Module 4

General Purpose Machine Tools

Lesson
24
Forces developing and acting in machine tools

Instructional objectives

At the end of this lesson, the students will be able to;

(i) Identify the sources and pattern of the forces that develop in machine tools during machining.
(ii) State the effects of the forces in machine tools and its operations.
(iii) Comprehend the purposes of analysis of forces acting in machine tools
(iv) Visualise and evaluate the forces originated and distributed in machine tools.

(i) Sources And The Types Of The Forces That Develop In Machine Tools During Machining.

- **Cutting forces originating at the cutting point(s)**
    - In continuous type machining;
        - — Main cutting force, P_Z along the velocity vector, V_C
        - — Feed or thrust force, P_X along the feed direction
        - — Transverse force, P_Y normal to $P_Z - P_X$ plane
          in turning, boring and similar single point cutting process
        - — Torque and thrust force
          in drilling, counterboring, counter sinking etc.
    - In impact initiated type;
        - — Shaping, planing, slotting, gear shaping etc.
    - In intermittent type;
        - — Fluctuating forces due to intermittent cutting in milling, hobbing etc.
- **Gravitational forces**
    - Dead weight of the major and heavy components of the Machine – Fixture – Tool – Work (M – F – T – W) system, e.g., workpiece, headstock, tailstock, saddle, bed and moving tables etc.

- **Frictional forces**
    - Due to rubbing at the sliding surfaces.
- **Inertia forces**
    - Due to acceleration and deceleration at the end points of sliding and reciprocating motions of heavy parts like carriage or saddle, turret slide, tool slides, moving beds, reciprocating tables, rams, jobs etc.
- **Centrifugal forces**
    - Due to high speed rotation of eccentric masses
    - Due to wide run out or eccentric rotation of jobs, machine tool parts, spindle, shafts, tools etc.

(ii) Effects Of The Various Forces On Machining And Machine Tools

- Energy or power consumption
- Increased cutting zone temperature and its detrimental effects
- Dynamic forces resulting vibration and chatter cause poor surface quality and reduction of life of cutting tools as well as damage of the machine tools
- Elastic deflection and thermo-elastic deformation of several bodies leading to dimensional inaccuracy
- Rapid wear and tear at the sliding surfaces
- Noise and inconvenience
- Chances of premature mechanical failure of cutting tools and other components due to excessive stresses, thermal fracture, wear, fatigue, resonance etc.

(iii) Purposes Of Analysis And Evaluation Of The Forces Acting In Machine Tools.

It is essentially needed to know or determine the magnitude, location and direction of action and also the nature of the forces that develop and act during machining to enable :

- Estimate the cutting power and total power requirement for selection of type and capacity of the main power sources (motors)
- Design of the machine tool and cutting tool systems and the tool – workholding devices
- Design of the machine tool foundations
- Evaluate process capability of the machine tools

- Assess the machinability characteristics of various tool – work combinations under different operating conditions of the machine tools
- Determination of the role of the different process, geometrical and environmental parameters on the magnitude and pattern of the forces, which will help their optimal selection for good performance of the M – F – T – W system and overall economy.
- Comprehend the need and way of improvement in design, construction, performance, safety and service life of the machine tools.

(iv)Analysis Of Forces Acting During Machining In :

(a) Centre lathes
(b) Drilling machines
(c) Shaping machines
(d) Planing machines
(e) Milling machines

It has already been mentioned that forces of varying magnitude, location and direction develop in a machine tool mainly due to the machining action. Besides that forces also develop in various parts and locations due to dead weights, inertia, friction, impacts and eccentricity of rotating masses.

Here the forces that develop in different parts of the machine tool due to the cutting forces only have been discussed.

(a) Forces develop and act in centre lathes

Centre lathes are used for various machining work but mostly for straight turning.
Fig. 4.8.1 shows the location and direction of action of the different forces that develop in the headstock and tailstock being originated by the machining forces (components) :

- Tangential component, P_Z – main force
- Axial component, P_X – feed force
- Transverse component, P_Y – thrust force

- **Forces acting on the Headstock side :** [see Fig. 4.8.1]

  - **On the headstock (HT) centre** : -

$$P_{ZH} = P_Z\left(\frac{x}{L_w}\right) - \frac{W}{2}$$

$$P_{YH} = P_Y\left(\frac{x}{L_w}\right) + P_X\left(\frac{D_w}{2L_w}\right) \qquad (4.8.1)$$

$$P_{XH} = P_X + K$$

where, W = weight of the workpiece (rod)
L_W = length of the workpiece

D_w= maximum diameter of the workpiece
K = axial tightening force
X = distance of the cutting tool from the tailstock centre

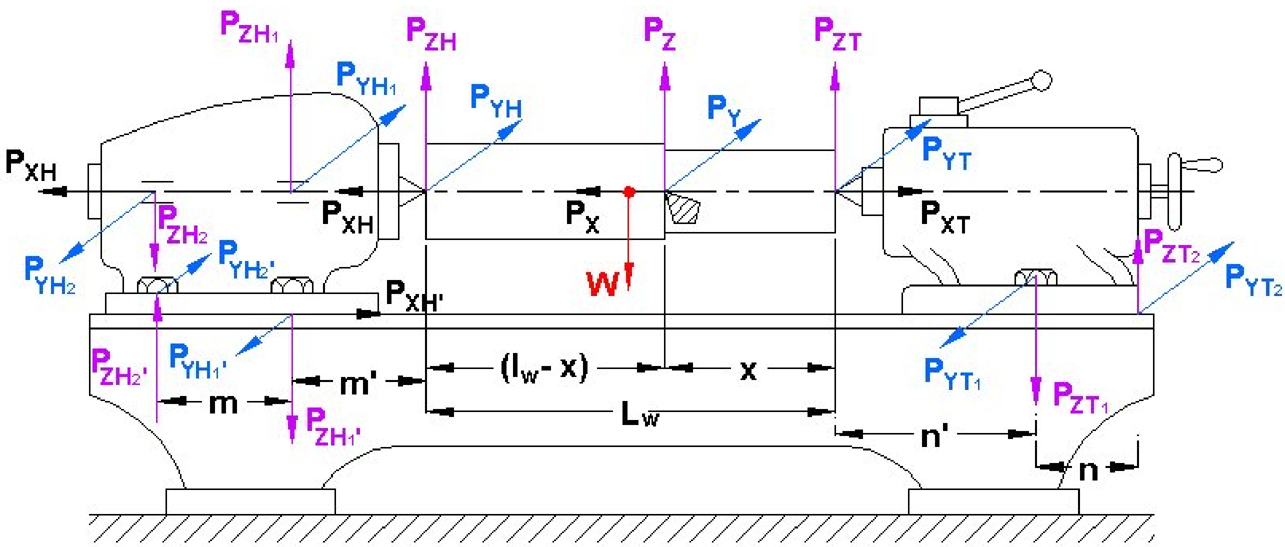

Fig. 4.8.1 *Forces acting on the lathe*

- **At the bearing housings**

$$P_{ZH_1} = P_{ZH}\left(\frac{m+m'}{m}\right)$$

$$P_{ZH_2} = P_{ZH}\left(\frac{m'}{m}\right) \qquad (4.8.2)$$

$$P_{YH_1} = P_{YH}\left(\frac{m+m'}{m}\right)$$

$$P_{YH_2} = P_{YH}\left(\frac{m'}{m}\right)$$

- **At the supports (bolting)**

$$P_{ZH_1'} = -P_{ZH_1}$$

$$P_{ZH_2'} = -P_{ZH_2} \qquad (4.8.3)$$

$$P_{YH_1'} = -P_{YH_1}$$

$$P_{YH_2'} = -P_{YH_2}$$

- **Forces acting on the Tailstock side**
  - **On the Tailstock centre**

$$P_{ZT} = P_Z\left(\frac{L_W - x}{L_W}\right) - \left(\frac{W}{2}\right)$$
$$P_{YT} = P_Y\left(\frac{L_W - x}{L_W}\right) - P_X\left(\frac{D_w}{2L_w}\right) \qquad (4.8.4)$$
$$P_{XT} = K - P_X$$

  - **At the bolting and rear bottom end (heel)**

$$P_{ZT_1} = P_{ZT}\left(\frac{n+n'}{n}\right) + P_{XT}\left(\frac{H}{n}\right)$$
$$P_{ZT_2} = P_{ZT}\left(\frac{n'}{n}\right) + P_{XT}\left(\frac{H}{n}\right) \qquad (4.8.5)$$
$$P_{YT_1} = P_{YT}\left(\frac{n+n'}{n}\right)$$
$$P_{YT_2} = P_{YT}\left(\frac{n'}{n}\right)$$

- **Forces acting on lathe bed**

The lathe bed receives forces through;

- The headstock and tailstock
- The saddle on which the cutting tool is mounted

  - **Forces through headstock and tailstock**

The headstock is kept fixed by two pairs of bolts or studs on the lathe bed and the tailstock is clamped on the bed by one bolt. The forces acting on the bed through the front and the rear pair of bolts are :

$$P_{V_1} = P_{ZH_1}$$
$$P_{V_2} = P_{ZH_2} \qquad (4.8.6)$$
$$P_{H_1} = P_{YH_1}$$
$$P_{H_2} = P_{YH_2}$$

where, PV_1 and PV_2 are vertical forces and PH_1 and PH_2 are horizontal.

Similarly the forces acting on the lathe bed through the tailstock are :

$$P'_{V_1} = -P_{ZT_1}$$
$$P'_{V_2} = -P_{ZT_2} \qquad (4.8.7)$$
$$P'_{H_1} = -P_{YT_1}$$
$$P'_{H_2} = -P_{YT_2}$$

- **Forces acting on the lathe bed through the saddle.**

The cutting tool receives all the forces P_Z, P_X and P_Y but in opposite direction as reaction forces. And those forces are transmitted on the lathe bed through the saddle as indicated in Fig. 4.8.2.
The saddle rests on and travels along the lathe bed. All the forces acting on the bed through the saddle are assumed to be concentrated at four salient locations, A, B, C and D within the saddle – bed overlapped area as shown. Then from the force diagram in Fig. 4.8.2 the vertical forces (V) and horizontal forces (H) can be roughly determined;

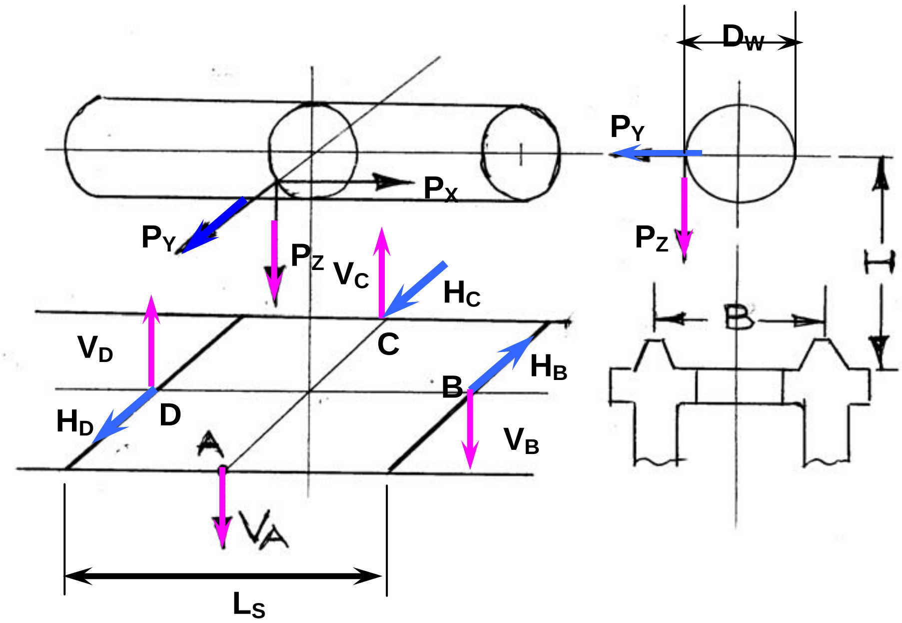

Fig. 4.8.2 Forces acting on the lathe bed through the saddle due to cutting forces.

$$V_A = P_Z\left(\frac{B+D_W}{2B}\right) + P_Y\left(\frac{H}{B}\right)$$
$$V_C = P_Z\left(\frac{B-D_W}{2B}\right) - P_Y\left(\frac{H}{B}\right) \qquad (4.8.8)$$
$$V_B = V_D = P_X\left(\frac{H}{L_S}\right)$$

$$H_B = H_D = P_X \left(\frac{D_W}{2L_S} \right)$$

where, B, L_s = width and length of the saddle
H = centre height

(b) Forces acting in Drilling machines

The main source and location of the originating forces in drilling machine are the cutting forces, i.e., torque, T and the thrust or axial force, P_X as shown in Fig. 4.8.3
The other sources of forces that develop and act in drilling machine are :

- Dead weight of the heavy unit;
  - Δ Drilling head
  - Δ Radial arm (if it is a radial drilling machine)
  - Δ Column
  - Δ Bed or table
  - Δ Workpiece, if it is large and heavy
- Balancing weight, if provided
- Sliding friction
- Inertia forces due to moving parts

Both the drill and the job are subjected to equal amount of torque, T and thrust P_X but in opposite direction as action and reaction as indicated in Fig. 4.8.3.

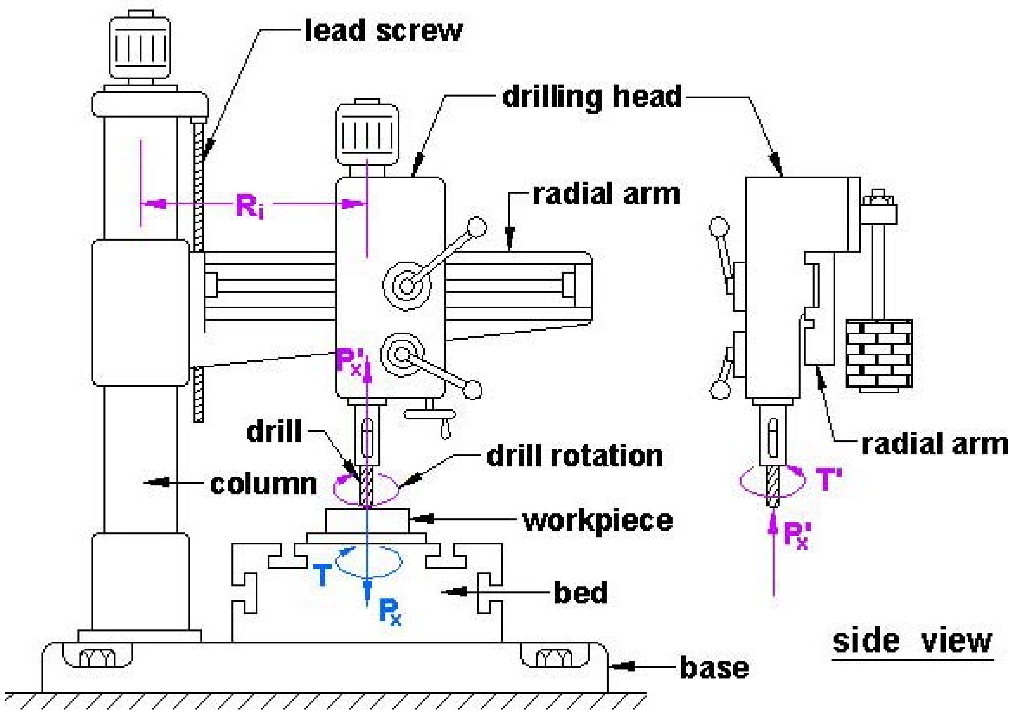

Fig. 4.8.8 *Forces acting in a drilling machine.*

Due to the torque and thrust, forces will develop and act on the several components of the drilling machine as follows :

- **Bed, base and foundation** –
  Both T and P_X will be transmitted to the base and the foundation from the job and through the bed, clamps and the foundation bolts
- **Spindle** –
  This salient component will be subjected to both the torque and thrust and is designed accordingly
- **The motor is selected** based on the maximum torque and spindle speed
- **Radial arm** –
  This cantelever beam is subjected to large bending moment, $P_X x R_i$ depending upon the magnitude of P_X and the distance R_i of the drilling head from the column axis. This arm will also be subjected to another twist in the other vertical plane due to P_X depending upon its distance from the mid-plane of the radial arm.
  Beside that the arm will bear the weight of the drilling head and its balancing weight, which will also induce bending moment.
- **Column –**
  This main structural part will have two axial forces, weight and P_X' acting vertically downward and upward respectively. The force P_X' will also induce a large bending moment, equal to P_X' x R_i in the column.

(c) Forces acting in shaping machine

The forces that develop at the cutting point and due to that act on the major components during machining in a shaping machine are schematically shown in Fig. 4.8.4.

- **The forces that develop at the cutting point** and
  — act on the job : P_Z, P_X and P_Y
  — act on the tool : P_Z', P_X' and P_Y' as reaction
  The magnitude of those force components depend upon the work material, tool geometry, feed and depth of cut and cutting fluid application
  Those cutting forces then are transmitted in the various parts as indicated;
    - The ram is subjected to R_{X1}, R_{X2}, R_{Y1} and R_{Y2} in addition P_X', P_Y' and P_Z' as shown and the friction forces.
    - The bed receives directly the forces P_X, P_Y and P_Z and is also subjected to the forces B_1 and B_2 as indicated.
    - The column of the shaping machine is subjected to the various forces coming from the cutting tool side and the bed side as shown.

The magnitude of those forces will depend upon the dimensions of the shaping machine, magnitude, location and direction of the cutting force components and other sources of forces. All those forces can therefore be easily evaluated.

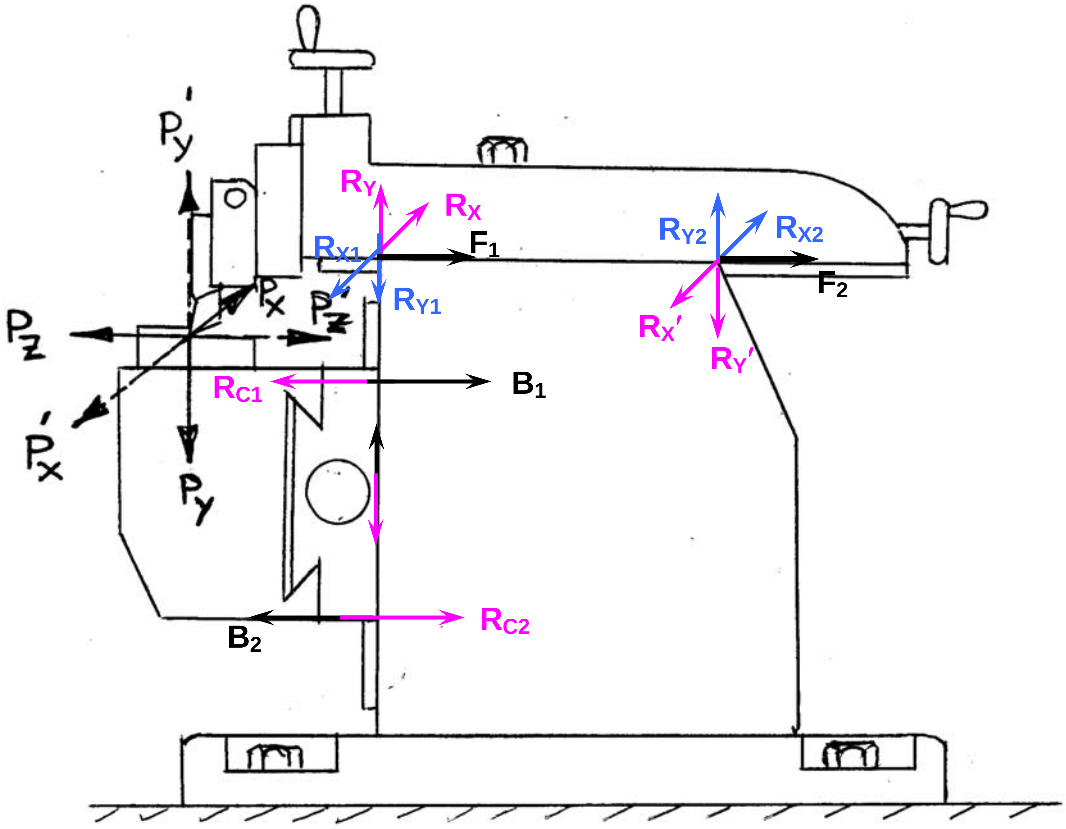

Fig. 4.8.4 *Forces that develop and act on major parts during shaping.*

(d) Forces that develop and act in planing machine

Since the basic principle of machining is same in shaping machine and planing machine, the characteristics of the forces; magnitude and directions are also same at the cutting pint. The forces that will act due to those machining forces on the major parts of planning machine will depend on the configuration and dimensions of the machine and its parts.

(e) Forces that develop and act in milling machine

Fig. 4.8.5 schematically shows the forces that originate at the cutting point and get transmitted to the major parts of the milling machine.

- The forces that develop at the cutting point are resolved into three orthogonal directions. Those forces, acting on the job as actions and on the cutting tool as reactions, have been indicated (in Fig. 4.8.5) by P_V, P_H, and P_A which are again transmitted to the different parts.

- Due to the cutting forces the different parts of the milling machine receive number of forces, such as;
    - The milling arbour holding the cutting tool is subjected to (in addition to P_V, P_H and P_A) P_{V1}, P_{H1} and P_{V2}, P_{H2} and also P_A (axially)
    - The overarm or ram is subjected to P_{V1}, P_{H1}, P_{V2}, P_{H2}, P_{V3} and P_{H3}. It also receives an axial force, P_A'.
    - The bed is subjected directly to the cutting forces, P_V, P_H and P_A, and also other forces, ($-P_{A1}$), ($-P_{H1}$), P_V etc. as shown in the figure.
    - Due to the cutting forces, the column is subjected to various forces (at its different locations) coming through the arbour and ram on the one hand and bed on the other side as indicted in Fig. 4.8.5.

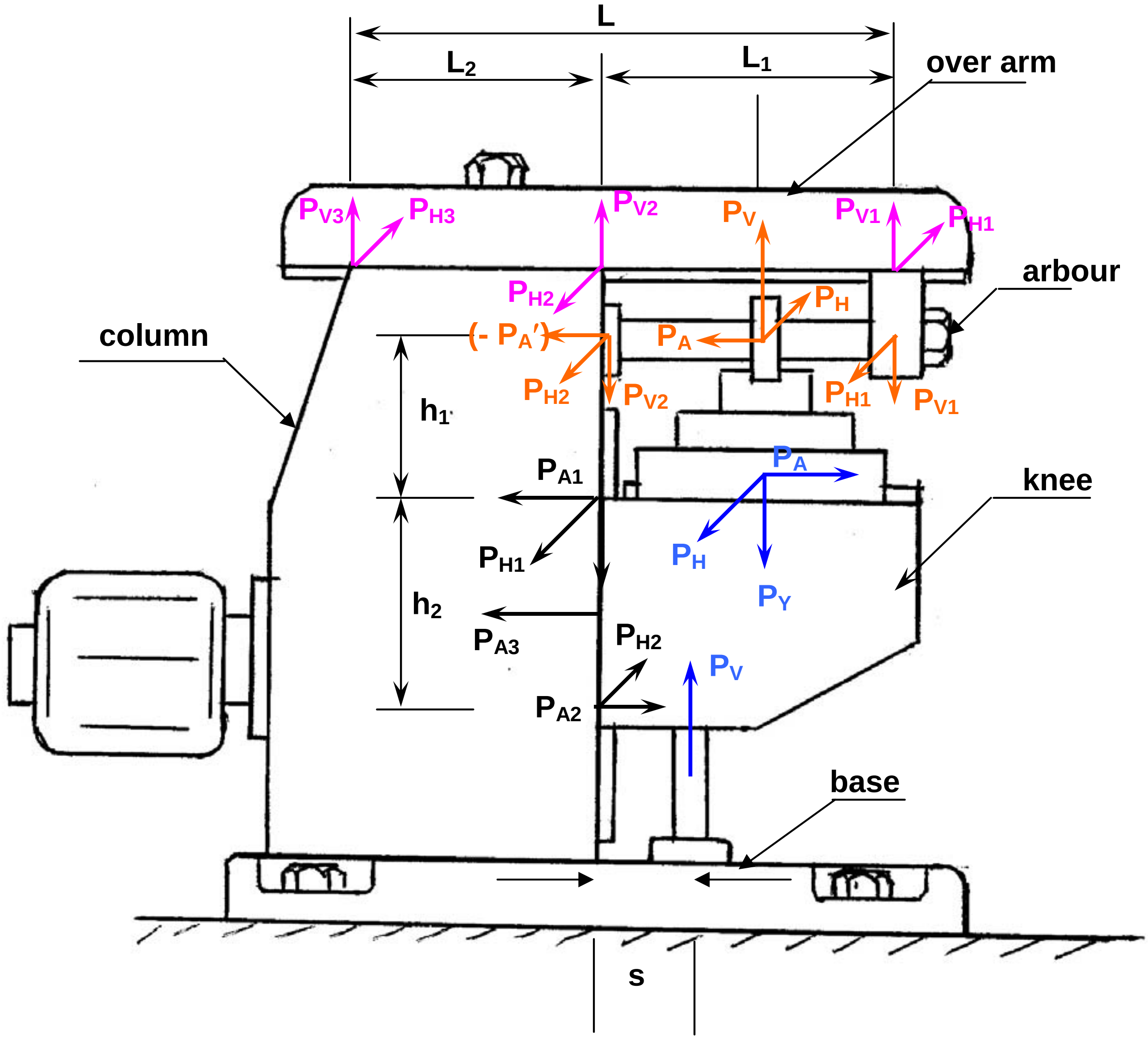

Fig. 4.8.5 Development of forces in milling machine.

Again, all those forces acting on the different components depend upon and can be evaluated from the values of the cutting forces, configuration and dimension of the machine and its major components.

Similarly, the forces acting on any machine tool can be determined for the different purposes.