Study of the cutting process parameters that influence the surface quality machined by end milling of the aluminum alloy

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Abstract. This research aims to carry out an elaborate experiment by which resulting in relevant conclusions that have practical applicability in the aeronautical industry. The surface roughness measured transversely and longitudinally on the feed motion direction of the cutting tool constitutes the dedicated objective function on which the study was conducted in this case. The end milling was chosen of an aluminum alloy used explicitly in the aeronautical industry. The actual experiments were carried out in the only aeronautical industry in Romania carrying out these types of machining and were made according to the methodology with rigorous experimental planning of the research. The experimental plan conceived after which the practical experiments were conducted led to applied research already put into practice within the above-mentioned industrial organization.

1 Introduction

A particularly important aspect of the cutting operations is the workpiece that has to be accurate, both in terms of surface quality and dimensional precision. These conditions must be achieved as soon as possible and at the lowest possible energy consumption. In order to meet these requirements, irrespective of the machining operation chosen, it is imperative to choose the machining parameters.

Among the representative studies carried out in this direction are the research carried out by Warhade, which analysed the optimal combination of feed rate, cutting speed and cutting depth, of aluminium machining in order to obtain the shortest processing time, with the lower CNC power consumed and the rate of removal of the material as high as possible [1].

We also stated that Jomaa, in his research, shows besides the feed per tooth, that the surface quality is also influenced by the sharpness of the cutting edge of the tool [2].

The quality study of the machined surface, depending on the process parameters of the aluminium alloys, is subject to a significant number of scientific papers, among which are mentioned: Gökaya [3], Kuttolamadom [4], Doddapattar & Lakshmana [5], Köklü [6], Patel [7], Singh [8], Vakondios [9], Durakbaşı [10], Gulhane [11], Kannan [12], Patel [13], Tammineni & Yedula [14].

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2 Planning the experimental research

Regardless of the considered objectives, before the actual experiments are carried out, a mandatory first step is the rigorous planning of all experimental research.

Therefore, all experimental research was planned, so it was established:

- Cutting operation: end milling process;
- The type of the cutting tool: SECO R217.69-1616.0-09-2AN with two teeth, carrying two cutting inserts of XOEX090308FR-E05, H15;
- The values of the cutting regime parameters:
- Cutting speed [m/min]: 495, 530, 570, 610, 660, and 710;
- Cutting depth [mm]: 2, 2.5, 3, 3.5, 4;
- Feed per tooth [mm/teeth]: 0.04, 0.06, 0.08, 0.11, and 0.14.
- CNC machine to conducting the experiments: HAAS VF-YT2;
- Workpiece material: 7136 aluminum alloy;
- Measurement device: Mitutoyo Rugosimeter SURFTEST SJ-210.

Considering the purpose of the paragraph, it is still necessary to establish an experimental plan. To track the influence of process parameters on the arithmetic average deviation of the surface profile, a full factorial experiment will be used.

For the three factors chosen for the study: feed per tooth, cutting speed and cutting depth, and their corresponding levels, 150 experiments are required. It will be determined by measuring the roughness R_a longitudinally and R_a transversely of the machined surfaces.

Regarding the experiments planning, according to Montgomery [15], there are three basic principles, namely:

- The principle of random character - which implies observations (or errors) required by the statistical methods in order to fulfill the requirement of a random character that is to be randomly distributed over the parameters. Randomizing observations makes this hypothesis to be valid.
- The Replication Principle - requires repetition 3 to 7 times the experiment of every combination of the input parameter values. This is essential to find the measurements consistency. Thus, replication will be performed seven times to get the most accurate results. That is, for each set of parameters some seven measurements will be performed.
- The principle of working in "blocks" – which is used in order to improve the precision of the comparison of the used factors. Therefore, the current research will work with some 7 blocks.

Based on this procedure, it was possible to realize the complete experimental factorial plan with the seven blocks. The number of R_a longitudinally measurements (7 measurements), respectively those measured R_a transversely (7 measurements) - accumulate a total of 14 (7 x 2) measurements. These were performed on each combination of set input parameter values resulting in a total of 300 (150 x 2) measurements.

Each sample will have 50 related machining of 50 combinations of the cutting regimes parameters. The end milled surface of a cutting regime will be 50 x 16 mm. Therefore, the 150 cutting regimes combinations will be analyzed by machining of 3 blocks with the mentioned dimensions, and the machining will be resumed in order to achieve the seven replications set. Finally, a total of 21 Al7136 blocks will be processed.

3 Study of the cutting parameters influence exerted on the surface roughness

After the carried out experiments according to the established experimental plan, the surface roughness measurements were obtained and based on these, a series of graphs were made

which centralizes these values and in which it can be followed the influence of each set cutting parameter exerted on the surface quality.

3.1 The cutting speed influence on the Ra long and Ra transv

In figure 1 are graphically represented the values of the Ra long, obtained at the set cutting speeds.

As a result of the graph analysis, it has been found that with the increase of the cutting speeds in the range of 495 to 660 m/min, the average of the values is increasing. Therefore: in the situation when we have the cutting speed of 495 m/min - Ra long has 0.27 μm , when the cutting speed is 660 m/min - Ra long is 0.57 μm , when the cutting speed is 710 m/min - the Ra long is 0.62 μm - 2 to 3 times higher.

Fig. 1. The cutting speed variation exerted on Ra long.

For 570 m/min, the roughness values distribution is quite high compared to the other cutting speeds, so the ratio of the maximum and the minimum value is eight times compared to the other values where the ratio is 2.2 (660 m/min) - 4.99 times (495 m/min).

To emulate specific hypotheses regarding the grand distribution of Ra values at 570 m/min, these phenomena were analyzed about the other parameters of the cutting process.

Fig. 2. Influence of the 570 m/min cutting speed, exerted the on Ra long.

In figure 2, one can notice the direct influence exerted on Ra long by the cutting depth together with the feed when the cutting speed is 570 m/min.

Analyzing the instantaneous dynamic behavior of the CNC – cutting tool-workpiece, overlapped with the tool loading, with the increase of the cutting depth at a small feed per tooth, the effect of vibrations in this technological context should be studied.

From the experimental data obtained we consider that this vibrations phenomenon does not occur regularly. This is because, at the same combinations of the cutting process

parameters, at which the highest values of roughness are obtained, values below 0.8 μm have been obtained in this case.

In figure 3 it can be seen that out of a total of 25 values corresponding to the speed of 570 m/min, 77.7% are over 0.8 μm .

Fig. 3. Distribution of Ra long experimental data on value ranges.

However, it should not be forgotten that under certain conditions (combinations of cutting parameters) the resonance phenomenon may lead to a lower quality of the surface.

In conclusion, the field of values of the predominant roughness below 0.8 μm , covering 77.7%, obtained when the cutting speed is 570 m/min, maintains the increasing tendency of the entire chosen range of speeds. The massive distribution of experimental data leads to a much lower estimate of roughness values resulting from combinations of process parameters.

Referring to the situation of Ra transv roughness obtained at different cutting speeds, this is shown in figure 4.

Fig. 4. Influence of the cutting speed variation exerted the on Ra transv.

After the analysis of this figure it was found that similar to the situation of Ra long, with the increase of the cutting speeds within the given interval, the average of the values of the Ra of the surface profile is increasing. Thus, for the cutting speed of 495 m/min Ra transv is 0.17 μm , at 660 m/min Ra transv is 0.31 μm , for 710 m/min, the Ra transv is almost 3 times higher, having a value of 0.5 μm , and for 570 m/min, the distribution of Ra transv values is quite high compared to the other cutting speeds. The ratio between the maximum and minimum recorded value is 30 times compared to the other values for which the ratio is between 8.06 (cutting speed of 660 m/min) and 10.6 times (cutting speed of 495 m/min).

Like the previous case, this phenomenon was analysed at the cutting speed of 570 m/min, related to the other parameters of the cutting process.

Fig. 5. Influence of the 570 m/min cutting speed, exerted the on Ra transv.

Figure 5 shows the direct influence on the Ra transv exerted by the cutting depth together with the feed per tooth at 570 m/min-cutting speed.

3.2 The influence of the cutting depth exerted on the Ra long and Ra transv

Figure 6 shows the Ra values obtained related to different cutting depths. The values represented are the minimum, the maximum and the average of the Ra long resulting in the experiment.

Fig. 6. Influence of the cutting depth variation exerted the on Ra long.

The significant distribution of the Ra long values using 570 and 610 m/min about the cutting depth also influence the maximum roughness values.

Since the obtained average values are almost linear, (figure 6) it was found that the cutting depth variation does not produce a significant fluctuation of the Ra long values.

As for the Ra transv, the situation is presented in figure 7.

Following the analysis of this figure, it was found that the influence of variation of the cutting depth on Ra transv is manifested by an irregular distribution of the experimental data. The maximum measured values of Ra transv are affected by the results obtained at speeds of 570 - 610 m/min, following the linear evolution of the average values, the cutting depth variation does not significantly influence the surface roughness in this situation.

Fig. 7. Influence of the cutting depth variation exerted the on Ra transv.

3.3 The feed per tooth influence exerted on the Ra long and Ra transv

Figure 8 present Ra long values obtained experimentally using different feed values.

Fig. 8. The feed per tooth variation exerted the on Ra long.

After analyzing the figure 8, it has been found that a feed increase, within the range recommended by the manufacturer, does not significantly affect the surface quality, due to the cutting speeds and feed rate correlation with the cutting tool manufacturer.

However, the high Ra values obtained at 570 m/min and a small feed per tooth are also highlighted here.

In figure 9, the influence of the feed per tooth variation on Ra transv was shown.

From this figure, following the average of the maximum and minimum values of the roughness measured in the experimental field, it was found that within the range recommended by the manufacturer, the increase in the feed per tooth does not substantially affect the surface quality, except for the cutting speed of 570 m/min. As general conclusions resulting from all the graphical analyses performed on the experimental data resulting from the measurement of the roughness of the surface profile, the following findings are presented:

- Cutting speed has the most significant influence on both the Ra long and the Ra transv;

Fig. 9. The feed per tooth variation exerted the on Ra transv.

- At certain cutting speeds, in combination with certain values of the cutting depth, respectively the feed per tooth, we assume that the vibration phenomenon occurs in the measured values of the Ra of the surface profile and its texture;
- The cutting speed along with the feed per tooth, have the greatest influence on the surface quality;
- The cutting depth along with the feed per tooth has a little influence on the surface quality.

4 Conclusions

Following this scientific research, a series of observations can be made on the individual influences of each process parameter applied on Ra of the profile of the machined surface:

Cutting speed is the parameter with the most considerable influence on surface roughness. With its increasing, Ra's average has an increasing trend. When the cutting speed is 570 m/min, with the increase of the cutting depth, at a small feed per tooth, following the analysis of the instantaneous dynamic behavior of the machine tool – cutting tool-workpiece, we consider that the vibration effect in this technological context, in view of the fact that large roughness is obtained after processing.

The cutting depth variation does not produce a large Ra fluctuation, so there are no significant influences.

Increasing the feed rate does not necessarily affect the surface quality, except in the case of 570 m/min (and a small feed per tooth), in which case the surface roughness increases.

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