ANNALS OF FACULTY ENGINEERING HUNEDOARA
- INTERNATIONAL JOURNAL OF ENGINEERING
Tome IX (Year 2011). Fascicule 3. (ISSN 1584 - 2673)

[1.] Zdenko LIPA, [2.] Dagmar TOMANÍČKOVÁ

UTILISATION OF ABBOTT-FIRESTONE CURVES CHARACTERISTICS FOR THE DETERMINATION OF TURNED SURFACE PROPERTIES

[1.] SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA, FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY
INSTITUTE OF PRODUCTION TECHNOLOGIES, TRNAVA, SLOVAKIA

ABSTRACT: This article is a study of the use of characteristics of Abbott-Firestone curves and impact of cutting conditions to determine the quality of surface roughness in turning. The quality of machined surface can be evaluated by roughness, while as the main parameter of surface roughness we consider median arithmetic deviation of surface profile. From the key factors affecting the quality of machined surface can be particularly chosen the impact of cutting parameters (cutting depth, feed rate, cutting speed) and tool geometry (angle of the main cutting edge, minor cutting edge and tip radius) on the surface roughness of components. This contribution to the 3-element experiment evaluates the impact of the chosen cutting parameters on surface finish in turning.
KEYWORDS: Surface roughness, turning, machined surface, planned experiment, Abbott-Firestone curves

❖ INTRODUCTION

Accuracy and quality of turned surfaces depends primarily on cutting conditions, especially the feed rate. Also the great influence has cutting edge geometry (especially κ_r, κ_r', r_ε), the quality of the cutting edge of the selected instrument and method of lubrication and cooling. For accuracy and surface roughness of turned surface, trembling has negative impact, therefore is very important the overall stiffness of the system: machine - tool - workpiece.

❖ ABBOTT-FIRESTONE CURVES AT TURNED SURFACES

When turning the machined surface is generated by moving a one cutting knife. During the process of surface formation by tools with defined cutting edge geometry, the tool profile is transferred to the work component. On the resulting structure of machined surface affects number of impacts associated with the conditions of production of parts, which determine the height, shape, layout and direction of inequality. Diversity can be observed according to the nature of profile curves, which illustrates the distribution of material within the profile height. With these curves we can characterize quality, surface roughness or bearing capacity, and also predict the behavior of the surface produced in different cutting conditions.

The problem is the roughness prescription and evaluation of turned (and not only turned) surface area. Surface roughness is not just a one-dimensional problem. Parameter Ra is only a height parameter. And because the measurement of roughness profile scans mostly the roughness in the expected direction of greater roughness, therefore is necessary to prescribe or evaluate another (linear) roughness parameter. There may be prescribed the shape of so-called curves of material profile share, also known as Abbott-Firestone curve.

Abbott curve has typical progress for some ways of machining process. For turning is generally concave, initially quite steep parabola similar course, exploitative area (30% - 40% from peak level) is relatively low adherenced to the axis of abscissas, bearing capacity of such a turned area is not very big. When turning, usually the ratio of depth of cut a_p and tip radius r_ε is smaller than for example in planing, which influences the shape of the so-called residual inequality shape of the profile formed over machined surfaces.

❖ EVALUATION OF ABBOTT-FIRESTONE CURVE BEARING CAPACITY

Bearing capacity of the area can be assessed by material ratio and by the shape of the so-called curves of surface profile material share (Abbott-Firestone curves).

Abbott-Firestone surface curves have a characteristic shape according to the method of machining, which may even be modified by the cutting conditions. These curves can graphically describe the distribution of material within the profile height. Abbott curves are also suitable characteristics for assessing the functional properties of surfaces and their possible exploitation. Course of Abbott-Firestone curve also allows to anticipate the surface wear of part.

Abbott-Firestone curve is not a simple curve, but it is possible to distinguish three parts:

- ✓ *Projection part* – contains a summary of the highest projections of the profile surface and generally it will disappear in the running-in operation (function) of part surface.
- ✓ *Central exploitation part*: is the most important and it also determines the life of parts.
- ✓ *Low depression part*: it is not available for the functioning of parts and serves for anchoring the lubricating film.

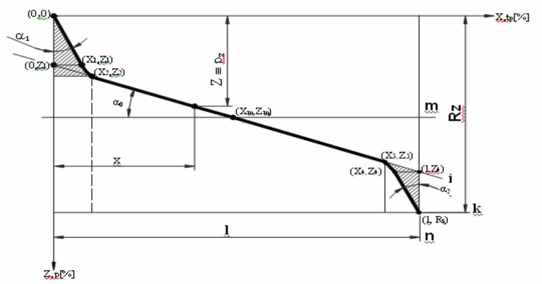

Figure 1. Illustration of the Abbott-Firestone curve

We expect that it would be sufficient to prescribe the shape of Abbott curve only in its exploitative zone. Three-segment approximation of Abbott curve can be changed to one-segment, if we approximate only its exploitation part, and we would be interested in particular section between 30% and 40% of the surface profile (position of profile cut).

❖ INFLUENCE OF TURNING CONDITIONS ON ANGLE A_0

Angles α_0, α_1, α_2 are important, in them particularly angle α_0 of line *j* with central profile line *m* (Fig. 1). Angle α_0 mostly represents character of material share curve of profile and it could be also prescribed for functional surface area by designer.

❖ PLANNING OF AN EXPERIMENT

Planning of experiments and the results analysis are important stages in the revelation of the nature and course of the technological process. For a description of technological process we use the linearized model. Linearization is performed with logarithm of power function model.

Experimental schedule presume to set values (called levels) for factors to be adjusted for experiment. For the linear model factors must have lower level (bottom, minimum) and upper level (top, maximum). Full factor experiment allows obtaining a mathematical description of examined technological process in the local area of factor space, which is lying around the selected point with coordinate's x_{j0}. This is a plan of 1st order and it's used to create a linear model. It is appropriate to organize coded values of factors for the individual experiments into the table, which is called the matrix of planned experiment.

❖ MATHEMATICAL MODEL OF AN EXPERIMENT

Parameter under consideration will be an inclination angle of central exploitative part of Abbott curve a_0 (Fig. 1). Owing to the depth of cut a_p, feed f and cutting speed v_c we can consider the dependence of power type:

$$\alpha_0 = C_{\alpha_0} \cdot a_p^{c_1} \cdot f^{c_2} \cdot v_c^{c_3} \quad (1)$$

where C_{α_0} - is empirically determined constant, c_1, c_2, c_3 - are constant exponents equation is transformed by logarithm into a linear relation:

$$\log \alpha_0 = \log C_{\alpha_0} + c_1 \log a_p + c_2 \log f + c_3 \log v_c \quad (2)$$

which can be presented as following linear mathematical model of the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \quad (3)$$

and if this model is introduced to $x_0 = 1$, we get

$$Y = B_0X_0 + B_1X_1 + B_2X_2 + B_3X_3 \quad (4)$$

The task is to determine the coefficients b_0, b_1, b_2, b_3. These must be ascertained experimentally, for example by method of experiments planning. The above variables a_p, f, v_c we call natural factors and variables x_0, x_1, x_2, x_3 we call coded factors. For natural factors we determine the upper and lower level setting of values for experiments, thus a_{pmax}, a_{pmin}, f_{max}, f_{min}, v_{cmax}, v_{cmin} and by transformation:

$$x_1 = \frac{2(\log a_p - \log a_{p\max})}{\log a_{p\max} - \log a_{p\min}} + 1 \quad (5) \qquad x_2 = \frac{2(\log f - \log f_{\max})}{\log f_{\max} - \log f_{\min}} + 1 \quad (6) \qquad x_3 = \frac{2(\log v_c - \log v_{c\max})}{\log v_{c\max} - \log v_{c\min}} + 1 \quad (7)$$

We receive the upper and lower level of coded factors x_1, x_2, x_3 in denominations of 1, -1.

❖ REALIZATION OF EXPERIMENT

For the evaluation of surface roughness and exploitation properties of components is particulary assumed the impact of cutting parameters (cutting depth, feed rate, cutting speed) and tool geometry (inclination angle of the main cutting edge, minor cutting edge and tip radius).

$$Ra = \varnothing\,(a_p, f, v_c, \kappa_r, \kappa'_r, r_\varepsilon) \quad (8)$$

where: a_p is depth of cut [mm]; f is feed [mm]; v_c is cutting speed [m.min^{-1}]; r_ε is tip radius [mm]; κ_r is setting angle of the main cutting edge; κ_r' is setting angle of the minor cutting edge

This is the default equation for roughness, which is related with Abbott curve.

Experiments were carried out in order to track the impact of changes of cutting parameters and tool geometry on surface roughness of components. According to the plan, in the first experiment varies the depth of cut, feed rate, cutting speed; in the second experiment varies the setting angle of the main cutting edge, minor cutting edge and tip radius. Planning experiments were applied to the linear model: 3-factor experiment.

To obtain samples of material was used machine: center lathe SUI 500 combi. Samples were treated with external turning action of a one cutting knife, while the surface roughness is also examined in terms of Abbott curves shape (curves of material share of the surface profile).

For experiment the tool was used: direct detracting right turning knife with a cutting plate of sintered carbide group P 20 (cutting plate mark DNMG 15 16 08 EM from Pramet, Czech Republic). Worked without cooling.

Workpiece: carbon constructional steel 12 050.1, non-alloyed, standartized anneal. Rod has a diameter ø 52,8 mm and consists of individual areas separated by grooving. Areas were turned by different cutting parameters according to the experiment.

On machined sample was measured profile roughness with profilometer Surtronic 3+ fy Rank Taylor Hobson connected to computer (Fig. 2), and with assistance of program ST3PL was achieved graphical output of Abbott curves. Each measurement was carried out three times and from the measured values was made the arithmetic mean. In the 1st experiment were constant values:

- main setting angle $\kappa_r = 81°$,
- minor setting angle $\kappa'_r = 44°$,
- tip radius $r_\varepsilon = 0{,}8$ mm;
- tip angle $\varepsilon_r = 55°$.

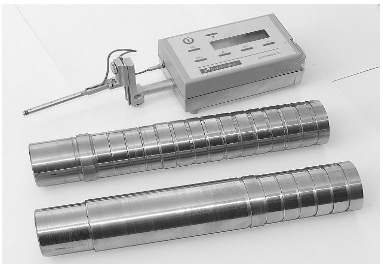

Figure 2. Profilometer Surtronic 3 and prepared samples for experiments (steel 12 050.1)

Turning conditions from 1st experiment are in the table 1.

Table 1. Matrix of α_0 plan for experiment no.1

Plan point	A_p	F	V_c	X_0	X_1	X_2	X_3	Arithmetic Mean, A_0	Y_i Log α_0	X_{1i},y_i	X_{2i},y_i	X_{3i},y_i
1	0,5	0,1	100	+1	-1	-1	-1	19,166	1,282	-1,282	-1,282	-1,282
2	2	0,1	100	+1	+1	-1	-1	14,666	1,166	+1,166	-1,166	-1,166
3	0,5	0,4	100	+1	-1	+1	-1	24,333	1,386	-1,386	+1,386	-1,386
4	2	0,4	100	+1	+1	+1	-1	35,333	1,548	+1,548	+1,548	-1,548
5	0,5	0,1	400	+1	-1	-1	+1	15,166	1,180	-1,180	-1,180	+1,180
6	2	0,1	400	+1	+1	-1	+1	18,833	1,274	+1,274	-1,274	+1,274
7	0,5	0,4	400	+1	-1	+1	+1	20	1,301	-1,301	+1,301	+1,301
8	2	0,4	400	+1	+1	+1	+1	32	1,505	+1,505	+1,505	+1,505
∑				8	0	0	0					

After calculating the regression coefficients (b_0, b_1, b_2, b_3) and coded factors (x_0, x_1, x_2, x_3), we inserted values to the equation of regression line:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \tag{9}$$

$$y = 1{,}33 + 0{,}043 \cdot \frac{\log a_p}{0{,}301} + 0{,}104 \cdot \left(\frac{2 \cdot \log f + 1{,}397}{0{,}602}\right) + (-0{,}015) \cdot \left(\frac{2 \cdot \log v_c - 4{,}602}{0{,}602}\right) \tag{10}$$

By adjustment and reverse logarithm we get linear model:

$$\alpha_0 = C_{\alpha_0} \cdot a_p^{c_1} \cdot f^{c_2} \cdot v_c^{c_3} \tag{11}$$

$$A_0 = 48{,}5 .\ A_P^{0,14} .\ F^{0,34} .\ V_C^{-0,05} \tag{12}$$

$$\sqrt{\alpha_0} = \sqrt{C_{\alpha_0}} \cdot a_p^{\frac{c_1}{2}} \cdot f^{\frac{c_2}{2}} \cdot v_c^{\frac{c_3}{2}} \tag{13}$$

$$\sqrt{\alpha_0} = 6{,}9 .\ a_p^{0,07} .\ f^{\,0,17} .\ v_c^{-0,025} \tag{14}$$

In the 2nd experiment were constant values:

- depth of cut $a_p = 1$ mm;
- feed $f = 0{,}2$ mm;
- cutting speed $V_C = 200$ m.min^{-1}

Turning conditions from 2st experiment are in the table 2.

Table 2. Matrix of α_0 plan for experiment no.2

plan point	κ_r	κ'_r	r_ε	x_0	x_1	x_2	x_3	Arithmetic mean, a_0	y_i log α_0	X_{1I},Y_I	X_{2I},Y_I	X_{3I},Y_I
1	63	27	0,4	+1	-1	-1	-1	23,666	1,374	-1,374	-1,374	-1,374
2	90	30	0,4	+1	+1	-1	-1	21	1,322	+1,322	-1,322	-1,322
3	63	67	0,4	+1	-1	+1	-1	21,666	1,335	-1,335	+1,335	-1,335
4	93	52	0,4	+1	+1	+1	-1	17,666	1,247	+1,247	+1,247	-1,247
5	63	27	1,2	+1	-1	-1	+1	19	1,278	-1,278	-1,278	+1,278
6	90	30	1,2	+1	+1	-1	+1	19,333	1,286	+1,286	-1,286	+1,286
7	63	57	1,2	+1	-1	+1	+1	17,166	1,234	-1,234	+1,234	+1,234
8	93	52	1,2	+1	+1	+1	+1	18,666	1,271	+1,271	+1,271	+1,271
∑				8	0	0	0					

After calculating the regression coefficients (b_0, b_1, b_2, b_3) and coded factors (x_0, x_1, x_2, x_3), we inserted values to the equation of regression line:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \qquad (15)$$

$$y = 1{,}29 + (-0{,}012)\cdot\left(\frac{2\cdot\log\kappa_r - 3{,}767}{0{,}169}\right) + (-0{,}21)\cdot\left(\frac{2\cdot\log\kappa_r' - 3{,}187}{0{,}324}\right) + (-0{,}026)\cdot\left(\frac{2\cdot\log r_\varepsilon + 0{,}318}{0{,}476}\right) \qquad (16)$$

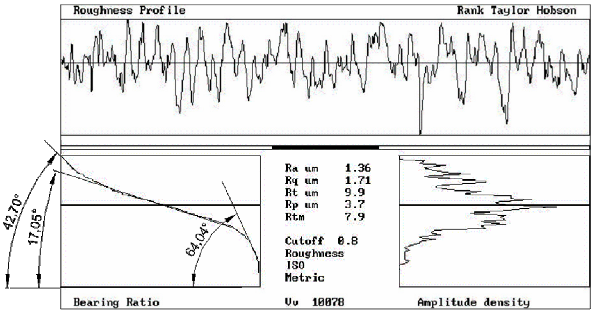

Figure 3. Graphical output from a computer cutting parameters: a_p 0,5; f 0,1; v_c 100; ε_r 55°

By adjustment and reverse logarithm we get linear model:

$$\alpha_0 = C'_{\alpha_0}\cdot\kappa_r^{C_4}\cdot\kappa_r'^{C_5}\cdot r_\varepsilon^{C_6} \qquad (17)$$

$$A_0 = 3981\ .\ K_R^{-0,14}.\ K'_R{}^{-1,27}.\ R_E^{-0,11} \qquad (18)$$

$$\sqrt{\alpha_0} = \sqrt{C'_{\alpha_0}}\cdot\kappa_r^{\frac{c_4}{2}}\cdot\kappa_r'^{\frac{c_5}{2}}\cdot r_\varepsilon^{\frac{c_6}{2}} \qquad (19)$$

$$\sqrt{\alpha_0} = 63{,}1\ .\ K_R^{-0,07}.\ K'_R{}^{-0,63}.\ R_E^{-0,05} \qquad (20)$$

The resulting statistical equation for angles α_0 according to basic equation

$$Ra = \varnothing\,(a_p, f, v_c, \kappa_r, \kappa'_r, r_\varepsilon) \qquad (21)$$

can be for example like this:

$$\alpha_0 = \sqrt{\alpha_0}\cdot\sqrt{\alpha_0} = \sqrt{C_{\alpha_0}\cdot C'_{\alpha_0}}\cdot a_p^{\frac{c_1}{2}}\cdot f^{\frac{c_2}{2}}\cdot v_c^{\frac{c_3}{2}}\cdot\kappa_r^{\frac{c_4}{2}}\cdot\kappa_r'^{\frac{c_5}{2}}\cdot r_\varepsilon^{\frac{c_6}{2}} \qquad (22)$$

$$A_0 = 435{,}4\ .\ A_P^{0,07}.\ F^{0,17}.\ V_C^{-0,025}.\ K_R^{-0,07}.\ K'_R{}^{-0,63}.\ R_E^{-0,05} \qquad (23)$$

The figure (No. 3) is a graphical representation of one measured profile from workpiece machined by turning, with values of surface roughness parameters, with the curve of the surface profile material share and the measured angles.

In our article we have pointed out to one possibility for the evaluation and utilization of the Abbott-Firestone curves characteristics for the determination of machined surfaces attributes. There are several ways to evaluate the angle of Abbott-Firestone curves inclination, but in this article we have suggested expression through so-called “figurative angle“, which means the angle between the axis of the base length and Abbott curve. We called this angle as “figurative“, because we can explain it as angle, where x-axis is the axis of the measured length and it is proportional 5-multiple lenght of base in millimeters. Axis *z* is relative value of roughness parameter *Rz* in micrometers. The size of diagram will remain the same. Height of diagram is always *Rz* and width is measured lenght. For *Rz* will always be valid this equation:

$$Rz = 5{,}67\cdot Ra \qquad (24)$$

From previous calculations, which resulted from the dissertation, we get calculation

$$RA = 2{,}16\ .\ A_P^{-0,08}.\ F^{0,58}.\ V_C^{0,03}.\ K_R^{0,10}.\ K'_R{}^{0,09}.\ R_E^{-0,40} \qquad (25)$$

then

$$Rz = 12{,}25\cdot a_p^{-0,08}.\ f^{0,58}.\ v_c^{0,03}.\ \kappa_r^{0,10}.\ \kappa_r'^{0,09}.\ r_\varepsilon^{-0,40} \qquad (26)$$

If we want to plot the Abbott - Firestone curve, we have to know the segment z_1.

Z_1 is the distance from point (0,0) in direction of *z*-axis to intersection of the line *j* with *z*-axis. (Fig.1) From the measured values of z_1, we get the resulting statistical equation

$$z_1 = 3{,}008\ .\ a_p^{-0,09}.\ f^{0,38}.\ v_c^{0,035}.\ \kappa_r^{0,07}.\ \kappa'_r{}^{0,067}.\ r_\varepsilon^{-0,4} \qquad (27)$$

❖ Conclusions

Benefit of this article is to create a simple methodology for research the parameters of Abbott-Firestone curves in the various possible ways of machining. We showed a case of turning. Such a methodology can be used to research the parameters of surface roughness, also for the research of cutting forces, cutting temperature and similar. Methodology of planning an experiment is still not very common.

❖ References

[1] BEKÉS, J., ANDONOV, I.: Analýza a syntéza strojárskych objektov a procesov. Bratislava: Alfa, 1986
[2] BUMBÁLEK, B., ODVODY, V., OŠŤÁDAL, B.: Drsnost povrchu. Praha: SNTL – Nakladatelství technické literatury, 1989.
[3] JANÁČ, A., BÁTORA, B., BARÁNEK, I., LIPA, Z.: Technológia obrábania. Bratislava: V STU, 2003. ISBN 80-227-2031-3
[4] JANÁČ, A.., LIPA, Z., PETERKA, J.: Teória obrábania. Bratislava: STU Bratislava, 2006.
[5] LIPA, Z., TOMANÍČEK, S., TOMANÍČKOVÁ, D.: Príspevok k teórii experimentov. In.: Zborník Vedeckých prác MtF STU Trnava, 2003, s. 55-61.
[6] LIPA, Z., TOMANÍČEK, S., TOMANÍČKOVÁ, D.: Príspevok k trojúsečkovej aproximácii Abbottovej krivky. In.: CO-MAT-TECH´2002, 10. medzinárodná vedecká konferencia, MtF STU Trnava, 2002, s.327-332.