RESEARCH ABOUT ROUGHNESS FOR MATING MEMBERS OF A CYLINDRICAL FINE FIT AFTER TURNING WITH SMALL CUTTING FEEDS

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Abstract. In this paper the turning with small cutting feeds for a shaft and bore of a fine fit has been studied experimentally. It has been measured obtained roughness Ra, Rz, Rq and has been correlated with shape of chips and their plastic deformation. In range of very small cutting feeds, the plastic deformations have a much higher influence on roughness than for normal or great values of cutting feeds. In range of small cutting feeds, some disturbances ratio geometrical roughness appear because of phenomena from plastic deformation in cutting area. Also, appear elements of chips that make uneven into geometrical flutes generated by cutting tool and, thus, the measured value of roughness is non-uniform. Viewing under microscope of micro-asperities of surfaces allowed finding explanations about measured values of roughness parameters. It has been measured the roughness after turning with small cutting feeds for shaft and bore and these have been correlated with plastic deformation phenomena. They are presented microscopic images of surfaces and chips, calculated results and diagrams, tables with final results and diagrams of roughness depending on cutting feed values for small cutting feeds range. Conclusions will show the advantages and disadvantages of using small cutting feeds.

Keywords: roughness, clearance fit, turning

1. Introduction

Geometrical generation of surfaces indicates that course roughness is obtained for large cutting feeds and fine roughness for small cutting feeds [1, 2]. In fact, it is found that this rule is rarely observed because of phenomena that appear in cutting zone. Often, at small cutting feeds more course roughness that the theoretical, geometric, because depth of cut, appear radius of cutting tool changes in time, the forces are non-uniforms, chips are variable as shapes dimensions and so on [3, 4, 5]. In time, many studies about roughness depending on cutting feed have been achieved. Here are some more recent studies.

In [6] is studied the relative roughness depending on parameters of cutting process and system vibrations. In [7] the roughness and its correlation with processing errors are analyzed.

In [8] six parameters from turning and boring are taken into account and roughness is studied using Taguchi method for determining the optimal values of parameters that ensure a minimum roughness.

Small feeds between 0.08 mm/rot and 0.16 mm/rot are used. In [9] it is established the roughness of steel turning, on small cutting feeds, tacking into account the depth of cut and vibrations. Further, some results obtained in our research based on an experiment are presented.

2. Experimental Results

An assembly shaft-bore, the shaft being mounted by running fit into bore, has been designed. The shaft was also a piece bore type but processed on the external surface.

On both parts of fit, made by OL 37, has been executed 8 steps, each step being machined by cylindrical turning, with same cutting feed for each step (for shaft and bore) but different cutting feeds for the 8 different steps. The initial parts into tolerance field prescribed have been processed.

After processing, both parts were cut by longitudinal cutting for measuring the roughness for each step on bore and for visualization of the contact area between the matting surfaces that formed clearance fit.

It was used cutting feeds range.

Thus, in table 1 is presented the cutting feeds range used.

Table 1. The cutting feeds range used.

Number of step	1	2	3	4	5	6	7	8
Cutting feed mm/rot	0.053	0.059	0.075	0.083	0.088	0.096	0.46	0.5

Especially, it has in view the roughness on small cutting feeds.

For this reason it worked with 6 values of cutting feed less than 0,1 mm/rot ($f < 0.1$ mm/rot) and then, suddenly, it reached at high cutting feeds for an approaching evaluation of roughness for high values of cutting feeds.

The turning has been made on a centre lathe type SNB 400, with speed of 500 rot/min, therefore rate of cutting of 53.4 m/min and cutting depth of 0.3 mm. Carbide-tipped tools type P10 was used.

In table 2 are presented the geometry of cutting tools used for turning.

Table 2. The geometry of cutting tools used for turning.

Geometrical elements of cutting tool	Cutting tool for	
	Shaft	Bore
χ_r	90^0	90^0
χ_r'	18^0	12^0
ε	72^0	78^0
bevel	4 mm	3 mm
γ_n	8^0	7^0
α_n	10^0	18^0
r_ε	1.1 mm	1.4 mm
r_n	0.04 mm	0.03 mm
λ_T	4^0	10^0

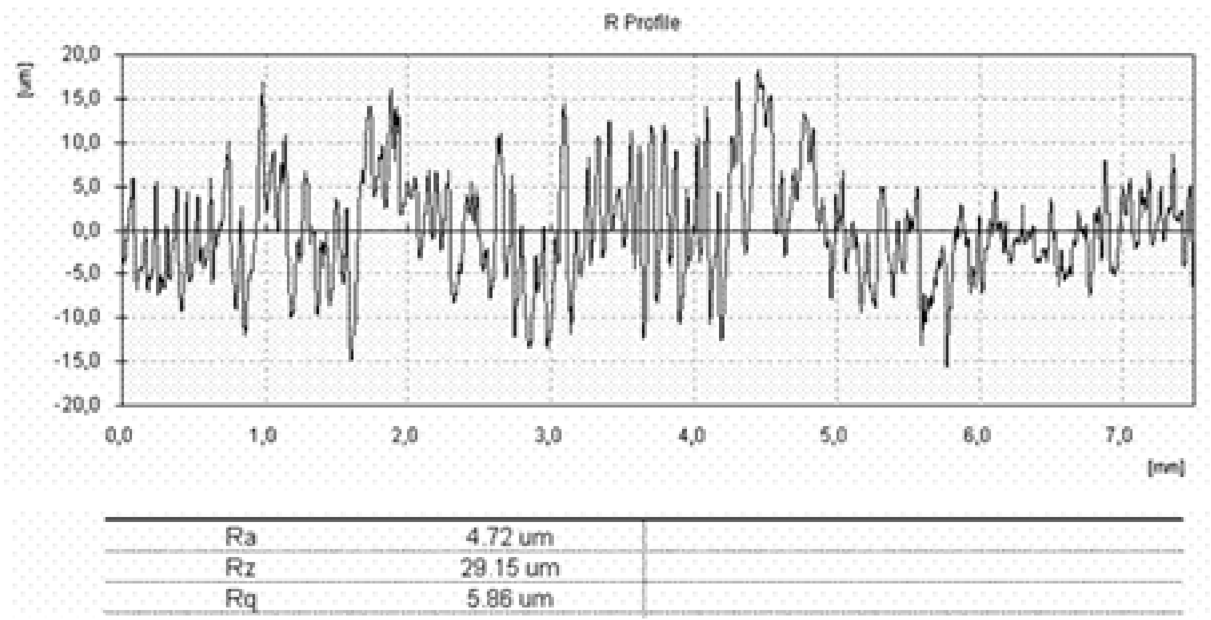

Figure 1. Surface roughness for shaft, at step 3

3. Resulted Roughness

It has been measured the roughness on each step for shaft and bore (bushing).

It was used an electronic roughness tester Mitutoyo, Japan, SJ-201P model.

In figure 1 the profile of micro-roughness for step 3 at shaft is presented (on abscissa are millimetres and on y-coordinate micrometers).

In diagram 2 the results for third step (step 3) after bushing turning with cutting feed f =0.075 mm/rot are shown.

The obtained values of final roughness parameters for each of 16 surfaces (8 for shaft and 8 or bore) are summarized in table 3.

From resulted roughness following is found:

- roughness surfaces is higher for shaft than resulted roughness for bushing; as a result radius r_ε is higher inside boring tool than the bull nose knife and this produced a cutting pressure of micro-asperities on piece;
- because of this, roughness for bore is more uniform than for shaft.

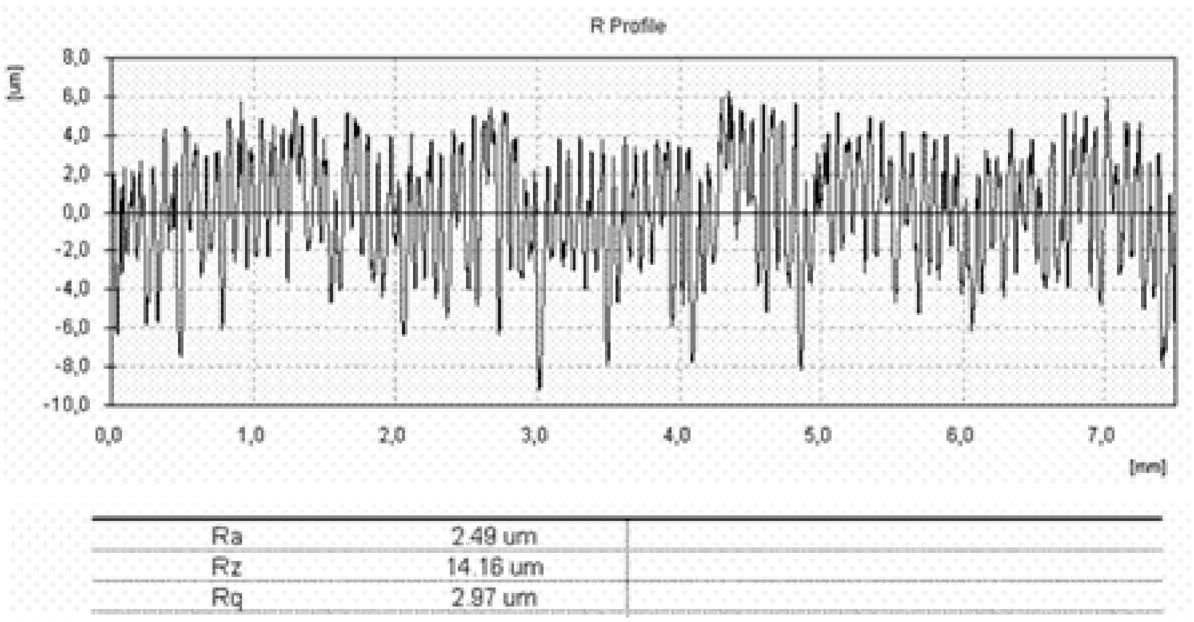

Figure 2. Surface roughness for bushing, at step 3

Table 3. Values of roughness parameters obtained after turning on different cutting feeds

Sample	Cutting feed	Shaft			Bore		
		Ra	Rz	Rq	Ra	Rz	Rq
1	0.053	4.85	28.53	6.01	2.19	14.56	2.73
2	0.059	4.58	27.94	5.65	2.21	13.28	2.71
3	0.075	4.72	29.15	5.86	2.49	14.16	2.97
4	0.083	4.84	32.29	6.10	2.68	15.49	3.20
5	0.088	5.43	35.86	6.76	2.48	13.80	2.98
6	0.096	6.18	36.16	7.75	2.88	17.80	3.53
7	0.46	5.83	29.11	7.15	3.60	20.76	4.41
8	0.50	5.26	28.01	6.35	3.78	20.11	4.49

4. Micro-Roughness and Clearance for Insertion

In figure 3, both pieces mounted one in the other on both sides (flutes confine the processed areas with different cutting feeds).

In figure 4, both pieces (shaft and bore) in mounted position are shown when entire positive allowance was positioned in one part.

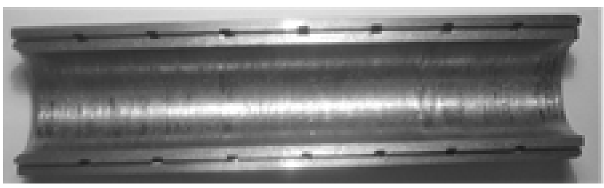
Figure 3. Shaft and bore mounted one in the other

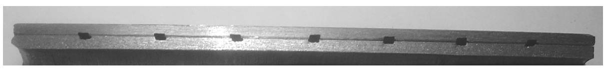
Figure 4. The positive allowance obtained at pieces assembling

Further on, the images of contact area for different steps on shaft and bore (bushing) have been pursued.

In figure 5 the assembly with clearance (added in one part) of step 1 for shaft and bore (cutting feed f=0.053 mm/rot) is shown.

The image obtained on microscope with enlargement (for measurements taken in the laboratory) by 162 times.

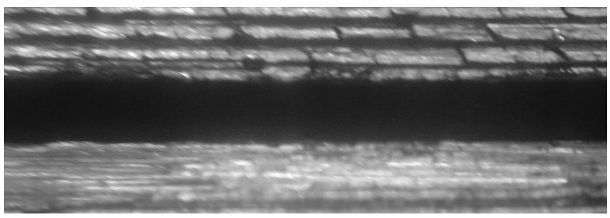
Figure 5. The assembly with clearance for step 1

It can be observed micro-unevenness and breakings in future contact areas. Some fractures occur because of cutting tool for both parts after processing.

In figure 6 the processed surface after turning with cutting feed f=0.083 mm/rot, step 4, is presented. It can be noticed that the surfaces which will form fits for respective steps have visible micro-irregularities in section and they into tolerance fields are enclosed but influencing the accuracy of clearance fit that they are formed.

Figure 6. The processed surface after turning with cutting feed f=0.083 mm/rot, step 4

5. Correlation between Accuracy and Roughness

Based on performed research, different obtained results have been compared for establishing some correlations between accuracy and roughness.

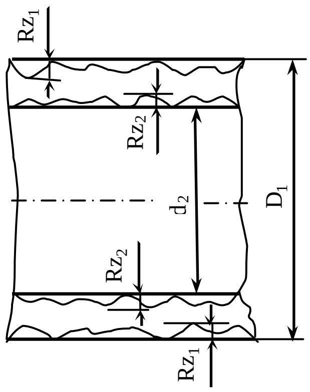

Figure 7. Scheme of surface roughness testing for shaft and bore

Considering the roughness at tolerances calculus on figure 7 basis the following relationship is established:

$$J = D_1 - 2Rz_1 - d_2 - 2Rz_2 \quad (1)$$

Shaft diameters steps and diameters at bushing terminals as resulted clearance after parts cutting (serried in one side) were measured.

In table 4 the values obtained are presented. From table 4, it can be noticed that the measured clearance is greater than the calculated backlash and this is explained by the measuring errors at half assembly (somewhat untrue) of parts.

Table 4. Calculated and measured values for clearance

Sample	Cutting feed – f [mm/rot]	Shaft diameter d_2 [mm]	Rz_2 [mm]	Bore diameter D_1 [mm]	Rz_1 [mm]	Calculated clearance $J_{calculated}$ [mm]	Measured clearance $J_{measured}$ [mm]
1	0.053	33.49	0.02853	34.00	0.01456	0.42382	0.51
2	0.059	33.51	0.02794	-	0.01328	-	0.53
3	0.075	33.51	0.02915	-	0.01416	-	0.58
4	0.083	33.57	0.03229	-	0.01549	-	0.59
5	0.088	33.59	0.03586	-	0.01380	-	0.57
6	0.096	33.58	0.03616	-	0.01780	-	0.60
7	0.46	33.65	0.02911	-	0.02076	-	0.58
8	0.50	33.68	0.02801	34.29	0.02011	0.51376	0.61

Then, were calculated the diameters of bushing steps which in table 5 are presented.

Further on, different correlations considering the measured roughness have been established.

Table 5. Calculated diameters for bushing

Sample	Cutting feed f [mm/rot]	Shaft diameter d [mm]	Bore diameter D [mm]	Clearance [mm]
1	0.053	33.49	34.00	0.51
2	0.059	33.51	34.04	0.53
3	0.075	33.51	34.09	0.58
4	0.083	33.57	34.15	0.59
5	0.088	33.59	34.16	0.57
6	0.096	33.58	34.17	0.60
7	0.46	33.65	34.23	0.58
8	0.50	33.68	34.29	0.61

Thus, the diameter of shaft varies with cutting feed by polynomial:

$$\begin{aligned} y = 33.47805 + (0.202265)x + \\ + (-9.703508)x^2 + \\ + (243.2589)x^3 + (-244.216)x^4 + \\ + (-1796.809)x^5 + (2786.123)x^6 \end{aligned} \quad (2)$$

Statistical data are:

<u>Source:</u>

sum squares = 3.142595E-02;
degrees of freedom = 6;
average squares = 5.237659E-03.

<u>Residue</u>:

sum squares = 3.730297E-03;
degrees of freedom = 1;
average squares = 3.730297E-03.

<u>Total</u>:

sum squares = 3.515625E-02;
degrees of freedom = 7;
coefficient of correlation = .9454596;
standard error estim.= 6.107616E-02.

x= .053
ydat= 33.49
ycalc= 33.49511
Er= 1.525195E-02 %;

x= .059
ydat= 33.51
ycalc= 33.50204
Er= .0237579 %;

x= .075
ydat= 33.51
ycalc= 33.52976
Er= 5.897925E-02 %;

x= .083
ydat= 33.56
ycalc= 33.54932
Er= 3.182703E-02 %;

x= .088
ydat= 33.59
ycalc= 33.56365
Er= 7.846306E-02 %;

x= .096
ydat= 33.57
ycalc= 33.59005
Er= 5.971473E-02 %;

x= .46
ydat= 33.65
ycalc= 33.64996
Er= 1.360368E-04 %;

x= .5
ydat= 33.68
ycalc= 33.68006
Er= 1.812208E-04 %.

It can be developed that errors are very small, so the application is correct.

In diagram 8 this curve is presented.

From the figure 8, it can be observed that the diameter increases which is normal, because the cutting forces increase and also, whippings of shaft accrue.

In addition, a polynomial for diameter of bushing as a function of cutting feed has been established:

$$\begin{aligned} y = 33.53446 + (12.33237)x + \\ + (-77.2955)x^2 + \\ + (218.548)x^3 + (-292.0554)x^4 + \\ + (147.342)x^5 + (15.59858)x^6 \end{aligned} \quad (3)$$

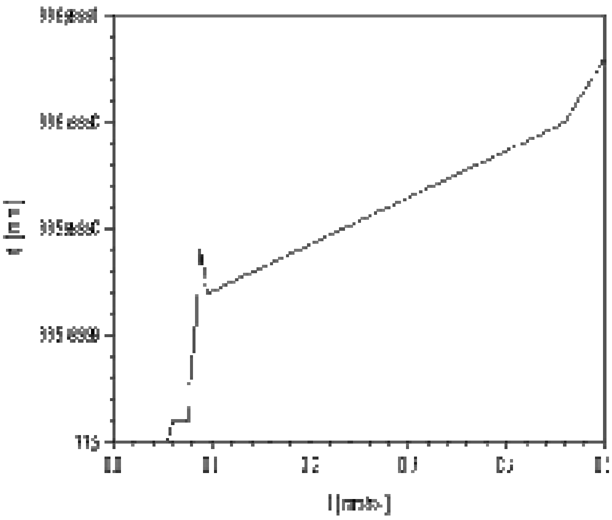

Figure 8. The variation of the shaft diameter with cutting feed

<u>Source:</u>

sum squares = 6.335002E-02;
degrees of freedom = 6;
average squares = 1.055834E-02.

<u>Residue</u>:

sum squares =1.265407E-04;
degrees of freedom = 1;
average squares =1.265407E-04.

<u>Total:</u>

sum squares =6.347656E-02;
degrees of freedom = 7;
coefficient of correlation =.9990028;
standard error estim. = 1.124903E-02.

x= .053
ydat= 34
ycalc= 34.00124
Er= 3.657621E-03 %;

x= .059
ydat= 34.04
ycalc= 34.03446
Er= 1.629427E-02 %;

x= .075
ydat= 34.09
ycalc= 34.10792
Er= .0525486 %;

x= .083
ydat= 34.15
ycalc= 34.13724
Er= 3.736504E-02 %;

x= .088	x= .096
ydat= 34.16	ydat= 34.17
ycalc= 34.15334	ycalc= 34.17577
Er= 1.950901E-02 %;	Er= 1.690211E-02 %;

x= .46	x= .5
ydat= 34.23	ydat= 34.29
ycalc= 34.23004	ycalc= 34.28997
Er= 1.225874E-04 %;	Er= 8.899848E-05 %.

Also, the accuracy that the polynomial determines the data is improved.

In figure 9 the graphical dependency of the diameter of bushing variation upon the cutting feed value obtained by statistical processing is presented.

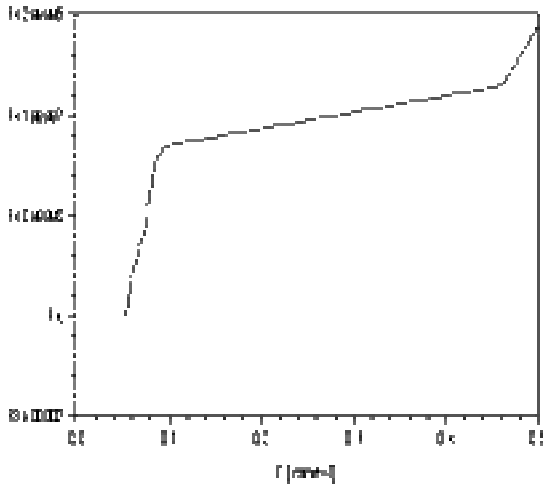

Figure 9. The variation of the bushing diameter with cutting feed

Therefore, the diameter increases with cutting feed enhancement because of large strains due to large forces.

6. Conclusions

✓ The roughness values depend on errors of shape of pieces because they are the results of the same technological process.

✓ With increasing of cutting feed, also the micro-irregularities increase but the errors of processed pieces set up.

✓ At more accurate quota the roughness is approaching on permissible deviation.

✓ At surfaces tolerances establishment must be take into account the roughness.

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