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Modeling of Coordinate Measuring Geometrical Parameters Form and Location Complexity Profile of Compressor Blade GTE

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Abstract: The study provides a method developed process modeling coordinate measurements of geometrical parameters of shape deviations and location complex profile. We investigate deviations shape and location of a series of compressor blades of the second stage Engine brand manufactured NC technology manual polishing. Estimated uncertainty of measurement error and geometrical parameters considered blades using the most commonly used algorithm for measuring the radius compensation tip by calculating the point of tangency along the normal to the measured nominal point.

Key words: Technique of modeling, complexity profile, deviation of form and location of profile, uncertainty, blade, coordinate measuring machine, method of compensation

INTRODUCTION

The complex surface geometry of a gas turbine engine blade airfoil has a significant impact on its performance characteristics (specific consumption, power, gas-dynamic stability, etc.). Achieved by the technology complex surface accuracy of a gas turbine engine blade airfoils is determined by the processing and measurement precision. During the manufacture of blades, the control of complex surface geometry is performed in the process of the equipment adjustment, during intermediate and final stages of processing. Thus, the provision of control accuracy is an essential element to ensure GTE performance characteristics.

In order to control the complex surface geometry of the airfoils the modern means of measurements become widespread. The basis of such measuring instruments is the use of a coordinate measurement method by an indirect comparison with a 3D Model of an airfoil complex surface which involves the computer support. The contact and non-contact measurement techniques are implemented. Each of the measurement methods has its advantages and disadvantages. It is known that the contact measurement techniques have significantly lower performance of measurements but it is a preferred one for a number of objectives. These problems include the control of surfaces with a high reflectivity, such as the compressor blades made of chromium-nickel alloys with low roughness (Ra 0.63-0.32 mcm). The control of such blades may be performed using three axis coordinate measuring device equipped with a trigger or a scanning sensor with a measuring tip of a spherical shape.

The modern coordinate measuring devices have a relatively low instrumental measurement error in the range of 1-7 microns, defined by measurable dimensions. However, their use in practice, the resulting measurement error may be greater. An important metrology and manufacturing task is to determine the actual measurement error.

The aim of this article is to develop a method of coordinate measurement process modeling for a complex profile to estimate the error of geometrical parameter measurement of the profile shape and location.

MATERIALS AND METHODS

The actual error and measurement performance depends on many factors (Wilhelm *et al*., 2001):

- Instrumental errors of measuring means
- Measuring method in use
- Shape and position of the part measured surface errors
- Measured points processing algorithms in use
- External factors

The manageable factors in order to reduce the measurement errors: the measurement procedure in use, the algorithms used for measured points processing and external factors. Let us consider each of them.

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The external influencing factors include temperature, humidity and ambient debris. They may be maintained at a desired level or be compensated, for example, by temperature compensation inclusion. The method of measurement performance is a measurement sequence, which includes the rough (start) and finished basing by the measurement of base surfaces, the sequrnce and method of measuring the points on other surfaces, the used algorithms for measured data processing, the method of construction and calculation of geometrical parameters from the known measured parameters, the order of data presentation in a report. The used algorithms of measured points processing are of particular importance. There are several types of used algorithms for measured points processing. For example, the approximation of the measured base surfaces which include planes, cylindrical surfaces are often carried out by the method of least squares. During the measurement of complex surfaces or profiles with a spherical measuring tip the radius compensation problem appears. Since, the center of a measuring tip is known during measurement when the surface is touched and the actual point is obtained by calculation. There are several ways of a measuring tip radius compensation. The most common is the swing point calculation on the basis of the known coordinates and the normal vector of its nominal measurement point.

With this method of compensation an additional error will arise caused by the deviation of the actual profile normal direction in a measured point from the nominal direction (probe radius compensation error, Fig. 1).

This error in case of a spherical tip use may be obtained according to the Eq. 1 (Savio *et al*., 2007):

$$\Delta = R\times(1 - \cos(\alpha)) \tag{1}$$

Where:

R = a measurement tip radius

α = The angle between the calculated (nominal) and the actual normal at a measured point (Fig. 1)

The above model does not allow to estimate the error of geometrical deviation parameters measurement and the profile shape. The simulation procedure is developed for their joint assessment. This procedure reproduces the process of coordinate measurements (Fig. 2).

The method of simulation comprises a sequence of steps. Let's describe in detail each of these steps. The first stage sets a plan of experiments. The elements of the plan include the information about the simulated values of shape deviations and profile positions.

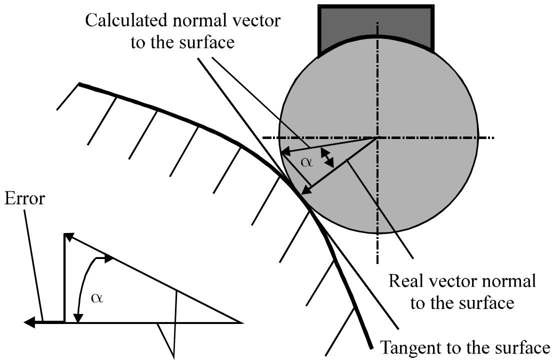

Fig. 1: Estimation of error Δ, caused by the non-compliance between the nominal and real direction of normal to the surface

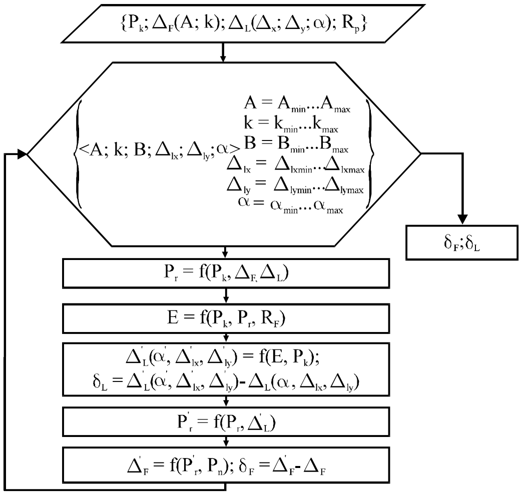

Fig. 2: Block diagram of the coordinate measurement error research program

At the second stage, the loading of point coordinates for a nominal profile P_n and the shape deviation (Δ_F) and location (Δ_L) parameters are simulated. The profile shape error is simulated as the shape including harmonic and random components as follows:

$$\Delta_F = \Delta_H + \Delta_R \tag{2}$$

where, Δ_H is the harmonic component of the profile shape error of the profile points which is obtained according to the following formula:

$$\Delta_H = A.\cos\left(\frac{k.x.2.\pi}{L_{pr}}\right) \tag{3}$$

Where:

A = The harmonic component amplitude

k = The harmonic error frequency

L_{pr} = The reference profile length along X-axis point coordinate

x = P_n point coordinate
Δ_R = Random shape error component of the point profile that simulates the instrumental error of the measuring device
Δ_L = Profile location error consisting of three parameters: the angle of profile rotation α and the displacement along the coordinate axes Δ_{lx}, Δ_{ly}

Finally, the coordinates of an actual profile are obtained from the nominal profile point coordinates according to Eq. 4:

$$P_r = P_n + \Delta_F + \Delta_L \tag{4}$$

where, P_r is the coordinates of an actual (measured) profile points. The continuous representation of the simulated and the nominal profile is performed by the interpolation of the corresponding coordinate arrays of the profile points with the use of 3rd degree NURBS spline (Rogers and Adams, 2001; Lee, 2004).

During the third step, the simulation of a measurement tip touch is performed for a simulated profile which is a measured one. During the simulation process of the coordinates of the probe and the profile touch points and the probe center coordinates are determined. In order to find the basic coordinates, an improved algorithm is developed as an alternative to the algorithm presented by Rajamohan *et al.* (2011). The determined and set parameters are shown by Fig. 3.

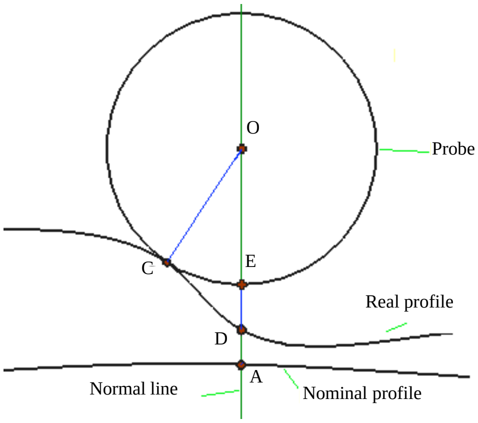

Fig. 3: Scheme of complex surface profile measurement (A: the measured point of a rated profile; D: the real profile point which crosses the normal at the point A; C: the point of probe tip and the actual profile touch; O: the center of a measurement tip at the moment of surface contact; E: the point located at the intersection of the point A normal and the probe circle

The measurement of a profile point is as follows: the probe is moving along the normal to the point A at the nominal profile. The situation refers to the real profile that does not match the nominal value at point C. The point E calculated by computer is located at the intersection of a probe theoretical normal and a circle probe, the point D is located at the intersection of the normal theoretical and a real profile. The program modules are developed to evaluate the measurement error. These modules reproduce the process of a complex profile measurement which is described earlier.

The fourth step implements the determination of the best combination for a simulated (point E) and a nominal (P_n point) profile. At that the parameters of profile location are developed measured during simulation. The obtained parameters of profile location are used to calculate the best match of a nominal and a measured (estimated) profile (adjustment) which looks like:

$$M_{ПР} = \begin{bmatrix} \cos\alpha' & \sin\alpha' & 0 \\ -\sin\alpha' & \cos\alpha' & 0 \\ \Delta'_{lx} & \Delta'_{ly} & 1 \end{bmatrix} \tag{5}$$

The measurement error of location deviation from the nominal value may be characterized by the deviations between a received and a set up experiment plan, the angle of profile rotation and the offset along the coordinate axes:

$$\delta_L = \begin{cases} \alpha' - \alpha, \\ \Delta'_{lx} - \Delta_{lx}, \\ \Delta'_{ly} - \Delta_{ly} \end{cases} \tag{6}$$

During the fifth stage the simulated profile point coordinates are adjusted to exclude the error of location. In this case, the coordinates of a simulated profile are determined to estimate a shape error:

$$P'_r = E \times M_{pr} \tag{7}$$

During the sixth stage the NURBS spline is set according to the points of a fit profile. After that, the normal are calculated within P_n points to the nominal profile, the coordinates of intersection points for these normal and a fit measured profile E_1 are obtained. P_nE_1 distances characterize the estimated error of the profile shape Δ_F. The error of found deviation is an array of differences for evaluated and pledged deviations of the profile shape at the points:

$$\delta_F = \Delta'_F - \Delta_F \tag{8}$$

The obtained values δ_F and δ_L for each set of input parameters and are used for further analysis. Thus, the measurement errors of a shape deviation and location are determined for each element of the experimental plan are determined by measuring the deflection errors of shape and arrangement. The developed technique will be used to assess measurement errors of geometrical parameters for complex profiles and the determination of measurement results uncertainty allowing to distribute them for a part of manufactured blades.

RESULTS AND DISCUSSION

Initially, the study of shape deviations and the serial blade profiles location was carried out at "Kuznetsov" OJSC using the coordinate measuring machine DEA Global Performance 07.10.07.

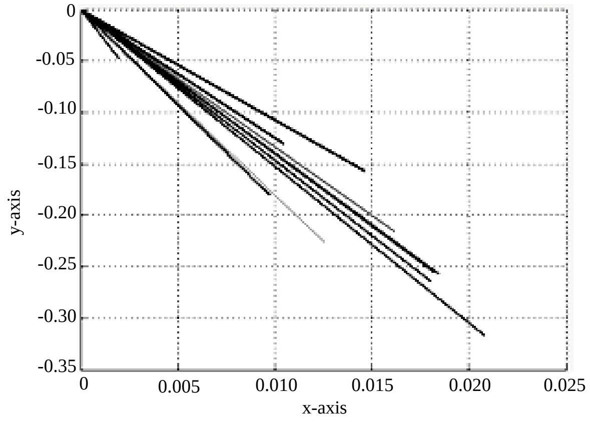

Fig. 4: The results of linear deflection location measurements according to the series of blades (mm)

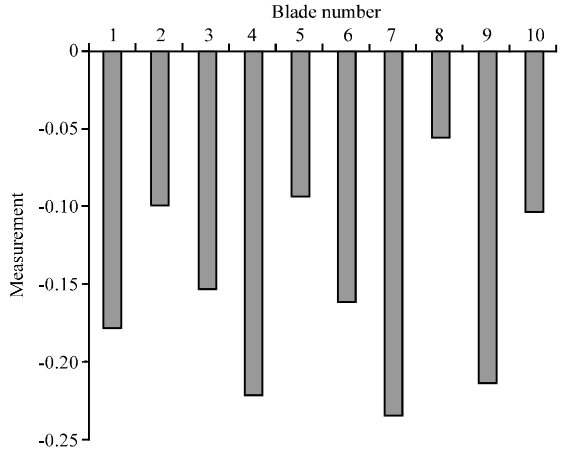

Fig. 5: The results of measurements of angular deflection location according to the series of blades (rad)

During the measurements the results concerning shape and location deviations were obtained. The deviation of location is shown by Fig. 4 and 5. Figure 4 contains the vectors of locations deviations from the nominal (zero) value to select blades according to sections. Analyzing the figure one may note that there is a close correlation between the offset values along X and Y-axis. The higher the modular deviation value along one axis, the higher the amount of displacement along the other axis.

Figure 5 shows the values of the angular deviation of location concerning the nominal position for the corresponding measured blades. The measured deviation of sample blade shape are shown in Fig. 6.

The measurement results show that the measured items have a similar shape error. The largest deviation of the scanned blade shape from the nominal detail shape is observed on the input and output edge of the item, in the central part the deviation is an ingignificant one. On the basis of blade batch measurements one may conclude that the manufactured blades, made according to a similar technological process will have a close shape deviation.

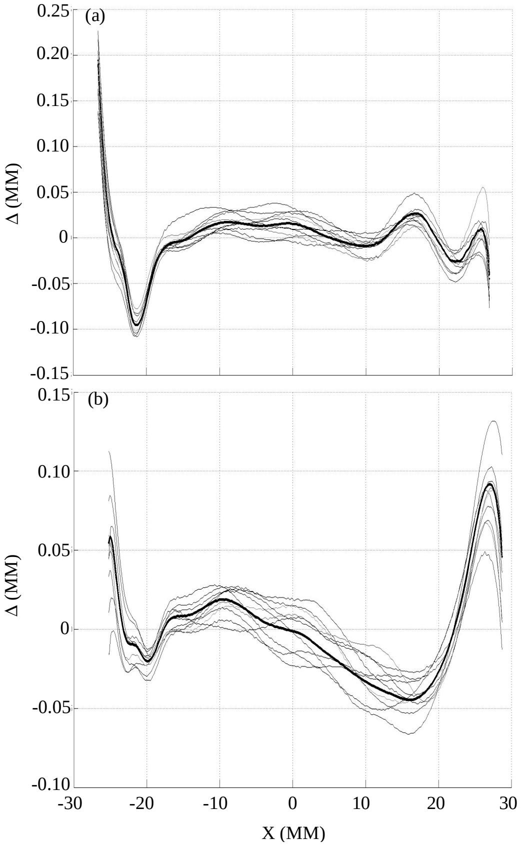

Fig. 6: The shape deviation for launder section at the height of: a) 17 mm and b) 172 mm

The similarity of shape deviation will allow to extend the assessment of measurement error with the measured batch of blades on all batches of blades produced according to a similar process technology.

On the basis of the performed measurements the boundary conditions of profile shape deviations were determined and the test plan for modeling and the measurement error determination was developed (Table 1). On the basis of experimental plan the modeling of the measurement process with the simulated deviation of shape and the measured profile position was performed. Thus, the following dependences on measurement errors were obtained. Figure 7 demonstrates the dependence of the measurement error for profile shape deviation on the

Table 1: Experiment plan

Sections			A (mm)		k (u.n.)		B (rad)	
Name	Surface	Height (mm)	Min.	Max.	Min.	Max.	Min.	Max.
K17	Launder	17	0.01	0.25	2.5	18	0	2×π
C17	Back	17	0.02	0.25	2.0	28	0	2×π
K100	Launder	100	0.03	0.20	6.0	26	0	2×π
C100	Back	100	0.01	0.28	3.0	19	0	2×π
K172	Launder	172	0.01	0.13	4.0	19	0	2×π
C172	Back	172	0.01	0.15	2.0	16	0	2×π

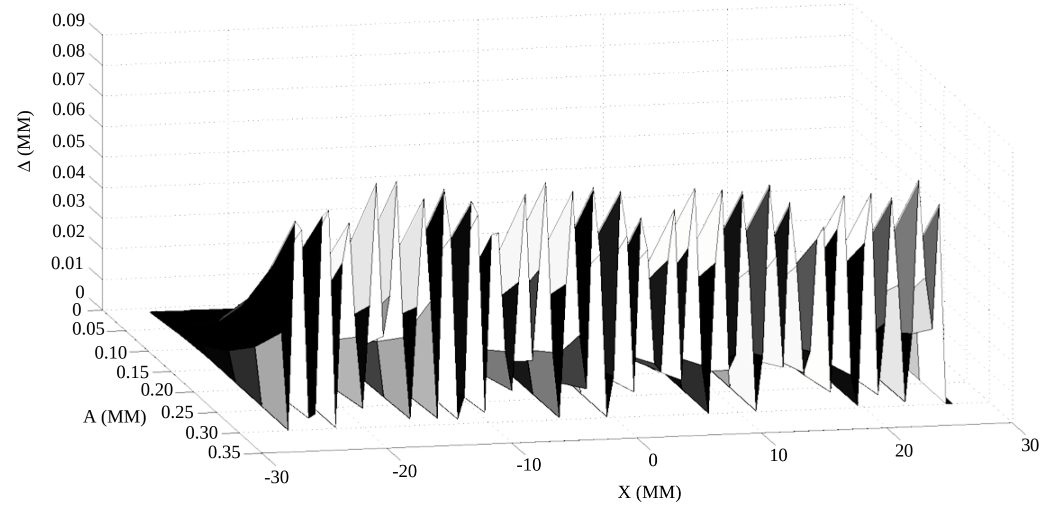

Fig. 7: The dependence of the profile shape measurement error on the amplitude of the harmonic component along the profile

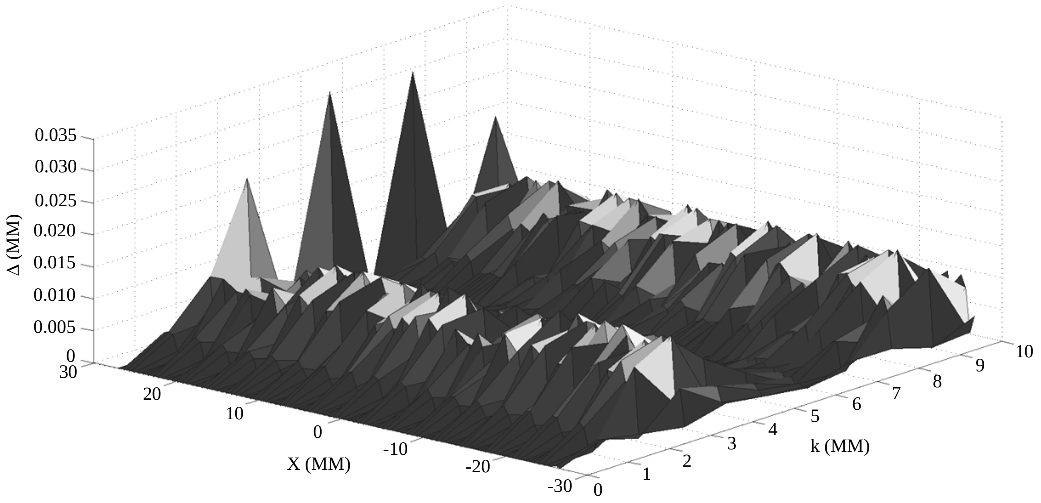

Fig. 8: The dependence of profile shape measurement error deviation on the frequency value of the harmonic component k

amplitude of the harmonic component along the profile. Figure 8 shows the dependence of the profile shape measurement error for profile shape deviation on the frequency value of the harmonic component k.

CONCLUSION

Analyzing the obtained results one may noted that the dependence of profile shape deviation measurement error on the harmonic component parameters is not a linear one. When the value of the actual shape deviation makes 0.1 mm it makes 0.005 mm.

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