ANALYSIS OF MATERIAL REMOVAL ON RADIAL COMPRESSOR WHEEL OF AIRCRAFT ENGINE AFTER FINISHING PRODUCTION OPERATIONS USING CMM

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This paper deals with the dimensional analysis of the turboprop aircraft engine radial compressor wheel. The radial compressor wheel is very complex component. This part is manufactured by turning and five-axis milling technology. Due to the high stress of this part in service life, the residual stress in the surface layer is important. Desirable are the compressive stress levels to prevent cracks. For this reason, research is being carried out on technologies that influence the surface layer. They are the finishing technologies vibrational tumbling and superfinishing. The article describes the method used to measure the thickness variation of blade of the compressor wheel after vibrational tumbling and superfinishing. In terms of shape complexity a coordinate measuring machine with a rotary table was used.

KEYWORDS

coordinate measuring machine, compressor wheel, finishing technology

1 INTRODUCTION

The object of the dimensional analysis was the turboprop engine radial turbine wheel (Fig. 1). The finishing operations of the impeller were made by vibrational tumbling and then superfinishing technology. The purpose of the analysis was to determine the material removal during the individual finishing operations. In the first step was necessary to inspect the wheel dimensions in the initial state (after milling). Then was the surface of the wheel vibrational tumbled and a second inspection was performed. Another and final operation was superfinishing and third geometry inspection.

The radial compressor wheel is a form complex part containing free form surfaces. To geometry inspection was necessary to use Coordinate Measuring machine (CMM).

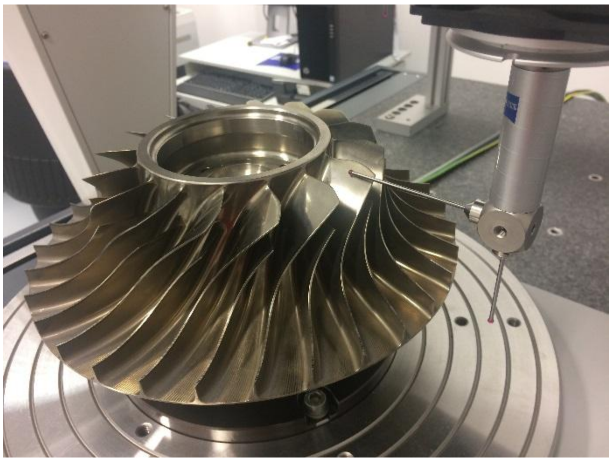

Figure 1. Compressor radial wheel

2 MEASURING MACHINE

The dimensional analysis of the impeller was performed on the Carl Zeiss Prismo coordinate measuring machine (Fig. 2). The workspace dimensions of this machine are: X = 900mm, Y = 1200mm, Z = 700mm. This machine is equipped with active Vast scanning system and Calypso software. The basic uncertainty of this machine is MPEE = 2.7+L/300 μm. This is a contact measurement where the geometry of the measured elements is calculated from the points scanned by the physical probe (ball, cilinder, disc). The used scanning system Vast is so-called fixed. This means that it is not possible to position the inspection stylus. This CMM is equipped with a mobile rotary table (RT). Rotary table is an add-on device - the fourth controlled axis used to measure more complex parts. RT is used in active inspection mode or as pointing device. [Bosch 1995]

Figure 2. CMM Zeiss Prismo

3 STYLUS SYSTEM CONFIGURATION PREPARATION

The stylus system configuration is assembled so that the desired elements can be measured. For inspection were used two configurations. The first configuration, for the compressor wheel inspection, contained two styli. The vertical stylus was used for the local coordinate system inspection. The side-facing stylus was used to measure the points on the individual blades. The diameter of both styli was 3 mm, see Fig. 3. The configuration was mounted by connecting and extension elements on the clamping plate (adapter plate), which is clamped into the measuring head. The second configuration contained only one stylus in the vertical direction, the stylus diameter was 12mm (Fig. 4). This configuration was used for rotary table axis alignment.

Before the measurement it is necessary to qualify the configuration. For this purpose calibration normal (a calibration sphere) is used. The position of the sphere is measured by the masterprobe. Then the individual styli of the configuration are gradually qualified. The result is the determination of the position and dimension of the functional parts of the stylus, in this case the spheres. The position of the stylus is relative to the center of the masterprobe sphere. Styli with ruby spheres were used. [Pfeifer 2018]

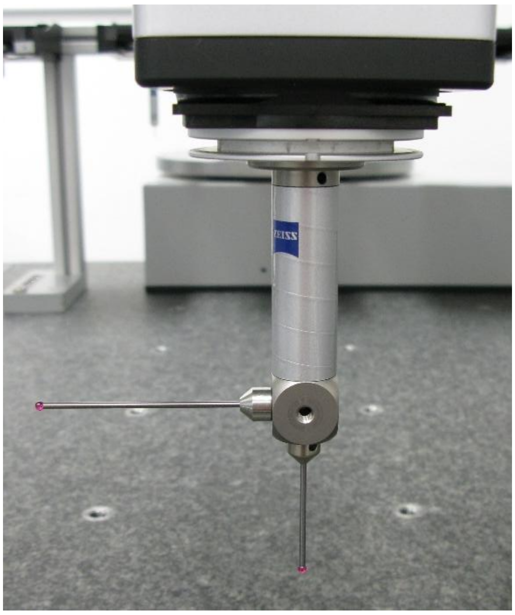

Figure 3. Stylus system configuration for compressor wheel measurement

Figure 4. Stylus system configuration for axis RT measurement

4 ROTARY TABLE PREPARATION

The mobile rotary table can be used throughout the measuring space of the measuring machine. Before the start of the measurement the rotary table must be mounted to the granite table of CMM with screws. Next step is the alignment of the axis of rotary table. The rotary table was placed in the front of the measuring space (Fig. 5). To define the position of the table and the axis of rotation method based on measurement of the exact cylindrical artefact in two positions (0 ° and 180 °) had been used, see Fig. 6. Symmetry is calculated from those two measurements and line in symmetry is set as a rotation axis of rotary table in this specific position. This makes it possible to transform points measured on rotating part into a fixed coordinate system of CMM.

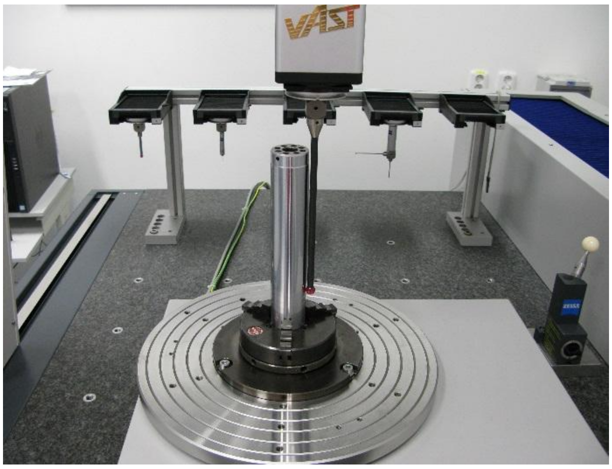

Figure 5. Installed rotary table (RT)

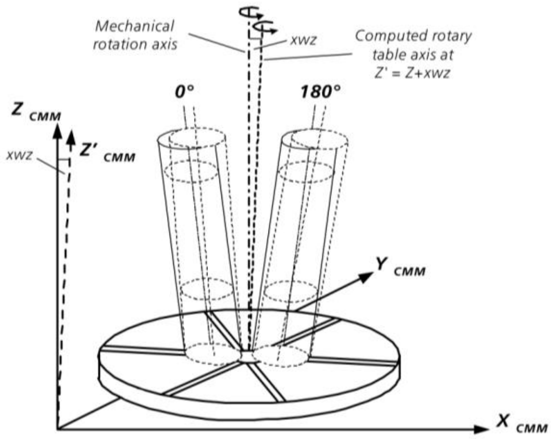

Figure 6. Calculating the RT axis

5 WORKPIECE FIXTURE

The main requirements for the measurement is that the clamping of the measured part is stiff enough and that all the measurements can be made on one clamping. During the compressor wheel inspection the same universal chuck was used (Fig. 7) as during the rotary axis alignment.

Figure 7. Compressor wheel fixture on RT

6 WORKPIECE ALIGNING, BASE COORDINATE SYSTEM DEFINITION

Part alignment is used to define the position and orientation of a part in the measuring space, to define a local coordinate system, and fit of model (if any) on a part. From physical view is it fixing all six degrees of freedom that each body has in space.

Three elements were used to define the basic coordinate system (Figure 8). The normal vector of plane Plane 1 determines the space axis (Z) of the coordinate system. The plane Plane 1 is also the zero point of the Z axis, circle Circle 1 determines the zero point of the X and Y axes. Circle Circle 2 fixes the rotation of the coordinate system around the main axis (Z).

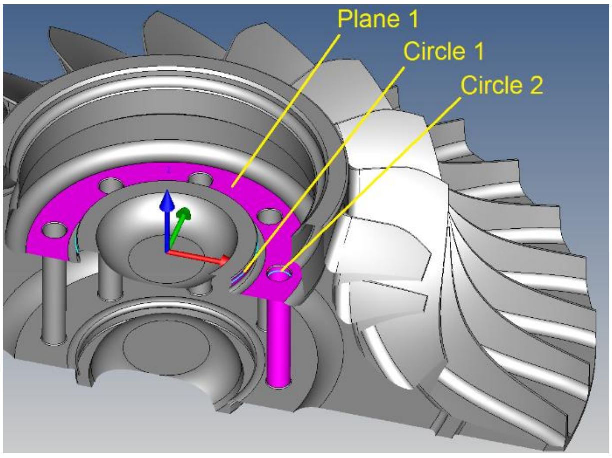

Figure 8. Compressor wheel aligning

For the measuring machine movement without collision was defined clearence plane in distance 20 mm from the part model. The stylus system cannot enter in this space during the movement between the measured elements and during the rotation of rotary table, see Fig. 9.

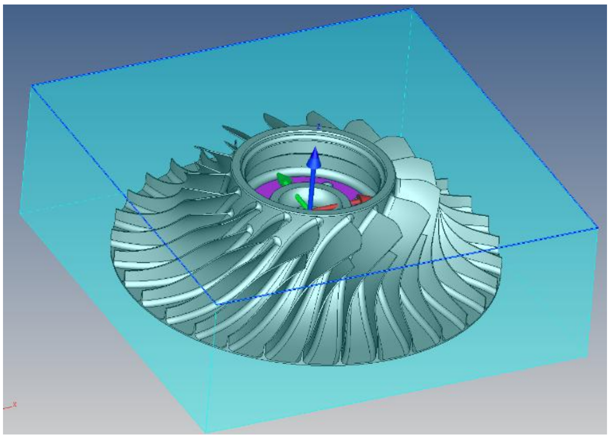

Figure 9. Clearance plane

7 MEASUREMENT CHARAKTERISTICS

The aim of the measurement was to determine the material removal after individual finishing operations. For this measurement was chosen a method of measuring the thickness of the rotor blades in selected locations. In inspection points have been defined a space points. Space points were defined from both sides in pairs against each other (Figs. 10 and 11). The 3D distance of the measured points was evaluated. The compressor wheel contains two types of blades - big and small. On the large blade was defined 8 measuremet points (Fig. 12) and on the small blade 6 measuremet points (Fig. 13). Because it is a repeating geometry, the measurement strategy (group of measurement points) was transferred to the other blades. It was used function Polar pattern offset. This combined with the use of a rotary table ensured the automatic positioning of the measured part in the subsequent measurement. The measured radial compressor wheel has 16 large and 16 small blades. The inspection was performed out on seven blades. [Izol 2013]

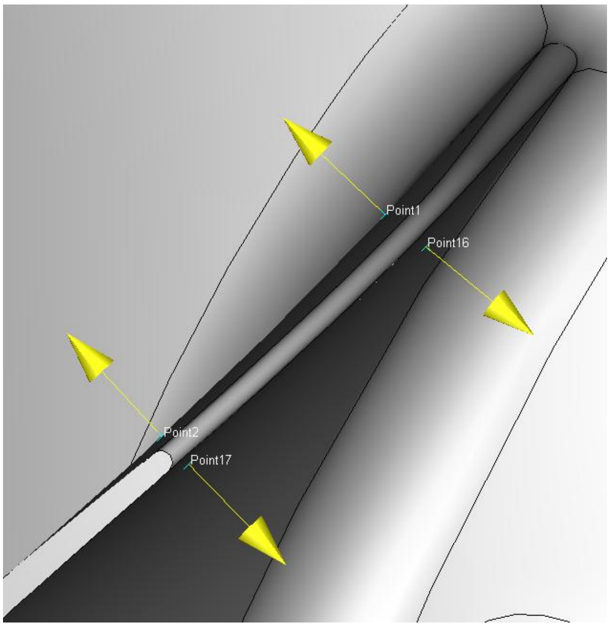

Figure 10. Points for thickness measurement

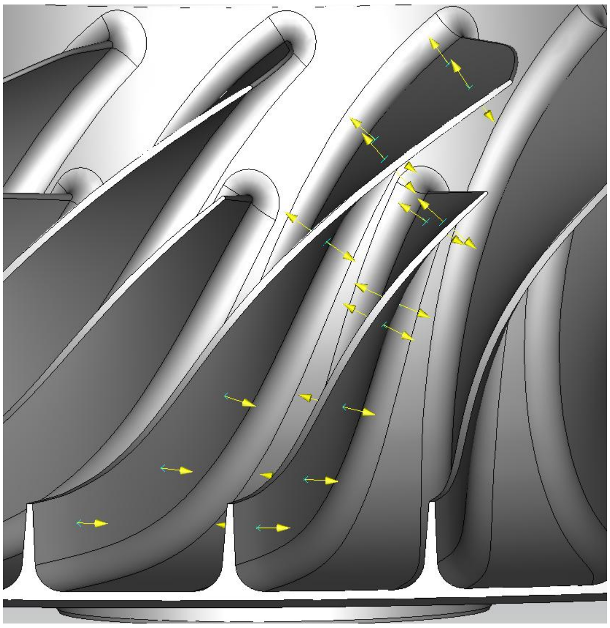

Figure 11. Measurement points group

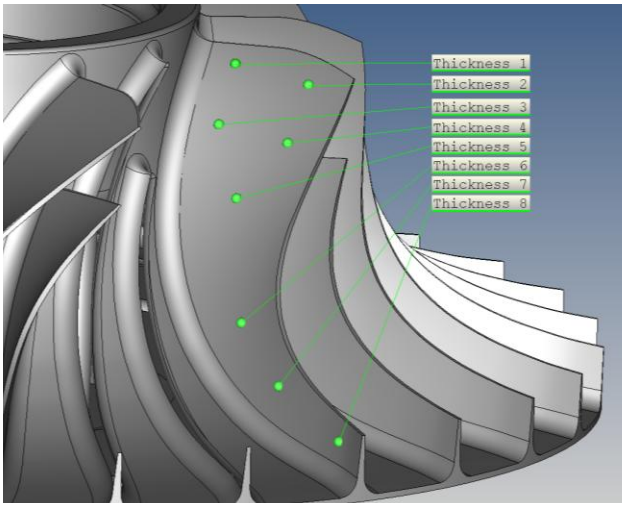

Figure 12. Inspection points on big blade

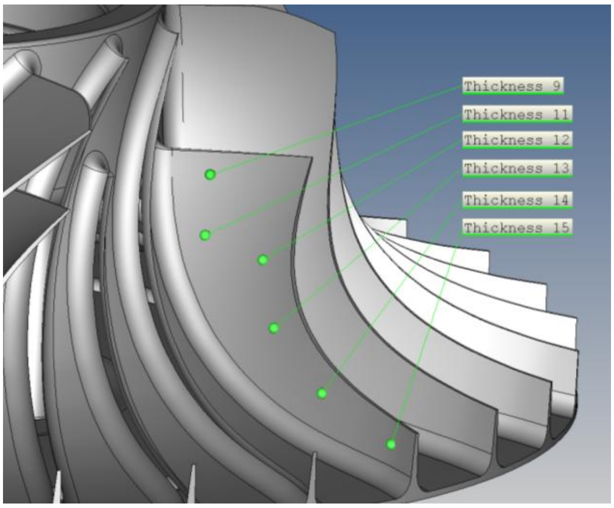

Figure 13. Inspection points on small blade

8 INSPECTION EVULATION

Measured values of blade thicknesses in defined points were exported in tabular format and processed in MS Excel. The absolute dimensions were not important by evaluating the measurement. They were only used to calculate the thickness difference after each finishing operation. The monitored value was therefore the thickness variation of the part.

Table Tab. 1 shows the thickness variation afte vibrational tumbling in millimeters. The starting state for this technology was the wheel machined by milling. Measured thickness variation values are in micrometer units, which confirmed the expectation. A positive value means that the thickness increases in the given place, the negative value represents a reduction in thickness. The thickness variation after the vibrational tumbling is minimal and can be considered insignificant.

Table Tab. 2 shows the thickness variation after the superfinishing operation. The highhest material removal occurred on a large blade in points T1, T2 and T4 on a small blade in point T15. This was in line with expectations. In other points was the material removal negligible. The values in the table represent the thickness variation, which is the material removal from both sides of the blade. The material removal from the surface (one side) – it is need to divide the measured value by two. It was considered the symmetrical materiál removal from both sides. For the exact determination of material removal from one side would have to be used another measurement method (different technology).

	Big blade – inspection point								Small blade – inspection point					
Blade number	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 11	T 12	T 13	T 14	T 15
1	0.005	0.005	-0.002	-0.001	-0.001	-0.002	-0.002	-0.003	-0.001	-0.002	-0.002	-0.002	-0.001	-0.003
2	0.003	0.004	0.000	-0.001	-0.001	-0.001	-0.002	-0.003	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002
3	0.004	0.004	-0.001	0.000	-0.002	-0.002	-0.002	-0.003	0.000	0.000	0.000	-0.001	-0.002	-0.004
4	0.001	0.004	-0.002	-0.001	-0.002	-0.005	-0.003	-0.005	-0.002	-0.002	-0.001	-0.001	-0.001	-0.002
5	0.004	0.004	-0.001	0.000	-0.001	-0.004	-0.003	-0.003	-0.001	-0.003	0.000	-0.004	-0.001	-0.002
6	0.003	0.004	0.000	-0.001	-0.001	-0.004	-0.002	-0.003	-0.001	-0.001	0.000	-0.001	-0.002	-0.003
7	0.003	0.004	-0.002	-0.001	-0.002	-0.001	-0.002	-0.004	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003
Average variation of thickness	0.003	0.004	-0.001	-0.001	-0.002	-0.003	-0.002	-0.003	-0.001	-0.001	-0.001	-0.002	-0.001	-0.003
Max.	0.001	0.004	-0.002	-0.001	-0.002	-0.005	-0.003	-0.005	-0.002	-0.003	-0.002	-0.004	-0.002	-0.004
Min.	0.005	0.005	0.000	0.000	-0.001	-0.001	-0.002	-0.003	0.000	0.000	0.000	-0.001	-0.001	-0.002

Table 1. Thickness variation after vibrational tumbling [mm]

	Big blade – inspection point								Small blade – inspection point					
Blade number	T 1	T 2	T 3	T 4	T 5	T 6	T 7	T 8	T 9	T 11	T 12	T 13	T 14	T 15
1	-0.014	-0.023	-0.001	-0.010	-0.004	-0.002	-0.001	-0.005	-0.001	-0.001	-0.002	-0.002	-0.002	-0.006
2	-0.016	-0.029	-0.006	-0.012	-0.004	0.000	-0.002	-0.004	-0.002	-0.002	-0.002	-0.004	-0.003	-0.006
3	-0.014	-0.023	-0.003	-0.009	-0.004	-0.002	-0.001	-0.004	-0.002	-0.002	-0.002	-0.002	-0.002	-0.006
4	-0.011	-0.013	-0.002	-0.005	-0.001	-0.001	-0.001	-0.003	0.000	0.000	0.000	0.000	0.000	0.000
5	-0.011	-0.012	-0.003	-0.006	-0.003	-0.002	0.000	-0.006	-0.002	-0.001	-0.002	-0.001	-0.002	-0.008
6	-0.011	-0.015	-0.002	-0.006	-0.002	-0.001	0.000	-0.005	-0.002	-0.001	-0.002	-0.001	0.000	-0.010
7	-0.012	-0.019	-0.003	-0.008	-0.003	-0.001	-0.002	-0.007	-0.002	-0.001	-0.003	-0.002	-0.001	-0.010
Average removal	-0.013	-0.019	-0.003	-0.008	-0.003	-0.001	-0.001	-0.005	-0.002	-0.001	-0.002	-0.002	-0.001	-0.007
Max.	-0.016	-0.029	-0.006	-0.012	-0.004	-0.002	-0.002	-0.007	-0.002	-0.002	-0.003	-0.004	-0.003	-0.010
Min.	-0.011	-0.012	-0.001	-0.005	-0.001	0.000	0.000	-0.003	0.000	0.000	0.000	0.000	0.000	0.000

Table 2. Thickness variation after superfinish [mm]

9 CONCLUSIONS

During the geometry inspection the radial compressor wheel was measured after three operations. First was measured the initian state - after milling. Then the second inspection was made after operation vibrational tumbling. The third inspetion was performed after the final operation - superfinishing. When analyzing the measured values, it was found that vibrational tumbling technology had a negligible effect on the change in blade thickness. The thickness variation did not exceed ± 0.005 mm.

After superfinishing technology was material removal at all inspection points. As expected the highest material removal was measured on large blades near the leading edge (point T2 – avg. value -0.019 mm, max. value -0.029 mm).

A repeated measurement was performed to verify the repeatability of the used measurement method. This measurement was performed on the part after the last operation - superfinishing. The part was measured with a time distance, with a new calibration of the stylus systems, a changed position of the rotary table and a new determination of the axis of the rotary table. It was imitated situation that had occurred during the previous inspections, between which the surface of the compressor wheel was finishing (vibrational tumbling, superfinishing). Of the 98 thicknesses inspection was in one point the repeatability deviation 5 µm, in 2 points deviation 2 µm and in the remaining 95 points the deviation is one micrometer or less, rounding the measured values to 3 decimal places. It follows that the chosen measurement methodology shows very good repeatability.

REFERENCES

[Bosch 1995] BOSH, J. Coordinate measuring machines and systems. New York: MARCELL DEKKER, 1995. 444s

[Izol 2013] Izol, P., et al. Evaluation of machining strategies for productionof free form surfaces using 3-axle milling. Manufacturing Technology, 2013 12(4), 458-465.

[Pfeifer 2006] PFEIFER, T., IMKAMP, D., SCHMITT, R., Coordinate Metrology and CAx-Application in In-dustrial Production: Basic, Interfaces and Integration, Munich: Carl Hanser Verlag, 2006. 205s.

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