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Determination of cutting resistance in the process conventional and trochoidal milling

Wyznaczanie oporów skrawania w procesie frezowania konwencjonalnego i trochoidalnego

GRZEGORZ SKORULSKI *

Cutting forces in the process of conventional and trochoidal milling of aluminum 2017 alloy were determined and analyzed. A machining strategy, testing guidelines and the possibility of using a measuring platform based on resistance tensometry elements were developed. The paper also presents an analysis of the results concerning the distribution of the cutting forces in the processes of conventional and trochoidal milling, carried out with the same cutting parameters and tools. An attempt was made to interpret the results.

KEYWORDS: milling, cutting forces, measuring platform, trochoidal milling

Each cutting process, including milling, requires the use of force necessary to deform the scratched layer, separating it from the material in the form of chips, deforming this chip and overcoming the frictional resistance occurring mainly between the tool and the workpiece [1, 2] .

Conventional milling is increasingly replaced by high-performance methods. It became possible as a result of the development of machine tools and programming of machining in CAD/CAM systems. It is possible to distinguish TPC (trochoidal performance cutting), included in the strategy of HSM (high speed machining) [6]. This is not related to similar machining parameters, as these are different, but with gentle tool movements and high volumetric productivity of processing [7]. The advantages of this method include the possibility of machining thin-wall elements and a favorable system of the component cutting forces due to the large depths of the cut layers [5]. In addition, this technology is used in the treatment of alloys in the hardened state [9, 11].

Knowing the nature and distribution of cutting forces during the process is necessary to evaluate the tool load. This knowledge will be useful for technologists and operators of numerically controlled machine tools; it will allow them to control work parameters in such a way as to shorten the machining times without a sudden increase in the forces acting [3, 4].

Based on the knowledge of the value and direction of the total cutting force, it is possible to counteract critical situations related to the strength of the tool. Comparison of the actual distribution of constituent cutting forces in conventional and trochoidal milling allows to assess the suitability of these methods for machining tasks in which improper selection of technological parameters can lead to damage to an object or tool (in the case of flaccid objects), small clamping forces in the holder).

Initial assumptions and preparation of tests

A cube (fig. 1) with dimensions 50 mm × 50 mm × 20 mm (length × width × height) was designed for processing. In the center of the dial there is an open pocket 16 mm wide and 6 mm deep, and on both sides there are grooves - 44.5 mm × 12 mm × 4 mm (*L* × *W* × *D*). The block was made of aluminum alloy PA6 (2017) with hardness in the range 101÷110 HB.

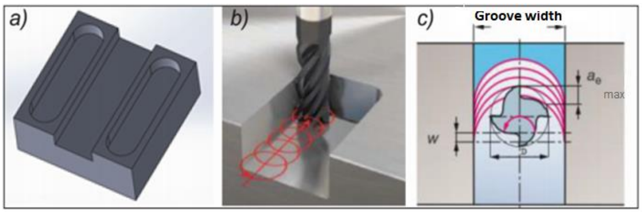

Fig. 1. Workpiece: *a)* visible open pocket and two grooves, *b)* fragment of the tool trajectory, *c)* scheme of adjustable trochoidal milling parameters [7]

During programming in the CAM system, two parameters are defined. According to fig. 1c, the maximum width of the cutting layer has been pre-selected: a_{emax} = 4 mm and the tool pitch: w = 0.8 mm.

Measuring platform

The MC6 measuring platform is used to measure forces in perpendicular planes and torque components [5]. In its construction, strain gauges were mounted on a structure ensuring high stiffness, sensitivity and repeatability of measurements. The design of the transducers ensures the stability and negligible influence of the measured quantities. The solution is protected by a patent: U.S. Patent # 4493220.

The housing is made in water and oil-tight version. A measuring platform is used where it is necessary to simultaneously record several quantities of forces and moments or measurements of changes in their value and return. The platform used in the research has six outputs corresponding to the forces F_x, F_y, F_z and moments M_x, M_y, M_z [5]. The equipment of the station is shown in fig. 2.

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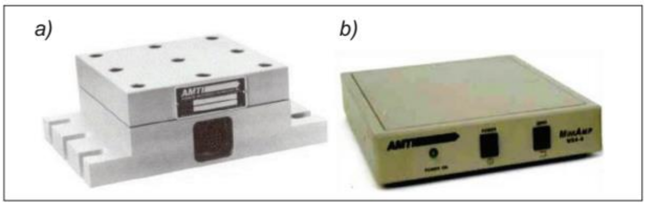

Fig. 2. Measuring station equipment: *a)* AMTI MC6-6-4000 measuring platform, *b)* MiniAmp MSA-6 measuring amplifier

Thanks to the display of real-time values by dedicated NetForce software, it is possible to monitor current data from multi-axis force sensors [10]. This is a similar function in the operation of the oscilloscope, but instead of the electrical signals, the output from the converter (e.g. an amplifier) is displayed. When applying force or load to the sensor (or platform), the change in value will be shown in the NetForce real-time signal window [4].

Research

An end mill Ø12 mm was used to machine an open pocket with a width of 16 mm. The following parameters were selected:

- feed speed = 500 mm/min,
- spindle speed = 4509 rpm,
- cutting depth = 3 mm.

The grooves were made with a face mill with a diameter of ⌀8 mm at the parameters:

- feed speed = 450 mm/min,
- spindle speed = 5570 rev/min,
- cutting depth = 2 mm.

A platform with a machine vise was mounted on the machine tool table (fig. 2). The signal from the platform was transmitted by the amplifier to the desktop computer. The measurement results have been saved in text files. From the received, averaged on the basis of 15 points, the maximum values of forces were calculated (according to fig. 3) the active force of the cutting F_a, the measured force $F_p = F_z$ and the calculated total cutting force F.

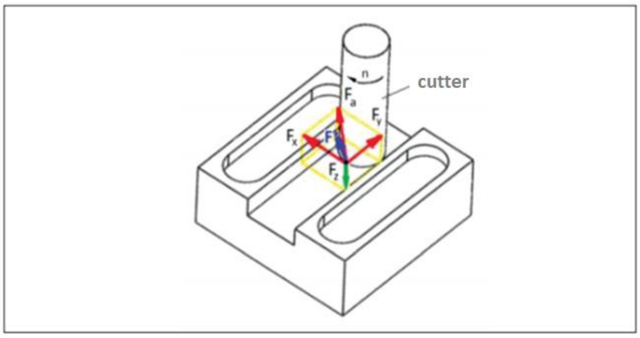

Fig. 3. Diagram of the components of the determined cutting force

Test results

The results in the form of text files have been transformed in Excel into graphs of components of cutting forces, obtained for milling with both machining methods, using the same tools and the same machining parameters.

Exemplary results regarding registered cutting forces in grooving with a bevel cutter, ⌀8 mm, by conventional method are presented in figs. 4-6, and with a trochoidal method - figs. 7-9.

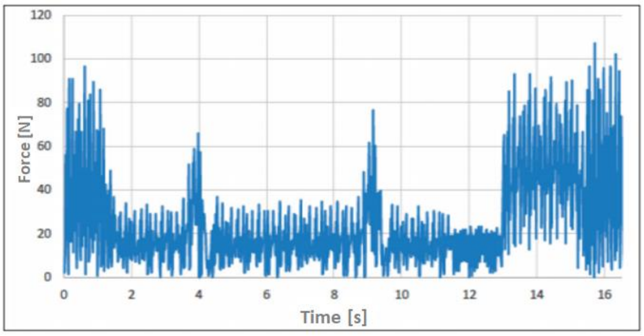

Fig. 4. Graph of the force component F_x when milling the groove with the conventional method

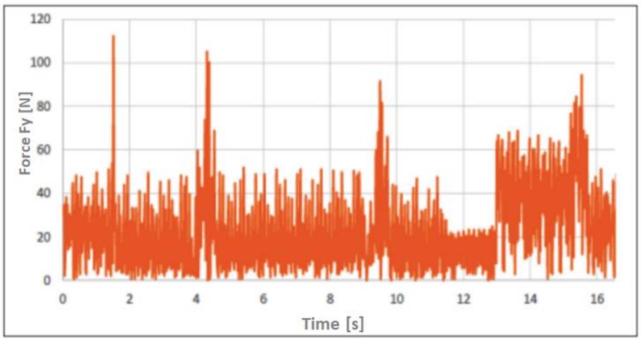

Fig. 5. Graph of the F_y force component when milling a groove with the conventional method

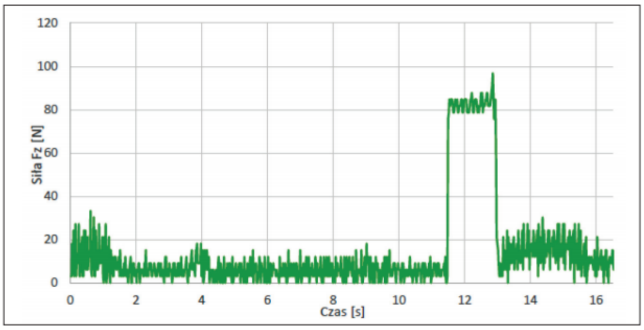

Fig. 6. Graph of the F_z force component when milling the groove with the conventional method

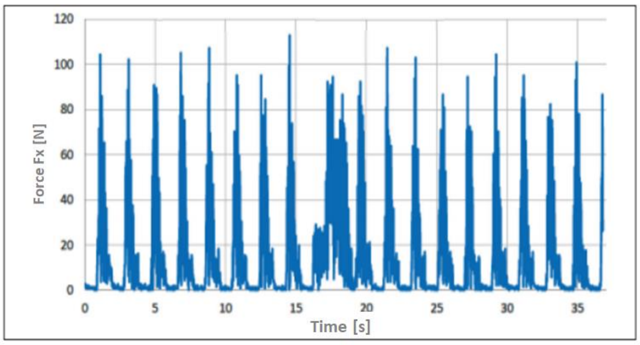

Fig. 7. Graph of the F_x force component when milling the groove with a small-scale method

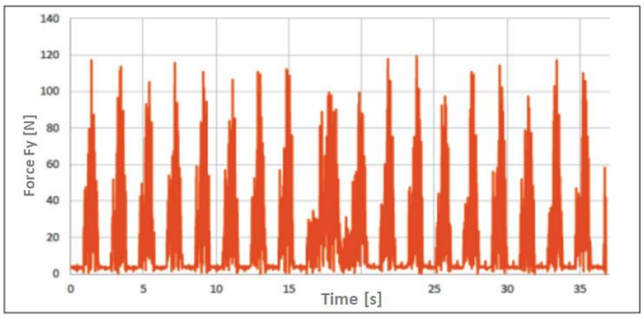

Fig. 8. Graph of the F_y force component when milling the groove with a small-scale method

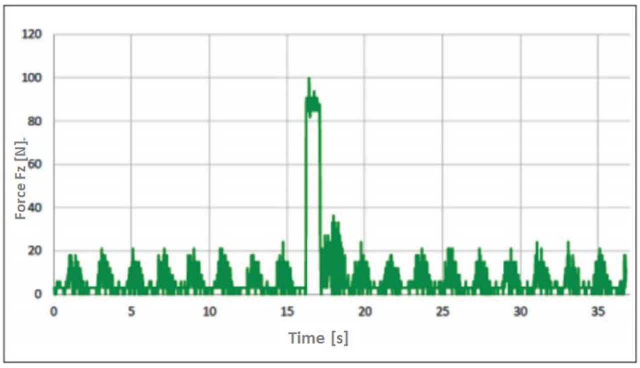

Fig. 9. Graph of the F_z force component when milling the groove with a small-scale method

The rapid changes in the measured forces visible in the diagrams are caused by changes in the geometry of the cut layer (fig. 4 and fig. 5) and the tool motion with infeed at the beginning of slot milling (fig. 6 and fig. 9). As mentioned, 15 measurement points were selected within the range of the freelancing process for the maximum values of individual components. This is shown in fig. 10; there are additionally calculated analytical values of the total cutting force F.

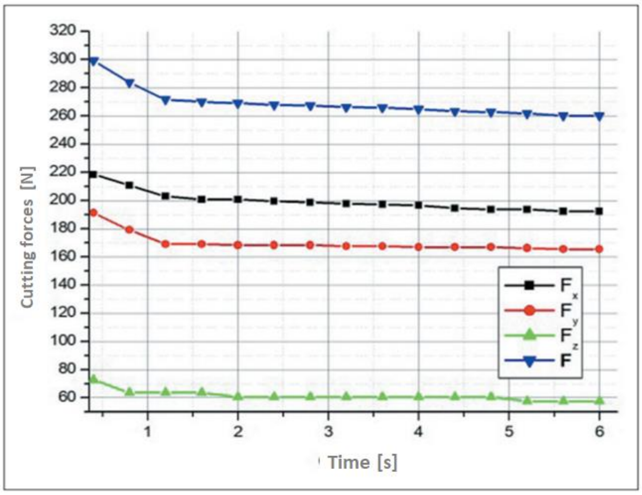

Fig. 10. Graphs of components and total cutting force *F* on the basis of 15 measuring points

Conclusions

The following conclusions can be made on the basis of cutting force charts:

- selection of 10 or 15 measuring points is sufficient to estimate the maximum values of the constituent forces and allows to determine the average value of the total cutting force,
- with the same machining parameters and using the same tools, the average total cutting forces in the conventional treatment of both the open pocket and the groove were: 268 N and 129 N and were lower than the forces obtained during trochoidal milling, which were: 307 N and 154 N,
- two methods of machining were compared, analyzing instantaneous maximum forces; another interpretation reduces their value for periods of non-contact of the tool with the machined material when the forces are close to 0,
- with the same machining parameters, the trochoidal milling time was three times longer than the conventional machining time lasting 2 min 51 s - this is due to the difference in the tool path length,
- the trochoidal machining can be significantly reduced by increasing the cutting depth a_p to a value of approx. 1.5 tool diameters; but then it would not be possible to compare both processes,
- rapid increases in measured components occurring in conventional machining during geometry changes of the cutting layer are eliminated in a somewhat idle process - this should be considered an advantage of this method (lower probability of vibrations),
- CAD/CAM systems allow you to design machining in such a way as to avoid deformation of the thin wall of the workpiece. To do this, leave a rather large allowance after roughing. When finishing for finishing, reduce the depth and width of cutting, as well as guide the tool along an arc, tangentially to the work profile, which results in a gentle build-up of forces,
- in the case of identical parameters of conventional and trochoidal milling, there are no significant differences in cutting resistance. This may be due to technological parameters set in the CAM system. The two most important of them are: maximum width of the machined layer (4 mm) and radius depending on the width of the pocket - groove (2 mm).

Based on the analysis of the results, it can be concluded that the presented method of measurements using the measurement platform, despite the need to use specialized equipment, gives good results, is quick and legible for the user. Its advantages also include high functionality and the ability to adapt to virtually any type of treatment.

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