The article presents an unconventional method of machining rolling surfaces. This method is called face rotary turning tools (FRTT) or spinning tools technology. Advantages and limitations of the method were discussed and its effectiveness in modern machining processes was shown, based on the proposed simple models.

KEYWORDS: spinning tools technology, spinning tools, face rotary turning tool

Introduction

During the research on the possibility of self-rotating tools applications [2–4], marked with the acronym SPRET (self-propelled rotary edge tool), for cylindrical surface machining on milling machines equipped with special device for workpiece fixing and rotation (fig. 1) was checked the tool design, which use the bearing of machine tool spindle for their rotation.

Designed and constructed tool with uniform edge with shank (fig. 1a – high speed steel tool) or tool with replaceable edge as cemented carbide insert (fig. 1b), placed in a simple, shank-shaped body, was mounted in milling machine spindle using clamp. Once the tool design with conical mandrel has been prepared (fig. 1c) was mounted directly in spindle.

Due to the high bearing resistance of the spindle and inseparably connected components of drive system, edge tool rotation under the cutting force influence was impossible, and with greater cutting depth ($a_p = 2.3$ mm), unacceptable with low system rigidity (fig. 1a) – very irregular and random (in spite of disconnection of most important drive system components, i.e. motor and back gears). However, this failure can be simply change to the new machining method.

Characteristics of machining process with face rotary turning tools (FRTT)

SPRET tools, which construction is shown in fig. 1 can work very efficiently as driven. The only condition is start the spindle drive with the tool mounted in the holder. The additional impulse the such use of tested tools was the development of rapid machining centres and multi-axis machines with numerical control, which guaranteed: concentration of technological processes (milling, turning, boring, drilling), required angular positioning of the tool and workpiece (often in several planes), kinematics consisting of simultaneous tool and workpiece rotation and performance of relative feed movements (fig.2).

In case of classic milling machines numerically controlled in three axes, machining with face rotary turning tool required the use of attachment for mounting and rotation of workpiece on the machine table (fig. 1a), and in case of turning machines - special attachment for mounting, angular positioning and face rotary turning tool drive.
The possibility to implement new machining method has been confirmed by, representing the company Kennametal, authors of the American patent [8], which related to methods and design of assembly for rotating a cutting insert during a turning operation. Patented machining method and tool design acclaimed as the greatest revolution in the development of machining processes [11].

The tools were called face rotary turning tools – FRTT. During the recent years in the English literature, mainly in Japan [1,7,12,14] this method has been assigned name spinning tools technology. Currently, both names are used in Polish - face rotary turning tools and spinning tools technology. The article present the characteristics of processing method and tool designed for this operation (fig.1).

Machining process with face rotary turning tools is similar to turn-milling. In both cases workpiece and tool perform rotary motion, and additionally tool or workpiece perform feed motion (fig. 2). Surface processing with face rotary turning tool is characterised by continuous, uninterrupted presence of the blade in the workpiece, while successive blade fragments are changing. This clearly distinguishes this process from milling or turn-milling. Cutting edge rotation allow for continuous change of its active edge - so that during cutting process each part has been in very short contact time with workpiece, in high temperature zone and high loads [5]. Cutting edge rotation in tools type FRTT is stable and not depend on other machining conditions, e.g. material machinability, process parameters, blade geometry or cooling method. Those conditions (especially related to optimal edge geometry resulting from its angular setting in tool holder) were relevant for previous designs with rotary edges tool - RET type SPRET [2]. Design of different type of tools RET, i.e. DRET (driven
rotary edges tool) with own drive for blade rotation in body was complicated and expensive. For this reason, these tools have not found any application in the industry [2–4].

In turning process with rotary face knife on modern machining centres and multi-axis machines can be ensured the optimal tool geometry - thanks to the possibility of changing (even continuous!) its settings - in the layout and working system (fig. 2) (for over 150 years the angular position of the tool relative to the workpiece in the turning process remained fixed[2]). The main difference in relation to e.g. to SPRET tools consists of the possibility angular inclination (fig. 1 i 3) of tool straight blade in tool system by angle δ, which usual is 20°÷40°. Inclination angle affects chips flow direction, but the most important effect is large value of the tool rake angle, without affecting the quality of cutting edge. This ensures favourable stress state in cutting edge zone. During machining process the chips deformation is very small due to small plastic deformations of removed material. This enable the increase of cutting speed vc, which is often limited by high temperatures, which can be observed in the case of conventional turning tools, in particular during difficult-to-machine materials machining [1, 3, 7, 9, 11–14].

For example, in performed machining tests of hardened materials (steel 100 Cr6 tempered to hardness approx. 52 HRC) cutting without rotatory movement of edge with parameters vc = 180 m/min, fz = 0,10 mm/obr and ap = 0,25 mm was not possible, and in the event of rotatory movement the blade resistance reaching T = 50 min.

In researches carried out in collaboration with three companies – DMG Mori Seiki, DP Technology Corp. and Kennametal (which is the patent owner [8]) – has been obtained increase of tool resistance by 2000% and increase of machining efficiency by 500% [8].

The possibilities and limitations of machining with face rotary turning tools (FRTT)

Analysing basic types of turning tools available on the market, it can be noted that the tools with round edges have considerable technological capabilities and wide range of applications. In this case the only limit is ratio of blade radius to expected workpiece geometry. At the same time, round edges, even in in their classic field of application are sensitive to vibration, as confirmed by years studies on tools RET [2–4]. Although, this tools are characterized by high endurance and wear resistance, but their tendency to vibration is difficult to handle, because dynamic properties of machine–tool holder–workpiece–tool (MHWT) system are specific and hard to identify.

An additional obstacle for the effective implementation and use of tools FRTT constitute need to specify, apart from typical technological parameters (feed fz, cutting depth ap and speed vc, resulting from workpiece rotation n) new parameters, such as:
- tool rotation nt and the resulting speed vt,
- tool settings in relation to workpiece, described with angles ε and δ,
- optimal diameter of insert.

Experiments results and recommendations collected in available publications are not enough. Greater ef-
fort to careful selection of working conditions and technological parameters (including experimental verification of adopted MHWT system, in which the tool FRTT will be applied) may contribute to significant increase of the machining efficiency. This concerns not only mass and serial production, but also small series production.

The sample illustration of possible effects which can be achieve is the assessment of edges costs shown in fig. 2 carried out on the basis of test results of resistance in steel 100 Cr6 machining process. To undertake such assessment, related to classical turning tools with edges with any blade geometry, it is necessary to use of two simple models, specifying:

- an equivalent number of elementary edges on round inserts, also in tools with rotating edges RET;
- increase blade resistance factor resulting form insert rotation, includes the impact of physical phenomenas, characteristic for RET tools, on their resistant.

For the purposes of determining the alternative number of elementary edges \( i_e \) on round inserts and round ones in tools with rotary edges RET \( i_{er} \) it is assumed that entire edge of round insert consist of edge \( k \) called elementary edge. Values \( i_e \) and \( i_{er} \) can be calculated as a quotient of the insert circuit and length of active cutting edge, depending on cutting depth:

\[
i_k = \frac{\pi D i_s}{2 l_c} = \frac{2 i_s \pi}{\pi - \arcsin \left(1 - 2 \frac{a_p}{D_c}\right) + \arcsin \left(\frac{f}{D_c}\right)}
\]

where: \( l_c \) – length of active cutting edge, \( a_p \) – cutting depth, \( f \) – feed [mm/r], \( D_c \) – insert diameter, \( i_s \) – the number of available edges on round insert (usually \( i_s = 1 \) or \( 2 \)).

In calculating the resistance of rotatory insert the RET tool only as a sum \( i_k \) resistance periods (designated for conventional insert) of elementary blade of approximating insert, significantly understated result is obtained, not in accordance with observations [1,3–7]. The reason is different kinematics of cutting tool RET, ensuring a lower cutting temperature, and thus lower intense impact of adverse physico-chemical phenomenas in cutting zone on blade wear [4]. It is proposed that the impact of listed phenomenas on tool RET resistance take into account with factor \( W_r \) expressing an increase of tool blade resistance with a rotatory insert in relation to resistance of the tool with the same insert, but fixed.

The conventional coefficient \( W_r \) may be expressed by means of the following formula:

\[
W_r = \frac{i_{2r} T_{cr}}{i_{kr} T_c}
\]

where: \( W_r \) – increase of blade resistance factor resulting from insert rotation, taking into account the impact of phenomenas characteristic for tools RET on resistance; \( T_c \) – resistance period for tool with fixed insert; refer to single edge of multi-blade insert or single section of round insert blade (or contractual elementary edges; \( T_{cr} \) – resistance period of tool RET edge, e.g., type FRTT.

Factor \( W_r \) should be interpreted as a quotient of rotator insert resistance and stationary insert durability or as a quotient the resistance of contractual elementary rotatory insert and durability of the conventional elementary blade of a round stationary insert. Comparing with multi-edges inserts, the role of elementary blade is held by single edge multi-blade cutting insert.

The value of the coefficient \( W_r \) was experimentally determined on the basis of the results of the cutting edges tests in RET and stationary tool [3,4].

Based on the results of wear and tool resistance test it can be shown that in case of turning process of series of shafts, to the execution of which was necessary to use 20 cemented carbides inserts, round – diameter \( D = 12 \) mm, worth 100 €, the estimated cost alternatively used square, 4-edged inserts would have amounted to 2000 €, and diamond, 2-edges inserts 4000 €. (fig.3)

It has been assumed in the undertaken analysis that the price of round and rhombic inserts is approximately equal and is approx. 5 €. It should be noted that costs of classic turning toolholders will be at least equivalent (if not more) to costs of simple turning tools FRTT toolholders. This follows directly from those tool holders design. Even the use of a uniform design of the FRTT tool holder with conical mandrel (fig. 1) will not change the advantageous correlations with respect to classic turning performed on the same machining center or on the same multi-axis machine.

REFERENCES

[1] Astakhov V.P. “Geometry of Single-point Turning Tools and Drills”. London: Springer-Verlag, 2010.
[2] Cieloszyk J., Fabisiak B. „Narzędzia z obrotowymi krawędziami skrącającymi – klasyfikacja i terminologia”. Mechan. 8–9 (2017): 674–676, https://doi.org/10.17814/mechanik.2017.8-9.100.

[3] Cieloszyk J., Zasada M. “The Self-Propelled Rotary Tools-Future Conception In Metal Cutting?”. The 15th DAAAM International Symposium “Intelligent Manufacturing & Automation: Globalisation – Technology – Men – Nature”. Vienna, Austria, 3–6th November 2004, 075–077.

[4] Cieloszyk J., Zasada M., Wieloch G. „Właściwości i perspektywy zastosowań aktywnie napędzanych noży obrotowych ADRT na wieloosiowych centrach obróbkowych”. Innovative Manufacturing Technology. Ed. P. Rusek. IZTW Kraków, 2012, 29–39, ISBN 978-80-228-2385-2.

[5] Dessoly V., Melkote S.N., Lescalier C. “Modeling and verification of cutting tool temperatures in rotary tool turning of hardened steel”. International Journal of Machine Tools and Manufacture. 44 (2004): 1463–1470.

[6] Ezugwu E.O. “Key improvements in the machining of difficult-to-cut aerospace superalloys”. International Journal of Machine Tools & Manufacture. 45 (2005): 1353–1367.

[7] Hosokawa A., Haruki Yoshimatsu H., Koyano T., Furumoto T., Yhashimoto Y. “Turning of difficult-to-machine materials with an actively driven rotary tool (ADRT)”. Journal of Advanced Mechanical Design, Systems, and Manufacturing. 12, 5 (2018): 1–9.

[8] Hyatt G.A., Andras L.R., Massa T.R. “Method and assembly for rotating a cutting insert during a turning operation and inserts used therein”. Patent US 7156006B2, Jan. 2, 2007.

[9] Kishawy H.A., Béce C.E., McIntosh G.G. “Tool performance and attainable surface quality during the machining of aerospace alloys using self-propelled rotary tools”. Journal of Materials Processing Technology. 152 (2004): 266–271.

[10] Kishawy H.A., Wilcox J. “Tool wear and chip formation during hard turning with self propelled rotary tools”. International Journal of Machine Tools & Manufacture. 43 (2003): 433–439.

[11] Mazakas A. “The evolution of revolution”. Cutting Tool Engineering. 60 (2008): 74–76.

[12] Nakajima K. et al. “Effect of rotary cutting tool posture on machining performance utilizing multi-tasking lathe”. Journal of Advanced Mechanical Design, Systems, and Manufacturing. 2, 2 (2008): 532–539.

[13] Sasahara H. et al. “High-speed rotary cutting of difficult-to-cut materials on multi tasking lathe”. International Journal of Machine Tools and Manufacture. 48, 7–8 (2008): 841–850.

[14] Yamamoto K., Satake K., Narita T., Sasahara H., Tsutsumi T., Muraki T. “Thermal Behavior and Chip Formation on Rotary Cutting of Difficult-to-cut Materials Utilizing Multi Tasking Lathe and MQL”. Tokyo University of Agriculture and Technology, report 2010.