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Measurement of Deflection Profile under Varying Clamping Pressure and Effect on Workpiece Accuracy after Machining

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Abstract: Thin wall parts have increasing demand in aerospace, surgical, power sectors, automotive industries etc., due to its high strength to weight ratio. The major serious challenge in machining complex thin-walled components is deformation caused during machining that disturbs its accuracy and surface quality and this is maintained with proper clamping and supports. The clamping ensures the dimensional and form accuracies, surface finish and accuracy of profile after machining. Developing a clamping approach, one need to understand how the workpiece is responding to applied forces. In view of this, in this paper, first numerical simulations are carried out in ANSYS 18.1 on Aluminium 6061-T6 workpiece which is held in 3-2-1 fixture with two hydraulic clamps. Next, measurement of workpiece deflection profile is carried out on CNC coordinate measuring machine under varying clamping pressures. Next, comparison of simulated and measured deflection profile is carried out and errors are calculated. The error between experimental and numerical measured and predicted deflection profile shows good agreement and results lie below 25%. Further dimensional and form tolerances and surface finish are compared before and after machining.

***Keywords* —Clamping pressure, deflection profile, form and dimensional tolerances, surface finish, thin-walled components**

I. INTRODUCTION

Demand of high strength to weight in aerospace industries has promoted machining of monolithic thin-walled components. They are machined up to 95% from a single prismatic block and have light weight, less cost, high strength to weight ratio. Machining and assembly by riveting of multi-part aeronautical structure is expensive and time consuming. Complex monolithic structures are replacing multi-part structures fast due to their exceptional strength to weight ratio and reduced cost of assembly. These complex integral parts have reduced thousands of hours of mechanical assembly work [1]. The major challenge in machining of deformation cased during machining process. The other problem is deflection and vibration of cutting tool and workpiece. As metal removal progresses and workpiece walls become thin, machining and maintaining accuracy of workpiece become critical. The deflection and vibration affect the dimensional accuracies, form accuracies and quality of surface finish of the workpiece [2]. This is achieved by proper clamping and supports. Insufficient clamping causes slip or lift-off of the workpiece during machining and excess clamping results into large excessive contact and workpiece deformations.

Vast research is carried out to minimize deformation and vibration of thin-walled components. To predict deformation of titanium alloy Ti6Al4V thin-walled component, Liu Gang developed finite element (FE) models of an end mill and component to simulate milling process. Simulated and experimental part deformation and surface error are compared to explore error compensation method [3]. Siebenaler and Melkote proposed a finite element model that studies the influence of fixture body compliance on workpiece deformation. Also, effect of friction and mesh density are taken into consideration for FE modelling to enhance model accuracy [4]. Ratchev et al. reported an integration method for multi-step simulation of low rigidity component machining process. Common data model represents part instances with cutting force model and metal removal algorithms during machining [5]. Tang and Liu proposed a theoretical model for part deformation using reciprocal theorem and presented deformation characteristics. Linear load, plate thickness and location of end mill cutter showed substantial effect on part deformation during simulation. It is suggested that to obtain smaller cutting forces and better accuracy, diverse cutting parameters should be used for each layer of machining [6]. Q. Wu et al. used finite difference method to predict deformation of thin-walled plate and experimentally verified [7]. Yadav and Mohite developed force deformation characteristics for thin-walled aluminium

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component from a numerical model predicting contact and structural deformations under varying clamping forces. The results are validated experimentally [8]. Cheng et al., developed 3D model of ball end mill and part deformation is predicted by FE [9]. Khandagale et al. developed a mathematical model for forced vibration deflection response of a thin plate in time domain during flank milling. Natural frequencies and mode shapes are obtained by FE and impulse response and compared. Also, vibratory response of FE model and experimental results are compared, but metal removal effect is not considered [10]. Delport et al. studied the clamping methods on titanium workpiece during machining. Alternative clamping method to reduce workpiece deformation is suggested [11]. Wimmer presented analytical model to estimate surface errors for thin-walled workpiece during peripheral milling. Expected surface error is compensated by compensating toolpath [12]. Masmali and Mathew proposed analytical method to predict deflection for thin-walled workpieces during end milling. Also, dynamic displacement of chip is linked with cutting forces to report. workpiece dynamic displacement due to chip load [13]. Wasik presented a special adjustment to improve machining accuracy of thin-walled components. Positioning error is predicted and threshold value is defined, below which the machining is not done [14]. To investigate dynamic response of a thin-walled component by using first shear deformation theory and Lagrange equation. Effect of plate thickness and the cutter moving path on workpiece deformation [15].

Apart from above efforts, there is a need to predict workpiece deformation correctly and devise a mechanism to compensate the deformation that can finely tune cutting and clamping forces. In this paper, numerical simulations are carried out to predict deformation profile of thin-walled component under varying clamping pressures and validated experimentally. Secondly, workpiece dimensional and form accuracies and quality of surface finish is measured before and after machining of thin-walled workpiece.

The next section describes numerical model to predict deformation profile of the workpiece.

II. NUMERICAL MODEL

Aluminium 6061-T6 pocketed prismatic workpiece, 100mm×100mm×70mm size is located in 3-2-1 fixture (L_1 to L_6) and clamped with two hydraulic clamps C_1 and C_2. The thin-walled workpiece has pocket size 91mm×91mm×66mm with wall thickness 4.5mm. Table 1 shows properties of workpiece and fixture elements.

A. Modelling Options

The workpiece and fixture element assembly with frictional contacts is subjected to static analysis in ANSYS Workbench 18.1.

Table 1 Properties of workpiece and fixture elements

Sr. No	Parameter	Workpiece	Spherical Locator
1	Material	Al6061-T6	Hardened steel
2	Young's modulus E, (GPa)	70	200
3	Poisson's ratio	0.3	0.285
4	Yield strength (S_y) (MPa)	270	(300-400)
5	Shear modulus (GPa)	26.31	77.82
6	Density (kg/m^3)	2700	7800
7	Weight (kg)	1.89	6 locator, 2 clamps
8	Friction coeff.	0.375	-

To investigate the workpiece deformations for 4.5mm wall thicknesses, clamping pressure is varied in the range of 1-30 kg/cm^2 in step of 5 kg/cm². Table 2 shows the modelling and meshing options in ANSYS 18.1

Table 2 Modelling and meshing options in ANSYS 18.1

Meshing	Options	Analysis setting	Option
Method	Hex dominant	Auto time-step	Off
Face size	2.5mm	Solver	Direct
Size fun.	Curvature	Weak springs	Off
Relevance	Fine	Large deflection	Off
Quality	0.8	Fixed Support	Locator
Elements	SOLID 186, CONTA 174, TARG 170	Clamp pressure at C_1 and C_2	1-30bar

The next subsection gives details of structural analysis.

B. Structural analysis to predict deflection profile

Two clamps and spherical tipped locators keep frictional contact with the flat faces of the workpiece. As the workpiece is having low rigidity, the fixture workpiece system is modelled as a flexible workpiece system resting on fixture elements like locators and clamps and hold with hydraulic clamps C_1 and C_2 respectively. Static analysis uses SOLID 186 elements and CONTA 174 and TARG 170 elements are used for contact analysis. Hex dominant mesh with face size 2.5mm and an advanced sizing function is used in static analysis. Fig. 1 shows the deflection profile at 35mm depth and 25 kg/cm^2 clamping pressure.

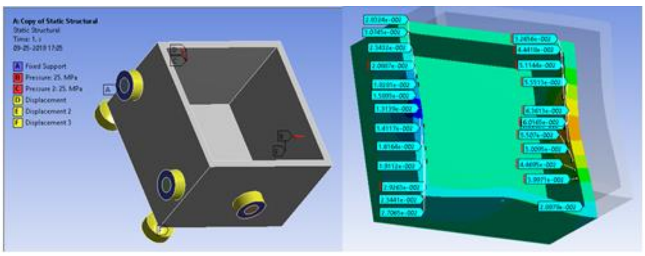

Fig.1 Undeformed and deformed workpiece geometry of aluminium 6061-T6 workpiece in ANSYS

The workpiece deflection profile obtained during static analysis is given in result and discussion section in detail. The experimental setup is explained in next section.

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III. Experimental Validation

The experimental validation of numerical deflection profile for thin-walled aluminium workpiece with already machined one. The workpiece is subjected to varying clamping pressure in the range of 1-30 kg/cm^2 in step of in step of 5 kg/cm². The experiments are carried out on CNC CMM machine on the aluminium workpiece of 4.5mm wall thickness at 25 kg/cm^2 clamping pressure, with two clamps C_1 and C_2 respectively. As shown in Fig. 2, Aluminum 6061-T6 pocket milled workpiece is held in 3-2-1 fixture workpiece system and clamped by two hydraulic clamps operated by hand pump for adjusting clamping pressure. The deflection profile of the workpiece is taken along horizontal line inside the pocket wall at depth of 35mm and points at distance of 5mm apart with 5mm probe size of CNC CMM and having MH20i probe head and TP 20 probe.

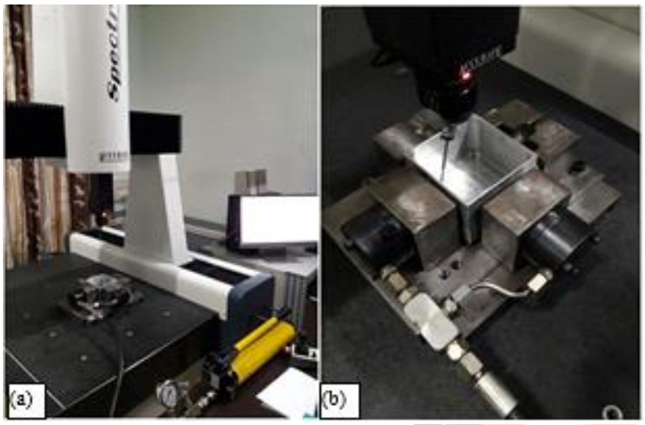

Fig. 2 (a) Experimental set up of fixture-workpiece assembly on CMM (b) CMM probe measuring deflection profile of pocketed workpiece

As the workpiece walls are fixed at three edges and free at one edge, the maximum deflection occurs at the centre of wall on free edge as compared to fixed edges. In the next section, comparison of simulated and experimental and deflection profile are presented. The deflection profile obtained numerically for Al 6061-T6 workpiece at 35mm depth of pocket show good agreement with that of obtained experimentally. The detailed discussion is given in the section IV.

IV. Results and Discussion

The results are presented in two subsections. In the first subsection comparison of simulated and measured deflection profile is discussed. In the second subsection, comparison of form tolerances and surface quality of workpiece is discussed.

A. Comparison of simulated and measured deflection profile

Table 3 shows comparative results of simulated and experimental deflection profile at 35mm depth of pocket wall C_2, in Y direction and wall C_1, in X direction, having 4.5mm wall thickness of workpiece at 25 kg/cm² clamping pressure.

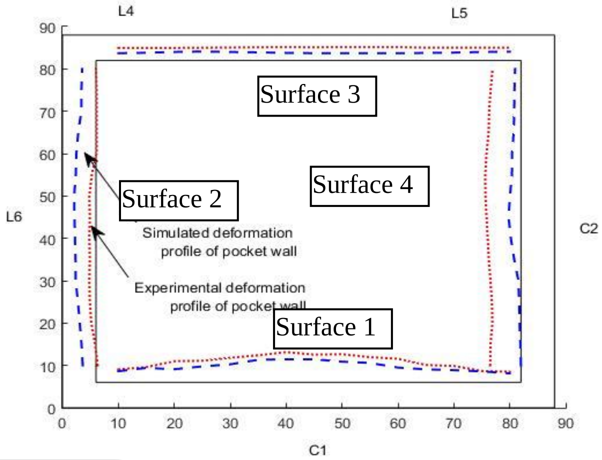

Fig. 3 Comparative deflection profile of simulated and measured values at 35mm pocket depth for 25 kg/cm²

Table 3 Deflection profile of pocket wall for C_1 and C_2 at 25 kg/cm^2 clamping pressure

Method Y → coordinate ↓	Workpiece deflection profile on C_1 face at 25 kg/cm² (μm)			Workpiece deflection profile on C_2 face at 25kg/cm²(μm)		
	δ_e	δ_n	% error $(\delta_e - \delta_n)/\delta_e$	δ_e	δ_n	% Error $(\delta_e - \delta_n)/\delta_e$
15	46.5	43.81	5.78	267	238.5	10.67
20	60	58.74	2.10	289.5	245.5	15.20
25	86.5	85.27	1.42	322.5	279.05	13.47
30	126	118.35	6.07	367	314.25	14.37
35	175	157.35	10.09	392.5	345.86	11.88
40	204	198.35	2.77	430.5	375.75	12.72
45	245	233.35	4.76	461	394.54	14.42
50	301	259.35	13.84	485.5	395.54	18.53
55	311	269.35	13.25	471	374.1	20.57
60	268	238.35	11.06	433.5	337.5	22.15
65	216	206.35	4.25	393	295.08	24.92
70	190	174.35	7.99	358.5	276.91	22.76
75	168	139.35	17.05	312	254.62	18.39
80	130	107.52	16.97	276.5	232.58	15.88
85	97	80.25	17.27	241.5	215.85	10.62

The experimentally obtained workpiece deflections have higher values than simulated deflections and lies in 25% for pocketed workpiece. Maximum deflection amongst four walls is observed on clamp side C_2 is 485.5 μm, followed by that of C_1 as 311 μm. It is cleared from the table that the error between simulated and experimental results lies within 1.42% to 17.27% for pocket wall on C_1 side and 10.62% to

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24.92% for pocket wall on C_2 side. The variation between measured and numerical obtained deformation profile is found to be within 25% which is good. The variation in experimental and numerical results is attributed to the fixture deformations. Backlash in fixture, hydraulic clamps and fixture elements which are not modelled in simulation. These variations can be reduced by careful control over the experiments and by incorporating correct modelling conditions.As shown in Fig. 4, the component is subjected to pocket milling under constant clamping pressure of 25 kg/cm² on CNC Maxmill Plus+ machine. End mill cutter of Ø8 mm dia., 4 flute and 45^0 helix is used for machining. Pocket milling operation is carried out at 200m/min cutting speed, 120mm/min feed rate, 33mm axial depth of cut and 0.2mm radial depth of cut.

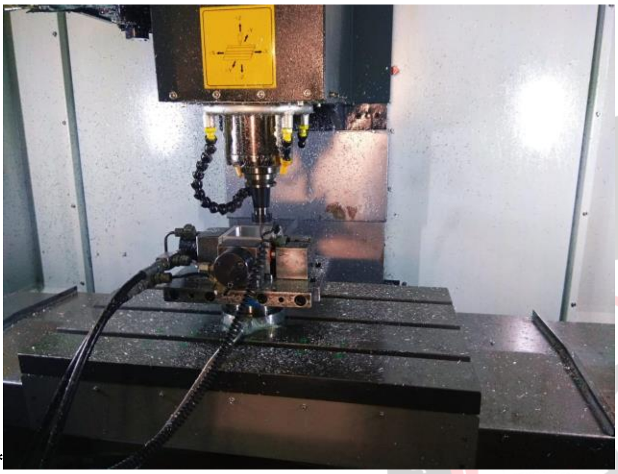

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Fig. 4 Experimental setup for pocket milling of thin-walled Al 6061 T6 workpiece held in 3-2-1 fixture with two hydraulic clamps

Fig. 5 Experimental setup for roughness measurement of thin-walled Al 6061 T6 workpiece after machining

After machining the component is found dimensionally correct. The form tolerances such as parallelism and perpendicularity are checked on CNC CMM for all pocket walls. The results of form tolerances and surface finish of thin-walled aluminium component before and after machining are compared and percentage error is calculated. Correspondingly, to check the surface quality of the workpiece before and after machining, SJ 200 Mitutoyo surface roughness tester is used (see Fig. 5). The next section presents the results of form tolerances and surface finish before and after machining for workpiece with 4.5mm wall thickness.

The detailed results and comparison of parameters is given in the next section.

B. Measurement of workpiece accuracies before and after machining

Table 3 and table 4, show the results of machining thin-walled workpiece at constant pressure 25 kg/cm² for form tolerances, parallelism and perpendicularity of pocket walls. Percentage error in parallelism between surface 1-3 and surface 2-4 is 18% and 22% respectively, after machining. Table 3 shows the comparison of parallelism between the parallel pocket walls before and after machining.

Table 3: Parallelism of pocket walls before and after machining

Workpiece wall (Surface)	Parallelism		
	Before machining(µm)	After machining(µm)	% Error
1 & 3	95	112	18
2 & 4	155	189	22

Similarly, the percentage error in perpendicularity between surface 1-4 and surface 2-3 is 26% and 7.2% respectively, after machining.
Table 4 shows the comparison of perpendicularity between the adjacent pocket walls before and after machining

Table 4: Perpendicularity checking of pocket walls before and after machining

Workpiece wall (surface)	Perpendicularity		
	Before machining(µm)	After machining(µm)	% Error
1 & 4	135	183	26
2 & 3	51	55	7.2

From these observations, we can conclude that as the machining continues the structural stiffness of the workpiece drops to greater extent leading to instability of workpiece which affects the form tolerances to considerable range which is not desirable. Therefore, a mechanism should be devised to control form tolerances within the given range.

Table 5 shows that surface roughness Ra values are improved from 7.8% to 23% for four pocket walls after machining. Further recommendations are given on the basis of these results to minimize deformation and improve workpiece accuracy.

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Table 5: Ra value before and after machining

Workpiece wall (Surface)	Surface roughness (Ra)		
	Before machining (μm)	After machining (μm)	% improvement
1	2.01	1.530	23
2	1.802	1.607	10.8
3	1.803	1.707	5.32
4	1.601	1.476	7.8

In the next section, conclusions of the study are summarized.

V. Conclusions

In this paper, we have compared simulated and measured workpiece deflection profile at varying clamping pressures to study the effect of clamping on workpiece deformation. The measured workpiece deflections have higher values than the simulated deflections and lies in 25% for four walls which is good agreement of results.

Next, after machining, the comparison of form tolerances and surface quality is done with that of before machining. It is observed that as thinning of wall progresses, there is considerable drop in structural stiffness of workpiece which leads to increase in instability. This further causes increase in percentage error in parallelism is 18%-22% and that of perpendicularity is 7%-26% which is not desirable. The surface finish is found to be improved after machining with 7.8% to 23% for four pocket walls.

It is recommended that to keep the workpiece accuracy intact, a mechanism or strategy should be developed to maintain workpiece form tolerances within given range.

Tuning online/in-process clamping forces may be the better solution as it may adaptively resist the time and space varying the cutting forces and sustain workpiece stability, yielding the desired workpiece accuracies and surface finish for thin-walled components used in various sectors.

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References

[1] Michiel Popma, “Computer aided process planning for high-speed milling of thin-walled parts: strategy-based support,” Ph.D. dissertation, Dept. Elect. University of Twente, Enschede, 2010.

[2] G. Sridhar. R. Babu, “Understanding the Challenges in Machining Thin Walled Thin Floored Avionics Components,” International Journal of Applied Sciences and Engineering Research, vol. 2, 1, pp. 93-100, 2013.

[3] Liu Gang, “Study on deformation of titanium thin-walled part in milling process”, journal of materials processing technology, vol. 209, pp. 2788–2793, 2009.

[4] Shane P. Siebenaler, Shreyes N. Melkote, Prediction of workpiece deformation in a fixture system using the finite element method, International Journal of Machine Tools & Manufacture 46 (2006) 51–58.

[5] S. Ratchev, W. Huang, S. Liu, A. A. Becker, Modelling and simulation environment for machining of low-rigidity components, Journal of Materials processing technology 153-154(2004)67-73.

[6] Tang Aijun, Liu Zhanqiang, “Deformations of thin-walled plate due to static end milling force”, journal of materials processing technology vol. 206, 345–351, 2008.

[7] Q. Wu, D. P. Li, L. Ren and S. Mo, “Detecting milling deformation in 7075 aluminum alloy thin-walled plates using finite difference method”, International Journal of Advanced manufacturing Technology (2015)1-12.

[8] M. H. Yadav and S. S. Mohite, “Controlling deformations of thin- walled Al 6061 components by adaptive clamping”, Procedia Manufacturing vol. 20, pp. 509–516, 2017.

[9] Y. Cheng, D. Zuo, M. Wu, X. Feng, Y. Zhang, “Study on Simulation of Machining Deformation and Experiments for Thin-walled Parts of Titanium Alloy, International Journal of Control and Automation, vol. 8, 1, pp. 401 -410, 2015.

[10] P. Khandagale, G. Bhakar, V. Kartik, S. S. Joshi, “Modelling time-domain vibratory deflection response of thin-walled cantilever workpieces during flank milling”, Journal of Manufacturing Processes, vol. 33, pp. 278–290, 2018.

[11] L. Delport, P. Johannes T. Conradie, G. A. Oosthuizen, Suitable clamping method for milling of thin-walled Ti6Al4V components, Procedia Manufacturing, vol. 8, 338 – 344, 2017.

[12] Sepp Wimmer Michael F. Zaeh, “The Prediction of Surface Error Characteristics in the Peripheral Milling of Thin-Walled Structures”, Journal of manufacturing and materials processing, 2018.

[13] Majed Masmali and Philip Mathew, “An analytical approach for machining thin-walled workpieces”, Procedia CIRP vol. 58 pp. 187 – 192, 2017.

[14] Mateusz Wąsik, Arkadiusz Kolka, “Machining accuracy improvement by compensation of machine and workpiece deformation”, Procedia Manufacturing vol. 11, 2187 – 2194, 2017.

[15] J. Shi, J. Gao, Q. Song, Z. Liu, Yi Wan, Dynamic deformation of thin-walled plate with variable thickness under moving milling force, Procedia CIRP 58 (2017) 311 – 316.

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