International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 9 Issue 7 ǁ 2021 ǁ PP. 22-28

Effects of the cutting parameters on the distortion during the milling of the thin-walled part

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Abstract
Machining thin-walled parts is a key process in the aerospace industry. The part deflection caused by the cutting force is difficult to predict and control. The distortion of the thin-walled part is significantly affected by the accuracy of the finished part. During the machining process, the distortions of the thin-walled part are quite complex. In this study, the influence of cutting parameters on the deformation of part in machining thin-walled parts made of aluminum alloy is studied. A Taguchi experimental model is proposed and shows that the cutting speed and cutting depth and cutting width are the factors that greatly affect the amount of deformation of the part. The deflection of machined part reaches to the minimum value with the cutting speed V=350m/min, feed rate fz=0.04mm/teeth, radial depth of cut a=0.6mm, and the axial depth of cut b=8mm.
Keywords: *milling, distortion, thin wall, cutting, Aluminum.*

Date of Submission: 21-06-2021 Date of acceptance: 06-07-2021

I. INTRODUCTION

Thin-walled parts are commonly used in many industries including automotive, aeronautical and precision machines. Since thin-walled parts are often deformed in the machining process because of their low ductility, it is difficult to control the machining accuracy, reaching to increase production costs. To ensure the machining accuracy, the deformation should be controlled during the working process. The deformations of the part can be divided into two types: deformation due to machining and deformation after machining. Machining strain is generated during cutting the part of the material containing the initial residual stress, while the post-machining strain (subsequent strain) (usually occurs due to the existence of residual machining stress) occurs after assembly is complete. Many cases have been reported from industry for similar examples where thin-walled parts were discarded because of subsequent deformation. In machining, milling is a common process used to machine thin-walled parts. The milling process of thin-walled details has been focused on by many researchers.

Machining residual stress studies often focus on analyzing and predicting residual stress patterns by considering various processing parameters, tooling parameters, and others. Khabeery and Fattouch (1988) found that the amplitude of residual stress generally increases with increasing feed rate, depth of cut and tensile strength of the part material [1]. Kuang and Wu (1995) found that cutting speed, feed amount, and tip radius have a significant effect on residual stress [2]. Coto et al. (2011) showed that increasing toolpath will increase tensile residual stress, however increasing shear speed will reduce tensile residual stress [3]. Navas et al. (2012) note that by reducing the amount of feed and increasing the cutting speed, it is possible to reduce the tensile residual stress when machining AISI4340 steel [4].

Thus, it is very difficult to control the form and magnitude of the residual stress of the machined surface. And there are no clear rules given when using different processing materials and with different technological parameters. For example, Mohammadpour et al. (2010) showed that the maximum value of surface layer residual stress (MMSRS) is 680MPa, and the depth of shear corresponding to the maximum compressive residual stress is 200 millimeters [5]. Liang and Su (2007) measured the MMSRS as 900 MPa, the DMCRS ranging from 25 to 100 micrometers [6]. However, Ulutan et al. (2007) found the MMSRS to be 1200 MPa and the DMCRS to be even smaller than 10 micrometers [7]. The influence of factors on different structures during heat reduction is studied and calculated. Robinson et al. (2011) discussed the mechanism of redistribution of residual stress after machining for Al7449 material after heating [8]. By removing the material in layers, the effect of residual stress redistribution on strain is discussed. While there is no indication of stress reduction, and the model is limited to the cubic rule. In summary, all studies are based on the thickness of each layer (equal or nearly equal) of the workpiece, so it is difficult to apply to the machining of thin-walled parts, where the depth variable machining. Therefore, it is necessary to further analyze the redistribution of the residual stress of thin-walled parts with different cutting depths during machining, thereby reducing the deformation of thin-walled parts.

Many researchers have focused on studying the process of machining thin-walled parts, the deformation that occurs during part milling. A few studies focus on determining the influence of technological parameters on deformation and surface roughness. Ning et al. [9] used the finite element method (FEM) to calculate the thin-walled structural deformations during machining. Budak [10] developed an analytical model to avoid vibration during high-performance milling without sacrificing productivity. Tang and Liu [11] simulated and calculated the deformation of the part using FEM. Shamsuddin et al. studied the best tooling strategy for machining aluminum alloy thin-walled parts [12]. Seguy et al. built a numerical model using stable zone theory to study surface roughness and vibration when machining thin-walled parts [13]. The dynamic interaction between the cutting tool and the spindle was analyzed using FEM by Mane et al. [14]. Davies et al. studied the oscillations of thin walls during milling [15]. Benardos et al. used different methods to predict the change of surface roughness [16]. Thevenot et al. aims to optimize cutting conditions and accurately identify milling cases where fluctuations are not apparent during machining of thin-walled parts [17].

Several articles also describe studies on the influence of toolpath planning strategies and tool-related parameters such as coating, tool diameter, helix angle on surface roughness and roughness. exact thickness of parts. Wan et al. developed a new theoretical method to study the working mechanism of the helix angle and obtain the optimal helix angle for milling cutters when milling the outer profile [18]. The author has proved that the maximum value of the shear force decreases when increasing the torsion angle in the case of single-edge cutting. Jabbaripour et al. improved the geometrical accuracy and surface integrity of thin-walled parts during the finishing process [19]. They analyzed the influence of cutting direction and cutting speed on the amplitude of the cutting force and the quality of the machined surface. Durakbasa et al. focused on studying the effect of tool coating and tool radius on surface quality in AISI H13 steel finishing process [20]. Herranz et al. proposes feed strategies by analyzing the static and dynamic phenomena occurring during high-speed milling. The authors have given some useful advice when machining low hardness parts [21]. Polishetty et al. studied tool wear, surface roughness and cutting force in machining titanium alloy Ti-6Al-4V using trochoidal toolpaths [22]. Izamshah et al. studied the influence of three toolpath strategies including “water line-step”, “overlapping-step” and “tree wise-steps” on machining accuracy [23]. The results show that the feed strategy affects the accuracy of thin-walled parts and the results show that the waterline-step tooling strategy has the most influence on the machining accuracy. Vakondios et al. also studied the effect of toolpaths on surface roughness during the aluminum alloy finishing process [24]. Subramanian et al. conducted an experimental study on the influence of milling cutter geometry parameters on vibration during milling [25]. Kadirgama et al. studied to optimize surface roughness when milling aluminum alloy (AA6061-T6) with carbide coated cutting tools [26]. Karkalos et al. used RSM to develop a quadratic relationship between input and output parameters in the peripheral milling of titanium alloys [27]. Furthermore, a simulation model based on an artificial neural network (ANN) is also developed. Thus, according to the published documents on the milling process of thin-walled parts, the study to determine the reasonable technological regime when processing thin-walled aluminum alloy parts has not been interested by many authors.

II. EXPERIMENT AND METHOD

The machining process is carried out on the Mazak 530 C machining center manufactured by Japan. Using end mills made of uncoated bits material with 3 cutting teeth, helix angle 450 of Korean YG company with code 36588, as shown in figure 1. This is a specialized cutting tool for machining aluminum alloys and non-ferrous alloys, used for finishing with high surface quality. The workpieces are made by the aluminum alloys 6061 and have thin wall 3mm as shown in figure 2.

Figure 1. The experimental device

With the purpose of investigating the influence of technological parameters on the deformation of part when milling aluminum alloy thin-walled parts using uncoated carbide milling cutters, the experiment to select survey parameters including: Cutting speed, feed rate, cutting depth and cutting width with survey values as shown in Table 1.

Table 1. Cutting parameters and level

	Cutting parameters	Ký hiệu	Level		
			1	2	3
1	Cutting speed– A (m/min)	A	250	300	350
2	Feed per tooth - B (mm/tooth)	B	0.02	0.04	0.06
3	Radial depth of cut – C (mm)	C	0.3	0.6	1.2
4	Axial depth of cut – D (mm)	D	8	12	16

Minitab 18 Software (Minitab Inc., USA) is applied to build experimental model for this research. A Taguchi model L9 was designed with 4 input parameters and three levels as table 2. The deflection of workpieces are measured by the Mitutoyo's Digital indicator gauge in the milling process. During the machining process, due to the impact of the cutting force and the thickness of the small part, it is deformed as shown in Figure 2. The largest amount of deformation of the part and the result is as shown in Table 3.

Table 2. Experimental model L9

No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

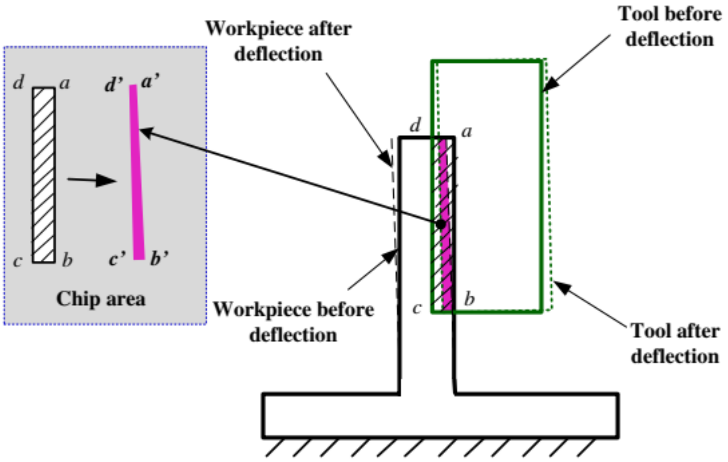

Figure 2. Deflection of thin wall workpieces in the milling process

Table 3. The experimental results and the S/N ratios for the deflection values

STT	V (m/min)	fz (mm/tooth)	a (mm)	b (mm)	x (µm)	S/Nx
1	250	0.02	0.3	8	60	-44.8110
2	250	0.04	0.6	12	48	-39.7354
3	250	0.06	1.2	16	174	-29.5424
4	300	0.02	0.6	16	97	-35.9868
5	300	0.04	1.2	8	30	-32.4650
6	300	0.06	0.3	12	63	-30.1030
7	350	0.02	1.2	12	42	-23.5218
8	350	0.04	0.3	16	32	-44.8110
9	350	0.06	0.6	8	5	-39.7354

III. RESULT AND DISCUSSION

Effect of cutting parameters to the deformation of the thin wall part

Using Minitab software, analysis ANOVA for deformation is determined. The analysis results show that the average value of deformation with different levels of cutting parameter and the order of influence of the input parameters on the value of deformation is shown in table 4. The analysis results show that among the survey parameters, the Radial depth of cut is the parameter that has the strongest influence on the average value of the deformation, the cutting speed has the second influence and the following is the feed rate and Axial depth of cut.

Table 4. Response Table for Means

Level	Cutting speed	Feed per tooth	Radial depth of cut	Axial depth of cut
1	94.00	66.33	51.67	35.00
2	63.33	36.67	53.33	51.00
3	29.67	84.00	82.00	101.00
Delta	64.33	47.33	30.33	66.00
Rank	2	3	4	1

The influence of the cutting parameters on the deformation is shown in Figure 3. This result indicated that the average value of part deformation decreased from 94 µm to 64.33 µm with increasing the cutting speed from 250 m/min up to 350 m/min. Thus, when milling aluminum with a small Radial depth of cut, increasing the cutting speed reduces the cutting force and reduces the deformation of the part. The results in the figure 3 show that the amount of deformation increased, when increasing the cut layer size (Radial depth of cut and Axial depth of cut). However, the amount of deflection increases more strongly with increasing the radial depth of cut. The reason may be that when the cutting depth are increased, the cutting force increases, and the rigidity of the thin wall part decreases, leading to an increase in the deformation of the part.

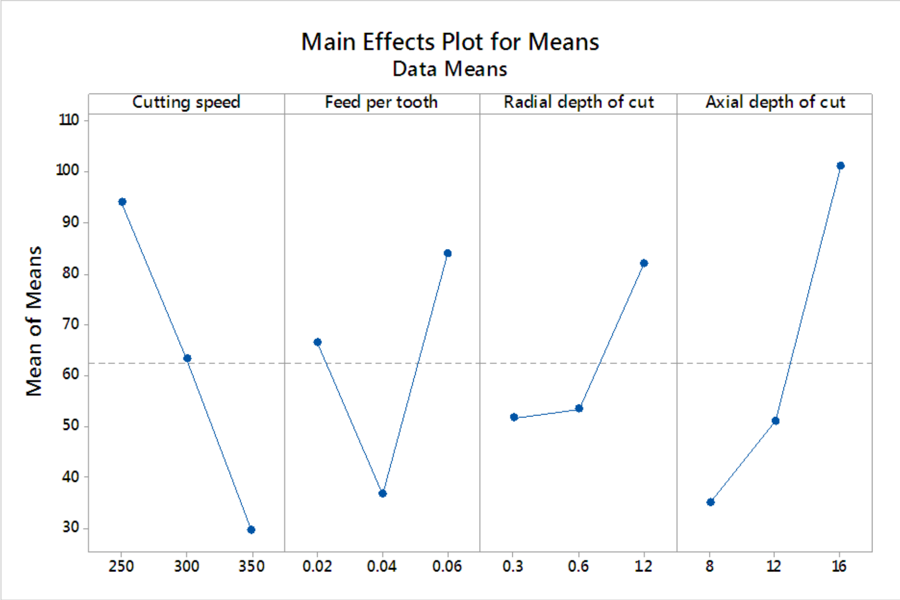

Figure 3. effects of input parameters on the average value of part deformation

The analysis results also show that the feed per tooth significantly affects deformation of part during the milling thin wall part process. The deformation of part decreases with increasing feed rate from 0.02 mm/teeth to 0.04 mm/teeth, and decreases with increasing of feed rate to 0.06 mm/teeth. Thus, basing on analyzing the influence of cutting parameters on the deformation of thin wall part, a set of cutting parameters can be selected as follows: V=350 m/min; fz=0.04 mm/teeth, a=0.3mm and b=8mm. Taguchi analysis also allows to evaluate the interaction influence betweenthe cutting parameters on the deformation of part, as shown in Figure 4. The results show that the interaction between the factors greatly affects the deformation of the part.

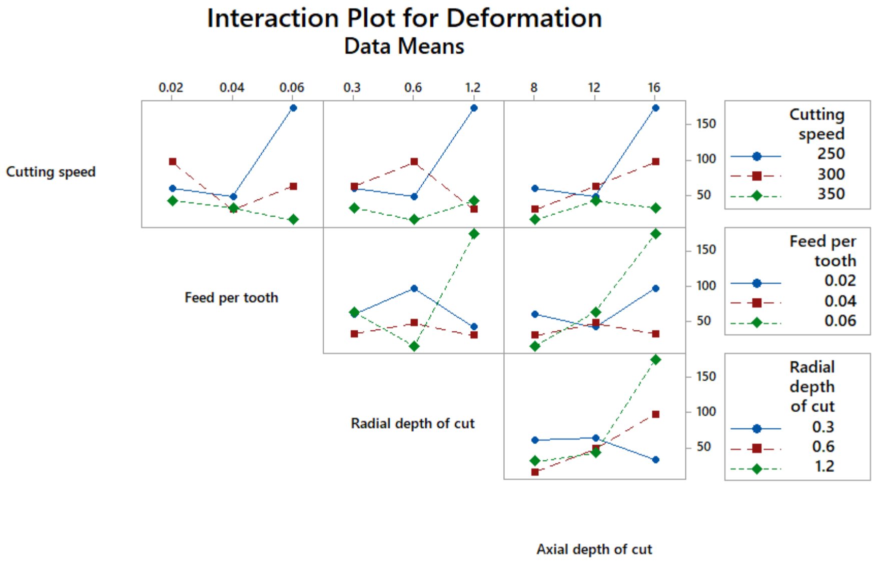

Figure 4. Interaction effect of cutting parameters on the amount of deformation of the part

The analysis results for the S/N ratio of the deformation are shown in Table 5. The analysis results show that the cutting speed and axial depth of cut are the parameters that have the strongest influence on the S /N ratio of the deflection. The influence of the cutting parameters on the S/N ratio of the part deflection in the milling thin wall part is shown in Figure 5. The results show that the ratio S/N increases rapidly with increasing cutting speed and has the greatest value with cutting speed 350m/min. At the same time, the value of the s/N ratio decreases sharply when the cutting width is increased. While the feeed rate and radial depth of cut do not have a strong influence on the S/N ratio of the part deformation. The S/N ratio of the part deformation reached the maximum value with the parameter set V=350m/min, fz=0.04mm/teeth, a=0.6mm and b=8mm.

Table 5. Response Table for Signal to Noise Ratios

Smaller is better

Level	Cutting speed	Feed per tooth	Radial depth of cut	Axial depth of cut
1	-38.00	-35.92	-33.88	-29.54
2	-35.09	-31.09	-32.29	-34.03
3	-28.70	-34.77	-35.61	-38.22
Delta	9.30	4.83	3.31	8.67
Rank	1	3	4	2

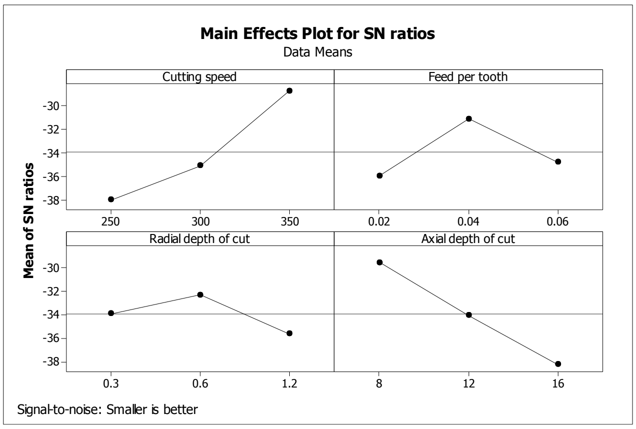

Figure 5. Influence of cutting parameters on the S/N ratio for the deformation of thin wall part

The interaction influence between the cutting parameters on the S/N ratio of the deformation is also analyzed and shown in the figure 6. The results also show that the interaction between cutting parameters affects quite a lot on the S/N ratio of the deformation, especially at cutting speed 250m/min, fz 0.06mm/tooth, cutting depth 1.2 mm and cutting width 16mm.

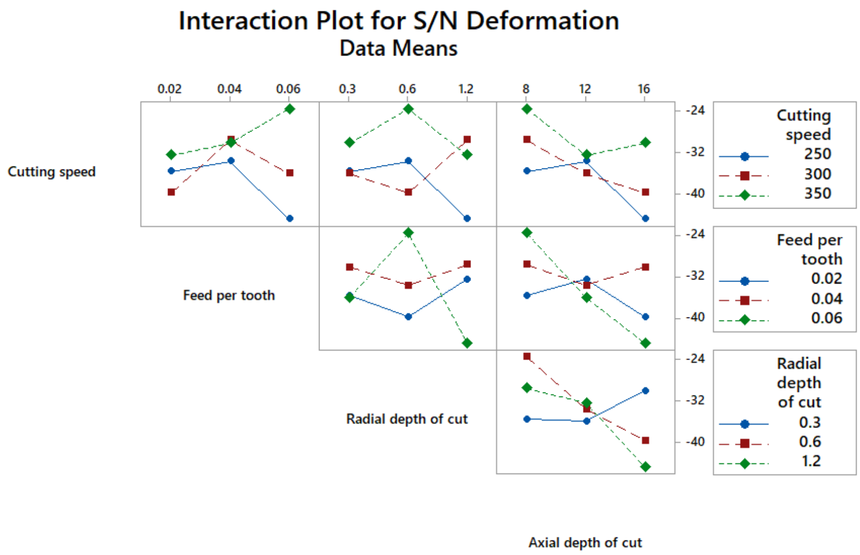

Figure 6. Interaction effect of cutting parameters on the deformation of the thin wall part

IV. CONCLUSION

The author has built an experimental model to analyze the influence of cutting speed, feed rate, radial depth of cut and axial depth of cut on the deformation of part in the milling thin wall part process. The Taguchi experimental planning method used showed that the cutting speed and axial depth of cut had the strongest influence on the deformation of thin wall part. Through analysis of the signal-to-noise ratio S/N, the author also showed that the set of parameters ensures the smallest deformation (V=350m/min, fz=0.04mm/tooth, a=0.6mm and b=8mm).

REFERENCES

[1]. Khabeery, M.M.El., Fattouh, M., 1988"Residual stress distribution caused by milling", Int. J. Mach. Tools Manuf. 29 (3), 391–401.
[2]. Kuang, H.F., Wu, C.F., 1995, "A residual stress model for the milling of aluminum alloy (2014-T6)", J. Mater. Process. Technol. 51, 87–105.
[3]. Coto, B., Navas, V.G., Gonzalo, O., Aranzabe, A., Sanz, C., 2011, "Influences of turning parameters in surface residual stresses in AISI 4340 steel", Int. J. Adv. Manuf. Technol. 53, 911–919.
[4]. Navas, V.G., Gonzalo, O., Bengoetxea, I., 2012, "Effect of cutting parameters in the surface residual stresses generated by turning in AISI4340 steel", Int. J. Mach. Tools Manuf. 61, 48–57.
[5]. Mohammadpour, M., Razfar, M.R., Jalili Saffar, R., 2010, "Numerical investigating the effect of machining parameters on residual stresses in orthogonal cutting", Simul. Model. Pract. Theory 18, 378–389.
[6]. Liang, S.Y., Su, J.C., 2007, "Residual stress modeling in orthogonal machining" CIRPAnn.: Manuf. Technol. 56 (1), 65–68.
[7]. Ulutan, D., Alaca, B.E., Lazoglu, I., 2007, "Analytical modeling of residual stresses in machining", J. Mater. Process. Technol. 183, 77–87.
[8]. Robinson, J.S., Tanner, D.A., Truman, C.E., Wimpory, R.C., 2011, "Measurement and prediction of machining induced redistribution of residual stress in the aluminium alloy 7449", Exp. Mech. 51, 981–993
[9]. H. Ning, W. Zhigang, J. Chengyu, Z. Bing, "Finite Elemet Method Analysis and Control Stratagem for Machining Deformation of Thin Walled Components", Journal of Materials Processing Technology, 139(1−3)(2003)332–336.
[10]. E. Budak, "Analytical Model for High Performance Milling. Part I: Cutting Forces, Structural Deformations and Tolerance Intergrity", International Journal of Machine Tools and Manufacture, 46 (12−13) (2006) 1489–1499.
[11]. Z.T.Tang, Z.Q.Liu, Y.Z.Pan, Y.Wan,X.Ai, "The Influence Of Tool Flank Wear On Residual Stresses Induced By Milling Aluminium Alloy", Journal of Materials Processing Technology, 209(9) (2009)4502–4508.
[12]. K.A. Shamsuddin, A.R. Ab-Kadir, M.Z. Osman, "A Comparison of Milling Cutting Path Strategies for Thin-Walled Aluminum Alloys Fabrication", The International Journal of Engineering and Science, 2 (3) (2013)1−8.
[13]. S. Seguy, G. Dessein, L. Arnaud, "Surface Roughness Variation of Thin Wall Milling, Related to Model Interactions", International Journal of Machine Tools and Manufacture, 48(3−4) (2008) 261−274.
[14]. I. Mane, V. Gagnol, B.C. Bouzgarrou, P. Ray, "Stability-based Spindle Speed Control During Flexible WorkpieceHigh Speed Milling", International Journal of Machine Tools and Manufacture,48(2) (2008) 184−194.
[15]. M.A.Davies, B. Balachandran, "Impact Dynamics in Milling of Thin Walled Structures", Nonlinear Dynamics, 22(4)(2000) 375−392.
[16]. P.G. Benardos, G.C. Vosniakos, "Predicting Surface Roughness in Machining, International Journal of Machine Tools and Manufacture", 43(8) (2003) 833−844.
[17]. V. Thevenot, L. Arnoud, G. Dessien, G. Cazenava-Larroche, "Influence of Material Removal on Dynamic Behavior of Thin Walled Structure in Peripheral Milling", Machining Science and Technology, 10(3) (2006)275−287.
[18]. M. Wan, J. Feng, W.H. Zhang, Y. Yang, Y.C. Ma, "Working mechanism of helix angle on peak cutting forces together with its design theory for peripheral milling tools", J. Mater. Process. Technol. 249 (2017) 570–580.
[19]. B. Jabbaripour, M.H. Sadeghi, Sh. Faridvand, "A study of the effects of cutter path strategies and cutting speed variations in milling of thin-walled parts", The 7th Jordanian International Mechanical Engineering Conference (JIMEC'7), (2010).
[20]. M.N. Durakbasa, A. Akdogan, A.S. Vanli, A.G. Bulutsuz, "Optimization of end milling parameters and determination of the effects of edge profile for high surface quality of AISI H13 steel by using precise and fast measurements", Measurement 68 (2015) 92–99.
[21]. S. Herranz, F.J. Campa, L.N. López, A. Rivero, A. Lamikiz, E. Ukar, J. A. Sánchez and Bravo U., "The milling of airframe components with low rigidity: A general approach to avoid static and dynamic problems", Proc. Inst. Mech. Engg. Part B: J. Engg. Manuf.219 (11) (2005) 789–801.
[22]. A. Polishetty, M. Goldberg, G. Littlefair, M. Puttaraju, P. Patile, A. Kalra, "A preliminary assessment of machinability of titanium alloy Ti6Al4V during thin wall machining using trochoidal milling", 12th Global Congress on Manufacturing and Management, GCMM 2014, Procedia Engineering 97 (2014) 357–364.
[23]. R. Izamshah, M. Zulhairy, M. Shahir, M. Hadzley, M. Amran, M. Amri, Sivarao, "Cutter path strategies for shoulder milling of thin deflecting walls", App. Mech. Mat. 529 (2014) 175–180.
[24]. D. Vakondios, P. Kyratsis, S. Yaldiz, A. Antoniadis, "Influence of milling strategy on the surface roughness in ball end milling of the aluminum alloy Al7075 -T6", Measurement 45 (2012) 1480–1488.
[25]. M. Subramanian, M. Sakthivel, K. Sooryaprakash, R. Sudhakaran, "Optimization of end mill tool geometry parameters for Al7075-T6 machining operations based on vibration amplitude by response surface methodology", Measurement 46 (2013) 4005–4022.
[26]. K. Kadirgama, M.M. Noor, N.M. Zuki, M.M. Rahman, M.R.M. Rejab, R. Daud, K.A. Abou-El-Hossein, "Optimization of surface roughness in end milling on mould aluminium alloys (AA6061-T6) using response surface method and radian basis function network", Jordan J. Mech. Ind. Eng. 2(4) (2008) 209–214.
[27]. N.E. Karkalos, N.I. Galanis, A.P. Markopoulos, "Surface roughness prediction for the milling of Ti–6Al–4V ELI alloy with the use of statistical and soft computing techniques", Measurement 90 (2016) 25–35.