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CONSIDERATIONS ON INCREASING THE PRODUCTIVITY OF MILLING PROCESS USING BRAIN SUPROGRAMS

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Abstract: *Machining is a complex process in which many variables can modify and interfere with the desired result. Productivity, as a measure of the milling operation efficiency, must follow both the technological elements of the machining process but also the geometrical elements - ways of removing the material and the trajectory of the tool. This paper approaches productivity growth using methods that improve the technological elements of machining. Selection by performance criteria in the field of productivity increase for the milling operation on machines with numerical control ensures an intensive economic growth, desired for any modern society.*
Key words: *milling; CNC; productivity; brains programs; vibrations.*

1. INTRODUCTION

The productivity growth by modifying the technological elements influences both the production costs and also the manufacture time without modifying the level of the obtained surface (reduced number of rejects, the precision of the part, high dimensional tolerances, superior finishing of the surface). Starting from these assumptions it is necessary to define which are the optimal parameters of the cutting regime but also how these processes are influenced by the vibrations that appear during the cutting process. It is known that the performance of the cutting process is influenced by the vibration level. Studies on vibrations and the extent to which they influence productivity have been addressed by numerous researchers. Adam G. Rehorn [1] performs an article analysis of the used sensors and methods for signal processing in order to monitor and improve the vibrations that appeared in the cutting process, regardless of the machine type (lathe, milling, drilling machine). The paper summarizes the studies that refer to the monitor and measurement of the main spindle power, wear, vibrations, acoustic signals, temperatures or cutting forces that use vibration measurement sensors: accelerometer, dynamometer, sensors that measure current power, microphones or sensors for measuring speed.

Krzysztof Kalinski [2] in his work monitors the vibrations that appeared in the cutting process by monitoring the programmed speed. The change of speed is transmitted through the standard serial port RS 232, connected to the machine equipment. The results showed that using a cheap solution, vibrations were reduced. Another study regarding minimizing vibration is performed by Y.S.Liao [3]. With the help of a dynamometer the received signals are sent to the computer and using the Fourier transform the power spectrum is determined. Simulations and tests have shown that vibrations can be eliminated quickly, and the system can be restored into stable state. Chang'an Zhou [4] studied the singularities of vibrations using Lipschitz exponent. It provides information regarding the regularity of the signal by making correlations between the HE values and the singular points of the vibration components. Milling experiments have been carried out on a Hartford CNC-168 machine on a Ti–6Al–4V material. Having the same cutting parameters, a number of 60 experiments have been carried out. Vibration have been measured using a triaxial piezoelectric accelerometers. Based on a machine learning model and a transition points identification method a tool condition monitoring was proposed. The results of the experiments underlined that modifying the TPIM data an improvement of 8.9% was achieved.

Caixu Yue [5] in the paper A review of chatter vibration research in milling identifies and tries to predict and control chatter vibration for milling operations. Experimental techniques and chatter prediction and detection between cutting chatter and process damping, tool runout, and gyroscopic effect have been analyzed.

The productivity of the milling operation was also studied in the paper Productivity and cycle time prediction using artificial neural network [6]. The author proposed a ANN structure that will predict cycle time for High Speed machining. The cutting regime was used to reduce the vibration level. The ANN simulation was designed considering the cutting regime during machining, for an Aluminum material.

Improvement based on simulation results were presented in paper [7]. The paper presents simulations for milling processes and improvements were proposed by identifying every input and output and by introducing them into a cause-and-effect matrix. The importance of each input can be mathematically calculated, and action can be taken for the critical ones in order to improve the process.

2. STUDIES REGARDING THE IMPROVEMENT OF THE MILLING OPERATION PRODUCTIVITY

2.1 Productivity measurement

The productivity is represented by the efficiency to which the production factors are used at company level, with the role of producing services or products. Depending on the used production factors and the obtained production, we can determine the productivity level.

The average productivity level (W) is expressed by the relation [8]:

$$W = \frac{Q}{F} \qquad (1)$$

where: Q is the actual volume of the production, and F the factor (s) of production used to obtain it.

Taking into account the level we are referring to, at a company level we distinguish the next productivity types:

- Company, department or job productivity;
- Economic sector productivity;
- National economy productivity.

Two types of productivity analysis can be applied: partial or global productivity.

Partial productivity refers to the analyses of the most important and decisive factor of activity. It is a single factor of production. The partial productivity can be calculated using the formulas:

- Average partial productivity:

$$W_x = \frac{Q}{L} \qquad (2)$$

- Partial marginal productivity:

$$W_{mgx} = \frac{\Delta Q}{\Delta L} \qquad (3)$$

In order to calculate the global productivity, all the production factors that are involved are included. The global productivity can be calculated using the formulas:

- Average overall productivity:

$$W_g = \frac{\sum Q}{\sum L} + \sum K + \sum Q \qquad (4)$$

Where L- the work done,
K - the invested capital.

- Global marginal productivity:

$$W_{gmg} = \frac{\Delta Q}{\Delta L} + \Delta K + \Delta P \qquad (5)$$

2.2. Measuring the productivity of the milling operation

The productivity of the milling operation can be improved using different techniques. The most important are mentioned above:

- establishment of the optimal production time;
- modify the cutting regime of the milled part;
- determine a predetermined milling time that will help the business to meet deadlines
- decrease the number of rejections;
- improving the process;
- improving the quality of the obtained surfaces;

The present paper aims to improve the productivity by improving the cutting regime used for milling. The challenge is to increase the volume of chips produced per unit of time, without changing the quality of the surface obtained, while maintaining a low level of vibration. A correct choice of tools and cutting regime results in high productivity, while contributing to a decrease in production time and power consumption [9-12]. The paper presents the results of a research team and were the subject of a doctoral thesis [13].

The performed experiments for optimizing the cutting regime according to the level of appeared vibrations were performed with a 6 mm milling tool, with 4 teeth, on a 3-axis Fanuc equipment. These are presented in Figure 1. For the simulation, the cutting regime of table 1 was used. The cutting regime was randomly called, according to an algorithm developed by the author [13]. For this paper, we used only the simulation for 1000 rpm, for all feeds rate.

Table 1

Used cutting regime

Speed [RPM] / **Feed [mm/min]**	**1000**	**1200**	**1400**	**1600**	**1800**
10	14	2	15	8	11
20	5	17	18	6	3
30	13	20	12	19	9
40	21	10	23	22	16
50	25	1	7	24	4

The experiment was carried out over a period of 12 seconds for each cutting regime. Then, a 12 seconds blank machining was programmed and so on, for each cutting regime. In order to obtain conclusive results, the milling was done using both variable feed rate but also with variable speed (Fig.1)

Regardless of the movement type, it is considered that the value of the feed rate is always the value of the tool relative to the part, being the vector composition of the speed on each axis [13].

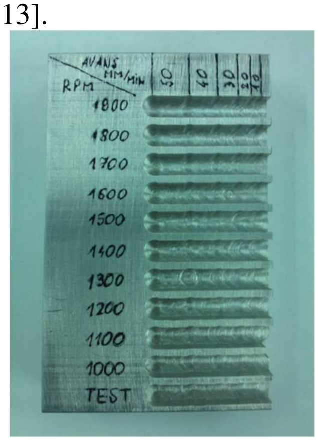

Fig. 1. Machined results [13]

The measurement of the vibrations is done using a IFM sensor. The sensor has the possibility of monitoring the vibration level in real time (Fig. 2).

Fig. 2. IFM sensor

How the sensor works is presented below. A signal in the 4-20mA range is measured. Then, the signal must be transformed using a microcontroller from an analog voltage signal (input) into a digital data (output). The computer needs to be equipped with a 4-pin system that will generate 16 signals. The 16 signals will be used by the machine equipment.

In order to obtain graphs for the measurement of the vibration level, a Java application was developed. The application uses the information received in real time from the sensor and transforms it into an analog signal.

The results obtained are shown in Figure 1. For this research, a speed of 1000 rpm was used and a feed rate in the range 10 mm / min to 50 mm / min. A total of 80 recording data were obtained, records obtained from the measurement made by the IFM sensor. The first 10% of these values were eliminated, the experiment considering only 70 values.

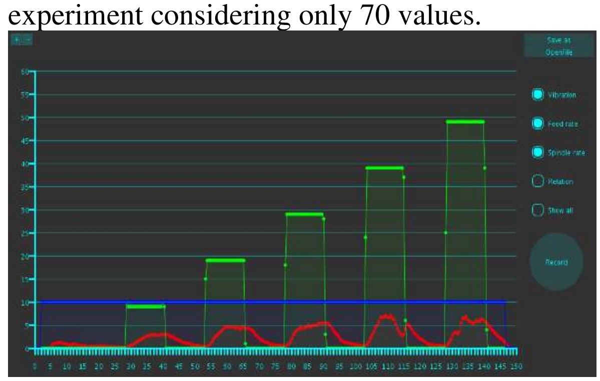

Fig. 3. Measured vibration level [13]

The vibration level is measured in RMS and is shown with red in Figure 3. The green indicates the level of feed rate - which varied in the range 10-50 mm / min, and with blue is indicated the speed level – for this experiment having a constant value. We observe that the maximum vibration peak was obtained for the value of 40 mm / min feed.

Taking into account the factors that influence the milling process, we obtained the formula for calculating the productivity of the milling operation:

$$w = \frac{Q}{abF} \qquad (6)$$

Where a represents the cutting width, mm; b represents the cutting depth, mm; F represents the feed rate, mm / min

3. CONSIDERATIONS ON IMPROVING MILLING PRODUCTIVITY

3.1 Use of “Brains” subprograms

The main objective of this research is to improve the productivity of the process. In order to achieve the goal, it was turns to the use of "Brains" subprograms, using Maple software. It receives the cutting parameters (in real time), and sends them via USB to the Java application, which has the role of monitoring thm (vibration level, cutting feed and cutting tool speed) [13].

The sent data are displayed as: # sensor value, speed value, feed value.

The role of the '#' character is to highlight that the data that follows are values separated by the comma character, maintaining the order: sensor value, speed value, feed value.

The software receives the vibration level and speed values from the sensor. It does not change them; it only introduces them in a data package. In order to read the value of the feed rate parameter, the Maple software receives the signals of the servo-motor drivers command impulses and calculates the velocity vector on each axis (figure 4). Having the values of this read vector, one can calculate the value of the vector relative to the tool speed for each axis.

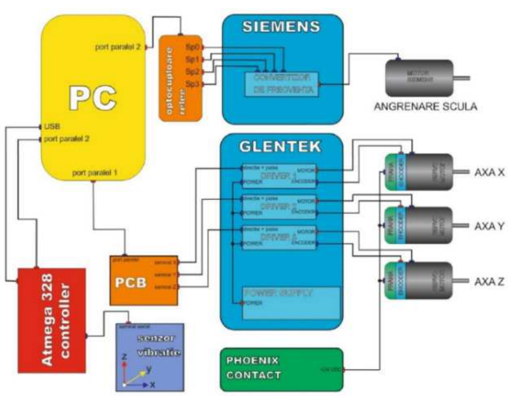

Fig. 4. Block diagram of the experimental stand [13]

The Maple software has the main objective of processing the signal received from the vibration sensor and to send it to the computer through the parallel port. All the information regarding the cutting regime (feed and speed – the speed being communicated through the relays of the milling motor converter) are received during this process.

The role of this research is to improve productivity by optimizing the cutting regime. Thus, the signal from the vibration sensor has been modified from analog signal (current between 4mA and 20mA) into analog voltage signal. The voltage is the one that was read and converted into digital value, ADC, by the microcontroller mounted on the second printed wiring intended for communication with the computer through the second parallel port.

The input signals of the Maple software are:

- The information from the vibration sensor is read as an analog signal, 4-20mA to 24V
- Feed: 3 digital signals, pulse / time
- Speed of the milling machine: 4 digital signals, binary value

The output values are:

- Vibration sensor reading: 10 digital signal, binary value
- Speed of the milling machine: 4 digital signals, binary value, sent to the converter
- Data from the sensor, speed and feed: digital signal sent through serial port

The paper does not present the algorithm, being a 10-page program, but it presents the steps that need to be taken to read the data:

- ✓ The pins are initialized. The pins have the role of reading the analog signal received from the sensor, of transferring this value to the computer and of controlling the bits of the engine speed and the signals for reading the feed rate.
- ✓ The variables that are used into the program are also being initiated.
- ✓ The configuration of the pin and the interruptions used by the algorithm are done using the function void setup (). The role of the interruption is to pause unimportant functions until priority

signals are read. It also initializes a time variable.

- ✓ The necessary functions of the program are accessed using a main loop (void loop). This loop has a repetitive character and is being used indefinitely.
- ✓ A function that accesses the digital-to-analog converter with the role of reading the signal received by the wave sensor in a value from 0 to 4096 is also used. We need to use also a function for the interpolation. The actual reading of the sensor is approximately between the threshold 700 and 1200, and to the computer is necessary to send a value in 10 bits, ie from 0 to 1024
- ✓ The value that is read from the sensor is then transformed from base 10 to base 2. The 10 signals will be transmitted via the parallel port.
- ✓ Then the signals that activate the relays that control the speed of the milling motor are read. They are transmitted further using the serial port.
- ✓ Also, the pulses sent to the drivers in a unit of time are read. They are used to calculate the actual feedrate of the mill. These pulses define the movements of the axes without taking into account their direction.
- ✓ The feedrate is also calculated using counters created by the defined functions and the equivalent ratio of transforming the rotation movement into translation of ball screws. The counters are then reset to be prepare for the next value that is transmitted.
- ✓ The readings from the sensor (feed rate and speed) are written into the serial buffer respecting an established transmission convention. These values are used for real-time viewing of data.

The electric scheme of the stand is presented in figure 5.

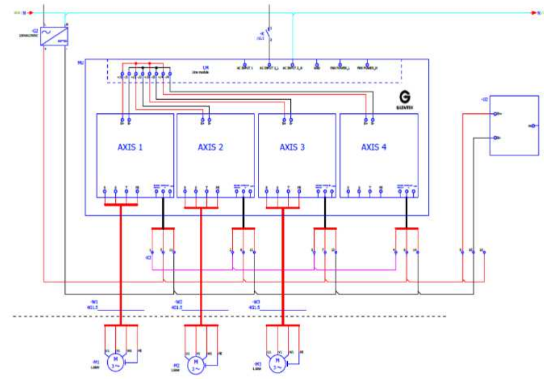

Fig. 5. Engine power supply

Then, the 10 digital signals are processed by the created "Brains".

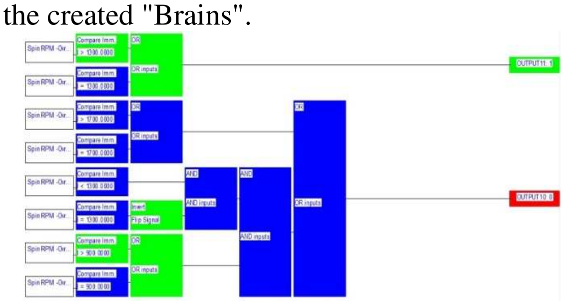

Fig. 6. Writing bit 1 and 2 in the Output11 and Output10

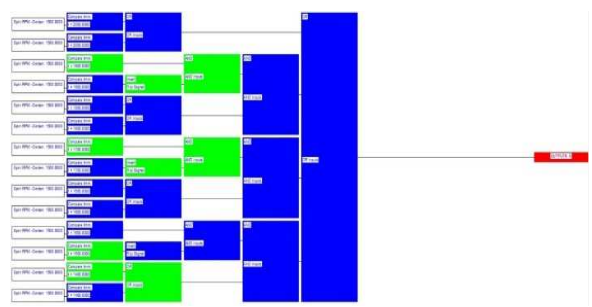

Fig. 7. Writing bit 3 in the Output9

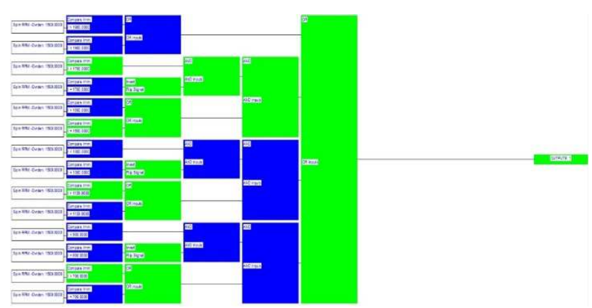

Fig. 8. Writing bit 4 in the Output8, case 1

Fig. 9. Writing bit 4 in the Output8, case 2

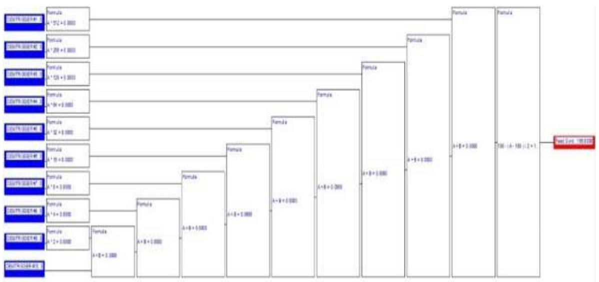

Fig. 10. Reading the 10 inputs representing vibration sensor reading

The sensor values from 0 to 1024 are read by the computer, which receives the 10 signals and converts them into decimals. Changing values occurs by rewriting the percentage of overwrites that is initially equal to 100.

Thus, for the feed rate we obtained the formula:

$$100 - (Cit.senz / 10.24)*0.5 \qquad (7)$$

where:

100 is the normal percentage (without overwrite)

Cit.senz is the value received from the sensor via Maple (between 0 and 1024), representing the sensor reading (between 0 and 7)

10.24 is a normalization factor

0.5 is an influencing factor

For the speed the obtained formula is:

$$100 + (Cit.senz / 10.24) * 0.2 \qquad (8)$$

3.2 Improving the milling operation

Analyzing formula (6), we can observe that the factors that can improve and increase the productivity of milling process are the feed rate. Thus, with the help of the developed "Brain", when the vibrations or excessive noise appear the software reduces one or more parameters - speed, feed rate or cutting depth so that the vibration level is reduced or even eliminated. Thus, a new set of tests was performed, tests in which the created subprograms were used. The conditions of the simulation remained the same (milling, number of teeth, diameter or clamping), the feed rate being the only factor that varied.

The results obtained are shown in Figure 11. In this case, a total of 80 data were obtained. The first 10% of these values were eliminated, the research considering only 70 values.

Fig. 11. Vibration level optimization using a 6 mm milling cutter

Comparing the graphs from Figure 11 with the ones from Figure 3, we can observe that decreasing the vibration level automatically increases the feed rate. Analyzing figure 11 it can be observed that when reaching the maximum level of vibrations, using the software, the value begins to decrease. The two are inverse dependent on each other.

The maximum difference obtained is 7.08 RMS, the difference reached in non-movement state, with both speed and feed rate equal to zero. When starting machining, the maximum difference was obtained for a feed rate value of 37 mm/min. The maximum difference for this case is -2.834 RMS.

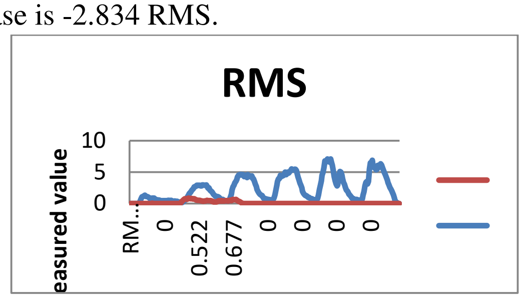

Fig. 12. RMS values, after optimization

In order to be able to visualize the extent to which the change of the feed influences the productivity, the obtained values were centralized in the table 2. The exemplification was made only for the first 10 values of 50 mm / min and 40 mm / min of the feed rate.

Table 1

Title of table - center aligned and justified, 10 point, bold.

RMS, after optimization	Optimized feed mm/min	RMS, before optimization	Increase of productivity
0.012	46	0.18	0.021739
0.024	48	0.24	0.020833
0.13	48	0.12	0.020833
0.323	48	0.12	0.020833
0.503	47	0.24	0.021277
0.671	45	0.37	0.022222
0.745	43	0.49	0.023256
0.739	42	0.68	0.02381
0.012	46	0.18	0.021739
0.024	48	0.24	0.020833
0.379	45	0.37	0.022222
0.385	46	0.37	0.021739
0.459	46	0.62	0.021739
0.466	45	0.99	0.022222
0.441	45	1.49	0.022222
0.584	44	2.11	0.022727
0.677	43	2.61	0.023256
0.609	43	2.85	0.023256
0.621	44	3.29	0.022727

4. CONCLUSION

The experimental program demonstrated the viability of the productivity improvement algorithm. So far, the research has focused only on changing the feed rate, keeping the speed constant. It is observed that following the change of the feed rate the best improvement was obtained for an improved feed rate of 16 mm / min, obtaining a productivity increase of 0.0625.

Previous research has indicated the decisive influence of the cutting regime parameters on the vibration level. Next, it is necessary to develop an experimental program in which both parameters of the cutting regime are modified.

5. REFERENCES

[1] Adam G., Rehorn J. J., Peter E. O. *State-of-the-art methods and results in tool condition monitoring: a review*, Int J Adv Manuf Technol 26: 693–710, DOI 10.1007/s00170-004-2038-2, 2005

[2] Kalinski K., Kucharski T., *Computer prediction of the tool-workpiece vibration surveillance in modern milling operations,* Advances in Technology of the Machines and Equipment, vol. 23, no 3, p. 17-42, 1999.

[3] Liao Y.S., Young Y.C., *A new on-line spindle speed regulation strategy for chatter control*, International Journal of Machine Tools and Manufacture, Volume 36, Issue 5, May 1996, Pages 651-660

[4] Zhou C., Yang B., Guo K., Liu J., Sun J., Song G., Zhu S., Sun C., Jiang Z., *Vibration singularity analysis for milling tool condition monitoring,* International Journal of Mechanical Sciences, 166, 2020

[5] Yue C., Gao H., Liu X., Liang S. Y., Wang L., *A review of chatter vibration research in milling,* Chinese Journal of Aeronautics, 32, 215–242, 2019

[6] Gelmereanu C, Morar L., Bogdan S., *Productivity and Cycle Time Prediction Using Artificial Neural Network*, Procedia Economics and Finance, vol.15, pages 1563 – 1569, 2014.

[7] Bodi Ş., Dragomir M., Banyai D., Dragomir D., *Process Improvements Using Simulation Software and Quality Tools,* Applied Mechanics and Materials, Volume 808, pages 376-381, https://doi.org/10.4028/www.scientific.net/amm.808.376, 2015

[8] Abrudan I., Candea C., *Manual de inginerie economica: ingineria si managementul sistemelor de productie*, Cluj-Napoca, Editura Dacia, 2002

[9] Budak E., *Improving productivity and part quality in milling of titanium based impellers by chatter suppression and force control*, Ann CIRP vol. 49(1):31–36, 2000

[10] *Elemente privind dinamica automatizării industriale şi a creşterii performanţelor de flexibilitate şi de progres tehnologic*, http://www.management.ase.ro/revecon omia/2000/11.pdf, accessed 22.11.2019

[11] Niu J, Ding Y, Zhu LM, Ding H., *Stability analysis of milling processes with periodic spindle speed variation via the variablestep numerical integration method*, J Manuf Sci E-T ASME, vol. 138(11):114501–11, 2016.

[12] Jin G, Qi H, Li Z, Han J., *Dynamic modeling and stability analysis for the combined milling system with variable pitch cutter and spindle speed variation*, Commun Nonlinear Sci, vol. 63, pages 38–56, 2018.

[13] Gelmereanu C., *Contribuţii privind proiectarea şi elaborarea unui stand de cercetare CNC,* PhD. Thesis, Cluj-Napoca, Universitatea Tehnică din Cluj-Napoca, 2013

Consideraţii privind creşterea productivităţii procesului de frezare prin utilizarea suprogramelor de tip brain

Rezumat : Prelucrarea prin frezare este un proces complex în care multe variabile pot modifica şi interfera cu rezultatul dorit. Productivitatea, ca o măsură a eficienţei operaţiei de frezare trebuie să urmareasca atât elementele tehnologice ale prelucrarii cat si elementele geometrice- modalitatile de indepartare a materialului si traiectoria sculei. Lucrarea de fata abordeaza creşterea productivitatii prin utilizarea metodelor care imbunatatesc elementele tehnologice ale prelucrarii. Selecţia pe criterii de performanţă în domeniul cresterii productivitati pentru operatia de frezare pe masini cu comanda numerica asigura o crestere economica intensive, deziderat pentru orice societate moderna.

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