Investigation of surface roughness in machining by single and multi-point tools

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Abstract

The goal of the dissertation is to determine the expected roughness of surfaces cut by tools with various geometry; the description of the differences of the necessarily existing unevenness on a given surface, and the determination of the minimal and maximal value of the surface roughness.

In order to achieve the above mentioned goals, one part of the work was to develop models and computer programs for the prediction of the surface roughness indexes for turning and face milling operations. The main basis for the calculations is the general mathematical model of the single-point cutting tools. Three different methods are introduced in the dissertation based on this model: one which is based on pure analytical calculations, one which uses numerical methods, and one which is based on CAD modelling. In-depth description of the methods is provided together with the introduction of the developed software. The main emphasis is placed on the determination of theoretical roughness on surfaces machined by face milling. The worked-out method allows taking the run-outs of the multi-point cutting tools into consideration, and the application of various insert geometries is also possible. After that, the developed CAD-based modelling is introduced which allows the calculation of 3D theoretical roughness indexes in face milling. Cutting experiments were performed for dual purpose: in one hand to show the differences between the calculated theoretical values and measurement data, and on the other hand to formulate the relations between these two datasets. Thus the expected value of the roughness can be calculated with the given cutting conditions. The experimental conditions are introduced and then the results of the practical investigations are presented. The comparisons of the obtained results have proven that the modelled and the measured surfaces are in good correlation with each other. Finally the calculated regression constants and coefficients are presented which allows the prediction of the expected value of the surface roughness.

Contents

Nomenclature

Symbol	Name	Unit
a_e	Radial depth of cut	[mm]
a_h	Semi-major axis of the hyperbola	[mm]
a_p	Axial depth of cut	[mm]
b	Intersection of the major edge section l´ with the y-axis	[mm]
b_1	Intersection of the major edge section l˝ with the y-axis	[mm]
b_2	Intersection of the minor edge section l_1´ with the y-axis	[mm]
b_3	Intersection of the minor edge section l_1˝ with the y-axis	[mm]
b_h	Semi-minor axis of the hyperbola	[mm]
C_1, C_2	Regression coefficients	-
D_e	Effective cutter diameter	[mm]
d_f	Depth of concavity	[mm]
D_m	Milling head diameter	[mm]
e_{rad}	Radial run-out error of the milling insert	[mm]
e_{ax}	Axial run-out error of the milling insert	[mm]
F_i	Profile elements which are limited by the x axis and the cutting edges	-
f	Feed per revolution	[mm/rev.]
f_t	Feed per tooth	[mm/tooth]
h_1	X size of the major cutting edge	[mm]
h_2	X size of the minor cutting edge	[mm]
h_3	Y size of the major cutting edge	[mm]
h_4	Y size of the minor cutting edge	[mm]
h_h	x coordinate of the centre of the hyperbola	[mm]
h_s	x coordinate of the centre of the torus	[mm]
iC	Inscribed circle size of the cutting insert	[mm]
k_h	Y coordinate of the centre of the hyperbola	[mm]
k_s	Y coordinate of the centre of the torus	[mm]
L	Cut length	[mm]
l, l´, l˝	Sections of the major edge of the cutting tool	-
l_1, l_1´, l_1˝	Sections of the minor edge of the cutting tool	-

Symbol	Name	Unit
l_r	Sampling length	[mm]
m	Mean line of the roughness profile	[mm]
m_h	Height of the theoretical cone	[mm]
n	Rotational speed	[rotation/min]
N	Intervals of the abscissa values in which the cutting edge sections are located	[mm]
$P(x_p, y_p)$	Intersection point(s) of the major and minor edges	-
P_{end}	End point of the theoretical profile	[mm]
P_f	Assumed working plane	-
P_r	Tool reference plane	-
P_{st}	Start point of the theoretical profile	[mm]
R, r_ε	Insert nose radius	[mm]
R^2	Coefficient of determination	-
Ra	Arithmetical mean deviation of the profile	[µm]
r_i	Rotational radius of the cutting insert	[mm]
r_g	Rolling circle radius of the curtate cycloid	[mm]
r_n	Edge rounding of cutting tool	[mm]
RMR(p)	Relative material ratio at sectioning level p	[%]
Rp	Maximum peak height of the profile above the mean line within the sampling length	[µm]
Rz	Ten-point height of the profile	[µm]
Rt	Maximum peak to valley height of the profile	[µm]
Rv	Maximum valley depth of the profile below the mean line within the sampling length	[µm]
Sa	Arithmetical mean height of the surface	[µm]
Sp	Highest peak of the surface from the mean plane	[µm]
Sv	Lowest valley of the surface from the mean plane	[µm]
Sz	Maximum height of the surface	[µm]
T_1	Area below the mean line and under the major edges	[mm^2]
T_2	Area below the mean line and under the minor edges	[mm^2]
T_3	Area above the mean line and above the major edges	[mm^2]
T_4	Area above the mean line and above the minor edges	[mm^2]

Symbol	Name	Unit
T_a	Rectangular area which exists only in case of $a_p < y_p$	[mm^2]
$T_{m,up}$	Area above the mean line of the roughness profile	[mm^2]
$T_{m,low}$	Area below the mean line of the roughness profile	[mm^2]
v	Cutting speed	[m/min]
v_f	Feed rate	[mm/min]
w	Workpiece width	[mm]
x_{apf}	Abscissa of the intersection point of the depth of cut with the major edge	[mm]
x_{apm}	Abscissa of the intersection point of the depth of cut with the minor edge	[mm]
y_{ma1}, y_{ma2}, y_{ma3}	Sections of the cutting tool major edge	-
y_{mi1}, y_{mi2}, y_{mi3}	Sections of the cutting tool minor edge	-
x_{mm}	Abscissa of the intersection point of the mean line with the minor edge	[mm]
x_{mf}	Abscissa of the intersection point of the mean line with the major edge	[mm]
x_p	Abscissa of the intersection point of the major and minor edges	-
y_p	Ordinate of the intersection point of the major and minor edges	-
y_{pmax}	Y coordinate of the highest peak of roughness profile	[mm]
y_{vmax}	Y coordinate of the lowest valley of roughness profile	[mm]
z_p	Z coordinate of the intersection point of the i^{th} intersection point between edge sections	[mm]
$\Delta\phi$	Angular rotation	[°]
Δx	Relocation of the x-points on the tool coordinate system	[mm]
Δy	Distance from the cutter centreline on the tool coordinate system	[mm]
ϕ	Half cone angle of the conical surface	[°]
ϕ_i	Roughness profile inspection angle	[°]

Symbol	Name	Unit
ϕ_p	Independent angle parameter of the curtate cycloid	[°]
κ_{r1}, κ_{r2}	Cutting edge angles	[°]
κ_{r1}', κ_{r2}'	Minor cutting edge angles	[°]
Θ	Spindle tilt angle of the milling machine	[°]

Abbreviations

AI	Artificial Intelligence
ANFIS	Adaptive Network-Based Fuzzy Inference System
ANN	Artificial Neural Network
ANOVA	Analysis of Variance
BUE	Built-up-edge
CAD	Computer Aided Design
CBN	Cubic Boron Nitride
CCD	Charge-Coupled Device
CNC	Computer Numerical Control
CSG	Constructive Solid Geometry
DoE	Taguchi Techniques for Design of Experiments
FFT	Fast Fourier Transform
GA	Genetic Algorithm
GEP	Gene Expression Programming
GUI	Graphical User Interface
HT	Hard Turning
MF	Membership Function (in Fuzzy Logic)
OEM	Original Equipment Manufacturer
RSM	Response Surface Methodology
SA	Simulated Annealing
SLE	Surface Location Error