SIMULTANEOUS TWIN CUTTER TECHNIQUE FOR MACHINING THIN WALL LOW RIGIDITY PART

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ABSTRACT: Machining of low rigidity components such as aerospace monolithic part poses several challenges. In common manufacturing practice, the wall thickness is further reduced by peripheral milling that lead to surface dimensional error resulting in tolerance violation. The surface errors are mainly induced by the acts of cutting force, which deflect the wall on the opposite direction. Additional post machining process are generally employ to compensate with the excessive error that leads to increase the production cost. Therefore, this paper aim to solve the discrepancies with the current techniques by using a simultaneous twin cutter machining technique. An in-house twin cutter adapter has been developed to transmit the rotation from the machine spindle. A set of machining test was performed to assess the effectiveness of the propose technique. The results indicated that the deflection of the thin wall part can be neglected and hence minimize the surface errors since the same cutting forces acts on both opposite sides of the wall surface. In addition, the proposed technique able to reduce the machining time up to 50 percent as the wall structure are machined with only one single pass.

KEYWORDS: *Thin Wall; Monolithic Component; Twin Cutter Adapter; Peripheral Milling*

1.0 INTRODUCTION

Thin wall low rigidity components are widely used in aerospace industry intend to replace with the large number of the assembled part by designing with one-piece flow of monolithic component [1]. In addition, these thin wall monolithic components are light in weight, has high strength to weight ratio and can reduced the overall manufacturing costs compared with the traditional structure. Thin wall machining can be explained as a structure containing of very thin feature plates that will deformed and deflected under the act of the cutting force. The deflection will result in surface dimensional error or undesired material that required secondary finishing process [2-4]. In general, the monolithic components are produced by machining of several thin wall flange and rib sections.

Owing to its low stiffness properties, the machining force will deflect the wall on the opposite direction causing a surface dimensional error which affects the component accuracy. To solve the problem, the required tolerance are achieve through several post machining process such as repetitive feeding and final 'float' cut [5-6]. Noticeably, the existing available techniques in machining thin wall part are difficult and inefficient in term of productivity.

2.0 CHALLENGES IN MACHINING THIN WALL LOW RIGIDITY PART

The tight dimensional tolerances and complex part design of aerospace component poses great challenge to the manufacturer. One of the main challenges in producing the thin wall component is the part deflection caused by the cutting forces. The machining force caused the thin wall part deflect away from the cutting tool resulting in uncut materials. The relationship between cutting forces and deflection of thin wall, δ can be described as

$$\delta = FH - \delta_{tool} \qquad (1)$$

where F is cutting forces; H is height of the wall and δ_{tool} is the deflection of the cutting tool.

Figure 1(a) shows the deflection of the thin wall part due to the acts of the cutting force which resulting in surface dimensional errors at the top of the wall. Figure 1(b) depicted the section view of the wall with the material in the ABCD areas need to be machine and remove. During the machining process, the engagement of the cutter will produce the opposite milling force which deflect the wall and make point A and B shifted to point A′ and B′. Once the cutter leaves the wall, only material in the AB′CD area are removed and resulting in dimensional surface errors in BCB′ area.

In addition, the problems that emerge due to high flexibility of the thin wall feature and the milling cutter are the chatter regeneration that can limits the productivity. Intermittent engagement of cutter and workpiece excites a wide range of structural natural frequencies that result as unstable chatter vibrations and stable forced vibrations.

In summary, based on most related work of machining thin wall component with single cutter, reveals that cutting force is the most prevailing factor that affect the wall deflection magnitudes. Besides that, chatter vibration in milling thin wall structure had a negative effect on the geometric accuracy and surface integrity due to the low stiffness of thin wall component [7-10]. It shows that cutting forces and chatter vibration had a negative impact on machining thin wall parts [11-13].

Therefore, it is necessary to control cutting forces and chatter vibration to reduce the surface dimensional error. Thus, this research proposed a simultaneous twin cutter milling strategy employed on normal CNC milling machine. By employing this technique, the deflection of the thin wall part can be neglected and hence minimize the surface errors since the same cutting force appears on both sides of the wall surface. Once the wall deflection is controllable, the accuracy of the part of is manageable to be increased [14-15]. To accomplish this simultaneous twin cutter milling technique, a twin milling cutter adapter is to be develop that suit to the normal single spindle CNC milling machine.

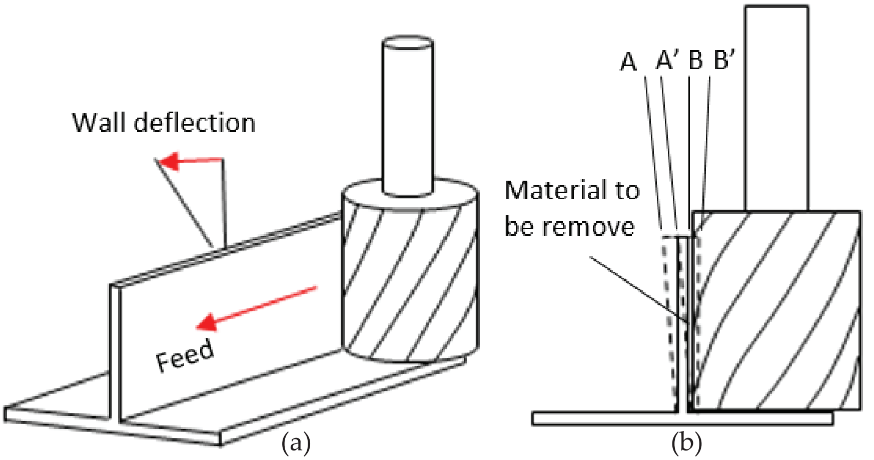

Figure 1: Un-cut materials in machining thin-wall feature

3.0 PRINCIPLE OF SIMULTANEOUS TWIN CUTTER MILLING

Twin cutter is a special purpose machining technique designed for milling thin wall low rigidity component using endmill cutter. It is an implementation of the simultaneous machining that removed the material on a single thin wall part by using dual spindles action process. Both sides of the thin wall are machined simultaneously by the left and right milling cutters. By implementing the simultaneous twin cutter process, deflection of the thin wall on the opposite direction of the cutting force can be controlled and neglected since the same cutting force acts on the both sides of the wall surface as shown in Figure 2.

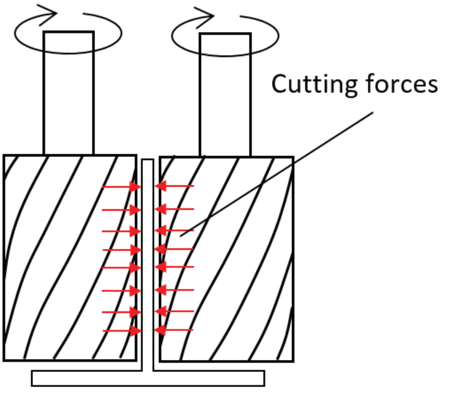

Figure 2: Act of cutting force in twin cutter machining technique

The twin cutter produce the down milling cut on the right side and up milling cut on the left side based on clockwise spindle rotation. It has two spindles driven by a BT40 taper head, and these two spindles holding the cutter are fed into the work piece simultaneously. The spindles are constructed so that their canter distance can be adjusted to any position as required by the desire wall thickness.

The main CNC spindle drive the twin cutter through the central gear and transmit to the twin spindle using set of align planetary gears arrangement. Thin wall is machined at the right side and the left side simultaneously by means of two separate spindles which hold the milling cutter and are fed against the thin wall work piece. Figure 3 demonstrates the arrangement of various elements of twin cutter machining adapter.

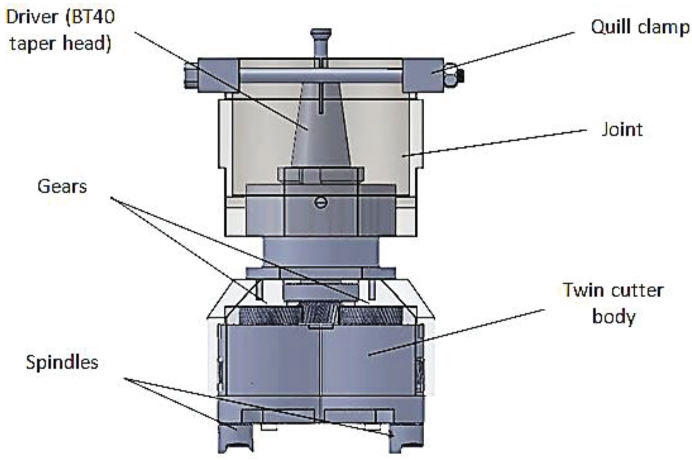

Figure 3: Principle of twin cutter machining technique

The device is designed ideally to be used on the CNC milling machine using interfacing connection kit that composed of quill clamp, driver and joint. The joint (Figure 4) is attached to the adapter body and lock into the machine quill slot. All the adaptor loads are hold by the machine quill for rigidity and stability. The top of the joint is cut using EDM wire cut machine to ensure the joint is gripped rigidly to the machine quill.

Figure 4: The joint

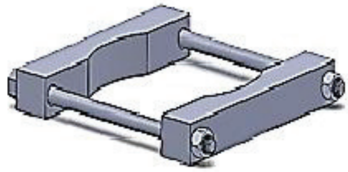

Figure 5: Quill clamp

Figure 6: BT40 driver

Quill clamp (Figure 5) used for tightening the joint and twin cutter body to the machine quill. After the joint and quill clamp is tightened, it may act as a stop block which avoid the body moving during machining. The function of the driver as shown in Figure 6 is to drive all the gears to make the spindles rotating by the speed of the CNC machine. It consists of BT40 taper head and shaft adapter for connection between the taper head with the center gear. Table 1 depicted others part of the twin cutter adapter.

Table 1: Twin cutter adapter parts and components

Part	Type of material	Quantity
Central gear (35 teeth)	Steel	1
Planetary gear (45 teeth upper with 27 teeth lower)	Steel	2
Shaft	Mild steel	2
Collet (ER20)	Stainless steel	2
Bearing	Stainless steel	1
Quill clamp	Aluminium	1
Twin cutter body	Aluminium	1
Joint	Mild steel	1
Driver (BT40 taper head)	High speed steel	1
Spindle	High speed steel	2

4.0 EXPERIMENTAL WORK

A set of machining test was conducted to show the effectiveness of the twin cutter technique compared to the single cutter on machining thin wall component. The experimental tests were conducted using 3-axis HAAS VF-1 CNC milling machine as shown in Figure 7. The thin wall part is made from aluminium alloy, 7076 and are pre-machined to 2 mm thickness, 30 mm height and 110 mm in length. Details of the mechanical properties for the Aluminum 7076 material are shown in Table 2. The thickness of the wall is to be machined from 2 mm to 1 mm with using both techniques i.e. single cutter and twin cutter approach. A 28 mm diameter and eleven flutes solid carbide end mill was used for both technique as shown in Figure 8 and Table 3. While Table 4 depicted the machining parameters used for the test. The machined wall accuracy and cutting force are measure using Carl Zeiss Coordinate Measuring Machine (CMM) and Kistler Dynamometer respectively.

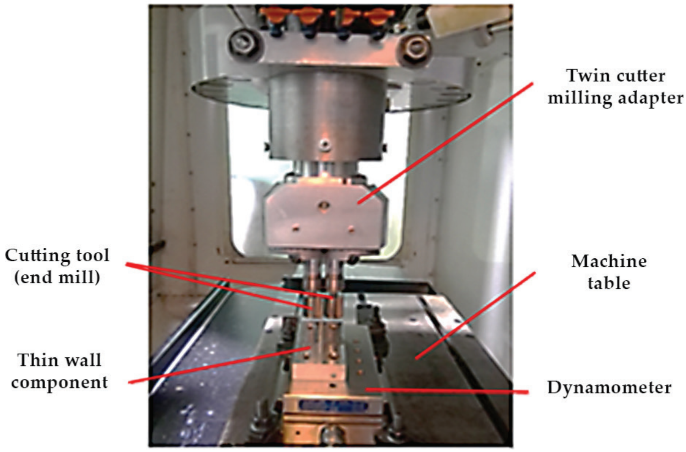

Figure 7: Experimental setup

Table 2: Chemical composition of al 7075-T6

Element	Al	Zn	Mg	Cu	Fe
Composition (%)	87.1 -91.4	5.1 -6.1	2.1 - 2.9	1.2 - 2	Max 0.5
Element	Cr	Mn	Ti	Si	
Composition (%)	0.18 - 0.28	Max 0.3	Max 0.2	Max 0.4	

Table 3: End mill specification

Parameter	Description
Material	Carbide (WC)
Helix Angle	45°
Rake Angle	12°
Clearance Angle	8°
Number of flute	11

Table 4: Machining parameter

Parameter	Description
Cutting speed	1500 rpm
Feed rate	200 mm/min
Axial depth of cut	30 mm
Radial depth of cut	0.5 mm

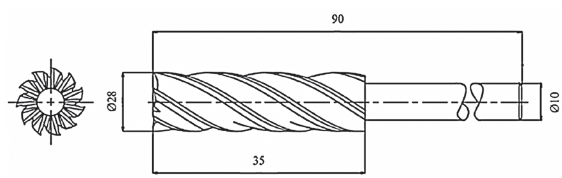

Figure 8: End mill specification for twin cutter adapter

5.0 RESULTS AND DISCUSSION

From the conducted experiment run, it showed that the developed twin cutter adapter capable to performed the simultaneous machining for the thin wall part. Figures 9 (a)-(c) show the comparison of surface error produced between single cutter and twin cutter technique at start (x=0), middle (x=55) and end (x=110) location respectively. Based on the graphs, it obviously illustrates the variable surface error values across the wall length due to the wall deflection that caused the inconsistency in depth of cut. The surface errors are more visible at the top of the wall and gradually decrease towards the bottom, which indicate the stiffness strength of the wall.

While for single cutter technique, the smallest surface errors also occurred at the bottom (h = 5) and gradually increased to the top (h =30 mm) as the wall flexibility increases as clearly observed in Figure 10(a) where the thickness the wall at the bottom is thinner than at the top. In addition, as the result of wall stiffness decrement due to material removal, form error value between start, middle and end regions (x = 0, x = 55 and x= 110) increased in the feed direction. In a bigger scale, increment of wall flexibility will lead to a higher surface error during machining. Besides that, in twin cutter technique the wall deflection magnitude at the start of the machining also will affect the pattern of the surface error to the rest of the wall surface. The maximum deformations are found to be at the places where the cutter exits from the thin wall workpiece. The form of surface dimensional error starts minimum at the start (x = 0) and increased gradually towards the machining feed until it reaches maximum at end (x =110). The form of surface dimensional error had a less variation on the value of surface error at all regions of machining where the thickness of the wall is consistent at the bottom and the top of the wall as depicted in Figure 10(b).

Single cutter technique produced high dimensional surface error compared to twin cutter technique due to the deflection of the thin wall part. However, in twin cutter technique the deflection of thin wall part can be neglected as the same cutting force appears on both sides of wall surface. In addition, apart from the surface error the twin cutter technique also produced smooth machined surface with less chatter which indicate the stability of the process.

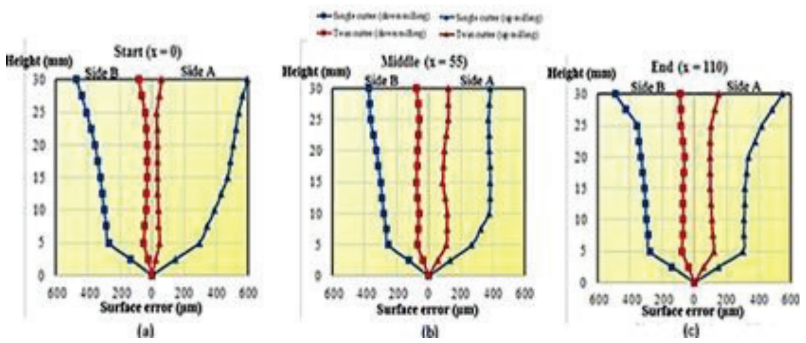

Figure 9: Comparison of surface error produced between single cutter and twin cutter technique: (a) Start (x=0), (b) Middle (x=55) and (c) End (x=110)

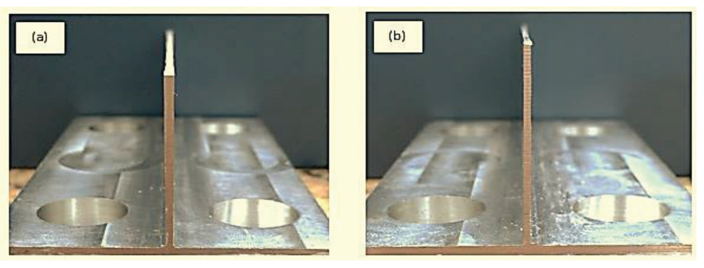

Figure 10: Wall thickness after machining with (a) Single cutter technique and (b) Twin cutter technique

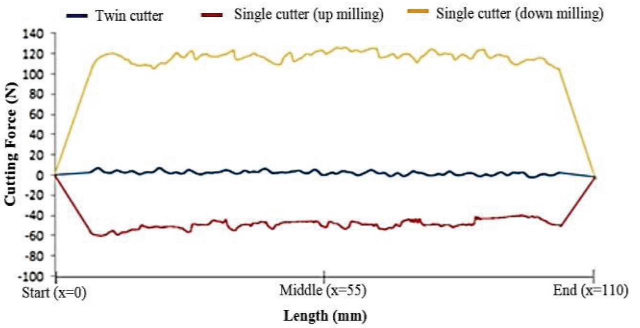

Figure 11: Cutting force exerted in Fx direction for single cutter technique and twin cutter technique

Figure 11 shows the cutting force magnitude in Fx direction for single cutter technique and twin cutter technique. From the graph, twin cutter had a smaller cutting force Fx compared to single cutter for both up milling and down milling cutting methods. This result indicates that the down milling cutting force is bigger than up milling cutting force. The value of cutting force of twin cutter technique is almost equal to zero from start (x = 0) until reach end (x = 110). It shows that, the twin cutter technique can be used to control the deflection of thin wall since both sides of the surface have been pressured simultaneously. The deflection can be controlled as the cutting force can be neglected because almost the same cutting force appears on both sides of wall surface. In single cutter (climb milling) side, the value of cutting force are negative since the material removal or cutting action occurred at the right machining side. The deflection moved to the left side where the dynamometer senses the negative value. It clearly shows that the value of cutting force in single cutter (up milling) is small compared to single cutter (down milling).

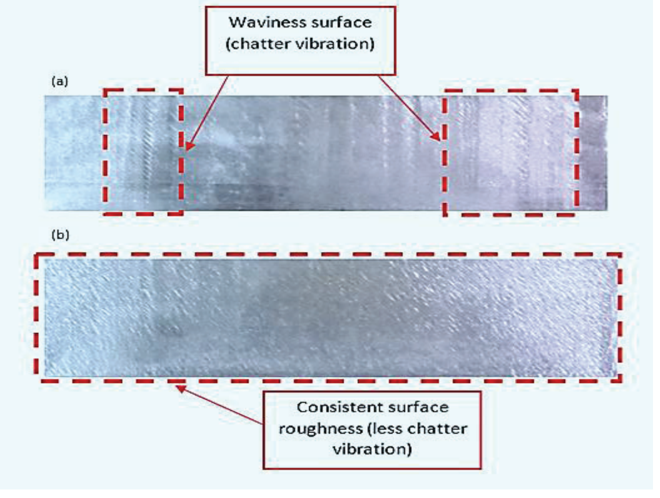

Figure 12: Machined surface condition for (a) Single cutter (b) Twin cutter technique

Figure 12 shows the machined surface produced with single cutter and twin cutter machining technique. From the observation, twin cutter machining technique gives consistent surface roughness with thinner cutter marks. Severe cutter marks occurred through single cutter machining technique which produce waviness surface that indicate a serious chatter vibration. From the obtained result it shows that the twin cutter machining technique able to reduce the accuracy of the machined part and can be employed in order to controlled the part deflection as well with part vibration.

6.0 CONCLUSION

This research has proposed a new twin cutter machining technique for effectively machining thin wall low rigidity component. The main results are as follows:

i. The developed twin cutter adapter capable to performed the simultaneous machining for the thin wall part with great accuracy and stability.
ii. The twin cutter machining technique capable in controlling the wall deflection and reducing the surface error produced.
iii. The twin cutter machining technique produced less cutting force and consistent surface roughness with thinner cutter marks that indicate a stable machining condition.
iv. The proposed technique able to reduce the machining time up to 50 percent as the wall structure are machined with one single pass compare with the current machining technique.

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