Selected Aspects of the Technology of Broaching of Internal Contoured Surfaces

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Abstract: *The technology of broaching is one of the machining methods used in mass production. It is a very rare technology. Its application is very economical and it achieves high quality parameters of machined surfaces. In our paper we describe two selected aspects: 1. the economical aspect - the use of statistical methods in the field of metal chip machining in the technology of broaching of internal contoured surfaces, 2. the technology aspect - the achieved surface roughness of internal contoured surfaces – the groove - in the conditions of mass production.*

Keywords: *broaching, statistical methods, profile shape, roughness*

1 INTRODUCTION

The technology of broaching [10] of internal contoured surfaces of workpieces stands for the production of internal profile which is being shaped on the components with through-hole [11]. In practice this through-hole *d* is typically machined by turning or drilling as a preceding manufacturing operation. The linear motion of the broaching tool through the machined workpiece leads to the required shape of the internal section. It is a negative contour of the toothing of the broaching tool on the shaped component [3]. In practice this shape is often in a form of a profile shape [2].

The authors in study [13] developed an automatic machine for measuring the irregular tooth contours of large ring parts in the broaching process, to ensure cutting tools are replaced when necessary. The authors in [14] measured the surface roughness at different vibration values at technology of broaching. In the paper [4], based on the productivity criterion, various machining technologies focused on the production of internal grooves were compared, and the technologies of broaching with HSS (broaching) tools and Carbide (broaching) tools were also compared.

It is suitable to use profile calibres and regulating gauges for the measurements of the section and it is suitable to use a roughness measuring device to determine the roughness of the surface after technology of broaching.

While indicating the effect of the process of broaching of the internal contoured surface on other parameters of the shaped component it is suitable to use the methods based on the statistical concept.

1.1 Statistical Methods

In the following part of this paper we will present a number of selected statistical methods which we will apply in the process of the evaluation of specific technology - broaching of internal contoured surfaces to achieve a diameter dimensional accuracy.

1.1.1 Six Sigma Method

It is a method use for the improvement of the processes and quality of a company formerly developed by Motorola. This approach to improvement was well-known in the 1980s. Six Sigma utilizes statistical methods and its goal is to minimalize process losses.

The aim of Sigma Six method presumes that per million pieces produced there may be a maximum of 3.4 deficiencies [1]. Six Sigma method tries to minimalize the process variability and seeks the factors which are responsible for it and which are subsequently to be handled. Lean [8] is exclusively interested in the process waste, Six Sigma focuses of their variability. Overall, Six Sigma offers two approaches - DMAIC (Define, Measure, Analyze, Improve, Control) and DFSS (Design For Six Sigma). DMAIC is used to improve the already-existing processes and DFSS is used in the designing of new processes [6]. When an organization decides to bring about improvements or changes into the organizational process, a good solution is to use the Six Sigma methodology. There are methodologies such as DMAIC and DFSS, which are used to bring about improvement in the existing processes and products, and even the development of new products and processes [12].

1.1.2 DMAIC Method

In order to successfully implement the changes or the management of the project aimed at the improvement this method is defined by 5 phases: Define, Measure, Analyse, Improve, Control [6]. DMAIC method can be used to solve various problems with the aim of the improvement of the processes. In Table 1. we present a method of use of DMAIC as a SIPOC (Supplier Input Process Output Customer) form [4] in which the task of the process of broaching of internal contoured surface is being solved.

Table 1. Overview of workpieces process in form of SIPOC

SIPOC *Six Sigma SIPOC-from* **DMAIC**				
Supplier	**I**nput	**P**rocess	**O**utput	**C**ustomer
Turning Welding Hardening	Component	Process of technology of broaching of internal contoured surface	Broached component section shape, geometric dimension	Turning

1.1.3 Monitoring of the machine and process capability

Describes an area of implementation of statistical control of the process and monitoring of the machine's capability. Under capability of the process we understand the evaluation of the process performance measured according to specifications. The ability is expressed by capability indicator.

Terms:

- Random factor - causes a constant variance which is typical for the process as a part of the total variance (e.g. fluctuations in the quality of raw materials).
- Systematic factor - causes an irregularly occurring variance (e.g. broken tool).
- Capability of the machine / process is a ratio of tolerance and accuracy of production.

To express the evidence of monitoring of the machine/process capability Table 2. includes the types of tests, methods and indicators of capability [9].

Table 2. Indicators of machine/process capability

Test type	Method	Capability indicators
Short-term test	Machine capability	C_m, C_{mk}
Short-term test	Preliminary process capability	P_p , P_{pk}
Long-term test	Continuous process capability	C_p , C_{pk}

Where P_p - describes the size of the process variance in comparison with the parameter tolerance, P_{pk} describes the size of the process variance and the position of the mean value to the tolerance limit of the parameter, C_m - machine capability index defining to which extent the variance of values acquired from measurement utilizes the prescribed tolerance, C_{mk} - machine capability index which, towards C_m index, also takes into account the position of the average value in the tolerance field, C_p - process capability index which represents the ratio of the process variability to customer specification, but does not take into account the deviation of the mean value from the reference value (Target), C_{pk} - process capability index which represents the C_p index for the side of specification to which the mean value is shifted (worse side).

Demonstration of machine and process capability is performed on critical and important features, or upon the requests of the customer.

There are 5 main factors: Machine, Human, Material, Method, Environment. These factors work randomly or systematically. In case of unsatisfactory test results these should be taken into account in the process analysis.

On the following example we will explain which approach can be used to express the effect the parameters have on other parameters in the process of broaching of internal contoured surface of the profile shape.

The description of the shaped component - it is a pump welded from two component parts, a tin circular pressing with the outer diameter $D1 = 280$ mm, an internal opening $D2 = 53$ mm, and a cartridge which is inserted into the internal opening of the pressing. The component parts are welded. The cartridge has a throughhole designated for the broaching of the internal contoured surface of a section shape as shown in Figure 1. The profile shape is a module 32.

As a test we can use a capability test with the assessed indicators of capability C_m and C_{mk}. A specific assessed parameter of the shaped component is the diameter $D = 48h10_{(-0,1)}$. A tested dose of the measured components is *50* pcs. A graphical demonstration of the capability assessment is shown in figures Fig. 2 – Fig. 4.

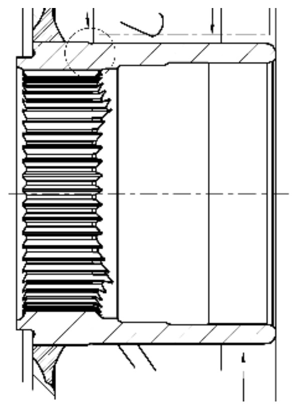

Fig. 1. A broach of the internal contoured surface

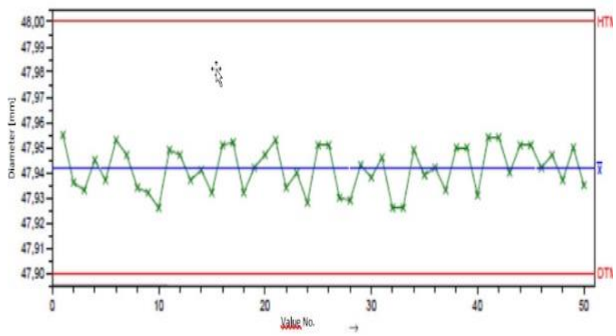

Fig. 2. A broach of the internal contoured surface

mm

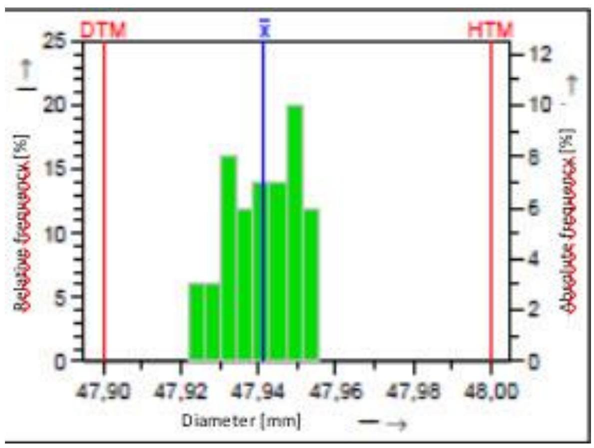

Fig. 3. A broach of the internal contoured surface

Table 2 shows he assessment of capability indicators C_m *and* C_{mk} and the ratio of these two indicators giving a value *1,67*. For the capability indicators Cm and Cmk applies that:

$$C_m/C_{mk} \geq 1{,}67 \qquad (1)$$

The result of the assessed capability indicators in this particular case shows that C_m has value *2,58* and C_{mk} has value *2,01* and the requirements were met.

1.2 The Achieved Roughness

In the following part of this paper we will present a achieved roughness the internal countered surfaces after the technology of broaching in the mass conditions.

The cutting conditions - the broaching speed was 3,5 m/min and the technological operation of broaching was performed in the environment of cutting oil.

1.2.1 Measurement of Roughness

Roughness measurements were performed on a MAHR meter (MarSurf XCR 20, V1.20-4).

Measurements of the roughness of the inner shaped surface after stretching were performed on a sample of *25* pieces.

In Figure 5 is a photograph from the measurement of a given internal countered surfaces. In Figure 6 is a graphical output from one measurement.

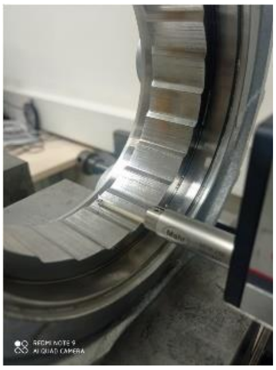

Fig. 5. A measurement of internal contoured surface

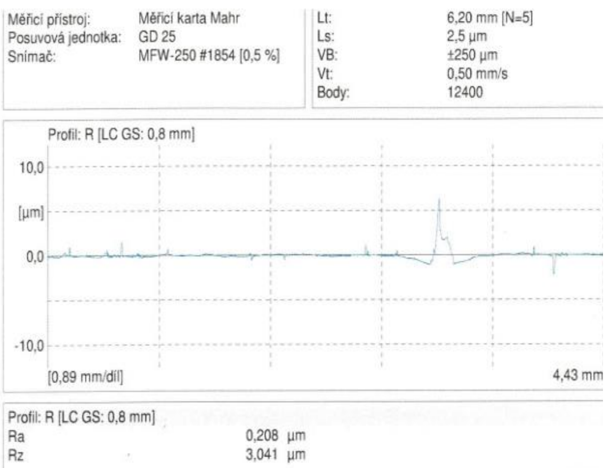

Fig. 6. A graphical output from one measurement

In Table 3 we shou the numerical average values of one measurement.

Table 3. The numerical average values of one measurement

Sam. Num.	Ra [µm]	Rz [µm]	Sam. Num.	Ra [µm]	Rz [µm]
1.	0,771	8,731	**14.**	0,241	2,883
2.	0,504	3,335	**15.**	0,107	1,673
3.	0,826	6,326	**16.**	0,846	5,576
4.	0,273	2,911	**17.**	0,131	1,870
5.	0,118	1,793	**18.**	0,294	2,397
6.	0,208	3,041	**19.**	0,213	1,671
7.	0,121	1,482	**20.**	0,224	2,078
8.	0,198	2,395	**21.**	0,113	1,065
9.	0,332	4,420	**22.**	1,493	10,825
10.	1,906	12,057	**23.**	0,164	2,893
11.	0,125	1,836	**24.**	1,228	7,585
12.	0,325	3,369	**25.**	1,883	10,837
13.	0,083	0,487			

Sam. Num. = Sample number
Ra - Roughness average R_a is the arithmetic mean of the absolute values of the roughness profile ordinates.
Rz - Mean roughness depth R_z is the arithmetic mean value of the single roughness depth R_{zi} of consecutive sampling lengths.

The achieved roughness of the machined surfaces of the internal grooves reached values for the mean arithmetic deviation *Ra* from *0,083* µm to 1,963 µm and for the value *Rz* from 0,487 µm to 12,057 µm.

Table 4. The calculated values of the ratio Rz/Ra

Sam. Num.	Rz/Ra [-]	Sam. Num.	Rz/Ra [-]
1.	11,324	**14.**	11,963
2.	6,617	**15.**	15,636
3.	7,659	**16.**	6,591
4.	10,663	**17.**	14,275
5.	15,195	**18.**	8,153
6.	14,620	**19.**	7,845
7.	12,248	**20.**	9,277
8.	12,096	**21.**	9,425
9.	13,313	**22.**	7,251
10.	6,326	**23.**	17,640
11.	14,696	**24.**	6,177
12.	10,303	**25.**	5,755
13.	5,867		

Sam. Num. = Sample number
Ra - Roughness average R_a is the arithmetic mean of the absolute values of the roughness profile ordinates.
Rz - Mean roughness depth R_z is the arithmetic mean value of the single roughness depth R_{zi} of consecutive sampling lengths.

The *Rz* / *Ra* ratio is in the range (5,755-17,640). E.g. this ratio is known for turning technology (4-5) [9].

The explanation can be assumed that only one cutting edge is involved in the formation of new surfaces during turning, but many cutting edges are involved in the formation of new surfaces during the technology of broaching.

CONCLUSION

The technology of broaching of internal contoured surfaces enables us to achieve high productivity level in the production process and it is applicable in series and mass-produced production. At present it is implemented mainly in the production of automotive components.

The first knowledge. A statistical control of the production process is already widely used in the production processes of the chip machining of metals. When addressing customer requirements, optimization of cost reduction and also when executing an actual research, the statistical methods represent a suitable tool in the solution of the goals. The result of the assessed capability indicators shows that the requirements were met and this method is suitable to statistical evaluation the technology of broaching of the internal contoured surfaces.

The second knowledge. High-quality surfaces can be achieved with the technology of broaching - which is a machining technology with a defined cutting edge. The surface roughness can be comparable to grinding technology - which is a machining technology with an undefined cutting edge, which usually achieves better roughness values of machined surfaces.

It is interesting to note that the range of the *Rz* / *Ra* ratio is larger compared to the turning technology and reaches higher values.

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