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RESEARCH

Considering Bearing Curves of Roughness on Face Milled Surfaces of Steel

The present contribution describes the statistical analysis of bearing (Abbott) curves of surface roughness produced by face milling of steel. Bearing curves parameters are found to closely correlate with feed rate and other surface texture parameters and to follow asymmetrical distributions over milled surfaces. Furthermore, bearing curves are modelled through Beta and Pearson statistical systems.

***Keywords**: surface roughness, bearing curve and parameters, statistical distributions, Beta and Pearson systems, metal machining, face milling, carbon steels*

1. INTRODUCTION

Milling operations are among the most popular removal processes in manufacturing industry. Especially, face milling is widely used in advanced machine tools and systems (CNC, IMS etc), where there are high requirements for precise predictive models of basic machinability parameters. Such a factor is surface roughness seriously affecting components tribological performance [1-2].

Roughness of engineering surfaces is expressed by various parameters, arithmetic and statistical. One of the latter is bearing area or Abbott curve; it provides representation of the existing material in various heights of the surface profile and corresponds to cumulative probability of profile amplitude distribution. By virtue of being statistical, bearing curves and corresponding parameters may describe well wear performance of surfaces under sliding and feed surface contact models. On the other hand, they are closely associated with the manufacturing process applied and this is the reason why they are established in surface texture analysis in view of both tribology and manufacturing science [3-4].

In the present study the correlation between bearing parameters and cutting conditions is investigated in face milling of steel, as well as the relevant bearing curves are represented and modelled via statistical functions. Also, the statistical distributions of bearing parameters over the milled surfaces are determined. The workpiece material was a Ck60 plain carbon steel for different face milling designations considered.

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2. EXPERIMENTAL PROCEDURE AND ANALYSIS

The vertical knee type milling machine used is of medium size in very good working condition and possesses sufficient static and dynamic stiffness.

Cubic specimens (40x40x40) mm^3 of Ck60 plain steel were face milled.

The cutting tools were sintered carbide P40 inserts mounted on a standardized five toothed milling cutter of the following geometry:

- diameter : 80mm
- side angle : 60 °

Special attention was paid for the tools to be kept sharp during the experiments.

All experiments were carried out free of cutting fluid.

Cutting conditions employed were: depth of cut a=0.5 mm, feed rate per tooth s_z (0.16-0.60) mm rev^{-1} for z=1 and (0.03-0.30) mm rev^{-1} for z=5, cutting speed v (210) m min^{-1}.

The face milling configuration applied was that of approximate coincidence of cutter and workpiece geometrical axes for two designations, namely one tooth (z=1) and five teeth (z=5) engagements.

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Surface texture measurements were carried out radially with respect to the cutter trace, as this is the direction of chip thickness variation. A profilometer with a skidless pick-up was used. The cut off length of the rolling filter was set at the range (0.8-2.0) mm depending on feed rate value.

The bearing ratio parameters considered were: $Rt_{p20\%}$ and $Rt_{p50\%}$: representing the cross section of surface material at the corresponding levels and they were assessed through software Talyprof. Analytical bearing curves were calculated via Mathematica as integrated functions of the Beta and Pearson functions representing corresponding measured roughness amplitude distributions.

The necessary statistical analysis of the results was conducted via the commercial software Statistica. Details on the interpretation and modelling of bearing curves according to Beta and Fisher-Pearson functions are given elsewhere [5].

3. RESULTS AND DISCUSSION

As a general remark, roughness profiles in the case of the five toothed cutter, especially in the medium to high feed rate values, markedly deviate from the regular case appeared when cutting with one tooth considering both shape and amplitude (Fig.1); also, waviness is increased in the former case.

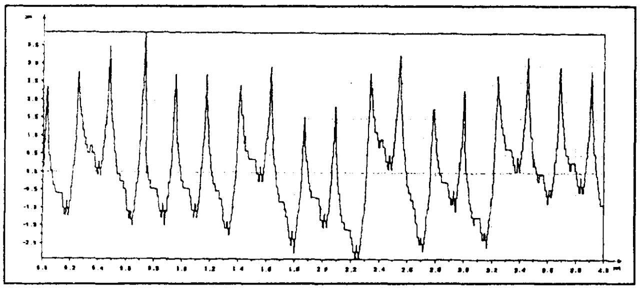

Figure 1a. Surface profile machined with 1 toothed mill cutter (s_z=0.1 mm rev^{-1}, v=210 m min^{-1})

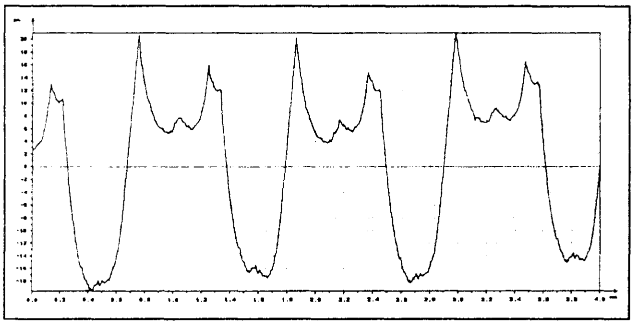

Figure 1b. Surfaces profile machined with 5 teeth mill cutter (s_z=0.1 mm rev^{-1}, v=210 m min^{-1})

An obvious explanation is that the significant three dimensional eccentricity of the cutter with z=5 is responsible for this effect, as it induces vibration that deteriorates roughness amplitude and on the other hand, successive teeth do not cut at the same depth or some of them do not contribute at all to the surface topography; in consequence the generated profile although periodic, is non regular compared to z=1 [1].

4. CORRELATION OF BEARING RATIO PARAMETERS

A very close correlation is revealed among bearing ratio parameters and feed rate, R_a surface roughness average and W_a surface waviness average for the z=1 cutter designation. Regarding z=5 cutter an increasing trend is detected among bearing ratios parameters and the aforementioned quantities, although correlation is fair but that was expectable owing to the very low feed rates and the smaller feed rate values range considered. Corresponding results are shown in Figs 2, 3 and 4.

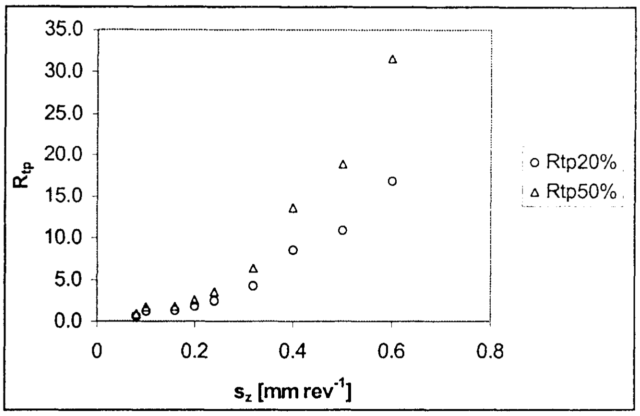

Figure 2a. Measured R_{tp} parameters for mill cutter with 1 tooth against feed rate

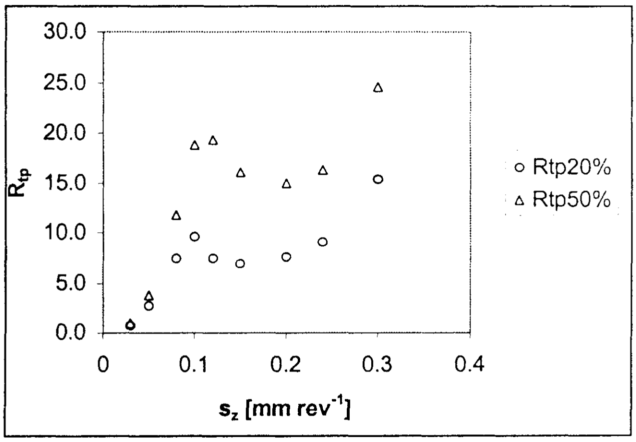

Figure 2b. Measured R_{tp} parameters for mill cutter with 5 teeth against feed rate

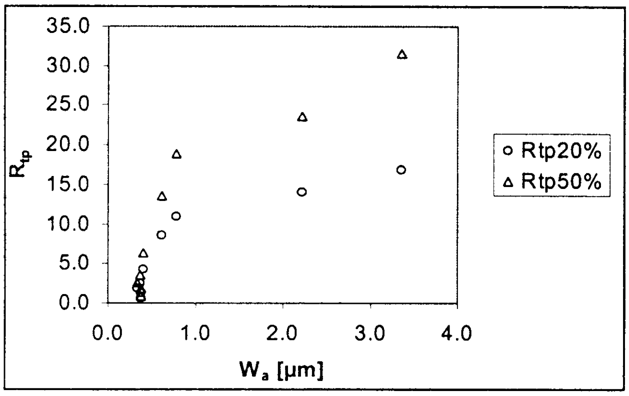

Figure 3a. Measured R_{tp} for mill cutter with 1 tooth versus roughness parameter R_a

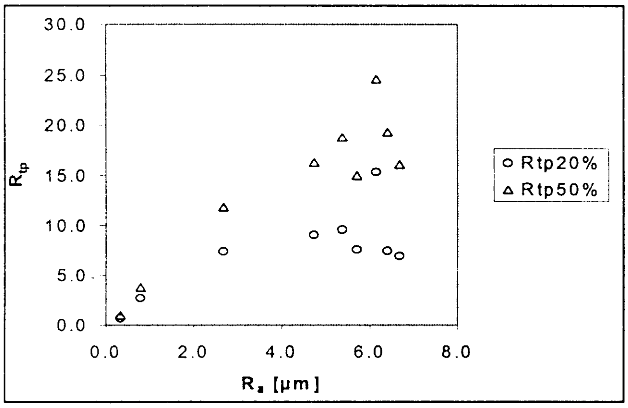

Figure 3b. Measured R_{tp} for mill cutter with 5 teeth versus roughness parameter R_a

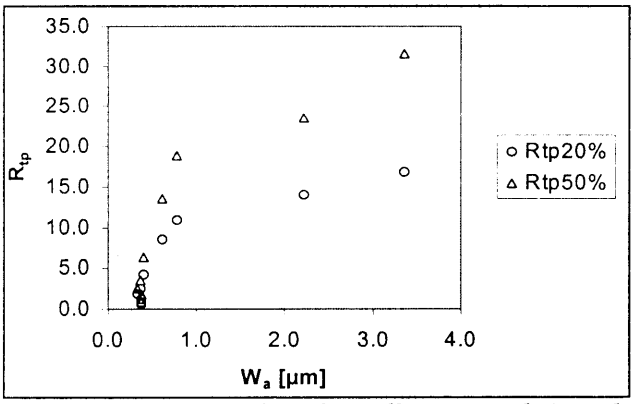

Figure 4a. Measured R_{tp} for mill cutter with 1 tooth versus waviness parameter W_a

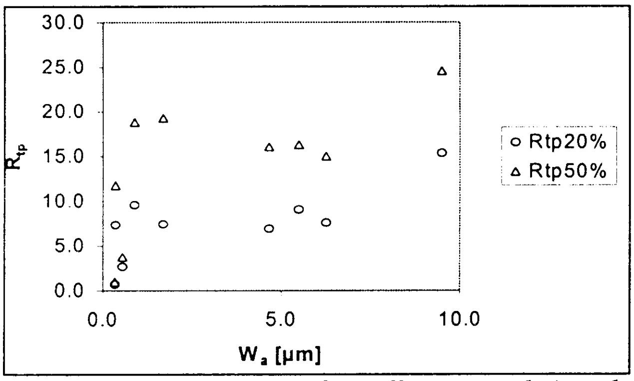

Figure 4b. Measured R_{tp} for mill cutter with 5 teeth versus waviness parameter W_a

5. DISTRIBUTION OF BEARING RATIO PARAMETERS OVER MILLED SURFACES

The distributions of bearing ratio parameters are modelled after Fisher-Pearson statistical system of disturbances by ''J'' form, see Fig. 5. This fact indicates inhomogeneity of roughness as characterized by bearing curves and is consistent with relevant distributions of amplitude parameters R_a and R_t [5]. A possible explanation is that roughness values are location dependent owing to the variation of cutting force. The latter implies more intense vibration and cutter run-out from the start of cut towards the cutting trace centre and vice versa.

6. REPRESENTATION AND MODELLING OF BEARING CURVES

In Fig. 6 indicative results are presented for measured curves in comparison to statistical representations (Fisher-Pearson and Beta functions). It is evident that there is a satisfactory agreement between experimental and calculated data. In this way, bearing curves of face milled surfaces may be described for ranges of cutting conditions by appropriate controlling of the relevant statistical distributions parameters.

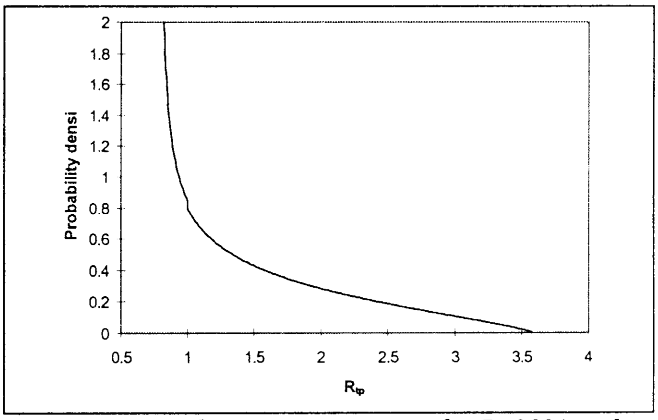

Figure 5a. Fisher –Pearson curve for R_{tp}20% to the whole milled surface with mill cutter of 1 tooth

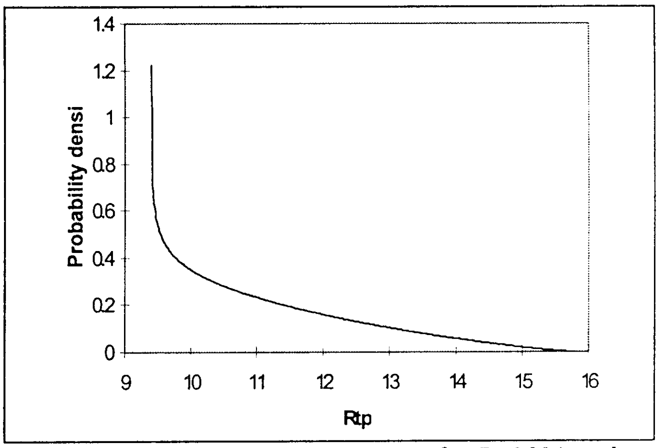

Figure 5b. Fisher –Pearson curve for R_{tp}20% to the whole milled surface with mill cutter of 5 teeth

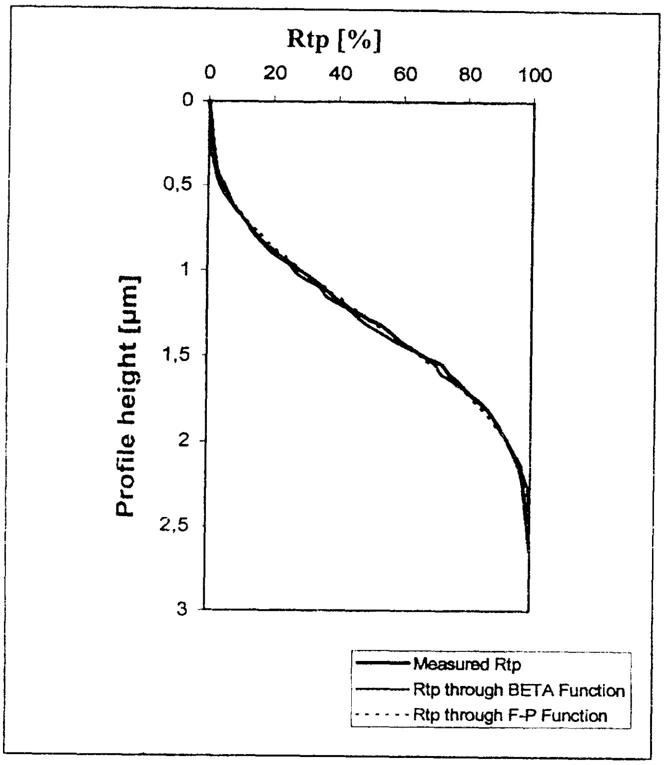

Figure 6a. Measured and calculated bearing curve for mill cutter with 1 tooth (s_z=0.1 mm rev^{-1}, v=210 m min^{-1})

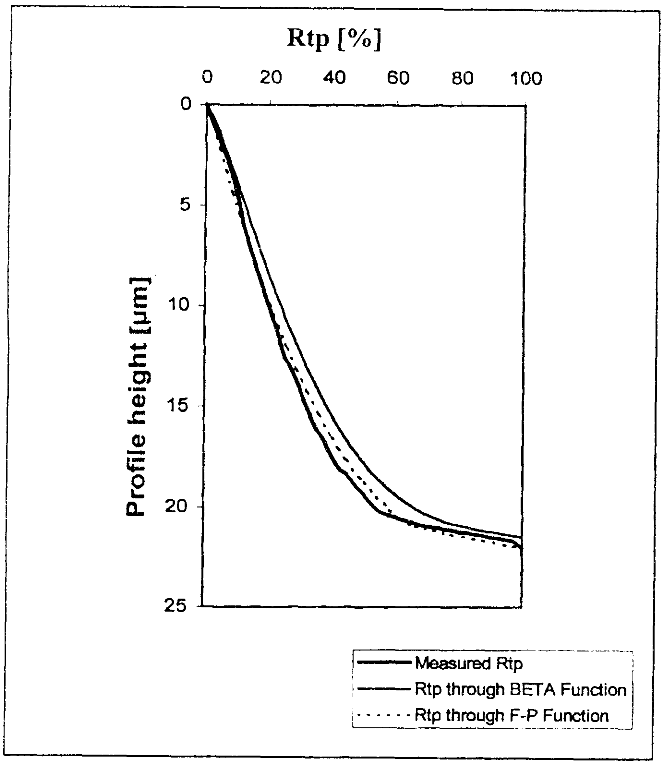

Figure 6b. Measured and calculated bearing curve for mill cutter with 5 teeth (s_z=0.1 mm rev^{-1}, v=210 m min^{-1})

7. CONCLUSIONS

Important remarks and conclusions which may be drawn from the present experimental - analytical study are:

a) A close correlation there exists between the bearing ratio parameters $t_{p20\%}$ and $t_{p50\%}$ and feed rate s_z, R_a surface roughness and W_a surface waviness in the range of regular chip formation, especially for the one toothed cutter designation. Bearing ratio parameters are higher in the case of the five toothed cutter due to the three dimensional eccentricity of cutter rotation, which induces irregular surface patterns.

b) Variation of the bearing ratio parameters over face milled surfaces conform to asymmetric statistical distributions modelled by "J" Pearson statistical functions form.

c) The bearing curves are expressed through Beta and Fisher- Pearson statistical systems (integrals of the relevant statistical profile amplitude distribution) and show a satisfactory agreement with the measured ones.

The present findings may provide a prediction of the functional performance of milled components, especially concerning their anti wear properties.

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