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Investigation of the Effects of CNC Tool Runout on Machining of 1.2379 Steel and Tool Life

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ABSTRACT

In the study, the effects of tool run-out caused by the CNC spindle mechanism on surface roughness, measurement accuracy, consumable expenses, maintenance costs and cutting tool life that may occur during the cutting process were investigated based on metal die manufacturing. Before starting the experimental studies, the machine spindle health was measured. Here, tool pulling force, 300 mm test bar run-out, inner conical run-out and spindle vibration values were examined and evaluated. According to the results obtained, the m3/life relationship was compared with the surface milling operation by eliminating the factors causing tool run-out before and after machine tool maintenance for cutting tool life. In order to examine the effect of run-out on surface roughness and measurement accuracy, the effect of run-out was examined and compared by applying outer contour and inner contour operations before and after maintenance with experimental studies. These operations were examined with 1.2379 steel, which is the most commonly used steel type in the metal die sector in terms of mechanical properties. The results showed that run-out has serious negative effects on the cutting process and cutting tool life, measurement accuracy and surface roughness. In operations performed with a healthy spindle after maintenance, the cutting tool life increased by an average of 40%, surface roughness and dimensional accuracy reached the desired levels. The stress during the machine operation decreased by an average of 15%.

Keywords: Tool Runout, Tool Life, Spindle, Periodic Maintenance, CNC Machine Tool

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1. Introduction

Milling operations are one of the most commonly used cutting operations in machining. In operations performed with multi-flute tools in milling, cutting tool runout affects chip removal performance, cutting tool performance, chip load and cutting parameters [1, 2]. In milling operations with multi-flute tools, the tool is never completely symmetrical. There is always a deviation along the axis of rotation of the spindle and the axis of the tool geometry. Tool runout greatly affects the actual cutting radius of the tool. It has been determined that affecting the tool radius negatively affects the quality and efficiency in cutting operations. There are many simulation modelling and studies on this subject, which enable cutting processes that lead to better surface precision, higher productivity, and longer tool life [3].

Tool runout is triggered by the lack of periodic maintenance of the conical, spindle bearings and drawbar springs to which the tool is attached on the spindle. These structures can be seen in Figure 1. Periodic maintenance brings many effects such as increased production efficiency and longer use of the machine in a better way [4].

Zhang et al. considering the spindle speed-dependent effect of cutter runout, an effective non-contact calibration method was proposed by [6], and the effect of cutter runout on milling mechanics and dynamics was discussed. The proposed models have been successfully validated through a series of experiments. It shows that the cutter runout has spindle speed-dependent properties due to the change of vibration response of the spindle system under different spindle speeds. An approach is presented to model the milling process geometry together with the cutter runout based on the actual tooth trajectory of the cutter in the milling process. The mathematical relationship between the trajectories produced by successive incisors and runout was analyzed. It has been observed that the change in the cutter radius for a tooth compared to the previous one causes variable metal removal loads and variable wear on the teeth in evaluating the effects of cutter runout [7]. Soshi et al. According to the studies of [8], there are software and studies that compensate for the dynamic conditions that will change depending on the cutting parameters. It is observed that the variability of spindle dynamic properties affects the run-out rotation of the tool, tool life and cutting parameters. With these studies, improvements in cutting tool life and spindle runout were observed [8]. It is also possible for cutting tool runouts to occur as a result of incorrect attachment of tools in milling operations. Accordingly, it has been observed that unequal cutting forces loaded on the cutting edges cause different wear rates on the cutting tool and, as a result, shorten the tool life [12].

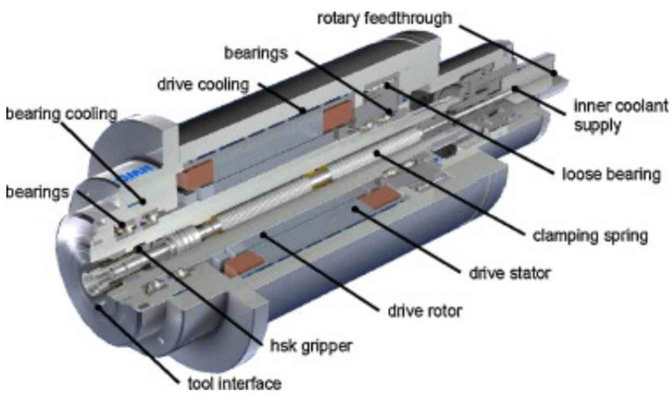

Figure 1. Appearance and layout of CNC spindle parts [5]

In milling operations, it is also possible for tools to be connected incorrectly and resulting in cutter run-out. Accordingly, it has been observed that unequal cutting forces loaded on the cutting edges shorten the tool life along with different wear rates on the cutting tool. Therefore, the variable cutting forces in the milling process were analyzed and a simulation was created. With the cutting parameters optimized as a result of the analysis of the variable cutting forces created by the epidemic, the epidemic is controlled and the factors related to the epidemic are prevented [9]. Cifuentes et al. In his study, it was observed that tool runout affected tool life and deteriorated the workpiece surface quality. In this study, actions that can be taken to reduce the effects of tool run-out are presented. The simulation and experimental results presented in this study demonstrate the effectiveness and benefits of this new tool runout correction procedure [10]. It is motivated by the fact that cutting forces are commonly calculated by mechanical or numerical models, which are considered time-consuming and impractical for various cutting conditions and workpiece-tool pairs, producing uneven distribution of cutting forces due to uneven cutting forces. Fu et al. The proposed analytical model of cutting forces has been validated with the obtained results and experimental data. While the effectiveness of the proposed analytical model is demonstrated, the importance of cutter runout on forces is emphasized [11]. The presence of cutter runout created a cutting force component at the spindle rotation frequency. The study used time-dependent spectral analysis of cutting force to estimate cutter runout characteristics of size and angular orientation; Given preliminary information about the part's material properties, tool geometry, cutting parameters and machining configuration, the instantaneous runout characteristics are repeatedly updated from their previous values and the last measurements of the cutting force. The recursive nature of this approach facilitates in-process implementation of runout monitoring and provides opportunities for control and optimization [12]. Cutting tool runout occurs in two different ways: radial and axial (Figure 2). It is a phenomenon that affects geometry accuracy in the milling process and is neglected in most studies on tool path planning. In this study, a new approach is presented to integrate the cutter runout effect into envelope surface modeling and tool path optimization for five-axis side milling with a tapered cutter. The results show that geometry errors caused by runout can be significantly reduced using the proposed method [13]. These errors can be eliminated through periodic maintenance and their effects on the final product can be minimized [15].

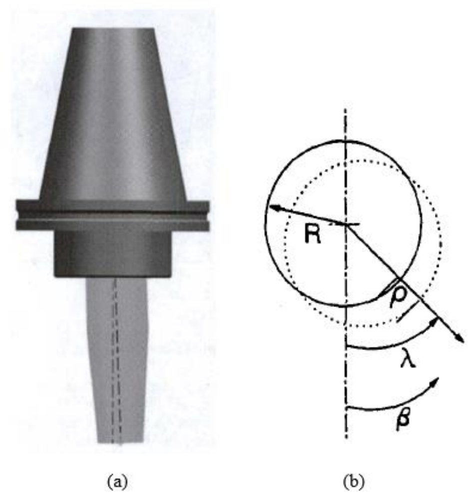

Figure 2. (a) cutting tool with axial runout [13] (b) cutting tool path with radial runout [14]

The study is about tool runout measurement in micro milling. Among the macro-to-micro effects of downscaling, tool runout plays an important role, affecting the cutting force, tool life, and surface integrity of the produced part. The results showed that the developed procedure can be used for tool runout prediction. The maximum measurement errors of tool run-out length and angle decrease as the spindle speed decreases [16] .

The purpose of this study is to reveal the effects of CNC spindle maintenance and health on the final product. In this context, the impact on consumable expenses and costs, in addition to the final product, will be examined. The study aims to present an innovative perspective that expresses the importance of periodic maintenance, which is constantly emphasized in companies, with numerical data. With this innovative perspective, new insights will be provided on various aspects such as labor costs, cutting tool costs, process times, and maintenance costs. The fact that this study is conducted experimentally and under real conditions, rather than mathematically, strengthens its innovative perspective. As a result of the study, it is aimed to contribute to the development of the literature by establishing a foundation for optimization in future research.

2. Materials and Methods

In the experimental study, 1.2379 steel (supplied by the Sağlam Metal Company) , which is the most preferred steel in terms of its technical properties in die manufacturing in the metal sheet forming industry, was used. Technical properties of steel are given in Table 1. In the machining of steel, cutting operations such as surface treatment, outer contour and inner contour are applied. At this point, with the experimental study to be carried out, the effect of CNC spindle tool runout on the cutting tool life during surface processing was examined. At the same time, the effects of runout on surface roughness and dimensional accuracy in outer contour and inner contour operations were also examined. CMM (Coordinate Measuring Machine) device was used for dimensional accuracy. Mahr Brand MarSurf PS1 model roughness device was used for surface roughness. Spindle technical specifications of the HAAS VM3 CNC vertical machining center used are given in Table 2. Again, the HAAS machine was checked for runout before maintenance, and the measurement values are given in Figure 7. After the maintenance, along with bearing maintenance, drawbar spring maintenance and conical grinding, the runout from 45 µm was reduced to 8 µm and the machine was brought to optimum operating values. Cooling liquid was used in the experimental study. It is known that the effect of coolant and the water used in the coolant on cutting tool life, surface roughness and production efficiency is very important [17]. During the cutting operation, Oemeta brand coolant suitable for general and heavy machining was used. The properties of the coolant and the water used are shown in Table 3. At the same time, the cutting tool, tool holder and processing parameters to be used are given in Table 4. Cutting parameters are given based on optimum processing conditions, adhering to the values in the product catalogue.

Table 1. Technical specifications of 1.2379 steel

Carbon (C)	Chromium (Cr)	Molybdenum (Mo)	Vanadium (V)	Hardness (HRC)
1.55	12.00	0.80	0.90	55

First of all, in the surface processing operation, the effects of the cutting parameters prepared in accordance with the parameters of the cutting tool in terms of "m 3 / tool life" and the current runout in the spindle) on the cutting tool life and chip formation during the process were examined. For the operation, 1.2379 steel was used, cut into billets measuring 280x280x100mm. After spindle maintenance, the process was repeated and compared with the same teething parameters and material.

Table 2. Spindle specifications of the HAAS VM3 machine

Spindle	Metric
Maximum Speed	12000rpm
Maximum Torque	122.0 Nm @ 2000 rpm
Conical Type	CT/BT40

In the outer contour operation, the workpiece called cavity die is processed in die manufacturing. 1.2379 steel with dimensions 110x90x85mm was used for the test. In addition, the cavity die was processed by performing the process called pool emptying with the inner contour operation. The dimensional accuracy and surface roughness of the metal dies, which will fit into each other by machining the inner and outer contours, were checked and after maintenance, the same operations with the same cutting parameters were repeated and compared.

In line with the determined parameters, the experimental study was repeated 5 times and the average was taken to estimate the cutting tool life. For measurement accuracy, a comparison was made with the average of measurements taken from 5 different points. For surface roughness, the average of the measurements from 5 different points was taken and compared. Surface processing, outer contour and inner contour operations during the experimental study are shown in Figure 3. The tools and holders used during the study are also shown in Figure 4.

3. Findings and Discussion

As a result of the studies and experiments carried out, when the cutting tool life is examined after the conical, drawbar springs and bearing maintenance, which may cause run-out before and after run-out, as seen in Table 5, run-out affects the cutting tool life by 40%. In the surface machining operation, 3 cutting inserts are connected to the tool holder. The wear images of the cutting tools as a result of the operation when there is tool run-out are given in Figure 5.

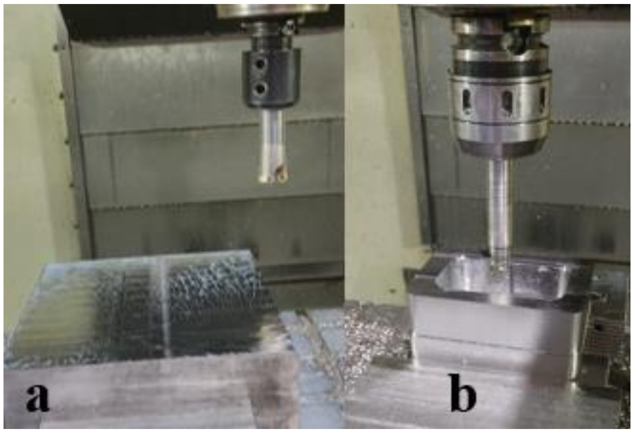

Figure 3. Cutting operation pictures (a) surface processing operation (b) Inner contour and outer contour operation

It is seen that the run-out creates different wear in the 3 cutting inserts on top of the tool wear. Figure 6 shows the wear resulting from machining before and after maintenance. Here (Figure 6a) is the cutting tool used with run-out, and (Figure 6b) is the image of the cutting tool that removes 40% more metal without run-out after maintenance.

Table 3. Coolant used and its properties

Brand	Product Code	Emulsion Rate (% refractometer)	Use Area	Product Type	Properties of Water
OEMETA	Unimet 227	5%	*General Machining *Heavy Machining	Semi Synthetic	*Hardness = 15 °dH *Chloride = 55 ppm *pH = 7.8 *Conductivity = 655 µs/cm

Table 4. Cutting parameters

Operation	F (mm/min)	Ap (mm)	Vc (m/min)	Brand code	Tool Holder	Team Brand
Surface Treatment	1250	1	150	RYMX 1205-M	Ø40 Ball	TaeguTec
Outer Contour	1000	0.5	125	APKT 1705 PER-EM	Ø32 Ball	TaeguTec
Inner Contour	2000	0.5	125	4NKT 060308R-M	Ø20 Ball	TaeguTec

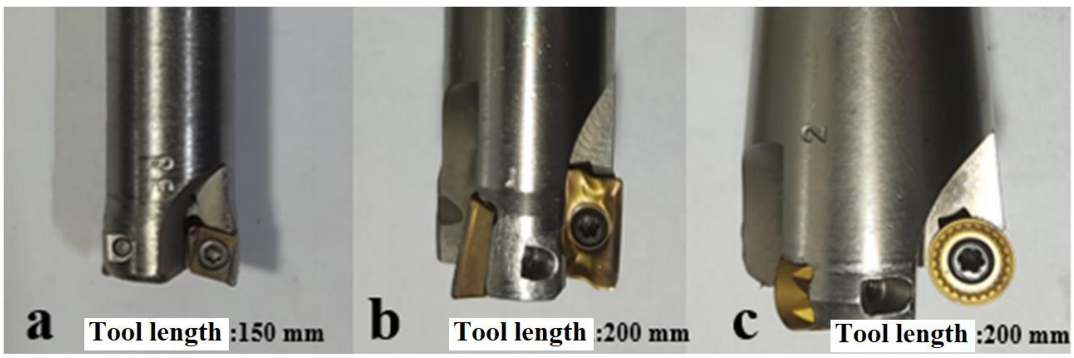

Figure 4. Insert and holders (a) Inner contour operation (b) Outer contour operation (c) Surface treatment operation

Table 5. Cutting tool life results

	Cutting tool life before maintenance (m^3/tool life)	Cutting tool life after maintenance (m^3/tool life)	% Difference
HAAS VM3	0.000131 m^3/tool life	0.0001834 m^3/tool life	40%

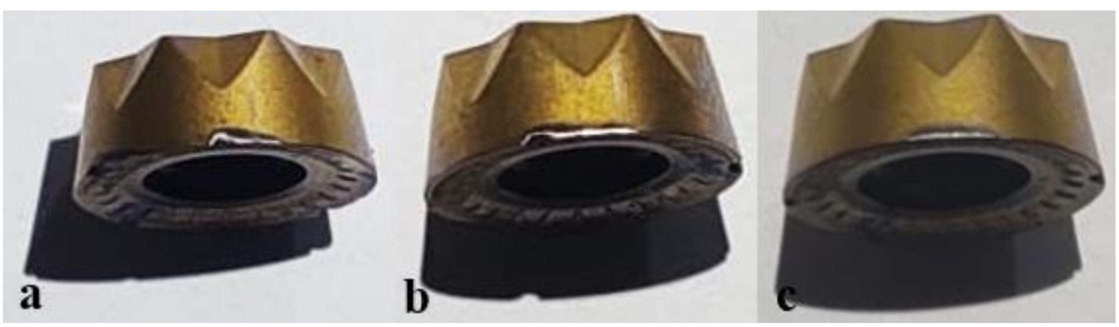

Figure 5. Different wear forms of the inserts in the tool holder when the tool is run-out

Dimensional analysis was carried out with the run-out effect of the CNC machine programmed to the specified dimensions in the inner contour and outer contour operations, and the studs in the machining dimensions were detected in the CMM (Coordinate Measuring Machine) device. After the maintenance was done in the same way, the steel processed with the same parameters was checked and compared on the CMM device. In terms of dimensional accuracy and precision in the inner contour and outer contour, the run-out loom showed an average deviation of 0.2 mm. Test results are shown in Table 6.

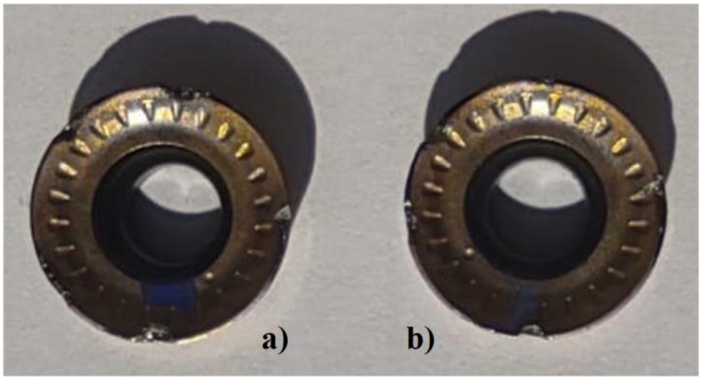

Figure 6. Tool wear during machining (a) before maintenance (b) after maintenance

Table 6. Effect of the epidemic on measurement accuracy

	Measuring range before maintenance (mm)	Measuring range after maintenance (mm)
Outer Contour	+0.25	+0.05
	+0.20	+0.00
Inner Contour	- 0.10	+0.05
	- 0.15	+0.00

The effects of run-out on the chips formed in machining and post-running operations are also discussed, and as seen in Figure 7, the chips produced by the tool working with and without run-out are seen. When working with a spiral operating spindle tool, there is no serious change in chip shapes, but the heat generated during chip processing reaches 300□C and above and suddenly oxidizes, forming different iron compounds on the surface. These compounds are of three types: Wüstite (FeO), hematite (Fe2O3) and magnetite (Fe3O4).Under normal conditions, during processing, the first layer formed is FeO (wüstite) due to the high oxygen density, and immediately afterwards a new layer forms as magnetite (Fe3O4). In the last stage, the final colour is given with Fe2O3 (hematite). The presence of a layer that gives a dark brown and blue colour in the chips produced with the run-out tool is understood to be due to temper oxidation, where the cutting temperature during machining exceeds 300□C (18, 19). The fact that the 2379 steel processed in the oscillating spindle set is alloyed suggests that it causes more heat generation because the steel is harder than normal steels. The change in chip color due to the high amount of heating occurring in the chip is seen very little or not at all in machining performed after maintenance. Since the physical values of the cooling liquid remain the same, the slight or no colour change indicates that the generated heat is absorbed by the cooling liquid and removed from the environment, unlike the situation in the gland tool.

While the machine axial loading varied between 45-50% before maintenance, the machine loading after maintenance varied between 40-45%. With the maintenance, a 10% improvement was observed in the machine axial load read on the machine monitor.

Surface roughness was measured as a result of the experiments and measurements were made from 5 different points before and after runout and their averages were taken. According to the experimental results, the surface roughness before and after the maintenance has a serious effect on the surface roughness, as shown in Figure 8.

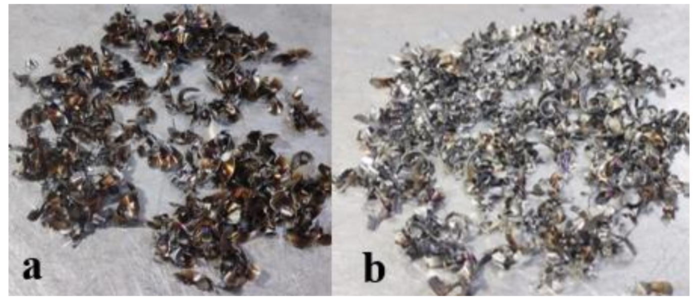

Figure 7. Chip structures formed during surface processing (a) chip before maintenance (b) chip after maintenance, (f=1250 rpm, ap=1mm, V=150m/min)

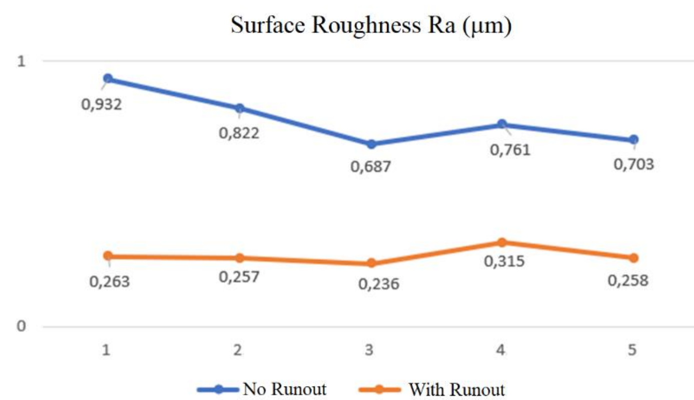

Figure 8. Surface roughness graphs before and after maintenance

4. Conclusions

CNC tool runouts are of great importance for machining. In metal forming dies, it is an opportunity to adapt and adapt the dies to each other and to prevent excessive hand levelling. It prevents cutting tool life and frequent replacement of cutting tools, and at this point, it is important to increase efficiency in terms of cost. At this point, it is very important to carry out periodic maintenance and controls on time and increase production efficiency.

After the maintenance has been carried out and the tool runout has been eliminated and the machine has been brought to optimum values:

•Cutting tool life was measured by the volume of chip removed in m3/tool life, and tool life increased by 40%.

•The dimensional accuracy improved by 0.2 mm after the maintenance for the outer contour operation compared to before.

•Dimensional accuracy improved by 0.15 mm after maintenance for the inner contour operation compared to before.

•Surface roughness improved by approximately 35% for Ra (µm) after maintenance compared to before.

•After the machine spindle was maintained and its runout was removed, the axial load of the machine, read on the machine monitor during the cutting process, decreased by 10%.

•Improvements in surface roughness and cutting tool life have yielded positive results in terms of reducing production costs.

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Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

Author Statement

M. Kubilay Askerden: Conceptualization, Supervision, **Mustafa Yazar:** Conceptualization, Writing-original draft, **Şükrü Talaş:** Data curation, Validation

References

1. Aydın, M. (2022). Parmak frezeleme sırasında takım salgısının etkisi dahil edilerek kesme kuvvetlerinin tahmini ve analizi. Politeknik Dergisi, 25(1), 157-167.
2. Kline, W. A., & DeVor, R. E. (1983). The effect of runout on cutting geometry and forces in end milling. International Journal of Machine Tool Design and Research, 23(2-3), 123-140.
3. Caixu, Y. U. E., Haining, G. A. O., Xianli, L. I. U., Liang, S. Y., & Lihui, W. A. N. G. (2019). A review of chatter vibration research in milling. Chinese Journal of Aeronautics, 32(2), 215-242.
4. Morales Méndez, J. D., & Rodriguez, R. S. (2017). Total productive maintenance (TPM) as a tool for improving productivity: a case study of application in the bottleneck of an auto-parts machining line. The International Journal of Advanced Manufacturing Technology, 92, 1013-1026.
5. Abele, E., Altintas, Y., & Brecher, C. (2010). Machine tool spindle units. CIRP annals, 59(2), 781-802.
6. Zhang, X., Zhang, J., Zhang, W., Li, J., & Zhao, W. (2018). A non-contact calibration method for cutter runout with spindle speed dependent effect and analysis of its influence on milling process. Precision Engineering, 51, 280-290.
7. Li, H. Z., & Li, X. P. (2005). A numerical study of the effects of cutter runout on milling process geometry based on true tooth trajectory. The International Journal of Advanced Manufacturing Technology, 25, 435-443.
8. Soshi, M., Ishii, S., & Yamazaki, K. (2012). A study on the effect of rotational dynamic characteristics of a machine tool spindle drive on milling processes. Procedia CIRP, 1, 319-324.
9. Matsumura, T., & Tamura, S. (2017). Cutting force model in milling with cutter runout. Procedia CIRP, 58, 566-571.
10. Cifuentes, E. D., García, H. P., Villaseñor, M. G., & Idoipe, A. V. (2010). Dynamic analysis of runout correction in milling. International Journal of Machine Tools and Manufacture, 50(8), 709-717.
11. Fu, Z., Yang, W., Wang, X., & Leopold, J. (2016). An analytical force model for ball-end milling based on a predictive machining theory considering cutter runout. The International Journal of Advanced Manufacturing Technology, 84, 2449-2460.
12. Hekman, K. A., & Liang, S. Y. (1997). In-process monitoring of end milling cutter runout. Mechatronics, 7(1), 1-10.
13. Li, Z. L., & Zhu, L. M. (2014). Envelope surface modeling and tool path optimization for five-axis flank milling considering cutter runout. Journal of Manufacturing Science and Engineering, 136(4), 041021.
14. Wang, J. J. J., & Liang, S. Y. (1996). Chip load kinematics in milling with radial cutter runout. Journal of Manufacturing Science and Engineering, 118(1): 111-116.
15. Usop, Z., Sarhan, A. A., Mardi, N. A., & Abd Wahab, M. N. (2015). Measuring of positioning, circularity and static errors of a CNC Vertical Machining Centre for validating the machining accuracy. Measurement, 61, 39-50.
16. Attanasio, A. (2017). Tool run-out measurement in micro milling. Micromachines, 8(7), 221.
17. Isik, Y. (2010). An experimental investigation on effect of cutting fluids in turning with coated carbides tool. Journal of Mechanical Engineering, 56(3), 195-201.
18. Andrews, J. (1977). Edge of the anvil: a resource book for the blacksmith. Intermediate Technology Publications, 147-153.
19. Tominaga, J., Wakimoto, K. Y., Mori, T., Murakami, M., & Yoshimura, T. (1982). Manufacture Of Wire Rods With Good Descaling Property. Transactions of the Iron and Steel Institute of Japan, 22(8), 646-656