

# MACHINING ACCURATE HOLES WITH REQUIRED ROUGHNESS

PAVEL DOSTAL, MAREK SADILEK, RADEK HRUBY

Faculty of Mechanical Engineering, Department of machining, assembly and engineering metrology  
VSB-TU Ostrava, Czech Republic

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Email: [dostal.pa@email.cz](mailto:dostal.pa@email.cz)

The knowledge gained from the theoretical and practical tests in the production of precise openings has been utilized in a wide range of technologies from simple machine parts to complex schemes requiring accurate placement of individual parts. The topic here deals with the production of precise holes of required roughness according to the customer's requirements, it is a sealing of hydraulic cubes with a ball plug. The article examines the possibilities of existing technology, proposes the possibilities of using other tools or changes in the machining parameters, all using one machine tool. All theoretical knowledge has been verified by practical tests with the use of measuring instruments such as hardness meters. All output measurements were recorded in tables and graphs for more clear results and used in practice.

## KEYWORDS

Machining, tools, roughness, precise holes, machining parameters

## 1 INTRODUCTION

Nowadays, more and more emphasis is placed on the precision in the production of machine parts. Manufacture of precision parts affects other important aspects such as size, shape, or roughness. Roughness is the most important for determining the surface quality, it affects a number of properties such as wear, corrosion resistance, and notched toughness. Precision in production is different and depends on the type of product, chosen manufacturing technology or customer need. This article deals with the production of precision holes for the needs of hydraulic devices. Describes the current way with innovations.

## 2 MACHINING OF INTERNAL SURFACES

This technology can be divided into three basic types according to tool characteristics and cutting geometry. In terms of technology, the accuracy parameters and the roughness of the machined surfaces are important. Machining methods are divided into basic, abrasive and unconventional. The basic machining method is characterized by defined cutting edge geometry and the most important parameters are described in Table 1. [Kocman 2005]

	MACHINING METHOD	ACCURACY OF DIMENSIONS IT		SURFACE ROUGHNESS RA [ $\mu\text{M}$ ]	
		MEDIUM	RANGE	MEDIUM	RANGE
TURNING	ROUGHING FINISHING	12; 10	11 $\div$ 13 9 $\div$ 12	25 3.2	12.5 $\div$ 50 1.5 $\div$ 12.5
DRILLING SCREW/AUGER	WITHOUT LEADERSHIP	13	12 $\div$ 14	6.3	6.3 $\div$ 25
	WITH LEADERSHIP	12	10 $\div$ 13	3.2	3.2 $\div$ 25
	ROUGHING REAMING	9 8	9 $\div$ 11 7 $\div$ 9	3.2 0.8	1.6 $\div$ 3.2 0.8 $\div$ 3.2
RECESSING	ROUGHING FINISHING	12 9	11 $\div$ 14 7 $\div$ 10	3.2 1.6	1.6 $\div$ 12.5 1.6 $\div$ 6.3
DRILLING ROUGHING FINISHING	FINE FINISHING TOOL SK FINE FINISHING DIAMOND TOOL	12	11 $\div$ 14	25	12.5 $\div$ 50
		10	9 $\div$ 11	3.2	1.6 $\div$ 6.3
		6	5 $\div$ 8	0.8	0.4 $\div$ 0.6
		5	4 $\div$ 7	0.4	0.2 $\div$ 0.8
STRETCHING	ROUGHING FINISHING	8 7	7 $\div$ 8 5 $\div$ 7	1.6 0.4	0.8 $\div$ 3.2 0.1 $\div$ 0.8
		MILLING ROUGHING	FINISHING FINE FINISHING TOOL SK	12	12 $\div$ 13
10	9 $\div$ 11			6.3	3.2 $\div$ 12.5
9	7 $\div$ 10			1.6	0.8 $\div$ 1.6

Table 1. Accuracy of machined surfaces [Kocman 2005]

Abrasive machining methods are characterized by undefined edge geometry, which is used in the production of machine parts with high demands on the quality of machined surfaces [Cep 2013].

Parameters of precision of machined surfaces are given in Table 2. [Kocman 2005]

	MACHINING METHOD	ACCURACY OF DIMENSIONS IT		SURFACE ROUGHNESS RA[μM]	
		MEDIUM	RANGE	MEDIUM	RANGE
INTERNAL	GRINDING ROUGHING COMPLETION FINELY	9 7 5	9 ÷ 11 5 ÷ 7 3 ÷ 6	1.6 0.8 0.2	1.6 ÷ 3.2 0.4 ÷ 1.6 0.05 ÷ 0.4
HONING	ROUGHING FINISHING FINELY	7 6 4	6 ÷ 8 5 ÷ 7 3 ÷ 5	0.4 0.2 0.1	0.2 ÷ 0.8 0.1 ÷ 0.2 0.05 ÷ 0.1
LAPPING	ROUGHING FINELY	4 3	3 ÷ 5 1 ÷ 3	0.2 0.02	0.01 ÷ 0.4 0.012 ÷ 0.05

Table 2. Parameters of roughness of machined surfaces by abrasive method [Kocman 2005]

A qualitative parameter in production is the roughness of the surface, which is marked as the sum of the inequalities that occur during the machining of the material [Adamczak 2010]. In the case of a machined surface, the marks are created by the cutting tool. The size of these roughness depends on the physical and mechanical properties of the machined material, but also on the shape and geometry of the cutting edge [Mital 2018]. Other parameters that can be affected are feed rate, cutting speed, cutting environment, and rigidity of the machine assembly [Krolczyk 2013].

### 3 PRODUCT DESCRIPTION AND EXISTING TECHNOLOGIES

For the possibility of making a precise hole, a part of the hydraulic motor is used. It is a hydraulic cube used for mining machinery hydraulics. The article deals with part of the technology of production of this cube by producing a precision hole designed for a ball plug.

PRODUCT	TECHNOLOGY	NUMBER OF HOLES [PCS / YEAR]	MATERIAL	HOLE DIAMETER [MM]	DEPTH OF HOLE [MM]	SURFACE ROUGHNESS [MM]	TOLERANCE
Hydraulic cube	Production of accurate holes	500-800	1.4021 (X20Cr13) by EN 10088-3	4	5	Ra 1.6 – 6.3. (Rz 10 – 30)	+0.1

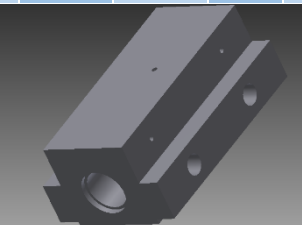

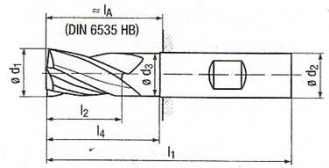


Table 3. Solved product design

In the first phase of making the required hole, it focused on existing production technology using machines and tools commonly used in production conditions. In the initial phase, the most logical way was to determine the holes first and to use the finishing method - reamer. However, this method did not meet the required surface roughness for the assembly of other hydraulic components. Therefore, another option was chosen. The hole was first drilled with a Ø3mm drill and then machined by a milling cutter with a roughing profile.

MACHINE	CNC machine MCFV – 1060	
CONTROL SYSTEM	Siemens	
CAM SYSTEM	Mastercam	
TOOL	Milling cutter φ3 – MULTI-Jet-Cut – Franken	

SIZE	$\varnothing d1h1$ [mm]	$l2$ [mm]	$l1$ [mm]	$\varnothing d3$ [mm]	$l4$ [mm]	$d2h6$ [mm]	$lA$ [mm]
		3	5	57	2.9	14	6

ENDMILL DIAMETER	SPINDLE REV.	CUTTING SPEED	AXIAL CUTTING DEPTH	RADIAL CUTTING DEPTH	FEED PER TOOTH	FEED
$d$ [mm]	$n$ [min <sup>-1</sup> ]	$v_c$ [m·min <sup>-1</sup> ]	$a_p$ [mm]	$a_e$ [mm]	$f_z$ [mm]	$f$ [mm·min <sup>-1</sup> ]
3	5300	50	-	-	0.012	254

Table 4. Precision hole machine [Tajmac-zps 2012, Multicut 2012]

#### 4 CHOOSING THE ORIGINAL CUTTING TOOL

In the initial phase of production, four holes were created using three tools (HSSCo - TITEX drill bit, Franken milling cutter) to determine the mean arithmetic deviation of the profile. The measurements were made using the MarSurS PS1 Portable Marsharm PS1 from the MAHR.

TOOL	HOLE NUMBER	RA VALUE [MM]
CUTTER FOR GROOVES	1.	0.85
	2.	1.04
	3.	0.79
	4.	0.93
DRILL HSSCO TITEX	1.	1.07
	2.	1.37
	3.	1.21
	4.	1.15
FRANKEN MILLING MACHINE	1.	6.23
	2.	6.27
	3.	6.14
	4.	6.18

Table 5. Roughness of holes

#### 5 VARIANTS OF USABLE TOOLS

There were several tools that met the necessary requirements and conditions for making holes. After the reamer rejection for too low


roughness values, other options were selected after the cutting conditions were determined on the machined material (X20Cr13).

Variant I. There were used existing tools with changing cutting conditions for:

- A) Carbide drill bit
- B) Drill bit HSSCo - TITEX
- C) Groove cutter

TOOL	SIZE					
	$\varnothing d1h6$ [mm]	$\varnothing d2h6$ [mm]	$l1$ [mm]	$l20$ [mm]		
Hard-core drill $\varnothing 4$ mm with cylindrical shank (sintered carbide, Van / 20)	4	6	50	20		
ENDMILL DIAMETER	SPINDLE REV.	CUTTING SPEED	AXIAL CUTTING DEPTH	RADIAL CUTTING DEPTH	FEED PER TOOTH	FEED
$d$ [mm]	$n$ [min <sup>-1</sup> ]	$v_c$ [m·min <sup>-1</sup> ]	$a_p$ [mm]	$a_e$ [mm]	$f_z$ [mm]	$f$ [mm·min <sup>-1</sup> ]
4	3200	40	-	-	0.0125	160

Table 6. Variant I.A. Hard-bore drill [Prostimzet 2012]

TOOL	SIZE		
Drill bit HSSCo $\varnothing 4,039$ mm - WALTER TITEX A1149TFL-NO21	$\varnothing d1h8$ [mm]	$l1$ [mm]	$l2$ [mm]
	4.039	55	22

ENDMILL DIAMETER	SPINDLE REV.	CUTTING SPEED	AXIAL CUTTING DEPTH	RADIAL CUTTING DEPTH	FEED PER TOOTH	FEED
d [mm]	n [min <sup>-1</sup> ]	v <sub>c</sub> [m·min <sup>-1</sup> ]	a <sub>p</sub> [mm]	a <sub>e</sub> [mm]	f <sub>t</sub> [mm]	f [mm·min <sup>-1</sup> ]
4	3200	40	-	-	0.025	160

Table 7. Variant I.B. Drill HSSCo [Titex 2009]

TOOL		Slot milling cutter with cylindrical shank				
SIZE		∅D1 [mm]	L1 [mm]	∅D2 [mm]	L2 [mm]	
		5	16	5	50	
ENDMILL DIAMETER	SPINDLE REV.	CUTTING SPEED	AXIAL CUTTING DEPTH	RADIAL CUTTING DEPTH	FEED PER TOOTH	FEED
d [mm]	n [min <sup>-1</sup> ]	v <sub>c</sub> [m·min <sup>-1</sup> ]	a <sub>p</sub> [mm]	a <sub>e</sub> [mm]	f <sub>t</sub> [mm]	f [mm·min <sup>-1</sup> ]
5	1200	15	-	-	0.025	60

Table 8. Variant I.C. Slot milling cutter [Prostimzet 2004]

### VARIANT II.

There was used an alternative tool: 4mm diameter countersink, HSS 221605. The countershaft design is four-pronged with straight teeth with a cylindrical shank and guide pin.

TOOL		Countersink φ 4 mm HSS 221605					
SIZE		∅D [mm]	∅d <sub>1</sub> [mm]	∅d <sub>2</sub> [mm]	L [mm]	l <sub>1</sub> [mm]	l <sub>2</sub> [mm]
		4	2.2	4	56	10	3
ENDMILL DIAMETER	SPINDLE REV.	CUTTING SPEED	AXIAL CUTTING DEPTH	RADIAL CUTTING DEPTH	FEED PER TOOTH	FEED	
d [mm]	n [min <sup>-1</sup> ]	v <sub>c</sub> [m·min <sup>-1</sup> ]	a <sub>p</sub> [mm]	a <sub>e</sub> [mm]	f <sub>t</sub> [mm]	f [mm·min <sup>-1</sup> ]	
4	600	7.5	-	-	0.03	100	

Table 9. Option II. Countersink [Mav 2012]

### 6 MEASURING THE ROUGHNESS OF THE MACHINED SURFACE

The following table shows the results of the mean arithmetic deflection of the profile Ra and the largest height of the profile Rz. With a constant cutting rate v<sub>c</sub>, the feed rate f<sub>t</sub> being different for each opening, a five-count measurement was performed on each of the openings, and the arithmetic mean value was written to the table.

TOOL NAME	CUTTING SPEED v <sub>c</sub> [M·MIN <sup>-1</sup> ]	FEED RATE FZ [MM]	VALUE RA [μM]	DIRECTION: DEVIATION S	VALUE RZ [μM]	DIRECTION: DEVIATION S
HSSCO TITEX DRILL BIT	40	0.025	1.38	0.01	8.53	0.18
		0.034	1.85	0.01	10.85	0.2
		0.044	1.97	0.19	11.57	0.64
		0.05	1.9	0.00	10.74	0.21
CARBIDE DRILL BIT	40	0.013	1.04	0.01	7.14	0.24
		0.017	0.82	0.01	6.08	0.29
		0.022	0.86	0.01	7.32	0.24
		0.025	1.07	0.08	9.81	0.94
GROOVE CUTTER	15	0.025	1.8	0.02	12.29	0.66
		0.033	3.01	0.04	18.21	0.42
		0.042	2.11	0.02	14.45	0.27

HSS COUNTERSINK INK	7.5	0.05	2.84	0.09	14.57	0.94
		0.025	2.97	0.02	16.29	1.08
		0.033	2.93	0.15	12.89	0.61
		0.042	1.52	0.02	13.68	0.38
		0.05	1.79	0.00	14.57	0.13

Table 10. Measured roughness depending on machining parameters

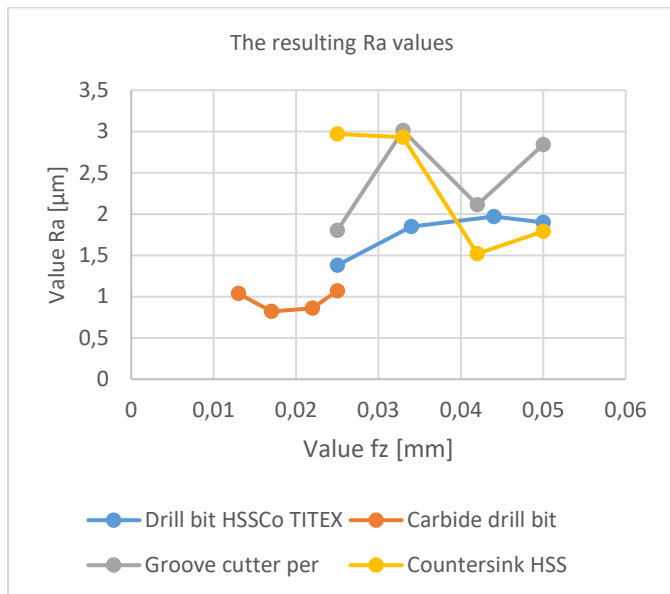


Figure 1. The resulting Ra values

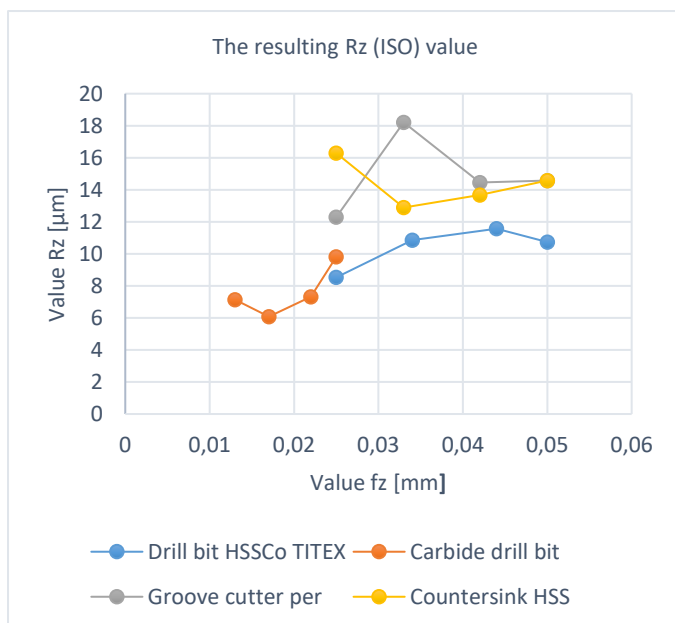


Figure 2. The resulting Rz (ISO) value

## CONCLUSION

The production of precision holes can be made using several types of tools or different technologies. The initial design of the tool was complicated because the diameter of the machined hole was  $\varnothing 4$  mm. It was necessary to achieve higher surface roughness than normal. In such small openings, it is usually a requirement to achieve surface roughness parameters at much lower values.

The KOENIG Expander manufacturer recommends a surface roughness range in the range of  $Rz 10 \div 30$  [µm] (when converted to Ra is csa 2.5 to 7.5 µm.) In view of the higher reliability of sealing of the hydraulic element, the surface roughness range  $Ra 3.2 \div 6.3$  [µm].

An alternative tool (HSS Countersink) also investigated the possibility of using tools with other cutting conditions. On a measured subject whose material (X20Cr13) corresponds to the hydraulic cube in production, sixteen holes were used to measure roughness using four tools (HSSCo - TITEX drill, carbide drill, HSS groove cutter and HSS countersink). The values of Ra, Rz at const. cutting speed  $v_c$ , but with rising  $f_z$  values.

For both drill variants (HSSCo - TITEX drill bit, carbide drill bit), the required roughness values were not obtained even when the feed rate was increased. These tools are not suitable for making the mentioned holes. The groove cutter has achieved more favourable results. The measured values varied to the lower limit of the required surface roughness. (as with the HSS countersink). Subsequent increases in tool feed values are not appropriate for damage to tool destruction. The resulting damage would be uneconomical and would reduce the efficiency of work. The solution could be a change in cutting speed, an increase in speed. Results show that current technology achieves better results than an alternative tool that has been the subject of research.

Surface roughness is a very complicated matter and the resulting solution is not always unambiguous. The resulting roughness affects a large number of factors. In many cases, there is no other option than performing several tests and adjusting settings before finding a production method that is reliable, efficient, and economically acceptable.

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#### **CONTACTS:**

Ing. Pavel Dostal  
doc. Ing. Marek Sadilek, Ph.D.  
Ing. Radek Hruby  
VSB-TU Ostrava  
Faculty of Mechanical Engineering  
Department of machining, assembly and engineering metrology  
[dostal.pa@email.cz](mailto:dostal.pa@email.cz); [www.vsb.cz](http://www.vsb.cz)  
[marek.sadilek@vsb.cz](mailto:marek.sadilek@vsb.cz); [www.vsb.cz](http://www.vsb.cz)  
[radek.hruby.st@vsb.cz](mailto:radek.hruby.st@vsb.cz); [www.vsb.cz](http://www.vsb.cz)