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Distortion Minimization of Avionics Thin Walled Thin Floored Components

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Abstract: With the advent of monolithic designs having features with thin walls and thin floors, machining on CNC machining centers has not only become indispensable but also a challenge to the manufacturers especially in the aircraft industries. 80% to 90 % of material has to be removed from prismatic blanks to produce final components. During machining the components distort and warp due to bulk stresses, and induced stresses due to machining and thermal gradient. Though controlling the machining parameters to reduce distortion is important, approach of machining these components play a vital role in minimizing distortion during machining. Comparative experiments have been carried out in understanding different approaches of machining to minimize distortion. It has been found with the experiments that machining of these slender thin wall thin floor components by high speed machining, using vacuum fixture (holding at the bottom) on horizontal machining centre using cutting oil having more heat carrying capacity has given good results in minimizing the distortion.

Keywords: Monolithic components, Distortion minimization, Holistic Approach

1. INTRODUCTION

With recent trends in designing lighter, strong and more accurate single piece components in aerospace industries, the components have be machined up to 90 to 95% on CNC machining centers from prismatic blanks [1]. This has posed a great challenge to manufacturers to produce the parts with both severe dimensional and geometrical tolerances. One of the important non-conformity and major concern in producing these components is distortion. It has been proved by many researchers that the main cause influencing the distortion of the component is cumulative result of several process variables including the material to be machined and design configuration [2]. Since last decade researchers have done lot of work to predict the component distortion by using Finite element method (FEM). Studies were done to predict localized static elastic deformation during milling operations [2]-[5]. Recent research has gained attention in seeing the distortion problem in total. Simulation studies were carried and found that redistribution of residual stresses is one of the main reasons for machining distortion [2] [6]-[8]. Studies were carried out to find the effects of distortion due to clamping conditions [9]. Though simulation studies with validation experiments were carried out by many researchers, very little work was done by experimental approach. So, comparative experimental work has been done by adopting different approaches of machining and setup configurations to find out best and effective approach of machining these thin wall thin floor components to reduce distortion.

2. EXPERIMENTAL WORK

An investigation on various techniques for distortion minimization was done based on which four different comparative experimental approaches with eight iterations were carried out. Also a holistic approach was experimented and validated for its concurrence with analytical hypothesis. The four approaches used in machining the component are as follows:

Approach 1:- Conventional Machining vs. High Speed Machining
Approach 2:- Using Neat oil vs. Using water soluble oil
Approach 3:- Using Horizontal Machining centre vs. Using Vertical Machining centre
Approach 4:- Using Conventional clamping vs. Using Vacuum Clamping

The representative component (Filter cover) used for machining is shown in fig1 and the details of which are mentioned in table 1. The details of the Machines, coolants, and the Vacuum fixture used in approaches 1, 2, 3 & 4 are mentioned in table 2.

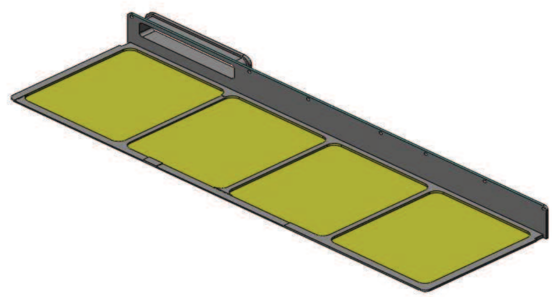

Fig. 1. Representative Component (FILTER COVER)

Table I: Details of the representative Component

Job Title	Filter Cover
Material	Aluminium Alloy 2014A T651
Overall Size	292.5 mm X 92 mm X 27 mm
Finish	1.6-8 microns
Flatness	0.05
Minimum Base Thickness	0.8mm
Ratio Of Raw Material Weight To Final Component Weight	20:1 i.e 1900gm : 95gm
Minimum Wall Thickness	1.6mm

Table II: Details of the Machines, coolants& Vacuum Fixture

Sl. No	Description	Details
1	Machine in approach 1	HARDINGE BRIDGEPORT VMC 600P3
2	Cutting oils in approach 2	SERVOCUT 335; BLASCOCUT
3	Machines used in approach 3	Horizontal machine: MITSUISEIKI HR5A Vertical machine: HARDINGE BRIDGEPORT VMC 600P3
4	Vacuum fixture in approach 4	Re-configurable vacuum fixture Vacuum pump (WITTIE Make), 16m3 /hr; 230 V ,75 kW

In these experiments the machining of the components are done in the following sequence

Step1: Sizing on conventional Universal milling machine
Step2: Rough milling on CNC by pocket out option
Step3: Finish milling on CNC.

The component is divided into squares of 20mm x 10mm and the distortion is measured before milling on CNC M/C and after final milling on CNC M/C. This is done by measuring the deviations in the readings on the flat surface before and after milling.

3. APPROACHES

Approach 1:

Conventional vs. High Speed Machining

In the first iteration (IT1) the rough milling and finish milling (step 2 &step 3) are performed by adopting the conventionally used machining parameters. In the second iteration (IT2) the same experiment is done by using High speed machining parameters (high rpm, high feed, & low depth of cut) and the profile deviation is measured. The surface profiles for the deviations measured in iteration 1 and iteration 2 are shown in figures 2 & 3 respectively. Based on the measured values for the above iterations it has been found that the maximum distortion in IT1 and IT2 are 0.8mm and 0.3mm respectively. The coolant used in IT1 and IT2 iterations is neat oil (SERVOCUT 335), and the method of clamping in both the iterations is conventional clamping (using clamps, bolts and nuts). The orientation of machining is Vertical in both the iterations.

Approach 2:

NEAT OIL vs. WATER SOLUBLE OIL

In the second approach the machining of the representative component (fig: 1) is done in the same sequence as it is done in the approach 1 (Step 1, 2 &3) except for the change in the coolant used. In the iteration 3 (IT3) the machining of the above component is done using neat oil (SERVOCUT 335) and in the iteration 4 (IT4) the machining of the component is done using water soluble oil (BLASCOCUT).The profile deviation is then measured. The surface profiles for the deviations measured in iteration 3 and iteration 4 are shown in figures 4 & 5 respectively. Based on the measured values for the above iterations it has been found that the maximum distortion in IT3 and IT4 are 0.6mm and 0.54mm respectively. The method of clamping in both the iterations is conventional clamping (using clamps, bolts and nuts) and the orientation of machining is vertical. The machining parameters used in both IT3 & IT4 are conventionally used parameters as used in IT1.

Approach 3:

Orientation of Machining (Vertical &Horizontal)

In this approach the machining of the representative component (fig: 1) is done in the same sequence as it is done in the approach 1 (Step 1, 2 &3) except for the change in the orientation of machining i.e. Vertical machining in iteration 5 (IT5) and Horizontal machining in iteration 6 (IT6). The profile deviation is then measured. The surface profiles for the deviations measured in iteration 5 and iteration 6 are shown in figures 6 & 7 respectively. Based on the measured values for the above iterations it has been found that the maximum distortion in IT5 and IT6 are 0.8mm and 0.68mm respectively. The method of clamping in both the iterations is conventional clamping (using clamps, bolts and nuts) and the machining parameters used in both IT5 & IT6 are conventionally used parameters as used in IT1.The coolant used in IT5 and IT6 is neat oil (SERVOCUT 335).

Approach 4:

Conventional Clamping vs. Vacuum Clamping

In this approach the machining of the representative component (fig: 1) is done in the same sequence as it is done in the approach 1 (Step 1, 2 &3) except for the change in the method of clamping i.e. conventional clamping using bolts and nuts in iteration 7 (IT7) and vacuum clamping in iteration 8 (IT8).The profile deviation is then measured. The surface profiles for the deviations measured in iteration 7 and iteration 8 are shown in figures 8 & 9 respectively. Based on the measured values for the above iterations it has been found that the maximum distortion in IT7 and IT8 are 0.8mm and 0.32mm respectively. The orientation of machining in both the iterations is vertical and the machining parameters used in both IT7 & IT8 are conventionally used parameters as used in IT1.The coolant used in IT7 and IT8 is neat oil (SERVOCUT 335).

4. ANALYTICAL HYPOTHESIS

From the above approaches it is observed that the distortion is reduced by using High speed machining (IT2), using water soluble oil (IT4), using Horizontal machining (IT6), and by using Vacuum clamping (IT8) individually. Hence analytically, a combination of all the above four iterations would result in minimizing the distortion effectively and so a holistic approach is attempted in (IT9).

5. HOLISTIC APPROACH

With the results of experiments it has been found that the results achieved with the combination of solutions in iteration 9 (IT 9) i.e. using HSM, using water soluble oil and machining by fixing the component using vacuum fixture in Horizontal Machining Centre it was found that the distortion has been reduced to 0.12 from 0.8 which is well within the limits required. The model of surface generated after machining the component using combined solution is shown in figure 10. The improvement of results is shown in table 3.

6. RESULTS& DISCUSSIONS

Analysis of approach 1:

In this approach, the distortion of the component is reduced by the concept of high speed machining. It is a proven fact that 90% of the heat generated in machining is carried away by chips produced and 10% is transferred to the tool and work piece. In high speed machining, the depths of cut are low and rpm is high resulting in large quantity of small sized chips. The amount of heat transferred is directly proportional to the surface area. As the smaller sized large quantity chips increase the surface area when compared to large sized small quantity chips the percentage of heat carried away by the chips is more in high speed machining. Hence the thermal gradients and the distortion during HSM is relatively low.

Analysis of approach 2:

In this approach the percentage of heat taken away by the cutting oil from the component is more when water soluble oil is used than when neat oil is used as coolant. As more amount of heat (generated during machining) is carried away by water soluble oil the residual thermal stresses in the component are reduced and hence the distortion is also comparatively low.

Analysis of approach 3:

In this approach during horizontal machining the chips produced during machining fall off from the work piece automatically due to gravity and force of the coolant very easily. The time required to transfer the heat generated during machining from the chips to the work piece is very low. So the percentage of generated heat carried away by the chips in horizontal machining is more than the heat carried away by the chips in vertical machining. The residual induced thermal stresses in the component are comparatively low in horizontal machining and hence the distortion is relatively less. In vertical machining the chips are flooded away forcibly by the coolant and it takes time for evacuation of chips.

Analysis of approach 4:

During machining the direction in which the distortion takes place depends on whether the portion being machined is in compressive stress or in tension. In the iteration 7 of this approach i.e. if the component is subjected to conventional clamping the component is free to distort itself in one direction. In iteration 8 the vacuum clamping ensures uniform suction i.e. the holding force from the bottom of the component uniformly enabling the component to have dimensional accuracy. Due to vacuum fixing the chances of induced stresses because of the clamping forces has been eliminated.

7. CONCLUSION

With the experiments conducted it can be concluded that a combination solution (Holistic approach) i.e., using HSM, water soluble coolant, holding the part from underneath using vacuum and machining on a horizontal machining centre would result in minimization of distortion.

Table III Maximum Deviations & Distortion in IT1 to IT9

Sl. No	Iteration Number	Type of Iteration	Maximum Deviation	Length	Distortion (%)	Percentage Of Improvement (Comparing With Maximum)
1	It1	Conventional Machining	0.8	292.5	0.2735043	0
2	It2	High Speed Machining	0.3	292.5	0.1025641	62.5
3	It3	Machining With Neat Oil	0.6	292.5	0.2051282	25
4	It4	Machining With Soluble Oil	0.54	292.5	0.1846154	32.5
5	It5	Machining In Vertical Cnc	0.8	292.5	0.2735043	0
6	It6	Machining In Horizantal Cnc	0.68	292.5	0.2324786	15
7	It7	Machining With Conventional Clamping	0.8	292.5	0.2735043	0
8	It8	Machining With Vacuum Clamping	0.32	292.5	0.1094017	60
9	It9	Holistic Approach	0.12	292.5	0.0410256	85

Figures (not to scale)
3D models of Measured values of distortion

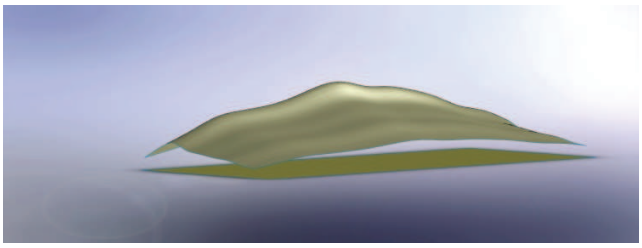

Fig. 2. Conventional machining

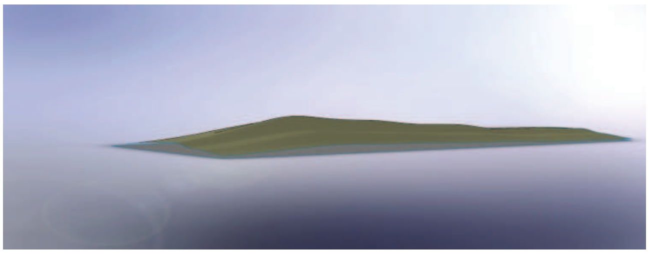

Fig. 3. High Speed Machining

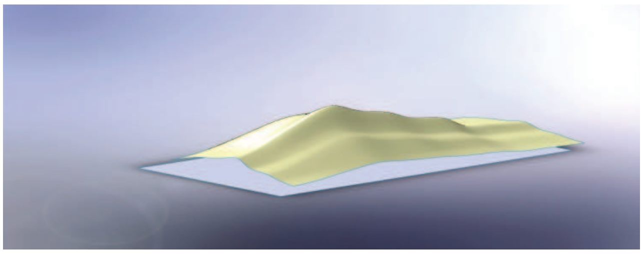

Fig. 4. Neat cutting Oil

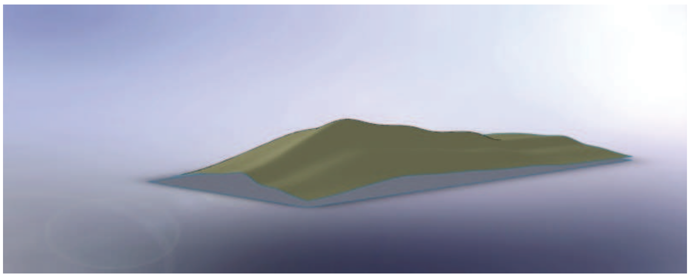

Fig. 5. Water soluble cutting oil

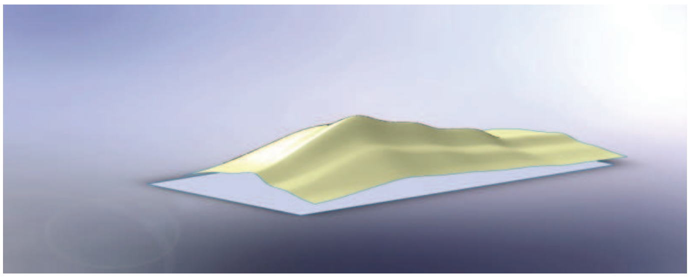

Fig. 6. Vertical Machining

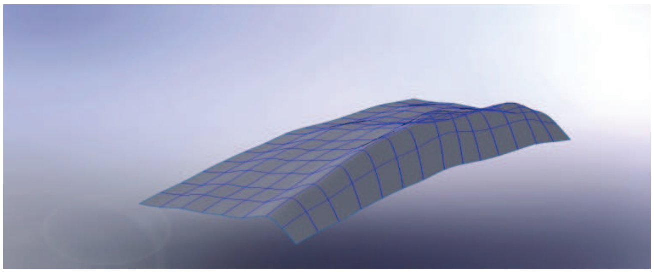

Fig. 7. horizontal machining

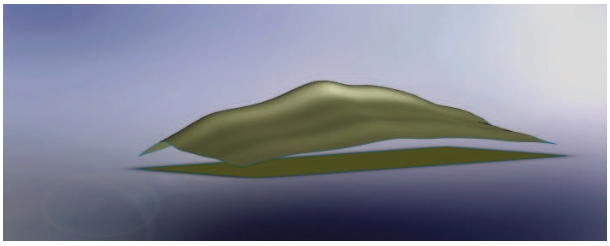

Fig. 8. Conventional Clamping

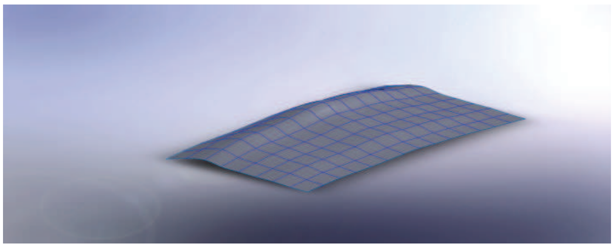

Fig. 9. Vacuum clamping

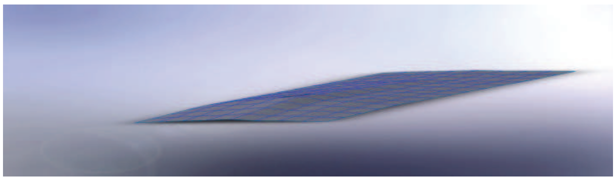

Fig. 10. Holistic Approach

8. ACKNOWLEDGMENT

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