ROTARY BROACHING - TECHNOLOGY, APPLICATION AND CAPABILITY

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Abstract: The present paper presents a relatively new technology called rotary broaching for processing external and internal profile surfaces –. The technology can be implemented on lathes (turning centers, multi-task machines) and milling machines with CNC, using a special holder with a tool having the geometry of the processed profile surface installed on it. The tool holder has a specific geometry, providing an angular location of the tool axis relative to the machined surface of 1˚, offering the possibility of machining. One of the main advantages of this technology is that it allows the processing of profile surfaces in blind holes and closed external surfaces, for example, on the steps of rotating parts. It requires preliminary preparation of the treated surface, where for internal profile surfaces, it is necessary to process a starting hole with a certain diameter and length, depending on the size of the profile surface. Furthermore, processing by this technology implies obtaining high productivity, as it works with feed for a speed of 0.01 ÷ 0.12 mm/rev and spindle speed (workpiece) 1000 ÷ 3000 min^{-1} depending on the processed material. According to the manufacturers of tools used for a rotary broach, various types of material with tensile strength Rm up to 1400 N / mm^2 can be processed, such as stainless steel, cast iron, aluminum and copper alloys, titanium, brass, and others.

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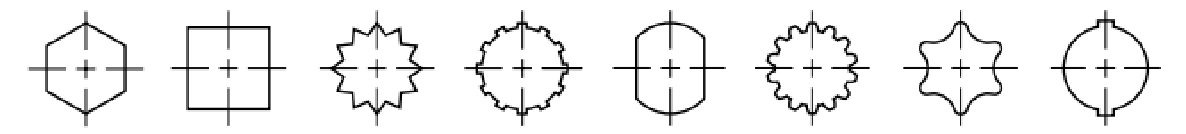
Introduction

Broaching (push broaching) and filamentary EDM are the main methods used for processing external and internal profile surfaces. However, in both cases the treated surface needs to be exposed.

Broaching is used for finishing external (flat, rotary, profile) and internal (round, multi-walled, profile, slotted, keyway) surfaces (Andonov, 2001). In the case of internal broaching, a hole is pre-machined with the required accuracy, then the final machining is performed with a tool passed through the hole by pulling or pushing. In the first case, the tool is called a broach, and the process is called broaching. In the second case, the tool is called push broach, and the process is push broaching. Broaching (push broaching) is performed on broaching (push broaching) machines. A broach is a multi-toothed tool with a specific purpose depending on the shape and size of the surface (Andonov, 2001). This method of processing is effective in mass production.

Rotary broaching is a relatively new method of machining external and internal profile surfaces. The main advantage of the method is that closed profile surfaces can also be processed (fig. 1). Machining is performed on lathes, milling, and drilling machines; therefore, it is not necessary to use a special machine. In this method, the tool's geometry corresponds to the geometry of the machined surface.

Figure 1: Machined profile surfaces



Source: (Slater Tools Catalog Rotary Broaching, 2022)

Nature of rotational broaching

A special holder and tool are required to implement the rotational stretching process. The holder performs two main functions: it provides an angular orientation between the axis of the tool and the axis of the machined surface of 1˚ and free rotation of the tool in the holder. When the tool comes into contact with the workpiece, it begins rotating freely in the holder due to friction between the tool's working surface and the workpiece surface. This way, a "wobble" effect is produced (fig. 2) as the tool moves forward with a swinging motion. In addition, each cutting edge removes the material by "wobbling" around the guide point. In this way, only one of the cutting edges is in contact with the workpiece at a time, which significantly reduces the cutting force required for machining (Rotary broaching, 2021). The tool's cutting edge has the same formation as on the machined surface (fig. 3) as in punch forming.

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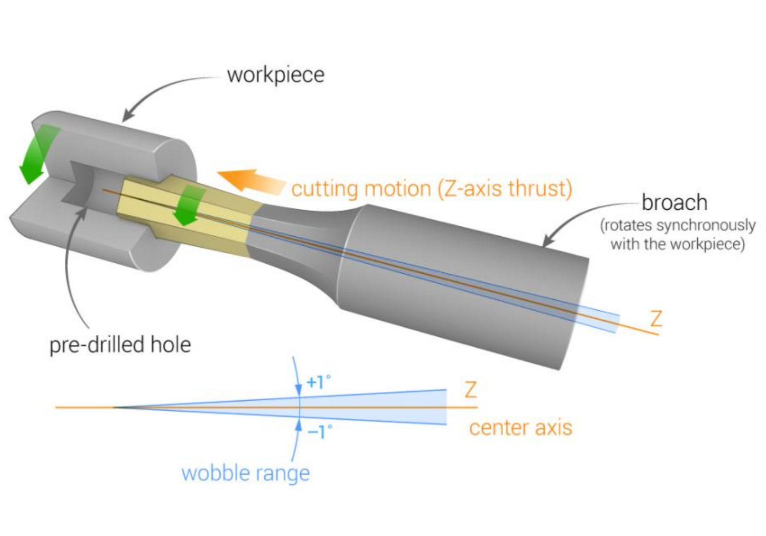
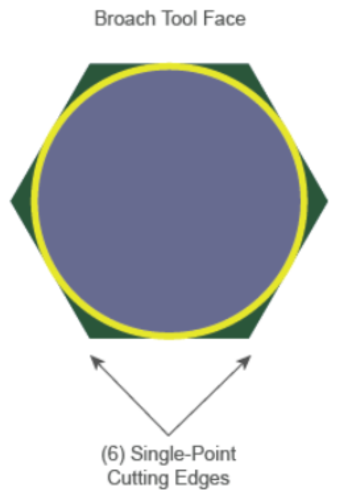
Figure 2: Rotary broaching



Source: (Linear Broaching & Rotary Broaching: Process Guide, 2018)

Figure 3: Tool cutting edge

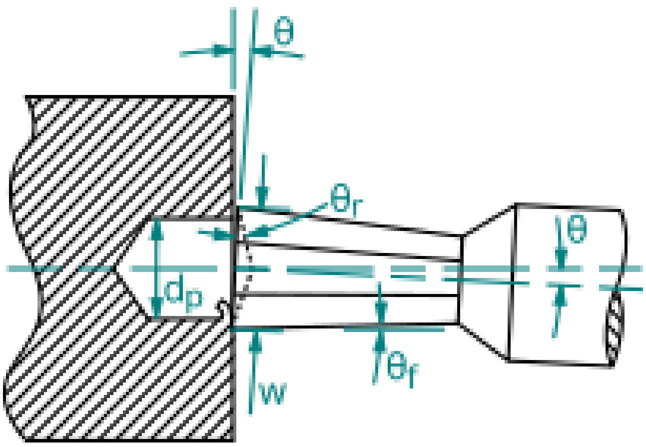


Source: (Rotary broaching guide, 2022)

Tool geometry

Fig. 4 shows the geometry of the tool. The figure illustrates that the tool has a rake angle θ_r, which determines the manner of formation and removal of chips on the front surface like other processing methods by chip removal. The Front relief θ_f ($\theta_f = 1.4° \div 1.5°$), the value of the accuracy of the treated surface depends on its value. At a higher value for θ_f, a spiral shape of the treated surface in the longitudinal direction is obtained (Offset Rotating Broach Information, 2022) (Fig. 5).

Figure 4: Geometry of a rotary broaching tool

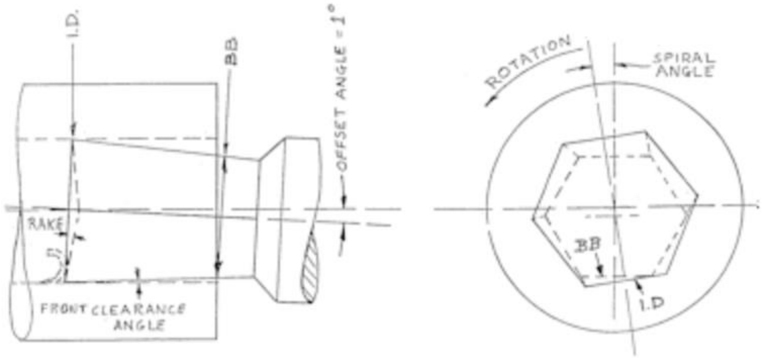


Source: (Wikipedia, 2022)

The tool is driven from the leading edge of the hole (ID) relative to the nearest surface of the side surface of the tool (BB). The space between the tool and the hole formed by the front relief allows the tool to rotate slightly, thus rotating the cross-section of the workpiece, as shown in fig. 5 (Offset Rotating Broach Information, 2022).

The materials from which the rotary drawing tools are made are high-speed steels M2, hard alloys M42, PM T15, or PM M4 (Poligon Solutions, 2022). When processing stainless steel, it is recommended that the tools should be made of T15 steel (Somma tool Company, Broaching tool & Holder, 2022), as it has high wear resistance, impact strength, and bending strength. When processing with this technology, the tool manufacturer Somma Tool (Somma tool Company, Broaching tool & Holder, 2022) recommends the use of oil-based coolant, as this significantly increases the life of the tool.

Figure 5: Error of the machined surface depending on the front relief

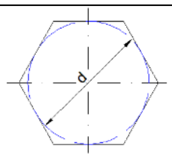
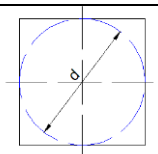
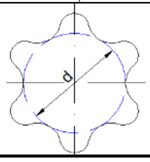


Source: (Offset Rotating Broach Information, 2022)

Preparation and machining of a profile surface

When processing external and internal profile surfaces, it is necessary to prepare for their treatment in advance. When machining an inner profile surface, it is necessary to process an opening, the diameter of which is determined by the diameter d of the inscribed circle of the profile surface. Table 1 shows the values for minimum and maximum diameter of the starting hole.

Table 1: Pre-drill hole diameter when processing an internal profile surface

Form		**Pre-drill diameter**	
		d_{min}	**d_{max}**
Hexagon		$d_{min}=d$	$d_{max}=d_{min}+(3\%\div3.5\%)d=1.035*d$
Square		$d_{min}=d$	$d_{max}= d_{min}+(11\%\div11.5\%)d=1.115*d$
Torx		$d_{min}=d$	$d_{max}= d_{min} +(5\%\div5.5\%)d=1.055d$

Source: Author

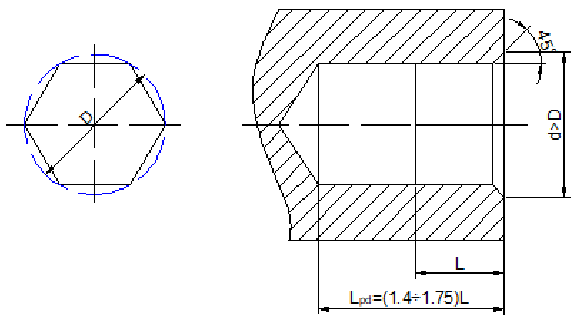
A 45˚ chamfer with a size larger than the diameter of the described circle D of the machined profile is machined. It is recommended that the depth of the hole L_{pd} be 1.4 ÷ 1.75 times greater than the length L of the treated profile surface (fig. 6) (Slater Tools Catalog Rotary Broaching, 2022), (Rotary broaching, 2021) to provide space for the chips. Fig. 7 presents the result of machining an inner hexagon, which shows that the chips are not separated from the machined surface at the end of the working stroke along the Z axis,. In these cases, it is recommended to process the groove in the hole so that it is possible to separate the chips, but this is not always possible as it depends on the diameter of the starting hole.

When machining an internal hexagon, the area A_Z taken from each cutting edge of the tool for one revolution of the spindle is determined by the equation (1)

$$A_Z = \frac{A_{hex} - A_{cir}}{6} \tag{1}$$

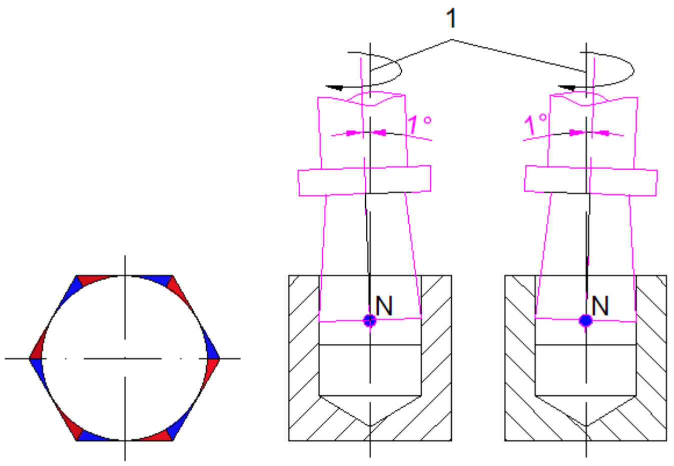
where A_{hex} is the area of the hexagon and A_{cir} is the area of the circle and are determined by equation (2)

$$A_{hex} = \frac{3\sqrt{3}\, s^2}{2} \qquad A_{cir} = \pi r^2 \tag{2}$$

Figure 6: Dimensions of the pre-drill hole	Figure 7: Processing result
	
Source: Author	Source: Author

While processing, the additive is removed from each cutting edge by alternating sections where the additive has zero value and reaches the maximum (marked in blue in fig. 8) and vice versa - sections from maximum to minimum (marked in red in fig. 8).

Figure 8: Removed allowance



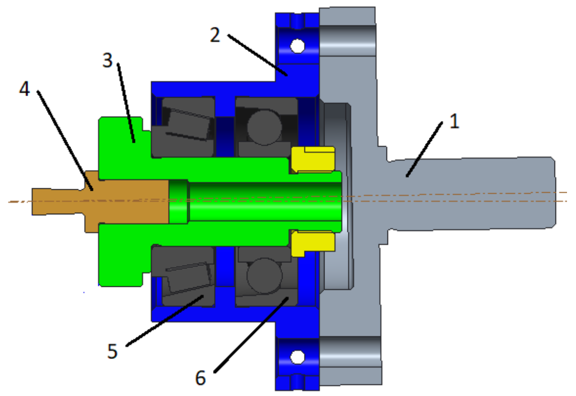
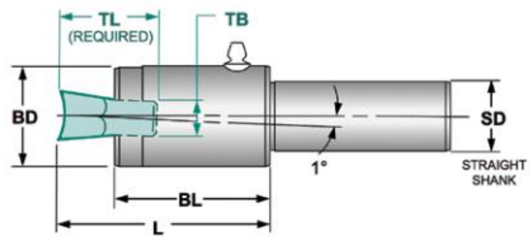
Source: Author

Machinable materials and cutting conditions

This technology can process various types of materials such as stainless steel, cast iron, aluminum and copper alloys, titanium, brass, and others (Brigetti, 2022). It allows wider application of this technology, like in manufacturing internal hexagons of surgical screws for implants (Dimova, 2021). Kamberov (2021) proposes a methodology for designing and manufacturing personalized spinal implants. Brigetti (2022) indicates a cutting mode, where the feed is set in mm/rev depending on the characteristics of the material. Depending on the size of the processed profile, the feed is of the order of 0.01 ÷ 0.12 mm/rev. The speed with which the spindle or the part rotates is 1000 ÷ 3000 min^{-1}. When starting the rotary extension operation, it is necessary to use lower speeds until the contact between the tool and the part is obtained, after which they are increased to those prescribed by the tool manufacturer. This has a beneficial effect on the life of the instrument (Rotary broaching guide, 2022).

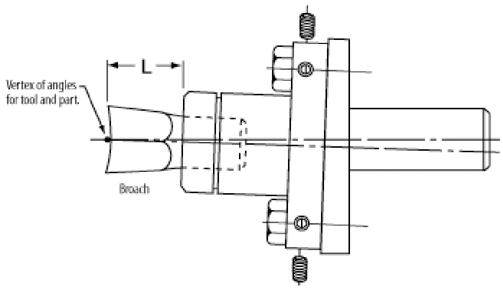
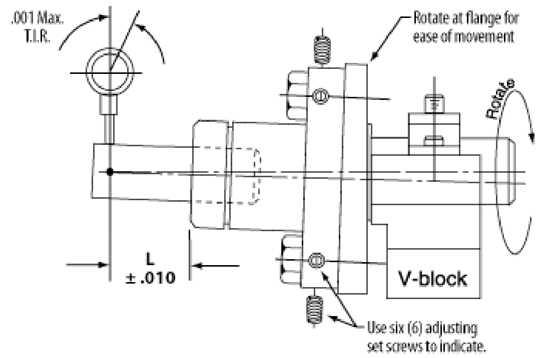
Toolholders. Adjustment

The purpose of the toolholder is to ensure the angular position of the tool axis relative to the machined profile surface of 1˚ (fig. 2). As can be seen in fig. 9, the forehead of the body of holder 1 is located at an angle to its axis. Tool 4 is installed in the central hole of spindle 3. In body 2 there are two bearings - conical roller 5 and radial 6. At the initial moment, the tool rotates with the spindle speed.

Figure 9: Adjustable toolholder	Figure 10: Non-adjustable toolholder
	
Source: Author	Source: (Slater Tools Catalog Rotary Broaching, 2022)

As soon as contact occurs between the tool's cutting edge and the workpiece, the rotational movement of the tool is interrupted as it begins to roll in the spindle 3 mounted in the body 14. When machining, the point around which the tool wobble (point N in fig. 8) must coincide with the intersection of the axis of the machine spindle (pos. 1 in fig. 8) and the tool face. It is realized using two types of tool holders - adjustable (fig. 9) and non-adjustable (fig. 10). The non-adjustable tool holders ensure this matching requirement as the spindle in which the tool is mounted is pre-set at an angle to the toolholder body. This construction is most often used in lathes and machines of the Swiss type, where the length of the tool used TL (fig. 10) is constant.)

In the case of adjustable tool holders, the position of item N is achieved by adjusting. For this purpose, the length L is measured after installing the tool in the tool holder (fig. 11 a). Then a mandrel is installed in the spindle of the holder, on which the measured length L is marked, and with the help of an indicator clock (fig. 11 b), the adjustment is performed using six screws 6, which move the body 14 relative to the body 1. (fig. 9). The permissible deviation within one revolution is 0.02 ÷ 0.03 (Slater Tools Catalog Rotary Broaching, 2022). The adjustment can be done using a tool or directly on the machine. These tool holders can be used for different tool lengths but with mandatory adjustment. A similar centering approach has been proposed by (Kaldashev, 2019) with a special device to compensate for the error of establishing the part.

Figure 11:	
	
a)	b)
Source: (Slater Tools Catalog Rotary Broaching, 2022)	

A study was carried out for machining of the hexagonal and square holes in Aluminum 6065 T6 and C45 steel, where the tools used were made of HSS-Co material on a grinding machine with the required geometry. Fig. 12 shows the adjustable holder for implementing the rotary stretching technology installed in the spindle of a milling machine Rais M400 with Heidenhain iTNC 530. The working modes used are: when processing Aluminum 6065 T6 – S1500 min^{-1} and feed 0.05 mm/rev.; for steel C45 - S1000 min^{-1} and feed 0.01 mm/rev. Fig. 7 shows the processing result.

Figure 12: Adjustable toolholder installed in the spindle of the machine

Source: Author

Conclusion

Rotary broaching can be applied for machining impenetrable profiles on external and internal surfaces, i.e., in the blind holes. The possible applications of rotational broaching are not limited to special machines, i.e., it can be used in lathes and milling machines with CNC. The process is realised using a special tool holder with an installed tool having a cross-section profile of the treated surface. Relatively high productivity is obtained by taking into account the cutting mode (feed from 0.01 ÷ 0.12 mm / rev) and spindle / workpiece speeds 1000 ÷ 3000 min^{-1}.

Acknowledgements

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