UNIT 14 DESIGN OF MACHINE STRUCTURES

Structure
14.1 Introduction
   Objectives
14.2 Functions of Machine Tool Structure
14.3 Design Criteria for Machine Tool Structure
14.4 Design of Beds
14.5 Design of Columns
14.6 Design of Housing
14.7 Summary
14.8 Key Words

14.1 INTRODUCTION

Machine tool consists of machine tool structure, bed, column, housings. These are the base of machine tool on which the guideways, spindle, carriage, etc. are mounted. These elements must able to withstand at higher permissible load. These elements are discussed in detail in the following section.

Objectives

After studying this unit, you should be able to understand

- functions of machine tool structure and the design criteria for selection of material for slideways,
- the design of bed,
- the design of column, and
- the design of housing.

14.2 FUNCTIONS OF MACHINE TOOL STRUCTURE

Machine tool structure consists of bed, base, columns, box type housings, overarms, carriages, tables etc.

The structures are divided into three categories according to their functions:

Category 1

An element, upon which various subassemblies are mounted, falls under this category. Example: bed and base.

Category 2

Elements consist of box type housings in which individual parts are assembled fall under this category. Example: Speed box housing, spindle head, etc.

Category 3

Elements consist of parts that are used for supporting and moving the workpiece and cutting tool fall under this category. Example: Table, carriage, knee, tailstock etc.
Machine tool structure must satisfy the following requirement:

(a) The initial geometrical accuracy of the structure should be maintained for the whole life of the machine tool.

(b) All mating surfaces of the structure should be machined with a high degree of accuracy to provide the desired geometrical accuracy.

(c) The shape and size of the structure should not only provide safe operation and maintenance of the machine tool but also ensure that working stresses and deformation do not exceed specific limits.

(d) The selection of material and high static and dynamic stiffness are the fundamental requirement to fulfill above-mentioned requirement.

SAQ 1

What are functions and requirements of machine tool structure?

14.3 DESIGN CRITERIA FOR MACHINE TOOL STRUCTURE

The simple machine tool bed with two-side wall is represented as a simply supported beam. Figure 14.1 depicts a simply supported beam. Point load $F$ acts at its center. The maximum normal stress acting on the beam is given by

$$\sigma_{\text{max}} = \frac{B_{\text{max}} \times D_{\text{max}}}{I_n}.$$ \hspace{1cm} (14.1)

where $B_{\text{max}} =$ Maximum bending moment $= \frac{Fl}{4}$,

$D_{\text{max}} =$ distance of outermost fiber from the neutral axis $= \frac{h}{2}$, and

$I_n =$ Moment of inertia of the beam section about the neutral axis $= \frac{bh^3}{12}$.

On substituting these values in Eq. (14.1), $\sigma_{\text{max}}$ changes to
The permissible normal stress under tension for the beam material is given by

$$\sigma_{\text{per}} = \frac{3}{2} \frac{Fl}{bh^2} \quad \ldots (14.3)$$

Or minimum volume of material \((V_{\text{min}})\) required to make sure that beam has sufficient strength is given by

$$V_{\text{min}} = b \times h \times l$$

$$= \frac{3}{2} \times \frac{Fl}{\sigma_{\text{per}}} \times \frac{l}{h} \quad \ldots (14.4)$$

The maximum deflection of simply supported beam is given by the following expression:

$$d_{\text{max}} = \frac{Fl^3}{48EI_n} \quad \ldots (14.5)$$

Where \(E\) is young modulus of beam material

If the deflection of the beam \(d_{\text{per}}\) is not to exceed a permissible value, then

$$d_{\text{per}} = \frac{Fl^3}{48EI_n} = \frac{Fl^3}{48E \times bh^3} \quad \ldots (14.6)$$

or

$$V_{\text{max}} = b \times h \times l$$

$$= \frac{F}{4Ed_{\text{per}}} \times \left( \frac{l^2}{h} \right)^2 \quad \ldots (14.7)$$

Where \(V_{\text{min}}\) = minimum volume of metal required to make sure that deflection of the beam under load does not exceed the permissible value.

The condition of optimum design is given by

$$V_{\text{max}} = V_{\text{min}}$$

$$\therefore \frac{Fl^3}{48EI_n} = \frac{3}{2} \times \frac{Fl}{\sigma_{\text{per}}} \times \frac{l^2}{h} = \frac{Fl}{4Ed_{\text{per}}} \left( \frac{l^2}{h} \right)^2$$

$$\therefore \frac{l^2}{h} = \frac{6Ed_{\text{per}}}{\sigma_{\text{per}}} \quad \ldots (14.8)$$

Hence Eq. (14.8) indicates that for every structure, there exists an optimum ratio \(\frac{l}{h}\) and

the ratio \(\frac{l}{h}\) depends upon:

(a) Operation constraint i.e. \(d_{\text{per}}\).

(b) The material of the structure i.e. \(E\) and \(\sigma_{\text{per}}\).

### 14.3.1 Materials for Machine Tool Structure

The commonly used material for machine tool structures are cast iron and steel. Earlier cast iron structures were widely used but due to advances in welding technology, welded steels are widely used now days.

The selection of material for machine tool structure depends upon following factors:
Material properties

(a) Cast iron has higher damping properties than steel. Welded steel also shows good damping properties.
(b) Cast iron has better sliding properties.
(c) Steel has higher strength under static and dynamic loading.
(d) The unit rigidity of steel under tensile, torsional and bending loads is higher than cast iron.

Manufacturing Problems

Welded structures of steel have much thinner wall thickness as compared to cast structure. Walls of different thickness can be welded more easily than casting it. Machining allowances for cast structures are generally greater than for weld steel structures. Machining allowance is necessary in casting to remove defects such as inclusions, scales, etc. Welded structure can be easily repaired as compared to cast structure.

Economy

The selection of material for structure will also depend upon its cost. The weight of steel is lesser and but actual metal consumption is higher than that of cast iron. Hence in such cases the cost increases. Holes are obtained with the help of core in the casting structure but holes are made in welded steel structure by machining. These will not only increase the material cost but also increases labour cost. Cost of patterns, welding fixtures, and cost of machining are considered while selecting material for structure.

On considering above factors, the cast iron and steel may be used for following application:

(a) Cast iron should be used for complex structure subjected to normal loading which are to be produced in large number.
(b) Steel should be used for simple and heavy loaded structures which are to be produced in small number.
(c) Combined welded steel and cast iron should be used where steel structure is economically suitable. Example: Cast bearing housings that are welded into the feed box.

SAQ 2

(a) Derive expression for design of machine tool structure.
(b) Explain the design criteria for selection of material for machine tool structure.

14.4 DESIGN OF BEDS

The machine tool beds consist of partially or fully closed box sections with ribs, partitions, etc. Beds are usually used in machine tools with wall arrangements and are evaluated as bars subjected to bending and torsion. This arrangement is shown in Table 14.1.
Design of Machine Structures

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Wall Arrangement</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Covered top closed profile bed</td>
<td>These are used in boring, Plano-milling and slotting machines.</td>
</tr>
<tr>
<td>2</td>
<td>Open top closed profile bed.</td>
<td>These are used in grinding machines. They are also used when the bed is also</td>
</tr>
<tr>
<td></td>
<td></td>
<td>required to serve as an oil reservoir.</td>
</tr>
<tr>
<td>3</td>
<td>Beds on legs : without stiffening diagonal wall.</td>
<td>These are used in lathes, turrets etc.</td>
</tr>
<tr>
<td>4</td>
<td>Beds on legs : without stiffening wall with 30-40%</td>
<td>These are used in multiple tool and high production lathes.</td>
</tr>
<tr>
<td></td>
<td>higher stiffness than (3).</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>With stiffening wall and provision of chip disposal</td>
<td>These are employed in large sized lathes and turrets.</td>
</tr>
<tr>
<td></td>
<td>through opening in rear wall</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>With stiffening wall</td>
<td>These are used in large size lathes and turrets.</td>
</tr>
</tbody>
</table>

The deflection of bar depends upon the product of young’s modulus of material \(E\) and moment of inertia about neutral axis \(I_n\) and angle of twist depends upon the product of modulus of rigidity of material \(G\) and torsional moment of inertia \(I_t\) for a given compound loading. The deflection and twist is resisted by \(G\) and \(E\). If the values of \(GI_t\) and \(EI_n\) are larger, the deflection and twist of the bar will be smaller.

The beds have perpendicular or diagonal stiffeners in every arrangement mentioned in Table 14.1. The reduced bending rigidity of a bed with diagonal stiffeners is given by the equation:

\[
EI_r = p_2 \cdot EI_A^2 
\]  
\[ \ldots (14.9) \]

The reduced bending rigidity of a bed for bending in horizontal plane, which have two walls and perpendicular stiffeners is given by the equation

\[
EI_r = p_1 \cdot EI_{min} 
\]  
\[ \ldots (14.10) \]

where

- \(E\) = young’s modulus of the bed material, kgf/cm²,
- \(L\) = length of the bed that undergoes deformation,
- \(A_c\) = area of cross section of the wall, cm²,
- \(I_{min}\) = moment of inertia of the wall cross section in the plane of minimum rigidity against bending, cm⁴,
- \(EI_r\) = reduced bending rigidity of the bed, kgf.cm², and
- \(p_1, p_2\) = coefficients that depend upon the arrangement of stiffeners.

The value of \(p_1\) and \(p_2\) are given in Table 14.2

Constant, \(\lambda_1 = 1 + \frac{36 \xi}{\psi^2}\)

Constant, \(\lambda_2 = \frac{3 + 4\eta}{3 + \eta} + \frac{36 \xi}{\psi^2} \left[ 1 + \frac{9 \psi \mu}{(3 + \eta)^2} \right]\)

Constant, \(\eta = \frac{1}{\psi} \left[ \frac{I_{min}}{I_{smin}} + 36 \xi \mu \right]\)
Constant, $\mu = \frac{A_c}{A_t}$

Constant, $\psi = \frac{L}{B(n + 1)}$

Constant, $\zeta = \frac{I_{\min}}{A_c B^2}$

$\theta$ = half of the angle between diagonal stiffeners

Table 14.2: Coefficient of $p_1$ and $p_2$ for different Stiffeners Arrangement

<table>
<thead>
<tr>
<th>Stiffener Arrangement</th>
<th>$n$</th>
<th>$p_1$</th>
<th>Stiffener Arrangement</th>
<th>$n$</th>
<th>$p_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beds with Diagonal Stiffeners</td>
<td></td>
<td></td>
<td>Beds with Vertical Stiffeners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>$\frac{8}{\lambda_1}$</td>
<td>2</td>
<td></td>
<td>$\frac{\sin \theta \cos^2 \theta}{12(\mu + \sin^3 \theta)}$</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>$\frac{4(4\lambda_1 + \lambda_2)}{\lambda_1 \lambda_2}$</td>
<td>4</td>
<td></td>
<td>$\frac{\sin \theta \cos^2 \theta}{12(\mu + \sin^3 \theta)}$</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>$\frac{32}{\lambda_2}$</td>
<td>6</td>
<td></td>
<td>$\frac{\sin \theta \cos^2 \theta}{12(\mu + 6.3 \sin^3 \theta)}$</td>
</tr>
</tbody>
</table>

Coefficient $p_2$ is evaluated as the arithmetic mean of values of $p_2$, if the number of stiffeners is different from tabulated value. These values are corresponding to the nearest available larger and smaller values of $n$ available in the above table.

The following points should be considered for selecting stiffeners:

(a) The distance between two adjacent stiffeners in perpendicular stiffeners should be approximately equal to the width of the bed, i.e. the distance between the parallel walls.

(b) The angle between two adjacent stiffeners in diagonal stiffeners should lie in between $60^\circ$ to $100^\circ$.

The reduced rigidity of the bed is determined by walls for bending in vertical plane. Perpendicular and diagonal stiffeners have no effect upon the overall bed stiffness. The reduced rigidity is evaluated by multiplying the analytical rigidity with coefficient $p_3$.

$p_3$ is given by the equation:

$$p_3 = \frac{1}{1 + \frac{30I_{\max}}{E^2 A'_v}} \ldots (14.11)$$

where $I_{\max}$ = moment of inertia of the cross section in the plane of maximum rigidity against bending, cm$^4$, and $A'_v$ = area of vertical portions of the all, cm$^2$.

The reduced torsional rigidity of a bed with perpendicular stiffeners is given by the expression,

$$GI_t = \frac{B^2 E I_{\max}}{\theta_1 kl^2 + \theta_2 \frac{E I_{\max}}{G A'_v}} \ldots (14.12)$$
where  \( B \) = width of bed, cm, \\
\( k \) = coefficient which depends upon the number of stiffeners, and \\
\( \theta_1, \theta_2 \) = coefficients which depends upon the bed profile.

For a bed consisting of two parallel walls and perpendicular stiffeners \\
\( \theta_1 = 1/6 \)  and  \( \theta_2 = 2 \)

Hence, reduced torsional rigidity of such bed is given by

\[
G_{I1} = \frac{B^2 EI_{max}}{kL^2 + 2EI_{max}} \frac{6}{G A_v} . . . (14.13)
\]

For a bed consisting of two vertical and one horizontal wall with perpendicular stiffeners,

\[
\theta_1 = \frac{\delta + 6}{12(2\delta + 3)} \quad . . . (14.14)
\]
\[
\theta_2 = \frac{3(3\delta_1^3 + 16\delta_1^2 + 42\delta_1 + 36)}{5(2\delta_1 + 3)^2} \quad . . . (14.15)
\]

where \( \delta = B/h_v \), and

\( h_v \) = the height of the vertical walls.

For a bed consisting of two vertical walls and an inclined wall with perpendicular stiffeners:

\[
\alpha_1 = \frac{\delta + 2}{12(2\delta + 1)} \quad . . . (14.16)
\]
\[
\alpha_2 = \frac{3(5\delta_1^3 + 16\delta_1^2 + 14\delta_1 + 4)}{5(2\delta_1 + 1)^2} \quad . . . (14.17)
\]

where 
\( \delta_1 = \sqrt{1 + \frac{B^2}{h_v^2}} \)

For Eqs. (14.12) and (14.13), the value of coefficient \( k = 1 \) for beds without partitions. In beds having one or more partitions perpendicular (particularly stiffeners), i.e. \( n > 1 \), the value of \( k \) is taken from design data book as a function of \( \delta, \delta_1 \) and \( \rho \). The coefficient \( \rho \) is obtained from following relationship

\[
\frac{1}{\rho} = \frac{L . G . I_{st}}{(n + 1) BEI_{max}} \quad . . . (14.18)
\]

where \( I_{st} \) is the torsional moment of inertia of the stiffener.

For beds having \( T \)-shaped walls, \( I_{st} \) is given by

\[
I_{st} = \frac{1}{3} \beta_s^3 (b_s + h_s) \quad . . . (14.19)
\]

where \( b_s \) is width of stiffeners, cm,

\( h_s \) is height of stiffeners, cm, and

\( \beta_s \) is thickness of stiffeners, cm.

If the wall has square shaped section, then
The reduced torsional rigidity of beds with diagonal stiffeners can be calculated from the expression

$$GI_i = q_1 EI_{\text{max}} \frac{B^2}{L^2}$$

where $q_1$ is coefficient that depends upon the shape and number of stiffeners.

It may be calculated from following expressions:

$$q_1 = \frac{1}{12n^2} \left[ 2 + 3\beta_1 + 6\gamma_1 \right]$$

where

$$\beta_1 = \frac{n^3 d^3 EI_{\text{max}}}{L^3 EI_{s_{\text{max}}}}$$

$$\gamma_1 = \frac{n^3 EI_{w_{\text{max}}}}{L^2 GA_w}$$

$$\gamma_2 = \frac{dn^3 EI_{w_{\text{max}}}}{L^3 GA_s}$$

where $I_{\text{max}} = \text{moment of inertia of the stiffener in the plane of maximum rigidity}$

against bending, cm$^4$,

$d = \text{length of the diagonal stiffener, cm}$, and

$A_s' = \text{area of the vertical projection of the stiffener, cm}^2$.

The reduced torsional rigidity of a rectangular box type section is given by the relation:

$$GI_i = G \cdot 4A_0^2 \sum_{i=1}^{n} \frac{\delta_i}{s_i}$$

**SAQ 3**

(a) Give details of bed section and wall arrangement with their application.

(b) Explain design of beds?

(c) What are the various considerations while selecting stiffeners?
14.5 DESIGN OF COLUMNS

The spindle head is mounted on the column in machine tool with fixed bed. The spindle head and knee table unit is mounted on the column in the knee type machine tool. The forces are acted on the columns in the symmetrical plane, e.g. drilling machine. The forces are also acted arbitrarily in space, e.g. milling and boring machine, vertical lathe etc. The principle design requirements of columns are high static and dynamic stiffness. These properties are achieved by proper selection of the column material and its cross-section. Sections of machine tool columns are shown in Table 14.3.

Table 14.3: Commonly used Column Sections and Their Application

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Section</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Square box type section with vertical ribs and spaced horizontal stiffeners.</td>
<td>It is used for columns subjected to three dimensional loading, chief application is in boring and milling machines.</td>
</tr>
<tr>
<td>2</td>
<td>Rectangular box type section.</td>
<td>It is used when forces act only in the plane of symmetry. It is used in vertical drilling and unit built in machine tools. Optimum a/b = 2 to 3</td>
</tr>
<tr>
<td>3</td>
<td>Rectangular box type section with vertical ribs and spaced horizontal stiffeners.</td>
<td>It is used in gantry type machine tools. The recommended a/b ratios are: For vertical lathe a/b = ¼, for planning machine a/b = 2-3, for plano-mailing machine a/b ratio = 2-3.</td>
</tr>
<tr>
<td>4</td>
<td>Circular section with stiffeners.</td>
<td>It is used when the load is small and it is necessary to provide for rotation of the column, e.g. in radial drilling machine and in bench.</td>
</tr>
</tbody>
</table>

The columns are generally made with thin walled circular or box sections. The section is made stronger by providing stiffeners. Number and size of holes and opening is kept as small as possible. Warping may takes place, if the height of the column is greater than its cross sectional dimensions under three dimensional loading. Hence warping is avoided by providing torsional stiffeners. These stiffeners are not employed in the absence of warping as they marginally improve overall section stiffness. The area of column gradually increases from top to the base where the bending moment is high. The section should be progressively changed from thin walled rectangle to a thin walled square.

The machine tool columns are experienced bending in two perpendicular planes, shearing in two perpendicular planes and torsion. The deflection in bending of the column is calculated by analyzing the column as a cantilever fixed at the base, and plotting bending moment diagram in both the directions.

The deflection due to shearing of the column is determined for following expression:

\[ d = \omega \frac{F_s \cdot l}{G \cdot A} \]  

(14.25)

where

- \( F_s \) = shearing force, \( N \),
- \( l \) = distance from the base of the section in which shearing deformation is being determined, mm,
- \( A \) = area of cross-section, \( \text{mm}^2 \),
- \( G \) = Shear modulus of column material
- \( \omega \) = coefficient of distribution of shearing displacement

The value of coefficient \( \omega \) can be calculated from Figure 14.2.
The displacement of the guideway (point A) of a rectangular box type section (as shown in Figure 14.3) due to torsion may be calculated from the following equations:

In direction $X-X$, deflection $\Delta X = \gamma \cdot \phi$

In direction $Y-Y$, deflection $\Delta Y = \frac{b}{2} \cdot \phi$.

The deflection of the base to which the column is bolted should also be taken into consideration. The base is used as a hollow box section for this purpose which is simply supported at the ends. The deflection at the top of the column due to bending of the base is obtained by multiplying the column height with the angle of slope of the deflected base in that section where it meets the column. The dimension of the column cross-section should be such that the total deflection of the guideways at the top of the column doesn’t exceed 3 to 5 µm/meter length in $Y-Y$ direction and 10 to 25 µm/meter length in $X-X$ direction.

If holes are closed by cover plates, the reduction in torsional stiffness due to the openings can be neglected provided each force is tightened by the force, $F_t$.

$$F_t \geq \frac{T(b_a + l_a)}{A_b \mu n} \quad \ldots (14.26)$$
where $F_i =$ tightening force of each bolt, $N,$

$T =$ Torque acting on the column, N.mm,

$\mu =$ coefficient of friction,

$n =$ number of bolts, and

$A_b =$ area of the cross section of the one bolt, mm$^2$.

The effect of ribs and stiffeners on the bending stiffness of column is very small and hence can be neglected. The vertical ribs also don’t have any appreciable effect on the torsional stiffness.

SAQ 4

(a) State and explain various column sections with their application.

(b) Explain design of columns.

14.6 DESIGN OF HOUSING

Housing is one of the important elements of machine tool structure. Housing may be split or solid. Solid housings are used in small and medium sized machine tools. Split housings are easier to assemble but stiffness is less as compared to solid one. Split housings are provided with a hinged cover to facilitate its opening for regulation of some mechanisms such as the speed box engine lathes with cone pulley drive. The stiffness of such housing is less than solid housing by 50 %. Housing type structures are designed for stiffness. The stiffness is determined by determining the displacement of point C. This displacement is due to a force acting normal to the wall at the same point. The housing type structure is shown in Figure 14.4.

This displacement is calculated from following empirical relation:

$$X = g_0 g_1 g_2 g_3 \cdot \frac{F \cdot k^2 (1 - \mu)}{E \cdot t^3} , \text{mm} \quad \ldots (14.27)$$

where $g_0 =$ coefficient that accounts for the type of connection of the loaded wall with adjoining walls.

$g_1 =$ coefficient that accounts for the effect of the bossing of the loaded hole.
\( g_2 \) = coefficient that accounts for the effect of unloaded holes and bossing.

\( g_3 \) = coefficient that accounts for the effect of the ribs and stiffeners.

\( F \) = force acting normal to the loaded wall, N.

\( t \) = thickness of loaded wall without bossing, mm.

\( 2k \) = the larger dimension of the rectangular loaded wall, mm.

\( \mu \) = Poisson’s ratio for the housing material.

\( E \) = Modulus of elasticity of the housing materials, N/mm².

The coefficient \( g_0 \) depends upon the ratio of \( 2k : 2m : 2n \) of the housing dimensions and point of application of the force \( F \). Different values of \( g_0 \) is given in Table 14.4 for different values of \( k:m:n \) when force \( F \) is acting at the center of the loaded wall. The value of \( g_0 \) is high for the force acting at the center when the loaded wall is connected to adjoining walls on all four sides. The value of \( g_0 \) is two to three times smaller for loads acting at the corners. When the loaded wall is connected to adjoining walls only on three sides, the value of \( g_0 \) reduces as the point of application shifts towards the constrained corners.

<table>
<thead>
<tr>
<th>Ratio a : b : c</th>
<th>All Four Edges of Loaded Wall 2k x 2m Connected to Adjoining Walls</th>
<th>Three Edges of Loaded Wall 2k x 2m Connected to Adjoining Walls, One Edge Free</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 : 1 : 1</td>
<td>0.35</td>
<td>0.48</td>
</tr>
<tr>
<td>1 : 1 : 0.75</td>
<td>0.44</td>
<td>-</td>
</tr>
<tr>
<td>1 : 1 : 0.5</td>
<td>0.5</td>
<td>-</td>
</tr>
<tr>
<td>1 : 0.75 : 1</td>
<td>-</td>
<td>0.45</td>
</tr>
<tr>
<td>1 : 0.75 : 0.75</td>
<td>0.3</td>
<td>0.42</td>
</tr>
<tr>
<td>1 : 0.75 : 0.5</td>
<td>0.33</td>
<td>-</td>
</tr>
<tr>
<td>1 : 0.5 : 1</td>
<td>-</td>
<td>0.28</td>
</tr>
<tr>
<td>1 : 0.5 : 0.75</td>
<td>-</td>
<td>0.27</td>
</tr>
</tbody>
</table>

The value of \( g_0 \) is approximately 3 times less at two constrained corners. If the point of application of the force \( F \) is shifted towards the free corner, the maximum value of \( g_0 \) occurs at the middle of the free edge. The value of \( g_0 \) may be about 2.5 to 3 times greater than the tabulated values for load acting at the center.

Bosses are made to increase the wall thickness locally where the stiffness has suffered due to hole. They are usually located on the internal surface of wall. Bossing dimensions are generally limited to

\[
D = (1.4 \text{ to } 1.6) \ d
\]

\[
H = (2.5 \text{ to } 3) \ t
\]

This is because any further increase in dimension doesn’t improve the stiffness. \( g_1 \) depends upon the ratios \( D/d, H/t, r/k \). It decreases sharply with increase in the value of \( H/t \). The different values of \( g_1 \) are given in Table 14.5.
In Table 14.5, \( H_b/t \) represents the active height of the bossing. The ratio \( H_b/t \) is taken from design data book. There is not any significant effect on the value of coefficient \( g_1 \) due to ratios \( D/d \) and \( r/j \). The values of \( g_1 \) are generally higher than that tabulated by 5-10%. The effect of \( r/k \) is not uniform. The reduction of ratio \( r/k \) to 0.6 has no effect on the value of \( g_1 \) for average values of \( \left[ \frac{D^2}{2k \cdot 2m} \right] \) and \( \left[ \frac{H_b}{t} \right] \) while it reduces by two to five percent for high values of \( \left[ \frac{D^2}{2k \cdot 2m} \right] \) as compared to tabulated values.

The coefficient 
\[
\Delta x = 1 + \sum \left( \frac{\Delta x_i}{x} \right)
\]

Where \( \Delta x_i \) shows the increment in deflection due to \( i^{th} \) unloaded hole. Its values depend upon the ratios of \( D/d, H_b/t \).

The values of coefficient \( g_2 \) are given in Table 14.6.

<table>
<thead>
<tr>
<th>( H_b/t )</th>
<th>( [D^2/(2k \cdot 2m)] )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.02 0.04 0.06 0.08 0.1 0.12 0.14</td>
</tr>
<tr>
<td>1.2</td>
<td>1.0 0.95 0.94 0.92 0.9 0.88 0.87 0.85</td>
</tr>
<tr>
<td>1.4</td>
<td>1.0 0.88 0.83 0.78 0.72 0.72 0.69 0.67</td>
</tr>
<tr>
<td>1.6</td>
<td>1.0 0.82 0.75 0.75 0.68 0.6 0.6 0.57 0.55</td>
</tr>
<tr>
<td>2.0</td>
<td>1.0 0.75 0.65 0.58 0.48 0.53 0.45 0.41</td>
</tr>
<tr>
<td>3.0</td>
<td>1.0 0.7 0.58 0.5 0.38 0.44 0.35 0.3</td>
</tr>
</tbody>
</table>

If coefficient \( g_2 \) increases by 5 to 10 %, ratio of \( D/d \) decreases from 1.6 to 1.2. The effect of \( R/k' \) on the value of \( g_2 \) depends greatly upon \( \left[ \frac{D^2}{2k \cdot 2m} \right] \) and \( H_b/t \). Here \( a' \) represents the distance between end of wall to the point at which load \( F \) is acting. The value of \( g_2 \) increases by 15 % with increase in the value of \( R/k' \) for average values of \( \left[ \frac{D^2}{2k \cdot 2m} \right] \) and \( H_b/t \). The value of \( g_2 \) decreases by 15 to 20 % if \( R/k' \) reduced to 0.3. The coefficient \( g_3 \) is 0.8 to 0.9, if the stiffening ribs are cast in the surrounding area of the loaded hole to increase the strength of bossing and wall. If the ribs are provided for a general overall improvement of housing stiffness, then \( g_3 \) is 0.75 to 0.85. The larger values are for non-intersecting ribs while smaller values are for interconnected ribs.

Hence, it is clear from Eq. (14.27) that thickness housing wall is most important factor that calculate overall deformation \( x \). Hence bossing of hole is most important step to provide sufficient stiffness to housing type structures.

**SAQ 4**

Explain design of housings.
14.7 SUMMARY

Machine tool structure consists of beds, bases, columns, box type housings, overarms, carriages, tables etc. The structures are used to hold subassemblies, to support and move the cutting tool and workpiece. The machine tool structures are designed for high wear resistance of guiding and guided and surface high static and dynamic stiffness. This unit particularly deals with various aspects in designing bed, column and housings.

14.8 KEY WORDS

<table>
<thead>
<tr>
<th>Bed</th>
<th>It is the base of machine tool on which whole assembly is mounted.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column</td>
<td>The spindle head is mounted on the column in machine tool with fixed bed.</td>
</tr>
</tbody>
</table>