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By Amrifan Saladin Mohruni

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M Yanis[1*], A S Mohruni[1], S Sharif [2], I Yani[1], M Zahir[1]

[1] Department of Mechanical Engineering, Faculty of Engineering, Sriwijaya University, 60662 Indralaya, South Sumatera, Indonesia.

[2] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81319 Johor Bahru, Malaysia.

[*] Corresponding author: mohrunias@unsri.ac.id

Abstract. In thin-walled Titanium Ti6Al4V machining, vibration is the dominant factor affecting the quality of components. Excessive vibrations can generate chatter, this condition occurs because it is not suitable in choosing machining parameters. Chatter is not expected because it causes dimensional errors, rapid tool wear and poor surface finish. This experiment tries to identify chatter-free conditions with the appropriate parameters. Uncoated carbide is used as a cutting tool with a diameter of 10 mm and machining under the MQL system with coconut oil as a cutting fluid. In the result of the milling showed if this machining is free of chatter, where from frequency was achieved is not equal to the natural frequency from simulation, then this is also approved from result surface roughness and surface photography. In surface roughness result, the value is smaller than minimum critical amplitude, where good result in high value of the cutting speed and small feed rate and result of the surface photography was identified no severe surface condition along thin-walled. The experiment also calculated for non-thin-walled Ti6Al4V as evaluation, where the result of both acceleration and surface roughness was obtained smaller than milling thin-walled.

1. Introduction

Vibration behavior is always related to low stiffness components, and this behavior is more significant occurring on the thin-walled shapes. The self-excited vibration vary the thickness of the chip and increases the amplitudes of vibration, called regenerative chatter. This chatter is the most harmful compare to other vibration such forced or free vibration. The chatter could occur by friction or wavy surfaces of workpiece. The increase of surface roughness is one of the consequence from chatter [1][2].

In the aircraft component, this thin-walled in monolithic offers a good solution in reducing component weight, and titanium-based alloy is commonly used as a based material, where this is a superior alloy with better ability and lower weight than Ni-based alloy. In the manufacturing of thinwalled Ti6Al4V component, the effect of vibration is more dominant in the machining than in an additive process. However, the less time in machining and good product result (homogeneity, near net shape and low internal material defect) are achieved with this process, and the result will be more significant if used appropriate parameters [3].

Chatter mitigation is one of the efforts by several investigation in avoid machining error, because this phenomenon happens in machining thin-wall Ti6Al4V as major obstacle. Generally, the unsuitable in milling parameters is expressed in stability lobe diagram (SLD), which is relation between the spindle speed and axial depth of cut [4]. Another study with 3-dimensional chatter stability with addition machining step or tool position [5].

The carcinogenic effect of polyaromatic hydrocarbons affects the reduced interest in the use of petroleum oil as cutting fluid. This matter provides an opportunity for the applied of vegetable oil.

Coconut oil was used in several studies as cutting fluid and indicated excellence property. Addition vegetable oil as cutting fluid bring better result in cutting force and tool wear than dry and wet cutting [6].

To overcome the more price of vegetable oil compared to petroleum oil, MQL is an alternative to lubricating method. Although MQL is also classified as green machining method but in its use could be aimed to reduce the volume of vegetable oil as cutting fluid [6]. There are studies were reported that applied commercial vegetable oil cutting fluid in machining Ti6Al4V under MQL [7][8]. Another studies applied rapeseed oil and palm oil in machining Ti6Al4V under MQL [9][10].

In this study, the prediction of chatter generation on the milling thin-walled Ti6Al4V will be compared with non-thin walled under Minimum Quantity Lubrication (MQL) using coconut oil. Then, the frequency domain from vibration result by accelerator will be depicted, and also the natural frequency from finite element simulation as indicator chatter free condition. As evaluation, we also measure the surface roughness and topography to identify chatter in thin-walled area.

2. Theory of Machining Stability

Extensive vibrations occur in thin-walled Ti6Al4V machining due to components with low rigidity. End milling dynamic equations in the system of the workpiece and the tool is written by equation (1).

$$m_y\ddot{y}(t) + d_y\dot{y}(t) + K_y y(t) = F_y(t) \quad (1)$$

where, m_y is the modal mass, d_y is the damping and K_y is the system stiffness. $\ddot{y}(t)$ is the acceleration of vibration, $\dot{y}(t)$ is the speed of vibration and $y(t)$ is the displacement of vibration. $F_y(t)$ is the cutting force in the direction perpendicular to the surface of the workpiece.

In the system of the workpiece and the tool that neglecting the influence of external cutting force and damping, equation (1) can be rewritten as shown by equation (2).

$$M\ddot{y}(t) + Ky(t) = 0 \quad (2)$$

where, M is the mass of the system, K is the stiffness matrix; n x n and y is an n-dimensional column vector. For systems with 1-degree of freedom, equation (1) can be written as equation (3) follows:

$$m\ddot{y}(t) + ky(t) = 0 \quad (3)$$

From the relationship $y(t) = y_0 \sin(\omega t)$, then equation (2) can be changed to $(-\omega^2 M + K)\, y_0 = 0$ and equation (3) to $(-\omega^2 m + k)\, y_0 = 0$. Where ω is the angular velocity and $\omega = 2.\pi.f$ so that it will give a natural frequency solution as shown by the equation (4).

$$f_n = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (4)$$

Relationship in equation $(-\omega^2 M + K)\, y_0 = 0$, can be rewritten as shown by the equation (5) below:

$$(K - \lambda M) = 0 \quad (5)$$

where, equation (5) reflects the equation for a set of the eigenvalues ($\lambda_n = \omega^2$) and eigenvectors.

To transform the vibration graph from the time domain to the frequency domain using the Fast Fourier Transform (FFT) shown in equation (6).

$$F(k) = \sum_{n=0}^{N-1} F(n)\, e^{-j\frac{2\pi}{N}kn} \quad (6)$$

where, $F(k)$ is the frequency domain samples, $F(n)$ is the time domain samples, N is the number of samples, $k = 0,\ldots, N-1$.

3. Methodology

The investigation is sequence from previous study which tried to define surface roughness and cutting force values in milling titanium alloy Ti6Al4V [11][12]. As an addition, this investigation tried to focus on vibration and predict chatter free condition on milling the thin-walled. The experiment also measures the value of non-thin-walled milling as an evaluation. Input parameters are cutting speed and feeding motion as tabulated in Table 1. The machining parameter is based on the previous study from lowest, centre and highest level variable. Output parameters are vibration, surface roughness and surface topography.

Table 1. The input parameters in experimental

Parameters		Input Values
Cutting speed	(m/min)	: 64, 100 and 156.64
Feed Rate	(mm/tooth)	: 0.025, 0.063 and 0.158
Radial Depth of Cut	(mm)	: 0.32
Axial Depth of Cut	(mm)	: 0.707

The process of removal used CNC milling type MAHO DMC 835 V with 3-axis, then the milling used tool solid helical end mill uncoated carbide, 10 mm of diameter, 4 flutes and 47 helical angles, where the process under MQL is using coconut oil. The thin-walled used titanium alloy Ti6Al4V Grade 5 with geometry size 100 x 3 x 22 mm, where experimental setup is shown in **Figure 1**.

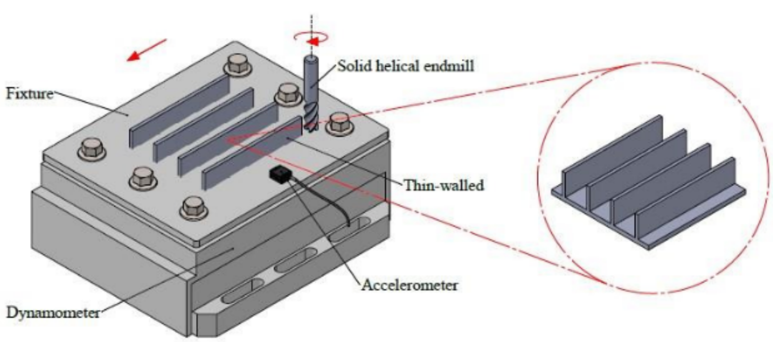


Figure 1. Experimental setup of milling thin-wall Ti6Al4V

The accelerator sensor is embedded on the fixture surface for measure vibration, which is achieved acceleration magnitude with time domain, then continued to define frequency domain using Fast Fourier Transform (FFT). For identification chatter-free condition, the result from accelerator in frequency domain will be related to result from the simulation using SolidWorks software. Output from simulation is several natural frequencies of mode shapes, if the frequency from milling equal to the natural frequency of simulation, then this condition is identified as chatter condition. The surface roughness and surface topography will be taken as evaluation that will be related to chatter-free condition. Chat conditions are generally indicated by unstable values or increased surface roughness and topographic surface values along thin walled Ti6Al4V.

Detect vibration signals using a Daqcard direct amplifier and software of Dewesoft 7.0.6. The Matlab R2012a software was used to analyze these vibration signals. Accretech-Handysurf E-35A/E Roughness Tester is used to measure the surface roughness of the workpiece. Surface topography with a Canon EOS 11000 camera, EFS lens 18-55 mm (focus length).

4. Result and discussions

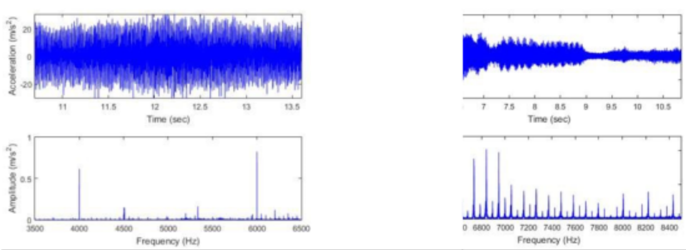
The experimental results of vibration for thin-walled and non-thin-walled in unit of m/s^2 as shown in **Figure 2**. The vibration value represents the mean value for the tangential direction of the cutting tool and is perpendicular to the workpiece. The results of thin-walled are more stable than those non-thinwalled. In other conditions, non-thin-walled show good results in acceleration and amplitude. Almost all parameters result in thin-walled milling under stable conditions in the range of 20 m/s^2 and increased in several times, but it changed not significantly.

In **Figure 2**, the graph is displayed in the time domain and frequency domain. Thin-walled results show that at some frequencies the amplitude increases at 4000 Hz, 5200 Hz and 6000 Hz, where a significant amplitude occurs at 6000 Hz. Furthermore, the result will be related to the natural frequency of thin-walled Ti6Al4V from SolidWorks software to determine chatter-free condition, where the simulation has set in upper bound frequency 10000 Hz.

The shape mode result with different natural frequency are shown in **Figure 3.** , where the first shape mode is achieved in frequency 4939.8 Hz with amplitude 11.64, the second in frequency 5468.6 Hz with amplitude 16.63 and the third in frequency 7053.6 Hz with amplitude 18.46. Almost of all the experimental results are close to simulation results, but this value not caused the chatter condition.

From result the accelerator on milling thin-walled and non-thin-walled Ti6Al4V, the mean value of the graphic acceleration that is shown in **Figure 4**, which is depicted acceleration in thin-walled increasing as equal as cutting speed linearly, and acceleration not tend to increase with effect of the feed rate. In non-thin-walled result, the acceleration decreased about cutting speed and increased in feed rate. The distinction value of the acceleration in thin-walled and non-thin-walled identified if the similar comparison value, has shown both cutting speed and feed rate value about 6 m/s^2. The vibration in thinwalled components was 84.4% greater than non-thin-walled components. The same result was obtained by other researcher [13].

As an evaluation in **Figure 5**, the result of surface roughness is also measured, where from the result identified if both the value of milling thin-walled and non-thin-walled decreased about cutting speed, and increased about feed rate parameter [14][15][16]. And also, this value indicates the fully stable vibration, where both thin-wall and non-thin-walled surface roughness result are smaller than minimum critical amplitude value A_{cr} or chatter-free condition [17].



f_z = 0.158 mm/tooth

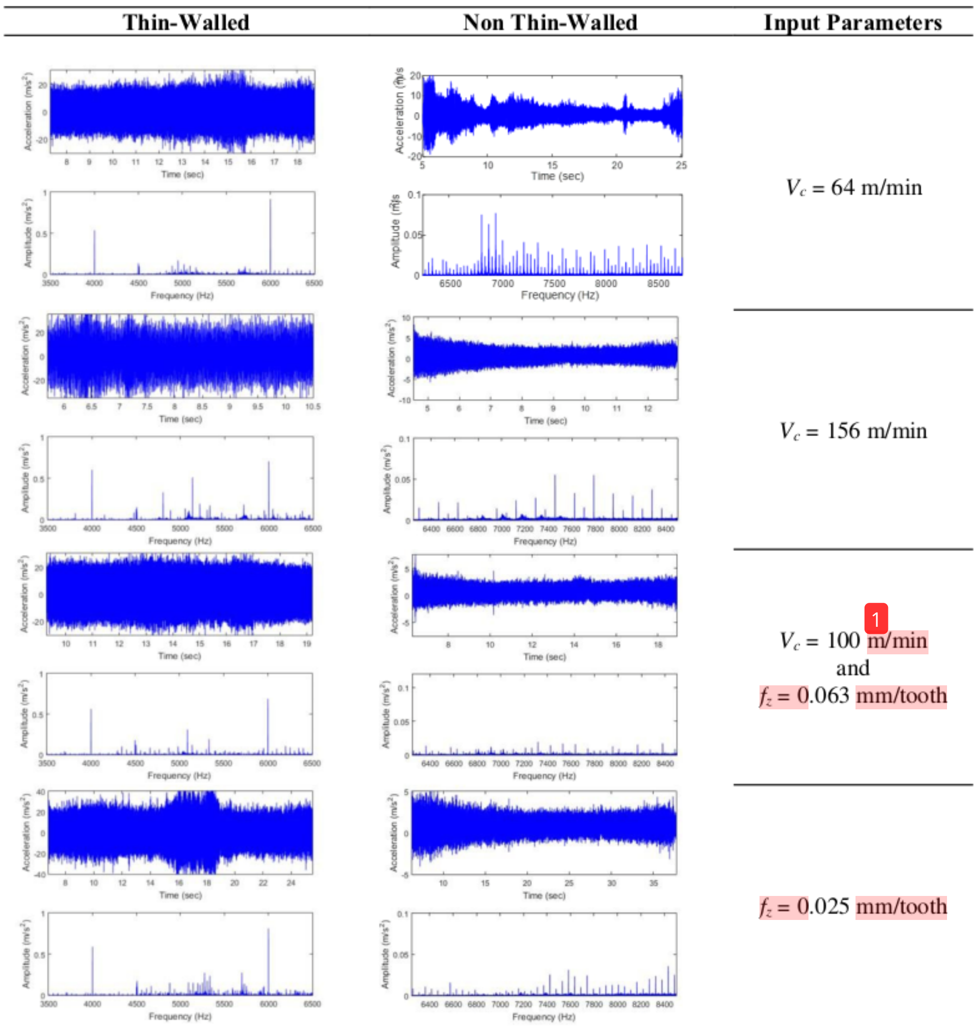


Figure 2. Time domain and frequency of vibration in V_c and f_z variation

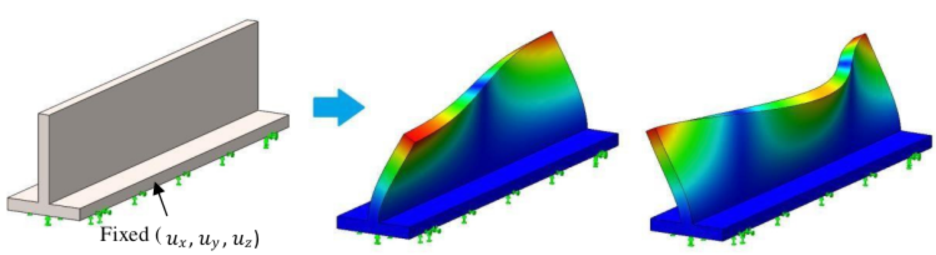


Figure 3. Natural frequency and shape mode thin-walled Ti6Al4V

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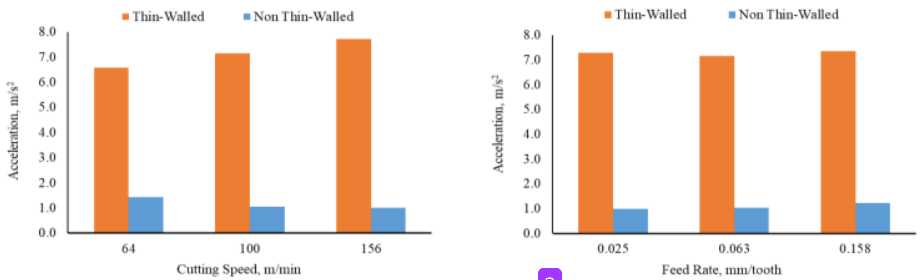

Figure 4. Acceleration results about the parameters of the cutting speed and feed rate

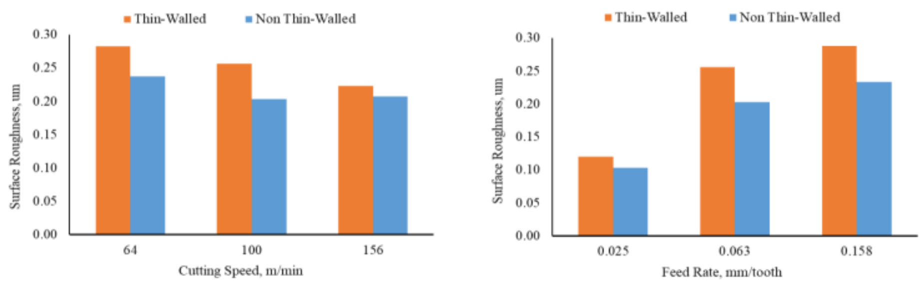

Figure 5. Surface roughness result about the parameters of the cutting speed and feed rate

The chatter mark is used to determine chatter condition on surface thin-walled topography, where this mark is easy to identify because it is not similar with former surface topography or severe surface [18][19]. As shown in **Figure 6**, result from surface photography of milling thin-walled parameters, which chatter did not appear along the surface. Although in several parameters did not show good surface topography at V_c = 156 m/min and f_z = 0.158 mm/tooth. The best result was achieved at V_c = 64 m/min and f_z = 0.025 mm/tooth and V_c = 100 m/min, f_z = 0.063 mm/tooth. The same method for analyzing chatter based on surface photography was also carried out by several other researchers [20][21][22][23].

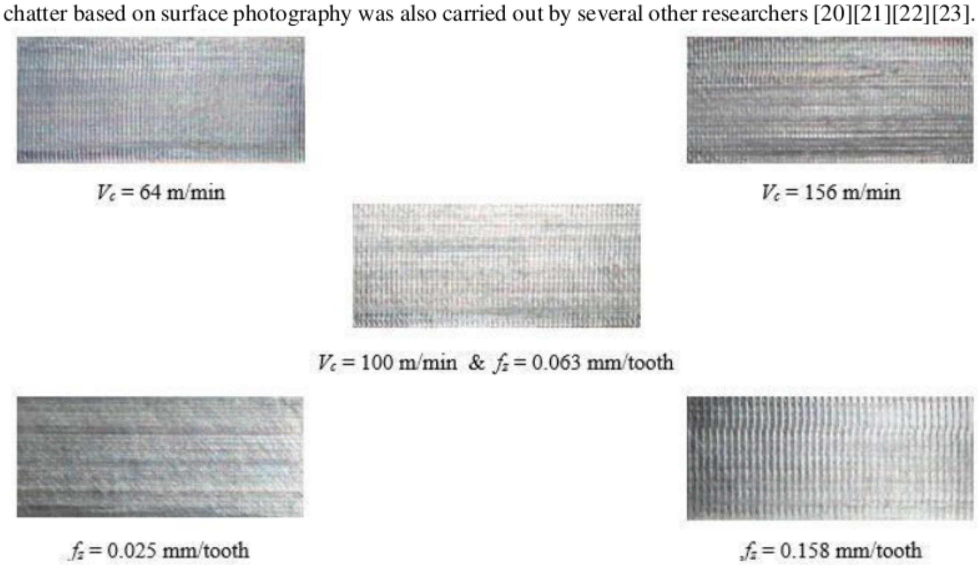

Figure 6. The thin-walled photography surface

Appropriate in determine parameter is able to avoid chatter, although without addition an object or clamper as damper to mitigate chatter [24][25][26]. Several methods to mitigate chatter, where this study is able to mitigate chatter with proper parameters in milling thin-walled Ti6Al4V. And several methods to identify chatter in above showed the free-chatter-condition, where from result surface roughness and surface topography showed the value increase about cutting speed and feed rate linearly.

5. Conclusion

The optimization in determining milling parameters from previous study in minimizing the cutting force showed if this parameter is able to use in chatter mitigation. It was approved from acceleration, simulation, surface roughness and surface photography result, where from resultant acceleration or FFT showed the frequency closed to natural frequency, but was not occurring chatter with small amplitude.

In the result of surface roughness and surface topography, where the small value of the surface roughness was obtained and further from minimum critical amplitude. Then, from surface topography result showed no severe surface or unstable surface.

On the other hand, surface roughness value increased significantly with the increasing of cutting speed and feed rate. Unstable condition was achieved in milling non-thin-walled acceleration result than thin-walled result, but lower amplitude was achieved in non-thin-walled than thin-walled amplitude.

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References

[1] Siddhpura M and Paurobally R 2013 Experimental Investigation of Chatter Vibrations in Facing and Turning Processes **7** 968–73
[2] Kilickap E, Yardimeden A and Çelik Y H 2017 Mathematical Modelling and Optimization of Cutting Force, Tool Wear and Surface Roughness by Using Artificial Neural Network and Response Surface Methodology in Milling of Ti-6242S *Appl. Sci.* **7** 1064
[3] Mohruni A S, Zahir M, Yanis M, Sharif S and Yani I 2019 Investigation of Finite Element Modelling on Thin-Walled Machining of Ti6Al4V using DEFORM-3D *J. Phys. Conf. Ser.* **1167**
[4] Dai Y, Li H, Xing X and Hao B 2018 Prediction of chatter stability for milling process using precise integration method *Precis. Eng.* 0–1
[5] Ding Y and Zhu L 2018 Investigation on chatter stability of thin-walled parts considering its flexibility based on finite element analysis *Int. J. Adv. Manuf. Technol.* **94** 3173–87
[6] Debnath S, Reddy M M and Pramanik A 2019 Dry and Near-Dry Machining Techniques for Green Manufacturing 1–27
[7] Gupta K and Laubscher R F 2016 Sustainable machining of titanium alloys: A critical review *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.* **231** 2543–60
[8] Liu Z Q, Chen M and An Q L 2015 Investigation of friction in end-milling of Ti-6Al-4V under different green cutting conditions *Int. J. Adv. Manuf. Technol.* **78** 1181–92
[9] Park K, Suhaimi M A, Yang G, Lee D, Lee S and Kwon P 2017 Milling of Titanium Alloy with Cryogenic Cooling and Minimum Quantity Lubrication (MQL) **18** 5–14
[10] Revankar G D, Shetty R, Rao S S and Gaitonde V N 2014 Analysis of surface roughness and hardness in titanium alloy machining with polycrystalline diamond tool under different lubricating modes *Mater. Res.* **17** 1010–22
[11] Mohruni A S, Yanis M, Sharif S, Yani I, Yuliwati E, Ismail A F and Shayfull Z 2017 A comparison RSM and ANN surface roughness models in thin-wall machining of Ti6Al4V using vegetable oils under MQL-condition *AIP Conf. Proc.* **1885**
[12] Yanis M, Mohruni A S, Sharif S, Yani I, Suzen Z and Ahmad Z A 2019 Cutting Force Prediction when Green Machining of Thin- Walled Ti-6Al-4V under Dry and MQL-Cutting using Response

Surface Methodology and Artificial Neural Networks-Algorithm *AIP Conf. Proc.* **2129** 020027: 1-11
[13] Huang P L, Li J F, Sun J and Jia X M 2015 Cutting signals analysis in milling titanium alloy thin-part components and non-thin-wall components *Int. J. Adv. Manuf. Technol.* **84** 2461–9
[14] Vijay S and Krishnaraj V 2013 Machining Parameters Optimization in End Milling of Ti-6Al4V *Procedia Eng.* **64** 1079–88
[15] Chen Y, Li H and Wang J 2016 Predictive modelling of cutting forces in end milling of titanium alloy Ti6Al4V 1–12
[16] Yanis M, Mohruni A S, Sharif S, Yani I, Arifin A and Khona'ah B 2019 Application of RSM and ANN in Predicting Surface Roughness for Side Milling Process under Environmentally Friendly Cutting Fluid *J. Phys. Conf. Ser.* **1198** 042016
[17] Ahmadi K and Ismail F 2011 Analytical stability lobes including nonlinear process damping effect on machining chatter *Int. J. Mach. Tools Manuf.* **51** 296–308
[18] Li Z, Sun Y and Guo D 2016 Chatter prediction utilizing stability lobes with process damping in finish milling of titanium alloy thin-walled workpiece *Int. J. Adv. Manuf. Technol.*
[19] Cao H, Zhou K, Chen X and Zhang X 2017 Early chatter detection in end milling based on multi-feature fusion and 3 σ criterion
[20] Arnaud L, Gonzalo O, Seguy S, Jauregi H and Peigné G 2011 Simulation of low rigidity part machining applied to thin-walled structures *Int. J. Adv. Manuf. Technol.* **54** 479–88
[21] Huang Y A, Zhang X and Xiong Y 2012 Finite Element Analysis of Machining Thin-Wall Parts: Error Prediction and Stability Analysis *Finite Elem. Anal. - Appl. Mech. Eng.* 327–54
[22] Zhang L, Gao W, Zhang D and Tian Y 2016 Prediction of Dynamic Milling Stability considering Time Variation of Deflection and Dynamic Characteristics in Thin-Walled Component Milling Process **2016**
[23] Sun C, Shen X and Wang W 2016 Study on the milling stability of titanium alloy thin-walled parts considering the stiffness characteristics of tool and workpiece *Procedia CIRP* **56** 580–4
[24] Bolsunovsky S, Vermel V, Gubanov G and Leontiev A 2013 Reduction of flexible workpiece vibrations with dynamic support realized as tuned mass damper *Procedia CIRP* **8** 230–4
[25] Shi J, Song Q, Liu Z and Ai X 2017 Partial Surface Damper to Suppress Vibration for Thin Walled Plate Milling *Chinese J. Mech. Eng.* **30** 632–43
[26] Zhang Z, Li H, Liu X, Zhang W and Meng G 2018 Chatter mitigation for the milling of thinwalled workpiece *Int. J. Mech. Sci.*

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