RESEARCH ON THE INFLUENCE OF CUTTING PARAMETERS ON THE ROUGHNESS SURFACE

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ABSTRACT: *The roughness of the machined surface is an important factor of quality in all machining operations, depending on the cutting parameters used and the functional conditions of the machined parts. The main objective of this paper is to analyze the influence of the cutting parameters on the surface roughness in the turning operation. An important and more difficult factor to measure in real processing conditions is the size and structure of the vibrations, which lead to the tool wear. In modern "on-line" tool wear monitoring systems one of the measurable indicators used is the acoustic emission, directly related to the vibrations in the process.*

KEY WORDS: *cutting parameters, surface roughness, tool wear, noise, Design Expert*

1 INTRODUCTION

The quality of the processed surfaces is an important characteristic for their behavior in operation and can be assessed by two categories of criteria, (Dawson & Kurfess,2000):

- geometric criteria - macro-irregularities, undulations and roughness; macroneregularities and undulations fall within the limits of dimensional accuracy; the roughness is assessed by the usual parameters (arithmetic mean deviation of the profile Ra and average height of the microneregularities Rz) and depends on the final mechanical processing operation;
- physical-mechanical criteria - structure, hardness and residual stresses; the mechanical and thermal actions generated by the cutting process lead to the appearance of zone III in which the metallographic structure differs from that of the base material and in which residual stresses are present and the hardness is higher than in the base material, due to the hardening phenomenon.

The roughness of the surface in the cutting process is one of the most important parameters, being included in the execution drawing of the part, (Srithara, Kumar & Durgaprasad, 2014). In addition to the usual indicators are roughness as an arithmetic average or the maximum in many cases must be considered more advanced parameters such as those related to the structure of the surface, load-bearing or even the direction of traces left on the processed surface.

The roughness of the processed surface is affected by the precision of the technological system, parameters of the cutting regime, geometry and microgeometry of the active surfaces of the tool and its wear, but also by the physical and chemical properties of the material to be processed, such as thermal conductivity, electrical conductivity, fatigue resistance and corrosion tendency (Abutlhakeer & Kumar, 2011). But, although the quality of the processed surface plays an important role in influencing customer satisfaction in the manufacturing process, nevertheless, the requirements related to the quality of the processed surface significantly affect the production cost and of course increase the price of the product. Therefore, monitoring the roughness of the processed surface in the cutting process is essential and it is necessary to choose the appropriate process parameters in order to obtain the desired quality through processing. More researchers discussed surface finish, and it was found that it varies when the cutting parameters vary. Statistical analysis of the experiment processed using ANOVA (analysis of variance) (Jayswal &Taufik, 2011*)* .

Considering the multitude of influencing factors of the roughness of the processed surfaces, its prediction becomes a rather complex task, requiring special experimental and theoretical research.

2 THE EXPERIMENT

In the cutting process, the cutting tool is considered the element with the lowest reliability. The tool wear process is a complex phenomenon, both in terms of causes and effects (forces, temperature, noise, vibration, acoustic emission), so the analysis of the wear state of the cutting tool is another area of interest. Starting from the parameters that can be monitored in a cutting process, the indicators that will be determined by experimental tests have been established:

- parameters R_a and R_z for the roughness of the processed surface;
- the noise.

Thus, in the plan of experiences will be considered dependent variables:

- parameters R_a and R_z for the roughness of the processed surface, the noise, Z

and, as independent variables, parameters of the cutting regime: cutting speed, feed, cutting depth, the tip radius of the tool.

2.1 Establishing the experimental plan and the levels of variation of the factors

From the first stage of establishing the experimental plan, after defining the input and output variables, the limits of the measurement range and the number of levels of variation of the factors must be determined.

In the experimental research, tests were performed in which the parameters of the cutting regime are varied between the limits:

- cutting speed, $v = 52 \div 102 [m/\min]$
- feed, $f = 0{,}07 \div 0{,}28 [mm/rot]$
- depth of cut, $a_p = 0{,}5 \div 1{,}5 [mm]$
- nose radius, $r_\varepsilon = 0{,}4 \div 0{,}8 [mm]$

In establishing the levels of the factors, it was chosen to: a factorial experiment 2^3 comprising three factors (feed, cutting speed and nose radius) at two levels of variation when measuring roughness.

In the experimental tests performed to monitor the wear of the cutting tool, both off-line techniques were used by measuring the roughness of the machined surface and on-line techniques by noise analysis.

2.2 Measurement of surface roughness

Since it is very important the roughness of the processed surface was paid attention to performed measures for this cutting parameter. To analyze the roughness influence a model of it was created as function of the parameters of the cutting regime. Because it can't take into account the influence of all factors on roughness, a calculation program was used based on the balance sheet method, considering as variables the tool nose radius, r_ε, feedrate, f and cutting speed, v.

Attempts to measure the roughness of the machined surface were performed on:

- machine tool: lathe SN 250,
- AISI 1045 workpiece, with a diameter of $D = 34$ [mm] and $L = 350$ [mm]

using

- turning tools with interchangeable inserts of the type of the TPUN type 11 03 04 ($r_\varepsilon = 0{,}4$) and TPUN 11 03 08 ($r_\varepsilon = 0{,}8$);
- and for measuring the microgeometry of surfaces the Surtronic 3+ roughness meter was used;

The installation for measuring the roughness is shown in the figure 1.

Fig.1 Measurement of surface roughness equipment

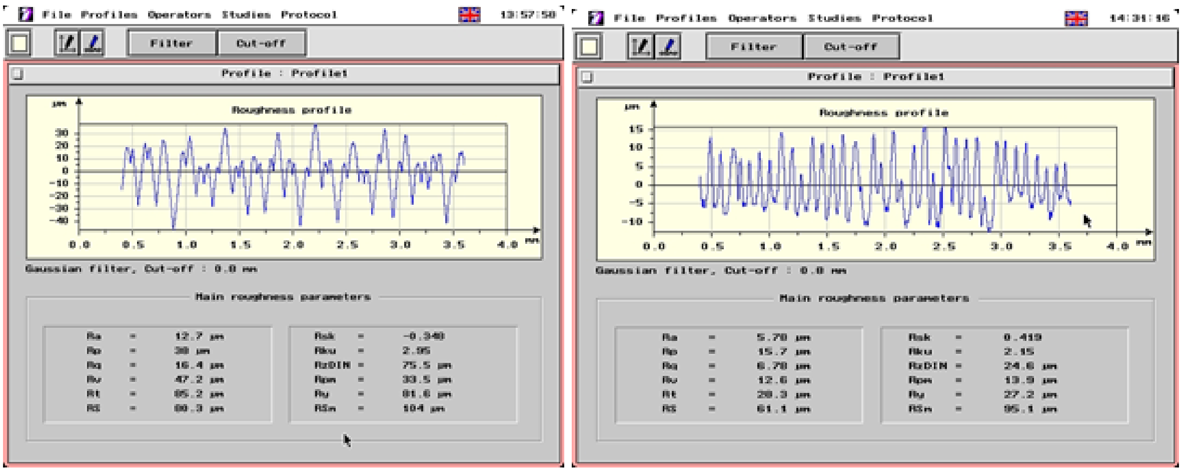
A series of experimental tests were performed according to the experimental plan to analyze the influence of the peak radius of the tool, the feed, the speed on the roughness and an attempt was made to obtain a more complex relationship which render

Table 1. Roughness surface values

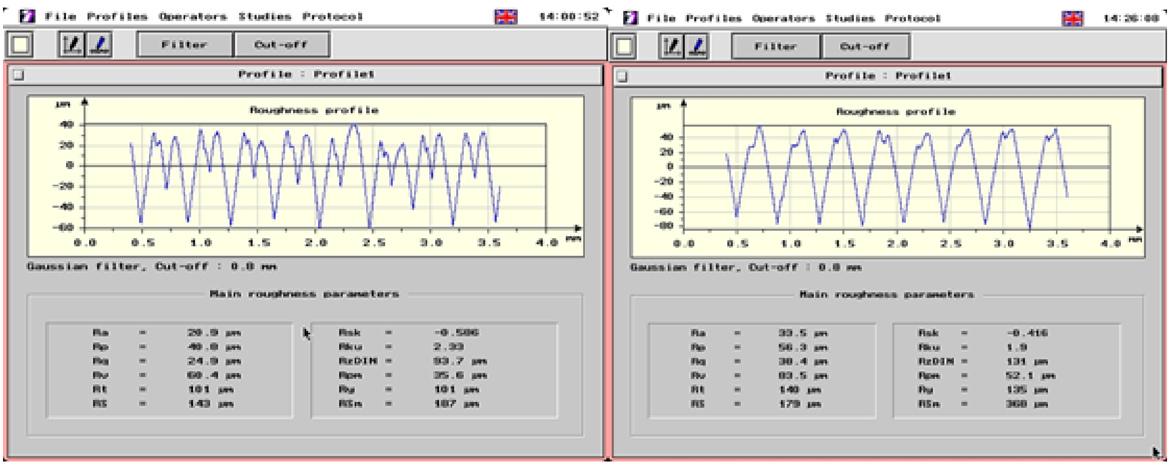
No.	r_ε	f [mm / rot]	v [m / min]	R_a	R_z	R_y
1.	0.4	0.152	61	7.14	34.1	41.3
2.	0.4	0.152	85	1.70	9.30	9.9
3.	0.4	0.304	61	8.60	40	56
4.	0.4	0.304	85	5.34	22.4	25.9
5.	0.8	0.152	61	2.62	14.6	20.8
6.	0.8	0.152	85	2.02	8.40	10.9
7.	0.8	0.304	61	4.44	22.9	26
8.	0.8	0.304	85	2.84	12.2	13.6

the variation roughness depending on these parameters.
The obtained results are found in table 1.

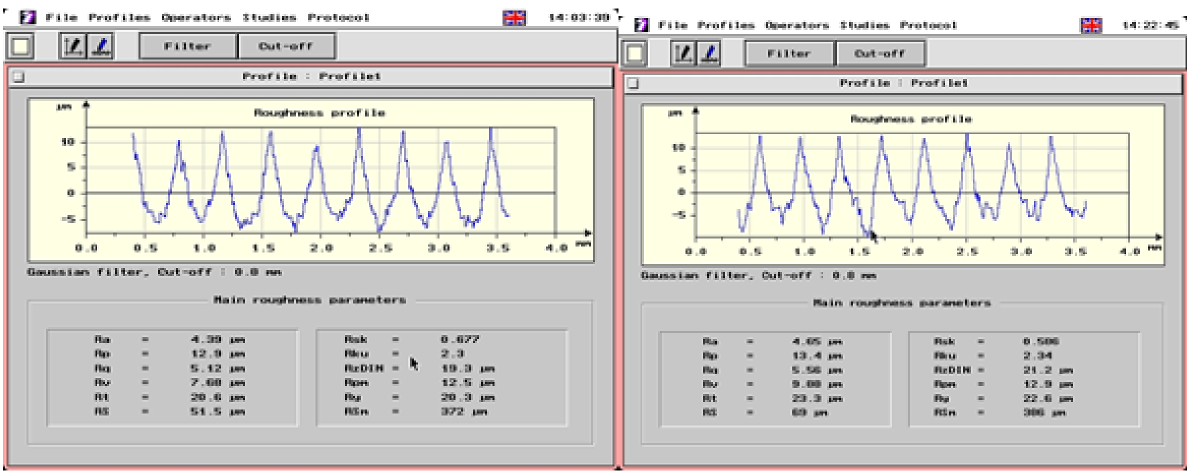
For a better image in figure 2 are presented the most representative profiles.



Sample 1 - New insert



Sample 2 - Insert with wear VB = 0.5 mm



Sample 3 - Insert with VB = 1.2 mm

Fig.2 Test profiles

2.3 Use of noise emission in order to automatically estimate the wear of the cutting tool

The noise produced in the cutting process is also a measure of lost energy. Its size gives us an indication of the process, so that the increase of tool wear leads to loud noises, more vibrations, so it turns out that the cutting process does not proceed normally.

In order to estimate the wear of the cutting tool by measuring the noise, experimental tests were performed in this case on the same machine tool and in the same cutting conditions.

The measurements were performed using:

- the sound level meter microphone which is of the Max BCM-5400 type, Uni-directional and is located at a distance of 20 - 30 mm from the tool tip;
- USB 6008 NI purchase card;
- LabVIEW 8.5 software;
- plate type TNMM 15 04 04.

Noise measurements were performed in the following situations:

- idling;
- in conditions of cutting with new insert;
- under cutting conditions with the same type of insert, but with different uses: $VB = 0.25mm$, $VB = 0.5mm$, $VB = 1.2mm$

The cutting started with a new plate and after every minute the parameters of the cutting regime were changed, and the wear of the tool was measured using a microscope. Cutting was resumed for each plate with different wear. The results obtained from the measurements are presented in the table below.

Table 2. Noise measurement

Nr.crt	ap [mm]	f [mm/rot]	V [m / min]	Z [dB]
New plate				
1.	0.5	0.07	52	76.30
2.	0.5	0.07	102	76.80
3.	0.5	0.14	52	77.30
4.	0.5	0.14	102	78.01
5.	1.0	0.07	52	79.21
6.	1.0	0.07	102	79.57
7.	1.0	0.14	52	79.89
8.	1.0	0.14	102	82.09
9.	1.5	0.07	52	82.11
10.	1.5	0.14	52	82.30
11.	1.5	0.14	102	82.50
Plate with VB = 0.5 [mm]				
12.	0.5	0.07	52	81.80
13.	0.5	0.07	102	82
14.	0.5	0.14	52	82.50
15.	0.5	0.14	102	82.93
16.	1.0	0.07	52	83.30
17.	1.0	0.07	102	83.40
18.	19.	0.14	52	83.35
20.	1.0	0.14	102	84
21.	1.5	0.07	52	84.20
22.	1.5	0.07	102	85.80
23.	1.5	0.14	52	85.25
24.	1.5	0.14	102	85.50
Plate with VB = 1.2 [mm]				
25.	0.5	0.07	52	80.10
26.	0.5	0.07	102	82.20
27.	0.5	0.14	52	82.30
28.	0.5	0.14	102	82.30
29.	1.0	0.07	52	83.30
30.	1.0	0.07	102	83.50
31.	1.0	0.14	52	83.35
32.	1.0	0.14	102	83.90
33.	1.5	0.07	52	84.20
34.	1.5	0.07	102	85.50
35.	1.5	0.14	52	85.25
36.	1.5	0.14	102	85.70

And, the noise was purchased using the 2100 Quest Technologies Sound Level Meter mounted very close to the cutting area together with the acquisition board and the virtual instrument made in LabView.

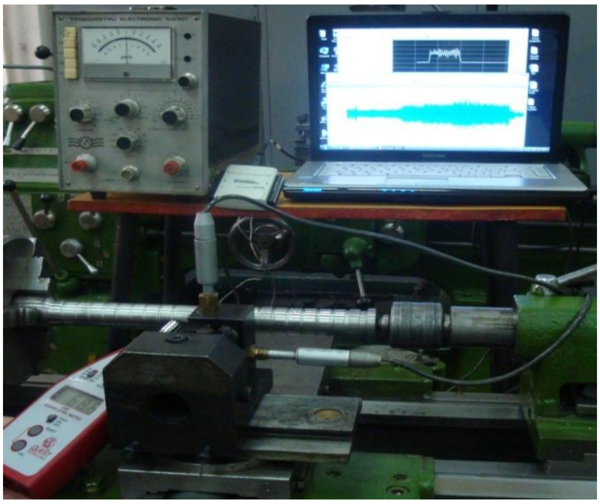


Fig.3 Experimental stand for noise measurement

To obtain a signal as clear as possible, eliminating other factors involved in the cutting process, use a band-pass filter in the noise measuring chain, which completely attenuated any signal outside the desired range. Thus, records were obtained for each type of plate, shown in Figure 4.

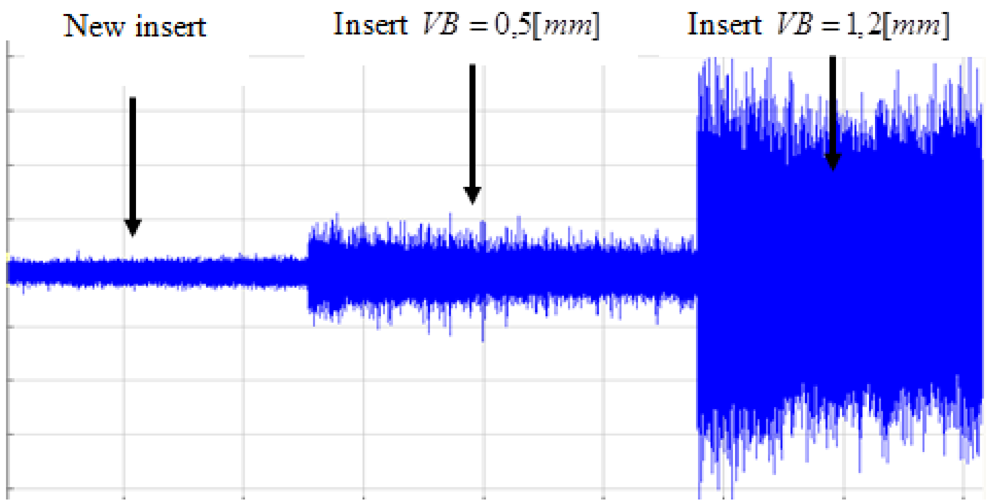


Fig.4. Recording the composite signal

After acquiring the signals, they were analyzed both separately and together. In the second case, a composite signal was made by gross recording of the three signals.

3 ANALYSIS OF EXPERIMENTAL DATA AND MATHEMATICAL MODELING OF THE RESULTS OBTAINED

The experimental researches had as objective the realization of some mathematical models based on some measurements of the output parameters of the process, in case of modification of the values of the input parameters. In this case, it was desired to obtain a roughness model, as an indirect indicator of tool wear, but also the analysis of the noise from the cutting process.

3.1 Mathematical modeling of roughness

The mathematical modeling of the dependent variables from the experience plan, the order of influence of the factors, the obtaining of the mathematical model, but also the adequacy test of the model was performed with the help of the Design Expert software.

The mathematical model obtained was statistically tested using the analysis of the ANOVA variance, to see to what extent they are chosen appropriately and to verify whether the independent variables significantly influence the dependent variables.

The adequacy test shows that no factors or their interactions were omitted from the mathematical model, and the influence test has the role of displaying the order of influence of the factors and / or removing from the formula of the mathematical model those independent variables that do not exert an influence. significant effect on dependent variables.

Factor influence testing is done based on the Fisher test depending on the variance due to the tested factor and the residue variance.

If this ratio is greater than or equal to an admissible limit value (eq 1.) the hypothesis is accepted, according to which the respective factor has a significant influence on the mathematically modeled variable.

$$F_{i\_calc} > F \qquad (1)$$

where:

Fi_calc is the Fisher coefficient calculated for each factor

F - minimum value selected from Fisher's coefficient table for a 95% confidence level ($\alpha = 0,5$).

In order to obtain the mathematical model, a complete factorial experiment was used, of type 2^3, from which can draw maximum conclusions. For model choice and factor influence study, multiple linear and polynomial regression.

By applying multiple polynomial regression, the relationship for roughness assessment was obtained with:

- coded factors

$$R_a = 4.34 - 1.36 \cdot A + 0.97 \cdot B - 1.36 \cdot C$$

- current factors

$$R_a = 13.79 - 6.78 \cdot r_\varepsilon + 12.90 \cdot f - 0.11 \cdot a_p$$

Using the ANOVA analysis on the obtained roughness model, we can find out the influences of each parameter and the adequacy of the model, as observed below (table 3 and 4).

Table 3. Ra - Model Adequacy Testing (ANOVA)

	The sum of the squares	**Degrees of freedom**	**The average of the squares**	**Fcalc**	**Prob> F ***
The variance explained by the inadequacy of the model	37.08	3	12.36	6.61	0.0497 ⇒ significant
Residual	7.48	4	1.87		
TOTAL	44.56	7			

* $F_{3,4}$ for a confidence level of P = 95% ($\alpha = 0,5$)

Table 4. Ra - Testing the significance of model factors

	The sum of the squares	**Degrees of freedom**	**The average of the squares**	**Fcalc**	**Prob> F**
factor A	14.74	1	14.74	7.89	0.0484⇒ significant
factor B	14.85	1	14.85	7.95	0.0479⇒ significant
factor C	7.49	1	7.49	4.01	0.1159
TOTAL	37.08	3			

Following the determination of the model coefficients and the analysis of the factors, it can be stated that the factor B (feed) have a significant influence on the Ra roughness.

In order to find out the influence of tool wear on the roughness of the machined surface, wear was introduced in the experiment, as the fourth factor, performing a factorial experiment 2^4. After introducing this parameter and analyzing the significance of the factors, the mathematical model presented below was obtained. respectively the current factors.

- coded factors

$$R_a = 11{,}86 - 7{,}68 \cdot A + 4{,}7 \cdot B - 0{,}68 \cdot C - 0{,}049 \cdot D - \\ - 3{,}53 \cdot A \cdot B - 0{,}36 \cdot A \cdot C - 0{,}16 \cdot A \cdot D + 0{,}28 \cdot B \cdot C$$

- real factors

$$R_a = -1{,}197 + 10{,}09 \cdot r_\varepsilon + 137{,}97 \cdot f - 0{,}02 \cdot v + 7{,}65 \cdot uzura \\ - 170{,}36 \cdot v \cdot f - 0{,}061 \cdot r_\varepsilon \cdot v - 0{,}61 \cdot r_\varepsilon \cdot uzura + \\ + 0{,}119 \cdot f \cdot v - 26{,}13 \cdot f \cdot uzura - 8{,}92 \cdot e^{-003} \cdot v \cdot uzura$$

Table 5. Model Adequacy Testing (ANOVA)

	The sum of the squares	**Degrees of freedom**	**The average of the squares**	**Fcalc**	**Prob> F**
The variance explained by the inadequacy of the model	1508.28	8	188.54	4.82	0.0261⇒ significant
Residual	273.63	7	39.09		
TOTAL	1781.91	15			

Table 6. Testing the significance of model factors

	The sum of the squares	**Degrees of freedom**	**The average of the squares**	**Fcalc**	**Prob> F**
factor A	943.72	1	943.72	24.14	0.0017⇒ significant
factor B	353.82	1	353.82	9.05	0.0197 ⇒ significant
factor C	7.43	1	7.43	0.19	0.6167
factor D	0.038	1	0.038	9.72e-004	0.9760

The adequacy test shows that there is no significant factor of the influence of the parameter R_a not to be taken into account by the proposed model.

Regarding the testing of the model factors, in the table above it is observed that factor A (tool nose radius) and factor B (feed) are the most significant.

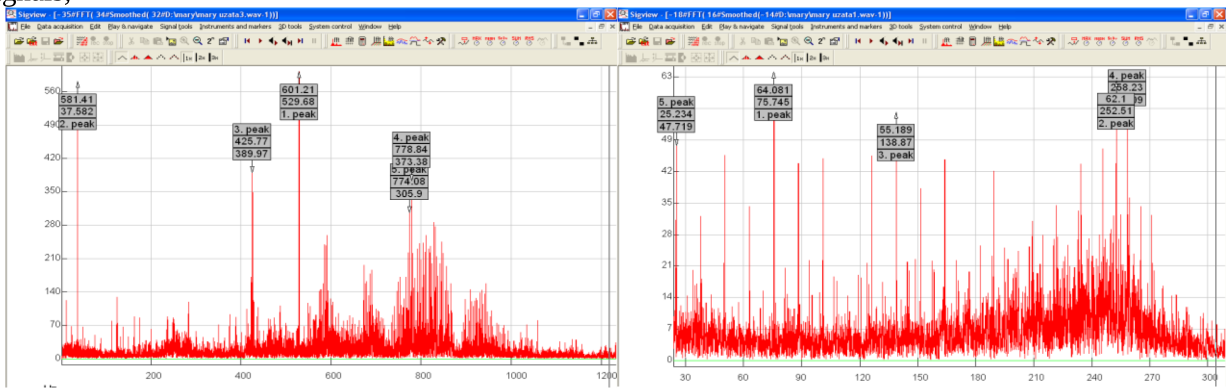
3.2 Analysis of the noise

The analysis and interpretation of the measurement results for the mentioned wear cases was performed using Sigview software, retaining the following significant results for monitoring (Chang-Fei & Houghton, 2001):

- raw signal filtering to improve the signal-to-noise ratio (Smoothening);
- FFT (Fast Fourier Transform) analysis;
- analysis of the highest 5 frequency peaks;
- determining the harmonics of the fundamental signals;
- probability of frequency distribution;
- RMS analysis (Root Mean Square);
- amplitude – frequency - time comparative 3D representation;
- 3D power-frequency-time sharing representation.

Following the analysis of the obtained signals, the following conclusions were drawn:

- from the FFT analysis of the filtered signal for the "most worn" plate VB = 0,5 mm a wide frequency range was noted with a clear maximum around 530 Hz and a secondary maximum around 800 Hz. In the case of the signal for the plate with permissible wear VB = 0,5 mm the frequencies are in much smaller areas, the highest amplitude being 258 dB (around the frequency of 260 Hz), and the rest of the frequencies being below 150 Hz (figure 5).



a) $VB = 1{,}2mm$ b) $VB = 0{,}5mm$

Fig.5 Analysis of the five highest peaks

- analyzing the first 5 highest peaks for the three cases, the following maxims presented in the table below are noticed, respectively the variation of the noise amplitudes in time in table 7.

Table 7. Variation of the noise amplitudes

No peak/ insert	insert „new”		Insert with VB = 0.5 [mm]		Insert with VB = 1.2 [mm]	
	Frequency	Amplitude	Frequency	Amplitude	Frequency	Amplitude
1.	254.70	33.26	75,745	64,081	529.68	601.21
2.	533.94	25,522	252.51	62.12	37,582	581.41
3.	266.97	21,888	138.87	55,189	425.77	389.97
4.	240.45	19,981	258.23	63.09	778.84	373.38
5.	747.48	18,657	25,234	47,719	774.08	305.9

- To determine the fundamental harmonics and eliminate the parasitic ones, the signal was filtered using Sigview software, identifying harmonics for certain significant frequencies.
- This helps to eliminate frequencies due to machine tool, external vibrations, unwanted noise. Following the filtration, it is observed the improvement of the signal-to-noise ratio due to wear;
- A very suggestive comparison of the recorded signals is presented in figure 6 by the 3D diagram elaborated in the case of the three composite signals acquired and processed.
- It is clearly observed the increase of the amplitude for the worn plate, as well as the displacement towards higher frequencies, which is also noticed by the previous FFT analysis;

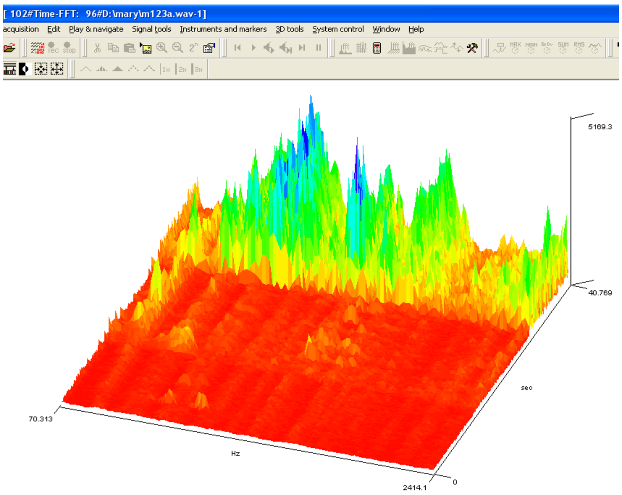


Fig. 6 3D power spectrum for all three signals processed

- But in order to analyze the noise in the cutting process are required in addition to advanced equipment for the acquisition of signals and software products for analysis and interpretation of complex signals.

4 CONCLUSIONS

Following the experimental results obtained and their analysis regarding the roughness of the processed surface, the following conclusions can be drawn:

- from the point of view of the obtained model, it has a high degree of accuracy (P = 95%) for the studied area.
- as the cutting speed increases, the surface roughness increases;
- it is doain bserved that the advance f, is the most significant parameter that affects the roughness of the machined surface. By increasing the feed f, the roughness increases;
- changing the tool geometry by increasing the radius at the tip, r_ε leads to a decrease in roughness;
- by increasing the cutting depth ap, the roughness also increases, but in small amount;
- wear influences little, but in a positive sense the size of the roughness, the explanation being the rounding by wear of the tool tip (r_ε), especially at low r_ε;
- analyzing the samples one can observe a difference in the structure and shape of the roughness R_a by the profile lift, which is lower, when the tool wear increases;
- from the point of view of tool wear monitoring, the R_a roughness can only be used in off-line systems. These systems involve stopping the cutting process for direct measurement of tool wear, interpretation of both roughness quantities and parameters related to its shape.

The increase in roughness with cutting speed and depth is explained by the increase in vibrations due to the kinematics and dynamics of the technological system used in the experiment, which does not have the best rigidity.

Regarding the analysis of the spectrum of the acoustic emission, this can be used for a monitoring of the state of the tool in real working conditions, helping to establish a threshold of the admissible wear of the tool.

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