Studies to avoid breaking tool in manufacturing by broaching operation

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Abstract: In the paper is presented a study on the conditions to be met by the clamping device for the processing of the internal surfaces on the broaching machines. It is especially emphasized that in most cases, devices with spherical support are used for clamping the parts on the machine tool. They provide good conditions for avoiding the breaking of the broaching tool and meeting the dimensional, quality and geometrical conditions required by the technical documentation of the parts. The paper specifies the maximum and minimum limits between the size of the spherical device for a good execution of the broaching operation.

Keywords: spherical device, concentricity, roughness, safety work.

1 Introduction

Broaching is a cutting process using a multitoothed tool, called broach, having successive cutting edges, each protruding to a greater distance than the proceeding one in the direction perpendicular to the tool length. In contrast to all other cutting processes, there is no feeding of the broach or the workpiece. The feed is built into the broach itself through the consecutive protruding of its teeth.

In comparison with other types of machine tools, broaching machines are notable for their simple construction and operation. This is due to the fact that the shape of the surface produced in broaching depends upon the shape and arrangement of the cutting edges on the broach. The only cutting motion of the broaching machine is the straight line motion of the ram. Broaching machines have no feed mechanism, as the feed is provided by a gradual increase in the height of the broach teeth.

Currently, horizontal machines are finding increasing favor among users because of their long strokes and the limitation that ceiling height places on vertical machines. About 47% of all broaching machines are horizontal units. Horizontal internal broaching machines are used mainly for some types up to 3 m, and cutting speeds limited to less than 12 m/min. Horizontal machines are seldom used for broaching small holes.

2 Spherical devices for broaching parts

For broaching the internal surfaces of workpieces on broaching machines, are used devices that provide more degrees of freedom for parts subjected to the cutting forces. These clamping devices are designed to ensure the concentricity of the broaching tool' axis with the workpiece' axis.

Also, these degrees of freedom provided by the workpiece device will have a good influence in achieving a superior surface quality resulting from the cutting action of the broaching tool.

Generally, the devices used to clamp the parts on the broaching machines are simpler constructively than the clamping devices on other cutting machines such as lathes, milling machines, drilling machines, etc. Most of the time, for clamping the parts on the machine tool, the spherical support method is used, which ensures a quick self-centering of the workpiece'axis with the tool axis. This leads to easier machining of the workpiece and greatly avoids breaking of the broaching tool when using a non-uniform blank product.

The spherical support device (Fig.1), provides the concentricity of the broaching tool axis with the workpiece' axis, avoiding the risk of breaking the broaching tool during broaching operation.

In the most general case, the blank has deviations from the perpendicularity of the end surfaces relative to the its axis.

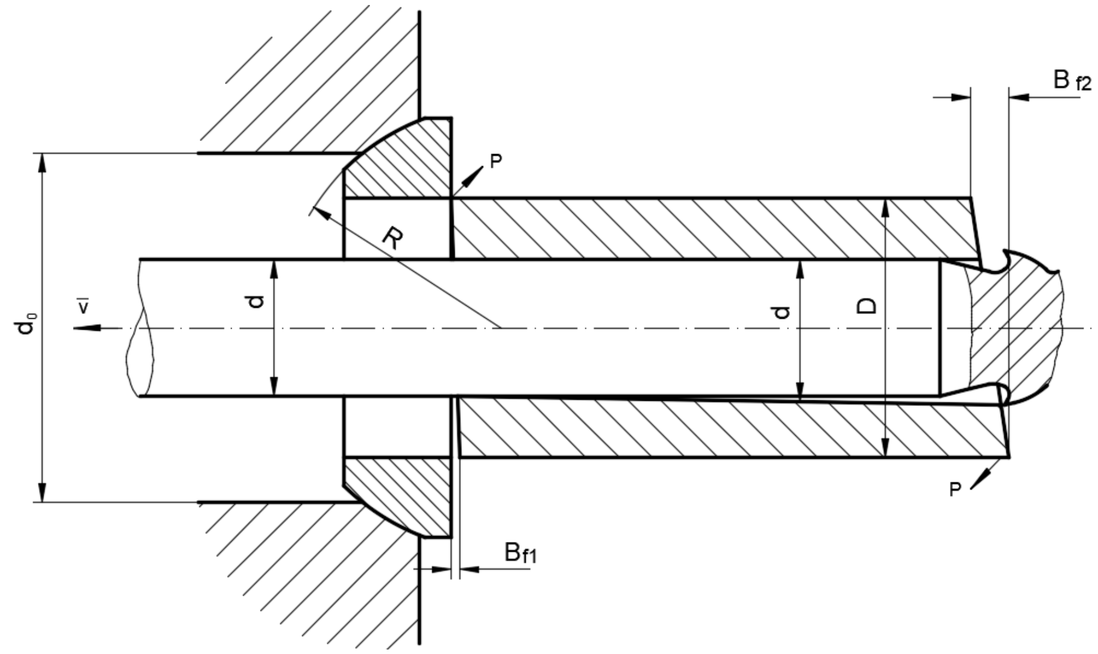

Fig.1 Spherical device used for broaching operation.

In Fig. 1 is the case of a part to be broached, which has on both end surfaces deviations from the perpendicularity to the axis of the part, marked Bf_l and Bf_2. It was considered that the two deviations are measured in the same plane that contains the axis of the inner surface of the part. Depending on the size and position of the Bf_l deviation to the Bf_2 deviation, the teeth of the broach will attack the part material first in the "a" or "b" area. As shown in Fig. 1, if the device did not allow self-centering of the part in its device, the forces that appear on the part material and the broaching tool are unfavorable to the cutting process. The P-P force torque influences the surface quality and dimensional accuracy of the internal surface of the workpiece and can even break the tool. On the other hand, the teeth of the broach that come in contact with the surface of the piece in the "a" area will tend to get out of the cutting area, having the tendency to rotate the blank in a direction that leads to minimize the Bf_2 deviation. This results in the same unfavorable effect of Bf_2 deviation on the brooch and the blank.

If the teeth of the brooch will attack the part material first in the "b" area (for another sense of Bf_2 deviation in relation to Bf_1 deviation), the effect will be the same, decreasing only the torque of the P forces. If the support can rotate in its place, then after rotation with the angle $\alpha_1 = arctg\frac{Bf_2}{D}$, the concentricity of the broaching tool axis and part axis is achieved. Thus the danger of breaking tool is removed and the conditions for achieving the dimensional accuracy and surface finish of the workpiece's surface are created.

The analysis did not take into account the influence between the hole size "d" before the broaching and the size of the guiding part of the broach d_g.

It can be seen the case when $tg\alpha_1 = \frac{Bf_1}{D} > \mu_1$, ($\mu_l$ being the friction coefficient between the blank and the spherical support) or $tg\alpha_2 = \frac{Bf_2}{D} > \mu_2$, ($\mu_2$ being the friction coefficient between the tooth of the broach and the blank), the part rotates at an angle φ = $\frac{d-d_g}{L}$. Since the angle φ is negligible, it does not significantly influence the cutting process. It was considered part of the negative influence of the Bf_2 deviation on the broaching process.

As can be seen from Fig. 1, engaging in the cutting process of the broach teeth are not simultaneously applied along the all length of the cutting edge. For this reason, the Bf_2 deviation can be regarded as a source of vibrations that will influence the quality of the surface finish of the part and the durability of the tool. This leads to the observation that by performing a chamfer or recess on the workpiece, the unfavorable influence of the Bf_2 deviation will be eliminated.

3 Calculation of radius of spherical support

As a result of the above, in order to ensure concentricity between the broaching tool and workpiece axis, the spherical support must be able to rotate in its place. For this reason, attention must be focused primarily on the dimensioning and execution of the spherical support

The force P which rotates the spherical support is denoted by P. It is considered that this force P has the lever arm $\frac{D}{2}$ relative to the axis of the cylindrical inner surface of the support. We note with $\overline{N}$ and $\overline{F}$ the normal force, i.e. the tangential (frictional) force corresponding to the surface element dA.

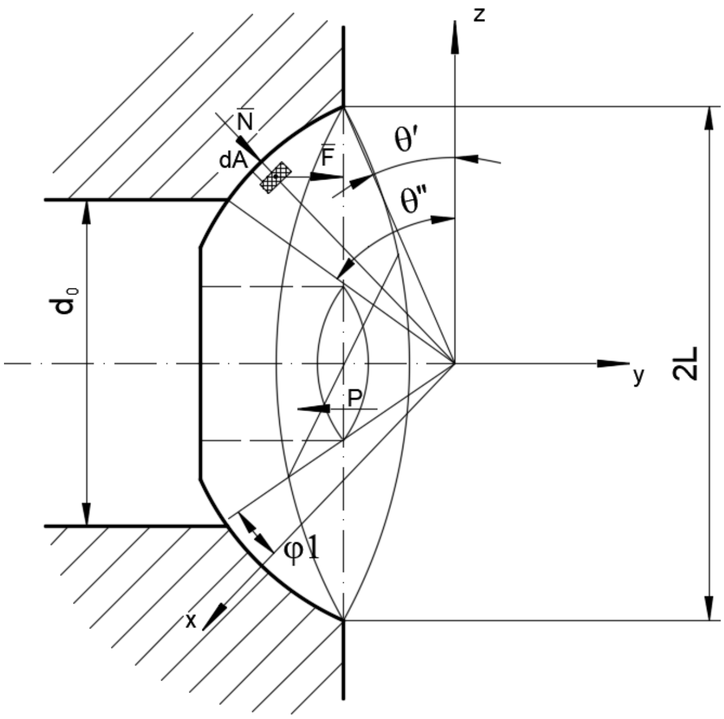

Fig.2 Calculation of radius of spherical support.

Under the action of the force, the spherical support will rotate around the Oz axis so that the forces F will be tangent to the parallel lines of the spherical surface.

The equations of equilibrium are:

$$\sum X = 0; \quad \int_{(A)} N_x \, dA + \int_{(A)} F_x dA = 0 \quad \sum M_x = 0 \qquad (1)$$

$$\sum Y = 0; \quad \int_{(A)} N_y \, dA + \int_{(A)} F_y dA = 0 \quad \sum M_y = 0 \qquad (2)$$

$$\sum Z = 0; \quad \int_{(A)} N_z \, dA + \int_{(A)} F_z dA = 0 \quad \sum M_z = 0 \qquad (3)$$

We take into consideration the next equations:

$$\int_{(A)} N_y dA + \int_{(A)} F_y dA = P \qquad (4)$$

$$\mathrm{P} \cdot \frac{D}{2} = \int_{(A)} F \cdot r \cdot dA \qquad (5)$$

Knowing the parametric equations of the spherical surface:

$$\Psi = x^2 + y^2 + z^2 - R^2 = 0 \qquad \begin{cases} x = R\ sin\theta\ cos\varphi \\ y = R\ sin\theta\ cos\varphi \\ \quad z = R\ cos\theta \end{cases} \qquad (6)$$

$$\rightarrow \overline{N} = x_1 grad\Psi = 2x_1\ (x\bar{i} + y\bar{j} + z\bar{k}) \qquad (7)$$

$$\overline{F} = x_2\overline{r_\theta} = R(\bar{i}\ cos\theta\ cos\varphi + \bar{j} cos\theta\ sin\varphi - \bar{k} sin\theta) \qquad (8)$$

$$dA = R^2 sin\theta d\theta d\varphi \qquad (9)$$

$\overline{F_y} = \overline{F}$ and equation (4) becomes:

$$\int_{(a)} N_y dA = P \ \text{sau} \int_{(A)} 2x_1 y dA = P; \qquad (10)$$

$$2x_1 \int_{(A)} R \sin\theta\ sin\varphi \cdot R^2 sin\theta d\theta d\varphi = P \qquad (11)$$

$$2x_1 R^3 \int_{(A)} sin^2\theta sin\varphi d\theta d\varphi = P \qquad (12)$$

$$\int_{(A)} (1 - cos2\theta) sin\varphi d\theta d\varphi = \frac{P}{x_1 R^3} \qquad (13)$$

For this case, we have:

$$\int_{\theta_1'}^{\theta_2'} d\theta \int_{\varphi_1'}^{\varphi_2'} sin\varphi d\varphi - \int_{\theta_1''}^{\theta_2''} d\theta \int_{\varphi_1''}^{\varphi_2''} sin\varphi d\varphi - \int_{\theta_1'}^{\theta_2'} cos2\theta d\theta \int_{\varphi_1'}^{\varphi_2'} sin\varphi d\varphi + \int_{\theta_1''}^{\theta_2''} cos2\theta d\theta \int_{\varphi_1''}^{\varphi_2''} sin\varphi d\varphi = \frac{P}{x_1 R^3} \qquad (14)$$

From Fig.2 it follows:

$$\theta_1' = \theta';\ \theta_1^{"} = \theta^{"};\ \theta_2' = \pi - \theta';\ \theta_2^{"} = \pi - \theta_2^{"};\ \varphi_1' = \pi - \varphi^2;\ \varphi_1^{"} = \pi + \varphi^{"};$$
$$\varphi_2' = 2 - \varphi';\ \varphi_2^{"} = 2\pi - \varphi^{"};$$

In which case the equation (14) becomes:

$$-\left[(\pi - 2\theta')2cos\varphi' - (\pi - 2\theta')2cos\varphi^{"}\right] - \frac{1}{2}\left(2sin2\theta' \cdot 2cos\varphi' - 2sin^2\theta^{"} \cdot 2cos\varphi^{"}\right) = \frac{P}{x_1R^3} \quad (15)$$

or

$$-\left[(\pi - 2\theta')cos\varphi' - \left(\pi - 2\theta^{"}\right)cos\varphi^{"}\right] - \frac{1}{2}\left(sin2\theta' \cdot cos\varphi' - sin\ \ 2\theta^{"} \cdot cos\varphi^{"}\right) = \frac{P}{x_1R^3} \quad (16)$$

Using Fig.2 will result:

$$sin\theta' = \frac{\sqrt{R^2-L^2}}{R}; \qquad sin\theta^{"} = \frac{\sqrt{R^2-\frac{d_0^2}{4}}}{R};$$

$$\varphi' = \theta' = arccos\frac{L}{R} \cong \frac{\pi}{2} - \frac{L}{R};$$

$$\varphi^{"} = \theta^{"} = arccos\frac{d_0}{2R} \cong \frac{\pi}{2} - \frac{d_0}{2R};$$

and equation (16) becomes:

$$4\left(\frac{L^2}{R^2} - \frac{d_0^2}{4R^2}\right) + \left(\frac{L^2}{R^3}\sqrt{R^2 - L^2} - \frac{d_0^2}{4R^2}\sqrt{R^2 - \frac{d_0^2}{4}}\right) = -\frac{P}{x_1R^3} \quad (17)$$

Knowing that:

$$r = \sqrt{x^2 + y^2} = Rsin\theta \ ,$$

Equation (5) becomes:

$$x_2R^2\int_{(A)} sin^2\theta d\theta d\varphi = P\frac{D}{2}$$

which after transformation becomes:

$$\int_{\theta_1'}^{\theta_2'} d\theta \int_{\varphi_1'}^{\varphi_2'} d\varphi - \int_{\theta_1^{"}}^{\theta_2^{"}} d\theta \int_{\varphi_1^{"}}^{\varphi_2^{"}} d\varphi - \left(\int_{\theta_1'}^{\theta_2'} cos2\theta d\theta \int_{\varphi_1'}^{\varphi_2'} d\varphi - \int_{\theta_1^{"}}^{\theta_2^{"}} cos2\theta d\theta \int_{\varphi_1^{"}}^{\varphi_2^{"}} d\varphi\right) = \frac{P \cdot D}{x_2R^2} \quad (17)$$

Taking into account the integration limits, equation (17) becomes:

$$4\left(\frac{L^2}{R^2} - \frac{d_0^2}{4R^2}\right) + \left(\frac{L^2}{R^3}\sqrt{R^2 - L^2} - \frac{d_0^2}{4R^2}\sqrt{R^2 - \frac{d_0^2}{4}}\right) = -\frac{P \cdot D}{x_1 4} \quad (18)$$

To avoid locking of the spherical support in place, it is necessary that $F > \mu N$.

But:

$$F = |x_2||\overline{r_\theta}| = R|x_2|;$$

$N = |x_1||grad\Psi| = 2R|x_1|$

and so:

$$|x_2| > 2\mu|x_1| \qquad (19)$$

Using equations (16) and (18), inequality (19) will become:

$$R < \frac{D}{2\mu} \qquad (20)$$

Expression (20) specifies the maximum limit of the nominal radius of the spherical surface of the support.
In order to determine the minimum radius, it is considered that, due to the execution, the contact between the spherical support and its seat is made as is shown Fig.3.
Obviously, in this case, the contact pressure between the spherical support and its seat is minimal. Given the general assumptions made for the determination of stresses and deformations in the case of pressure contact pressures, an indicative calculation is made, assimilating the case in Fig. 3 with the contact forces between a solid body and a plane.
Based on Fig.3, the load per unit of length is:

$$q \approx \frac{p_0}{\pi d_0 cos\xi}$$

where:

$$cos\xi = \frac{\sqrt{R_1 - \frac{d_0^2}{4}}}{R} \approx 1 - \frac{d_0^2}{8R_1^2}$$

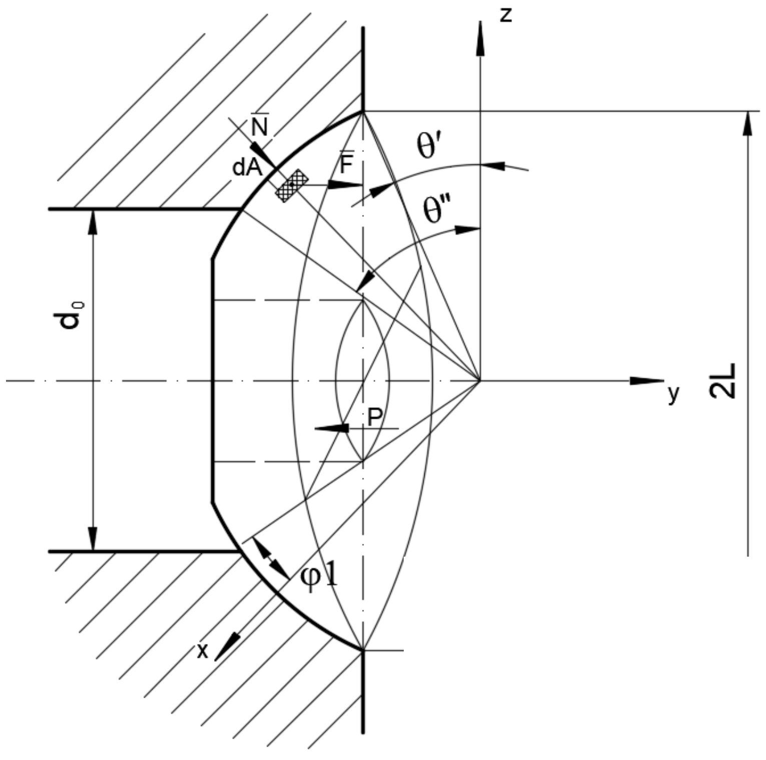

Fig.3 The contact between the spherical support and its seat.

Providing condition that the pressure developed in the contact area is less or equal to the allowable pressure p_a we have:

$$p_a \geq 0{,}418\sqrt{qE\frac{1}{R}} \quad (21)$$

Note with $m = \frac{0{,}418^2 E p_0}{\pi d_0 p_a^2}$ it results:

$$R_1 \geq \frac{m+\sqrt{m^2+\frac{d_0^2}{4}}}{2} \quad (22)$$

The relationship (22) allows us to verify the minimum radius R_1 of the support spherical surface. It should be noted that for the admissible pressure p_a can not be taken data from the literature. Its values should be determined for each group of steels used in the specific application case.

4 Conclusion

On the basis of the specified study, we can notice the high importance of how to attach the blank to the broaching machine, both to avoid breaking the broaching tool and to achieve a dimensional and geometric accuracy of the workpiece surface. It has been demonstrated that when installing the parts on the broaching machine in order to process the inner surfaces, a device with a spherical surface as support must be used which will largely meet the conditions required by the technical documentation of the workpiece.

In conclusion, the choice of radius of the spherical contact surface between the support and its place, should be based on the relationship (20), and in order to obtain a lower contact pressure, the tolerance of the radius of the spherical support must be plus, and for its place in minus.

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