Surface roughness at facing on a lathe

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Abstract. It is known that during the facing on a lathe, due to the cutting speed change along the workpiece radius, the generation of the built-up edge is possible. Because of this fact, a maximum of the surface asperities height could be highlighted. From the practical point of view, it is important to have information concerning the influence exerted by some input factors of the facing process on the values of the roughness parameters that corresponds to the surfaces obtained by such a machining process. An experimental research was designed and materialized to evaluate the influence exerted by the cutting speed, feed rate and turning tool corner radius on the values of the surface roughness parameters Ra and Rq. By mathematical processing of the experimental results, some empirical mathematical models were determined. One confirmed that a low value of the surface roughness could be obtained by using high turning speed and adequate values for the feed rate and turning tool corner radius.

1. Introduction

The surface roughness could be considered as the set of small-scale microasperities characterized by a relative low pitch in comparison with the depth and that determines the relief of the piece real surface [1]. In fact, the surface roughness is the surface error that corresponds to the so-called deviation of third order having periodic characters and the errors of fourth order that have a no periodic character [1, 2]. At present, the surface roughness parameters are defined relative to the so-called mean line that divides the surface profile so that the sum of the squares of the ordinates that correspond to the profile line is minimum.

There are some groups of parameters used to evaluate the surface roughness, like the parameters of prominent and empty amplitude, parameters concerning the mean amplitude of the ordinates, pitch parameters, hybrid parameters, curves and parameters associated to certain curves etc.

To obtain a surface characterized by certain values of the roughness parameters, a large set of machining methods could be used. For example, such machining methods applied to remove the material excess from the workpiece ant that ensure essentially the obtaining of a admissible known height of the surface asperities are the turning, milling, drilling, planning, grinding etc. The turning is the machining method that develops on lathes and involves a rotation motion achieved by the workpiece, while the turning tool performs a feed motion in a plane that contains the workpiece rotation axis. The facing is a turning method developed when the turning tool materializes a feed motion along a direction perpendicular to the workpiece rotation axis. Because of facing, a flat surface is obtained.

A low roughness is necessary especially in the cases when the analyzed surface takes contact with the surface of another part and when the two surfaces constitutes a joint. The surface roughness could be higher in the case of a fixed joint and lower when there is a mobile joint.
The main groups of factors involved in the manufacturing process and that are able to affect the values of the surface roughness parameters are the turning parameters, geometry of the turning tool active zone, wear level of the cutting tool edge, physical and mechanical properties of the workpiece material, rigidity and stability of the machine tool etc.

When establishing the values of the turning parameters, one takes into consideration the physical characteristics of the workpiece material, the nature and properties of the material that correspond to the cutting tool active zone, presence and nature of cutting fluids, technological possibilities of the lathe etc. In the case of facing, the cutting parameters are the cutting speed, the feed rate and the depth of cut that is measured along a direction parallel to the workpiece rotation axis.

The needs of obtaining by turning of surfaces characterized by pre-established values of the surface roughness parameters constituted an investigation object for many researchers. Thus, Al-Dolaymi developed experimental researches aiming to ensure the optimization of the cutting parameters when a low surface roughness is necessary [3]. Tanikić and Marinković have used the regression analysis to model and optimize the conditions for dry cutting using a metallic tool so that to ensure the minimization of the roughness of the surface obtained [4]. Jun and Shih have developed theoretical and experimental research finalized by the elaboration of a unique diagram that considers three roughness parameters and that could be used as an approximate processing guide [5].

The objective of the research presented in this paper was to develop an experimental research aiming to highlight the variation of the value of the surface roughness parameter in the case of facing. Due to the continuous change of the cutting tool active zone, one takes into consideration the physical parameters concerning the asperities heights, while the increase of the tool corner radius will lead to a diminishing of the sizes of the surface roughness parameters.

A more complex influence could be exerted in the case of steels by the turning speed. It is expected that in the field of low turning speeds, the continuous generation and removal of the built-up edge will determine an increase of the surface roughness parameter. In the field of higher values of the cutting speed, the built-up edge does not yet appear and the values of the surface roughness parameter could have a low decrease, and subsequently will remain approximately constant.

In the case of the research presented in this paper, taking into consideration the significance of the distinct surface roughness parameters that correspond to the arithmetic mean of the absolute values of the profile ordinates, and the average square deviation of the rated profile, one selected as parameters whose variation could be investigated in the case of facing the mean arithmetic deviation of the assessed profile $R_a$, that corresponds to the arithmetic mean of the absolute values of the profile ordinates, and the average square deviation of the rated profile $R_q$, that corresponds to the standard deviation of the heights profile distribution.

2. Theoretical considerations

As above-mentioned, the facing is the machining method, in which the main rotation movement is performed by the workpiece, while the secondary movement is achieved by the turning tool, with a depth of cut $a_p$, measured in a direction perpendicular to the machined surface (figure 1).

As in the more frequently applied case of the revolution surfaces turning, the main factors able to affect the sizes of the surface roughness parameters are the turning speed $v$, the feed rate $f$, and the corner radius $r_c$ of the turning tool. In accordance with the results of the theoretical and experimental research, the increase in the feed rate $f$ will determine an increase of the sizes of the surface roughness parameters concerning the asperities heights, while the increase of the tool corner radius $r_c$ will lead to a diminishing of the sizes of the surface roughness parameters.

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In the case of the research presented in this paper, taking into consideration the significance of the distinct surface roughness parameters that could characterize the machined surface and the available surface roughness meters, one selected as parameters whose variation could be investigated in the case of facing the mean arithmetic deviation of the assessed profile $R_a$, that corresponds to the arithmetic mean of the absolute values of the profile ordinates, and the average square deviation of the rated profile $R_q$, that corresponds to the standard deviation of the heights profile distribution.
As process input main factors whose values could be easier changed in production conditions and during the experimental research, one took into consideration the feed rate $f$, the cutting speed $v$ and the turning tool corner radius $r_c$. One noticed that for values of the depth of cut $a_p$ found in the common domain, this process input factor practically does not exert influence on the values of the surface roughness parameters. If the depth of cut $a_p$ has very low values, the turning process could record discontinuities and in such a case, higher values of the surface roughness parameters could be obtained. On the other hand, for higher values of the depth of cut $a_p$, due to big cutting forces, an instability could affect the turning process, intense vibrations could appear and the values of the surface asperities height could increase.

If the influence of the feed rate $f$ is considered, generally it is expected that the increase of this factor value will lead to an increase of the values that characterize the surface asperities heights. At the same time, one could emphasize that if the values of the feed rate $f$ are very low, the asperities height could increase, also due to the difficulties in the chips generation and this means that the decrease of the feed rate value could not always determine a diminishing of the surface roughness parameters that characterize the heights of the surface asperities.

In principle, the increase of the cutting speed $v$ determines a low decrease of the values that correspond to the surface roughness parameters. In the case of certain materials, as the carbon steels are, in the field of the low cutting speeds, the process of generation and removal of the built-up edge means a continuous change of the cutting tool functional angles and of the height of the machined surface asperities. When the cutting speed exceed the speeds field that corresponds to the built-up edge generation, it is expected a low decrease of the values that correspond to the surface roughness parameters and subsequently a stabilization of these value to a size specific to the certain values of the feed rate $f$ and corner radius $r_c$.

The increase of the turning tool corner radius $r_c$ has a result the diminishing of the surface roughness parameters that characterize the asperities heights.

### 3. Establishment of experimental conditions using axiomatic design

The axiomatic design was proposed by the professor Nam Pyo Suh when he was working in the Massachusetts Institute of Technology from Boston (U.S.A.) and when he was interested in systematizing and optimizing the process of designing the manufacturing processes and systems. Essentially, the axiomatic design is based on two axioms. The first axiom emphasizes the necessity of ensuring the independence of the design functional requirements. In accordance with the second axiom, the best design solution is the solution that needs a minimum quantity of information. Even initially, the axiomatic design was applied preferentially in the field of design of manufacturing technologies and systems, at present it is used in various fields of social and economic activities.

To apply the axiomatic design principles, the customer needs must be defined. One supposes that in our case, the customer need is to emphasize the variation of the surface roughness parameters as the turning conditions change in a facing process, because of changing of some proper cutting conditions.

In the next step, the functional requirement of zero order must be formulated. Taking into consideration the customer need, the functional requirement of zero order could be $FR0$: develop an experimental research to highlight the changes in the values of the surface roughness parameters when there is a variation of the cutting speed, feed rate and tool corner radius.

On the base of the functional requirement of zero order, some functional requirements of first order could be determined: $FR1$: Provide the base materials; $FR2$: Prepare the test samples; $FR3$: Design the experimental experiment; $FR4$: Develop the experimental tests and collect the experimental results; $FR5$: Mathematical process the experimental results.

Taking into consideration the above-mentioned main functional requirements (of first order), the functional requirements of second order could be stated: $FR1.1$: Provide the machine tool; $FR1.2$: Ensure the cutting tool; $FR1.3$: Provide qualified operators; $FR2.1$: Cut the test samples from the bar type workpiece; $FR2.2$: Prepare the frontal surface; $FR3.1$: Set the number of the input factors; $FR3.2$: Set the number and the types of the roughness parameters; $FR4.1$: Ensure the surface roughness tester;
FR4.2: Collect and records the experimental results; FR5.1: Ensure adequate software and computer; FR5.2: Process the experimental results and determine the mathematical empirical models.

Adequate design parameters must be allocated to the established functional requirements. As design parameters of second order, the followings were proposed: 

*DP1.1: Lathe SN450x1000;* *DP1.2: Turning tool;* *DP1.3: Saw type machine tool operator;* *DP2.1: Saw type machine tool;* *DP3.1: Three process input factors (feed rate \(f\), cutting speed \(v\), turning tool corner radius \(r\));* *DP3.2: Surface roughness parameters: Ra, Rq;* *DP4.1: Surface roughness tester (Mitutoyo);* *DP4.2: Table that facilitates the record of the experimental conditions and results;* *DP5.1: Software and computer system;* *DP5.2: Software and computer system.*

### Table 1. Matrix that includes functional requirements and design parameters in the case of a facing process.

| Line no. 1 | Design parameters | Functional requirements | Second-order functional requirements | Design parameter of zero order, DP0 | Design parameters of the first order | Design parameters of the second order |
|------------|-------------------|-------------------------|--------------------------------------|----------------------------------|-------------------------------------|--------------------------------------|
| 2          |                   |                         |                                      | DP1                              | DP2:                                | DP3:                                 |
| 3          |                   |                         |                                      | DP4:                             | DP5:                                |                                      |
| 4          |                   |                         |                                      | DP design parameters of the second order |                                      |                                      |
| 5          |                   |                         |                                      | DP1.1                            | DP1.2                                | DP1.3                                |
|            |                   |                         |                                      | DP2.1                            | DP3.1                                | DP3.2                                |
|            |                   |                         |                                      | DP3.2                            | DP4.1                                | DP4.2                                |
|            |                   |                         |                                      | DP4.2                            |                                      | DP5.2                                |
| 6          |                   |                         |                                      |                                  |                                      |                                      |
| Column no. 1 |                   |                         |                                      |                                  |                                      |                                      |
| 7          |                   | FR0                     |                                      |                                  |                                      |                                      |
|            |                   | FR1                     |                                      |                                  |                                      |                                      |
|            |                   | FR1.1                   |                                      |                                  |                                      |                                      |
|            |                   | FR1.2                   |                                      |                                  |                                      |                                      |
|            |                   | FR1.3                   |                                      |                                  |                                      |                                      |
|            |                   | FR2                     |                                      |                                  |                                      |                                      |
|            |                   | FR2.1                   |                                      |                                  |                                      |                                      |
|            |                   | FR2.2                   |                                      |                                  |                                      |                                      |
|            |                   | FR3                     |                                      |                                  |                                      |                                      |
|            |                   | FR3.1                   |                                      |                                  |                                      |                                      |
|            |                   | FR3.2                   |                                      |                                  |                                      |                                      |
|            |                   | FR4                     |                                      |                                  |                                      |                                      |
|            |                   | FR4.1                   |                                      |                                  |                                      |                                      |
|            |                   | FR4.2                   |                                      |                                  |                                      |                                      |
|            |                   | FR5                     |                                      |                                  |                                      |                                      |
|            |                   | FR5.1                   |                                      |                                  |                                      |                                      |
|            |                   | FR5.2                   |                                      |                                  |                                      |                                      |

The correspondence between the functional requirements and design parameters could be emphasized by the so-called decision matrix or by means of the information included in the table 1. The analysis of this information shows that there were identified design parameters that correspond to many functional requirements and this means that there are possibilities to improve the design solution to better meet the first axiom.

### 4. Experimental conditions

The experimental research was developed in the laboratory of machine manufacturing technology from the “Gheorghe Asachi” Technical University of Iași. A universal lathe type SN 400x100 was selected as machine tool on which the experimental research could be materialized. A turning tool endowed with carbide tips was taken into consideration as a cutting tool.

On appreciated that to design the experimental research, a factorial experiment with two independent variables at two levels could be applied.
The feed rate and turning tool corner radius were selected as process input factors. The two values of the process input selected factors were established considering the recommendations included in the handbooks guides used in determining the turning tool conditions. Thus, the following values were established:

\[ f_{\text{min}} = 0.2 \text{ mm/rev}, \quad f_{\text{max}} = 0.4 \text{ mm/rev} \]
\[ r_{\varepsilon_{\text{min}}} = 0.4 \text{ mm}, \quad r_{\varepsilon_{\text{max}}} = 0.8 \text{ mm} \]

For the third process input factor (cutting speed \( v \)), a variation between the current limit values was established (31.4-219.8 m/min).

The Mitutoyo type roughness meter was used to measure the values of the surface roughness parameters Ra and Rq.

As known, the values of the surface roughness parameters will change along the radius of the test piece machined surface and this fact could generate a difficulty in measuring the values of the surface roughness parameters.

Taking into consideration this situation, one decided to measure the values of the surface roughness parameter at previously established values of the test sample radius (that correspond to certain values of the cutting speed \( v \)).

Since the roughness meter needs a certain work stroke (whose value is established by considering the probable value of the surface roughness parameter), one appreciated that a general image concerning the values of the surface roughness parameters could be obtain in this way. Practically, due to the cutting speed variation along the test sample radius, the values indicated by the roughness meter correspond rather to mean values of the surface roughness parameter along the work stroke of the roughness meter sensor.

The experimental conditions and results were included in table 2.

### Table 2. Experimental conditions and results.

| \( n \), rev/min | \( R \), mm | \( v \), m/min | \( f \), mm/rev | \( r_{\varepsilon} \), mm | \( R_a \), \( \mu \text{m} \) | \( R_q \), \( \mu \text{m} \) |
|------------------|------------|---------------|---------------|-----------------|-----------------|-----------------|
| 5                | 31.4       | 1.70          | 2.22          |                 |                 |                 |
| 10               | 62.8       | 0.96          | 1.20          |                 |                 |                 |
| 15               | 94.2       | 1.44          | 1.79          |                 |                 |                 |
| 20               | 125.6      | 1.55          | 1.96          | 0.2             | 0.4             |                 |
| 25               | 157        | 1.06          | 1.35          |                 |                 |                 |
| 30               | 188.4      | 1.19          | 1.62          |                 |                 |                 |
| 35               | 219.8      | 0.90          | 1.14          |                 |                 |                 |
| 5                | 31.4       | 3.0           | 3.69          |                 |                 |                 |
| 10               | 62.8       | 2.40          | 2.97          |                 |                 |                 |
| 15               | 94.2       | 2.32          | 2.82          |                 |                 |                 |
| 20               | 125.6      | 1.87          | 2.33          | 0.4             | 0.4             |                 |
| 25               | 157        | 1.84          | 2.42          |                 |                 |                 |
| 30               | 188.4      | 1.74          | 2.19          |                 |                 |                 |
| 35               | 219.8      | 0.98          | 1.21          |                 |                 |                 |
| 5                | 31.4       | 4.50          | 5.26          |                 |                 |                 |
| 10               | 62.8       | 3.26          | 4.11          |                 |                 |                 |
| 15               | 94.2       | 3.03          | 3.82          |                 |                 |                 |
| 20               | 125.6      | 2.00          | 2.46          | 0.2             | 0.8             |                 |
| 25               | 157        | 1.16          | 1.50          |                 |                 |                 |
| 30               | 188.4      | 1.08          | 1.34          |                 |                 |                 |
| 35               | 219.8      | 1.19          | 1.56          |                 |                 |                 |
| 5                | 31.4       | 1.95          | 2.32          |                 |                 |                 |
| 10               | 62.8       | 2.48          | 3.05          |                 |                 |                 |
| 15               | 94.2       | 1.51          | 1.85          |                 |                 |                 |
| 20               | 125.6      | 1.72          | 2.17          | 0.4             | 0.8             |                 |
| 25               | 157        | 2.24          | 2.78          |                 |                 |                 |
| 30               | 188.4      | 1.71          | 2.08          |                 |                 |                 |
| 35               | 219.8      | 1.53          | 1.89          |                 |                 |                 |

### 5. Processing of the experimental results

Aiming to identify empirical mathematical models corresponding to the experimental results included in table 2, a specialized software based on the method of least squares [6] was used. In this way, the following mathematical relations were determined:

\[ Ra = 17.43 \times v^{-0.384} \times f^{0.266} \times r_{\varepsilon}^{0.326} \]  \( (1) \)
\[ Ra = 19.084 \times v^{-0.368} \times f^{0.230} \times r_{\varepsilon}^{0.302} \]  \( (2) \)

Based on the experimental results included in table 2, the graphical representation from figures 2 and 3 were elaborated. The examination of these graphical representations and of the empirical mathematical models constituted by the relations (1) and (2) confirmed the decrease of the surface roughness parameters Ra and Rq when the cutting speed \( v \) increases, and the increase of the values that correspond to the parameters Ra and Rq when the feed rate \( f \) increases, respectively. A certain
contradiction could be signalized in connection with the influence exerted by the corner radius \( r_c \), whose increase leads to an increase of the surface roughness parameters \( Ra \) and \( Rq \). An explanation of this fact could be based on the strong influence exerted however by the built up edge; due to continuous variation of the cutting speed, the maximum values of the surface roughness parameter are obtained when the proper turning conditions are favorable to an intense development of the built up edge.

6. Conclusions

An experimental research was designed and materialized to highlight the variation of the surface asperities heights along a radial direction of a flat surface obtained by facing, in the case of test samples made of a medium carbon steel. Due to the continuous variation of the cutting speed and, as a consequence, of the built up generation and removal, one confirmed the existence of high values of the surface roughness parameters in the field of low turning speeds. Empirical mathematical models were elaborated by mathematical processing of the experimental results and these models confirmed the diminishing of the values that correspond to the surface roughness parameters \( Ra \) and \( Rq \) when the cutting speed increases and the increase of the same parameters values when the feed rate increases, respectively. A certain contradiction was signalized in the case of the influence exerted by the turning tool corner radius; a possible explanation concerning this contradiction could be based just on the continuous generation, and removal of the built up edge in the field of low values of the cutting speed.
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