type housing in a machine tool are called structure and it constitutes about 70 to 90 % of the total weight of the machine tool.

The structure provides the stability to the machine tool, supports the various members and maintains alignment among the moving members. The operating properties of any machine tool are determined only by the degree of rigidity of individual parts which is defined as the degree of the deformation undergone by a member for an external load. During machining operation on the machine tools, structures are subjected to bending and twisting moments and if

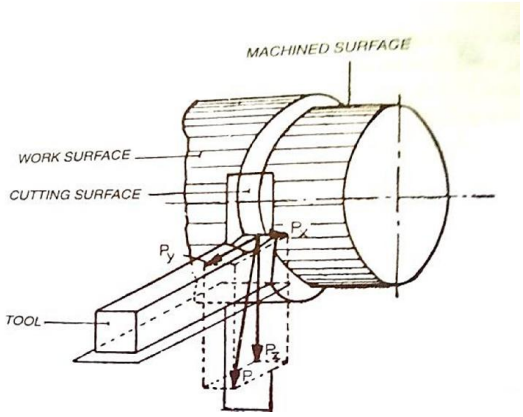
the structure does not possess high rigidity, it may undergo appreciable deformation. Thus rigidity of various parts in machine tools is important for ensuring the adequate accuracy of the items produced. Lack of rigidity also causes vibrations of parts due to elastic depression of joints. It is therefore necessary to design parts as statically indeterminate systems by employing the method of equalizing the displacements.

Design Requirement of Bed

The main requirement of a lathe bed is to provide a guide for continued accurate longitudinal movement of the carriage and tailstock. It has one or more slide ways cast as an integral part. The above requirement can be met as a result of the following:

- Ability of the structure of the bed to resist distortion effectively due to static and dynamic loads.
- Stability of the motion of the carriage under load
- Leveling
- Resistance to vibrations
- Freedom from slip-stick

Distortion due to static and dynamic loads : The Figure 1. below shows the forces acting on a turning tool resolved in three mutually perpendicular direction. These forces are transmitted to the bed in addition to the forces due to the weight of the parts on the bed and due to feed motion.

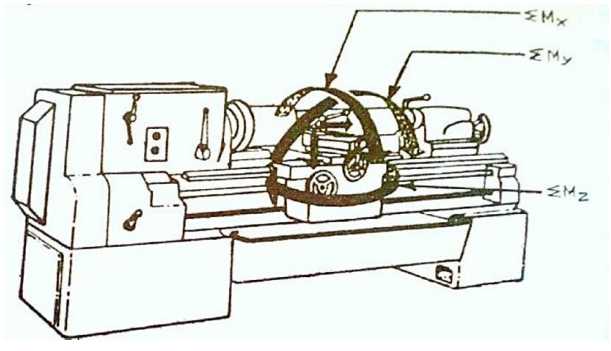


P_x = Feed force, P_y = Normal cutting force

P_z = Main cutting force, Usual proportions are;

$P_x = \frac{1}{4}$ to $\frac{1}{10}P_z$, $P_y = \frac{1}{2}$ to $\frac{1}{3}P_z$

The disposition of these forces with respect to the guideways introduces forces and couples in three directions as shown in Figure 2. From this Figure, $\sum M_x$ is the couple which is mainly responsible for the torsion produced in the bed. Various forms of bed are known to resist torsion effectively. It may be pointed out that as far as torsion is concerned the circular cross – section is the best while the I- section resists bending most effectively. As far as rigidity in bending and torsion is concerned, a section in the form of hollow rectangle is the most rational.



$\sum M_x$ = Resultant couple about X – axis

$\sum M_y$ = Resultant couple about Y– axis

$\sum M_z$ = Resultant couple about Z – axis

Since design considerations also favour this form of cross – section, it is the basis of all bed designs. For wall thickness 't' the following values have been found to be satisfactory in service :

- Light machine tools 12 to 15 mm
  Medium machine tools 18 to 20 mm
  Heavy machine tools 23 to 35 mm

- Thickness of the ribs can be from 0.6 to 0.8 times t.

(a) Stability of motion of the carriage. To get an accurate longitudinal movement, the carriage should have both static and dynamic stability. Static stability of a sliding pair can be increased by observing the following:
- By reducing the effect of forces which cause displacement.
- By proper selection of dimensions of guides with respect to the length of the sliding member.
- By proper selection of forms of guides
- By having broad based supports.
- By employing Hydrostatic guides.

(b) Wear resistance of guides: one of the most important factors which determines the period over which machine tool maintains its original accuracy is the wear resistance of its guides. Wear resistance is a function of the following factors.

- Material and its harness
- Surface finish
- Mean surface pressure and sliding velocities
- Friction, lubricant and lubricating conditions

(c) Residual stresses: Besides other factors, precision of a machine tool depends on the dimensional stability of casting. This depends on the following:
- Nature of the cast material
- Design of casting
- Foundry techniques
- Heat treatment
- Machining operations

(d) Levelling : To obtain an accurate feed motion, proper leveling is important. The bed should be leveled in both longitudinal and transverse directions within the limits prescribed by relevant standards and it should be installed on firm foundation.

Vibrations: In order to obtain a high surface finish the machine should be free from vibrations. Besides other factors, the design of the bed influences the vibration characteristics of the machine. Vibrations can be minimized by controlling the following factors with regard to the design of the machine tool structure.

1. The designer should attempt to arrange machine tool structure to have natural frequencies that do not coincide with those of the cutting action.
2. As the natural frequencies ω_n is proportional to the square root of static stiffness 'C' , the static stiffness of the structure should be as high as possible.

   $$\omega_n = K\sqrt{C},$$

   where = P/λ, P = straining force, λ = deformation in mm. This can be achieved by a judicious selection of ribs and partitions.

3. The natural frequency $\omega_n = K/\sqrt{m}$,

   where m = the mass of the vibrating system.

   In order to obtain a high frequencies, an attempt should made to reduce the mass to minimum.

4. The material of the structure should be capable of damping vibrations effectively. Spheroidal graphite iron is good in this respect while flank graphite iron is better. Concrete is good vibration damping material and it can be used to fill up the hollow spaces in the structure wherever possible.

- **Slides and Slideways**

  A slide is a moving element providing a straight line movement to a workpiece or tool holder at a prescribed feed rate. Slideways are provided on the machine tools to withstand heavy loads encountered during cutting action. Their purpose is also to maintain the alignment of the guided parts at all respective positions. The slideways may be integrated with structure and thus made by casting or joined separately at the top face of the structure. It is common to provide the slideways either in vertical or inclined plane so that falling chips do not rest over it.

  The main requirements to be fulfilled in the design of the machine tool slideway-bearings are:

  - Adequate load carrying capacity

- Selection of proper material for minimum wear and provision for compensating any wear developed after its being used over some time.
- Provision for effective lubrication for minimum friction
- High stiffness and less deformation under the action of cutting forces.
- Chip disposal should be easy and the possibility of its getting entrapped should be minimum.
- Slideways should be maintained in good condition by providing protective guards for safe guard against accidental damage.

- **Spindles and Spindle Bearings.**

Machine tools are generally equipped with spindles for locating the job (to provide centering), holding tool or work, rotating the work or the tool and feeding the tool also as in the case of drilling machine. The spindles are made out of hollow steel shaft with a tapered hole at the front end for receiving the centering element (spindle nose). Machining accuracy depends to a considerable extent upon the rotational accuracy of the spindle which transmits motion to the cutting tool or to the work. Generally machine tool spindles are made up of low carbon steel heat treated to give a case hardened surface.