The Deflection of Airframe Thin Plate Part after Milling

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Abstract

Aircraft components are mostly made by aluminum alloy as thin plate types. These parts are milled to required thicknesses and tight tolerances in specific areas with vacuum clamping system. During the milling process the plate is fixed by vacuum force and the surface get the stress induced from cutting force and heat. After unclamping the airframe thin plate is deformed without the vacuum force that fixed it tightly. This paper experiment and discuss to find the reason of airframe thin plate part deformation after milling process.

Key words: Airframe, Thin plate part, Deflection, Milling, Cutting force, Residual stress.

1. Introduction

The important factors of an aircraft are the stability and lightening. To meet those needs, aircraft components are mostly made by aluminum alloy as thin plate types. These parts have been milled to required thicknesses and tight tolerances in specific areas. The thin plate part is difficult to machine because they are easy to vibrate and deformed because of cutting force generated in processing [1,2]. Many technicians are trying to find out more rapid and safer method to improve machining quality. To scope with productivity and quality requirement, high speed machining equipment and technology is not an option but requirement. One of the most effective techniques for large thin plate part up to 2,000 x 2,000 mm is the vacuum clamping system Fig. 1. This technology allows secure clamping of thin-walled workpieces for milling pockets down to end thicknesses of 2 mm. Vacuum clamping technology offers individual solutions for safe machining of critical parts, especially if conventional clamping technology does not give acceptable results. Vacuum clamping can be used for nearly every kind of material and machining processes.

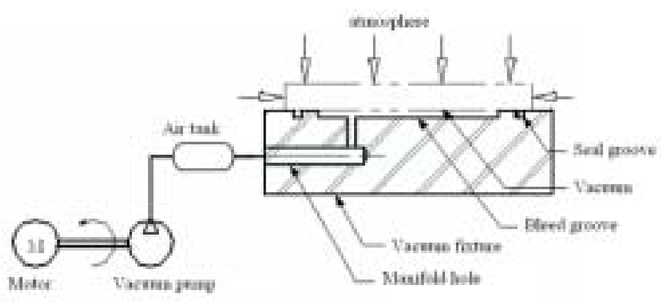


Fig. 1 Vacuum clamping system

The remained problem of thin plate milling is the deflection of it after milling. During the milling process the plate is fixed by vacuum force and the surface get the stress induced from cutting force and heat. After unclamping the airframe thin plate is deformed without the vacuum force that fixed it tightly. There were many researches related to the vibration and deflection of deep and thin wall structure [1, 2]. But there isn't research about the deformation of the large thin plate part after milling process. This paper experiments and discusses to find the reason of airframe thin plate deformation after milling process.

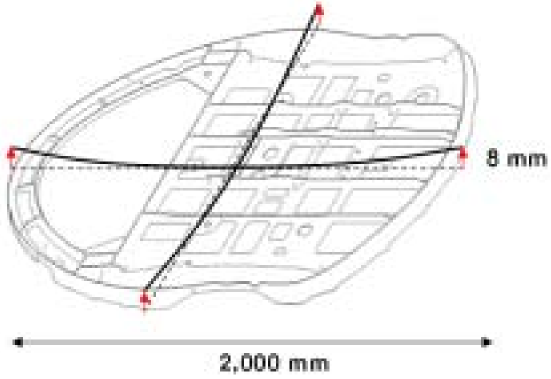


Fig. 2 Deflection of airframe thin plate part after milling

2. Experiment

2.1 Stock and plate geometry

The machining center used for experiment is WIA V25 as shown in Fig. 3. The experiment stock is duralumin (Al 7075) that is widely used as an aircraft structure. The size and shape of thin plate is simplified as cantilever plate as shown in Fig. 3. The size of rectangular stock is 50 mm x 75 mm x 20 mm. The upper and lower side will be cut by φ20 mm HSS flat end mill and final geometry of the plate will be 30 mm x 75 mm x 1 mm after cutting as Fig. 3.

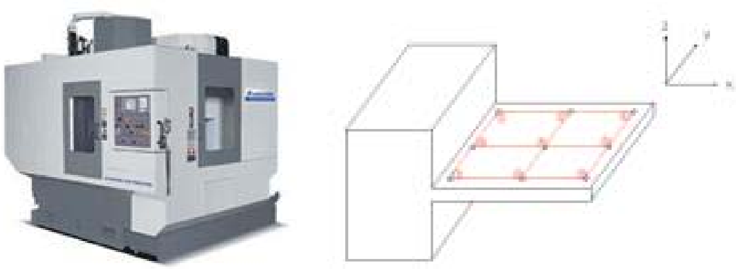


Fig. 3 Machining center and thin plate geometry

2.2 Experiment condition

The common experiment condition is shown at Table 1. For different experiments; I, II, III, IV were done as Table 2. The spindle is changed at I, the axial depth of cut is changed at II III and side milling is used at IV.

Experiment I is designed to watch if cutting temperate difference between lower and upper surface is related to deflection. The lower surface is cut by 8,000 rpm and 1,000 mm/min and upper surface is cut by 1,600 rpm and 200 mm/min to make the cutting force uniform and cutting velocity different. This condition sustains same cutting force to eliminate cutting force effect. The axial depth of cut is 2 mm for roughing and 1.5 mm for finishing.

Experiment II and III is designed to watch if cutting force is related to deflection. The axial depth of is 0.5 mm at II and 2.0 mm at III. The lower surface and upper surface is cut by same cutting condition. It can eliminate thermal deformation effect in this experiment. These experiments observe if the degree change of thin plate related to axial depth of cut.

Experiment IV use side milling method and watch if milling method change reduces deflection error. This experiment cuts final depth one time and divide side depth 15 steps. The axial depth of cut is 9.5 mm and radial depth of cut is 2.0 mm.

Table 1. Common experiment condition

Spindle speed	Feedrate	Radial depth of cut	Coolant
8,000 rpm	1,000 mm/min	10 + 10 mm	Oil

Table 2. Experiment condition of I, II, III, IV

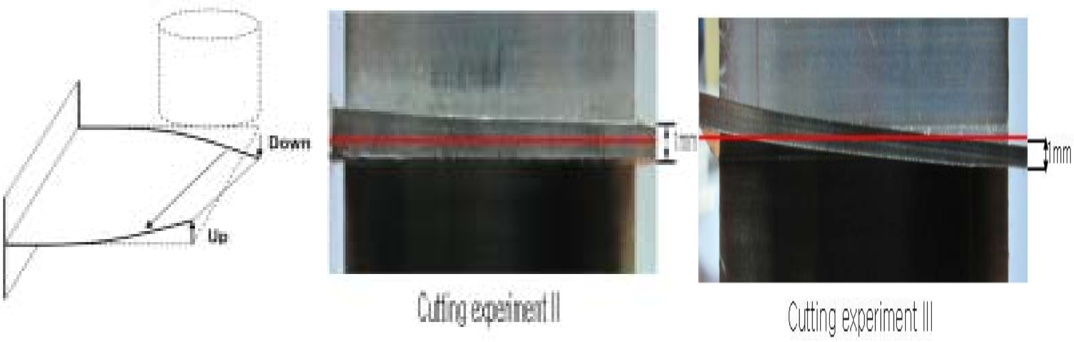
I	II	III	IV
Low surf: 8,000 Up surf: 1,600 rpm	Axial depth of cut: 0.5 mm	Axial depth of cut: 2.0 mm	Side milling, redial depth: 2.0 mm

2.3 Experiment result

The thin plate is twisted as shown in Fig. 4 (c) at experiment I. The deformation tendency is that end mill escape part rises. The pattern is different from predicted thermal deformation. If deformation cause by cutting heat, deformation tendency will be a one side deformation. This result is related to cutting force or residual stress rather than heat.

Experiment II and III changes the cutting force condition by increasing the axial depth of cut from 0.5 mm to 2.0 mm. The deformation pattern was same to Fig. 4 and the deformation was 0.3 mm at Fig. 4 (b) II and 1.5 mm at Fig. 4 (c) III. It is shown that deformation can be reduced by decreasing axial depth of cut.

Side milling was used at experiment IV and deflection was almost a same the other experiment. The milling pattern change is not effective to control deflection error.



(a) Deflection pattern (b) Experiment II (c) Experiment III

Fig. 4 Thin plate deflection after milling

3. Discussion

The cutting heat increase the temperature of cutting surface and it can deform the thin plate. The temperature increase of plate is assumed to 100°C at tested cutting condition based on the previous cutting temperature measurement and analysis researches [3-6]. The liner expansion coefficient of it is $23.0*10^{-6}$/°C. The thermal strain is about 0.0023 which is about half of yield strain and it is in elastic zone. If the temperature is decrease thermal deformation will be recovered. The cutting heat is not reason of deflection.

The cutting force can be computed by specific cutting energy and cutting area. The deflection of cantilever plate can be approximated from the cutting force and the geometry of the plate. The geometry is assumed to beam and the deflection was computed to about 0.43 mm. The stress is in elastic zone and the deformation happened from cutting force will be recovered after cutting.

There are researches about the residual stress remained at the cutting surface [7-9] which is not problem at thick part cutting but can deform part if thickness is not large compared to the depth of residual stress. The residual stress is about 400 MPa at the surface and it decreases to zero at about 0.05 mm depth [7-9]. If the stress is assumed to parallel to length direction of thin plate beam and upper surface assumed to get compression and lower surface expansion stress, the deflection is about 0.55 mm which is agree to experiment result.

From the experiment and computation the residual stress seems to be a main reason of the thin plate deflection after cutting. During milling process the cutting force deflect the plate but it can be neglected if vacuum fixture holds the part tightly during the milling process.

4. Conclusion

The aluminum alloy thin plate of 30 mm width and final thickness 1.0 mm was machined by flat end mill and deflected about 0.3 mm when final depth of cut was 0.5 mm, and about 1.5 mm when final depth of cut was 2.0 mm. The reason of deflection seems to be residual stress remained at the cutting surface because of concentrated cutting force. The residual stress is about 400 MPa at the surface and it decreases to zero at about 0.05 mm depth. If the stress is assumed to parallel to length direction of thin plate beam and upper surface assumed to get compression and lower surface expansion stress, the computed deflection is about 0.55 mm which is agree to experiment result.

The experiment was simplified to thin plate beam but the result will be able to apply to reduce the deflection of aircraft thin plate part happened after machining. The deflection error will be reduced if cutting condition that remains smaller residual stress.

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