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Try-Out of Estimation Method of Diameter for Stator Rings of Gas-Turbine Engine Compressor for Highly-Efficient Production Purposes

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Abstract: Previously, it is proposed a method for determining the diameter of non-rigid stator rings of GTE compressor in case of control using coordinate-measuring machine. In this study, the mathematical model is tried out in several areas.

Key words: GTE, non-rigidity, stator ring, accuracy, coordinate-measuring machine

INTRODUCTION

The tendency of increasing the thin-walled parts' lineup which is generally defined by the possibility of reducing metal consumption and manufacturing cost, is well-known and typical for all branches of mechanical engineering (Lastovskij, 2010). In case of propulsion engineering the above-mentioned tendency is explained also with peculiar characteristics which aircraft engine components and assemblies must possess for ensuring specified performance properties as well as reliability index, durability index and safety index (A number of design solutions for improving these indicators for different types of aircraft engine parts are presented in the following papers (Falaleev and Vinogradov, 2014; Shabliy and Dmitrieva, 2014)).

The stator rings of axial compressor of gas-turbine engine present one type of such thin-walled parts, the number of which reaches 80 units in 1 engine. In addition to problems associated with ensuring the specified parameters of parts' manufacturing accuracy, the problem of ensuring high-precision control of geometrical parameters for such non-rigid rings is not less actual. This problem occurs after machining due to transforming of residual stress, this stress is the cause of parts' deformation after detachment from machining widget, i.e. is the cause of appearance of permanent residual deformation (warping) (Barahtenko, 2010).

Under on-machine inspection the control of non-rigid ring diameter is carried out by means of a micrometric tool while the part is in the machining widget.

The situation is different when detachment. Due to the influence of residual stresses, significant out-of-roundness becomes essential for the ring. This out-of-roundness is eliminated during installation. However, it is unacceptable under the control of the ring diameter using the coordinate-measuring machines, widely used in industry due to their flexibility for several reasons:

- Least Square Method, used in CMMs Software doesn't correspond to the specifics of the task (significant out-of-roundness)
- Workpiece positioning on CMM together with the widget used for machining process, makes no sense

To solve the control problem of non-rigid ring diameter in a free state, a method of mathematical calculation of the equivalent diameter by determining the arc length, describing the profile of the controlled section, is proposed. This approach with explanation of any given stage as well as the experiments confirming its efficiency are presented in work (Cheveleva and Pronichev, 2013). Below try-out of the method is stated in the following areas:

- The accuracy of the mathematical model for estimation of the equivalent diameter
- Study of the sensitivity of the coordinate method for diameter control
- The impact of CMM accuracy parameters
- The influence of instrumental uncertainty on the accuracy of the algorithm

ANALYSIS

The accuracy of the mathematical model for estimation of the equivalent diameter: The experiment I was conducted for the circle with diameter of 500 mm and form deviation of 0.3 mm in the presence of instrumental uncertainty for DEA Global Performance 07.10.07 machine

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(Cheveleva and Pronichev, 2014). The sample of measuring point was generated one-time; further the curve fitting was performed 1E+04 times for ways under consideration and then equivalent diameter was calculated.

Thus, it was formed conditions when data, entered to the input of mathematical calculating unit was fixed; the accuracy of the mathematical apparatus was tested, namely mathematical apparatus of data-curve fitting. This curve allows predicting a profile of given section most precisely.

During this experiment, the values of standard deviations (Table 1) were obtained on basis of these values we can conclude that mathematical model for estimation of the equivalent diameter is stable. In spite of the fact, that with such considerable number of trial (1E+04) the range of any values is not evaluated in terms of statistics theory, the results obtained (Table 2) even more clearly confirm the stability of the mathematical apparatus.

Study of the sensitivity of the coordinate method for diameter control: In addition to the experiment I numerical experiment II was conducted for the circle with diameter of 500 mm and form deviation of 0.3 mm in the presence of instrumental uncertainty for DEA Global Performance 07.10.07 machine. However, measuring point sample which is subsequently used for curve fitting was generated for each playing the experiment (1E+04 times when four control points, 1E+04 times when ten, etc.).

Table 1: Standard deviation (μm) of diameter value for experiment (I) to verify accuracy of the mathematical model for equivalent diameter estimation

	No. of control points			
The calculation methods	4	10	20	1257
Spline	7.68E-08	2.64E-08	9.66E-08	7.86E-08
Second-Degree Polynomial Interpolation	2.30E-08	7.22E-09	1.18E-07	6.37E-08
Third-Degree Polynomial Interpolation	8.00E-08	6.34E-08	6.74E-08	3.31E-08
Second-Degree Polynomial Approximation	1.61E-08	8.81E-09	4.55E-09	5.46E-08
Third-Degree Polynomial Approximation	7.00E-08	1.48E-09	3.16E-08	1.15E-07
Least Square Method	1.29E-07	6.91E-08	3.98E-08	5.38E-08

Table 2: Range of deviation (μm) of diameter value for experiment I to verify accuracy of the mathematical model for equivalent diameter estimation

	No. of control points			
The calculation methods	4	10	20	1257
Spline	0	0	0	0
Second-Degree Polynomial Interpolation	0	0	0	0
Third-Degree Polynomial Interpolation	0	0	0	0
Second-Degree Polynomial Approximation	0	0	0	0
Third-Degree Polynomial Approximation	0	0	0	0
Least Square Method	0	0	0	0

Comparing experimental results I (Table 1) and II (Table 3), we can conclude: when a small number of coordinate points is used, the coordinate method for diameter control is sensitive to data on point, specifically to arrangement of points on the test geometry.

The impact of CMM accuracy parameters: The experiment III was conducted 1E+04 times for the circle with diameter of 500 mm and form deviation of 1.0 mm. For testing the influence of the instrumental uncertainty on the measurement results we chose coordinate-measuring machines which spatial errors are expressed in the form (Eq. 1):

$$MPE_E = \pm\left(A + \frac{L}{B}\right) \tag{1}$$

where, A and B are coefficients, namely machines of portal type or bridge type, also they correspond with specifics of measuring the aircraft parts. Moreover, machine models, presented in Table 4 have similar working space.

As a result of experiment III we obtained the following: for all ways of fitting (except approximation) the same situation: at starting value of control points vector Maximum (M) and minimum (m) of absolute error for each of ways of fitting have no a clear dependence on passport error. The values are mixed. It can be explained as follows (Fig. 1): when a small number of control points is used, the probability of the occurrence of an event when the magnitude of instrumental error for most fine (high-precision) machine has a greater impact on the

Table 3: Standard deviation (μm) of diameter value for experiment II that simulates completely stochastic process of measuring

	No. of control points		
The calculation methods	4	10	20
Spline	131.34	7.30	0.55
Second-Degree Polynomial Interpolation	78.09	3.63	0.61
Third-Degree Polynomial Interpolation	37410.18	7.48	0.56
Second-Degree Polynomial Approximation	33.00	10.43	4.77
Third-Degree Polynomial Approximation	131.34	25.07	11.05
Least Square Method	28.98	7.14	2.51

Table 4: CMMs' models and their characteristics

	Strokes (mm)			Precision factors	
Models	X	Y	Z	A	B
DEA GLOBAL Silver Performance 07.10.07	700	1000	660	1.7	333
DEA GLOBAL Silver Advantage 07.10.07	700	1000	660	1.4	333
DEA GLOBAL Silver Classic 07.10.07	700	1000	660	1.9	300
Sheffield explorer 07.10.07	700	1000	700	2.5	400
Ares 10.07.05	1000	650	500	2.8	333
LK V-SL 10.10.8	1000	1000	800	1.1	400
LK V-SL (HA) 10.10.8	1000	1000	800	0.7	600

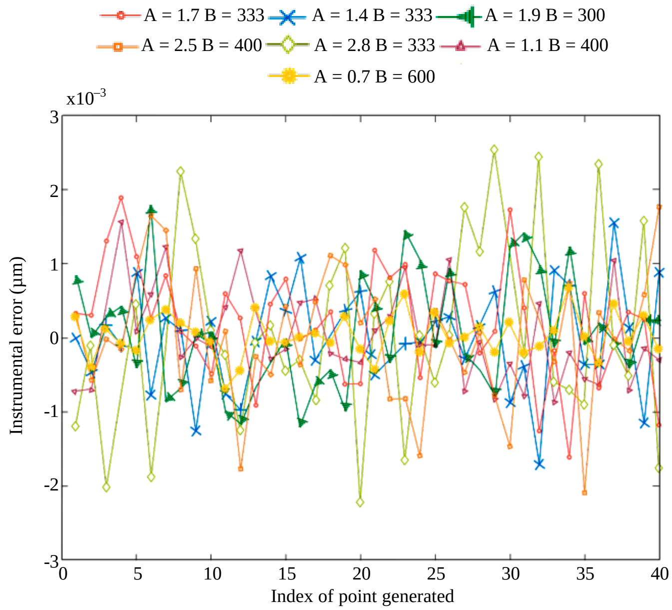

Fig. 1: Instrumental error involute for the first 40 points of total points matrix for various CMMs

Table 5: Absolute error (µm) for coordinate measurements III of non-rigid ring diameter, depending on points number and passport error of the coordinate-measuring machine in case of spline interpolation

No. of control points	CMM No. 1	CMM No. 2	CMM No. 3	CMM No. 4	CMM No. 5	CMM No. 6	CMM No. 7
4	792.10	769.21 m	781.16	783.62	776.84	789.62	792.84 M
5	950.62	943.86 m	952.66	967.25 M	944.06	947.46	957.25
6	515.23	524.43	508.31 m	526.94	520.38	532.79 M	523.53
7	163.72 M	162.89	162.95	162.86	156.66 m	160.72	162.42
8	37.57	36.85 m	38.52	37.66	37.10	39.78 M	38.76
9	38.57	38.37	37.93 m	37.94	39.07 M	38.14	38.07
10	38.94	38.55	38.72	38.36 m	39.08 M	39.02	38.48
11	33.43	33.59	33.65	33.77 M	33.30 m	33.54	33.71
12	26.75	26.50	25.98	26.67	26.40 m	26.81	27.13 M
15	11.13	11.06	10.84 m	10.92	11.45 M	11.18	10.97
18	4.73	4.90	4.75	4.79	4.94 M	4.78	4.62 m
20	2.76 m	2.82	2.98	2.78	3.03 M	2.82	2.78
25	1.13	0.98	1.01	1.14	1.41 M	0.98	0.87 m
30	0.71	0.58	0.72	0.82	0.98 M	0.60	0.39 m
35	0.61	0.44	0.49	0.68	0.88 M	0.51	0.26 m
42	0.52	0.40	0.47	0.60	0.83 M	0.42	0.20 m
47	0.48	0.36	0.44	0.56	0.76 M	0.40	0.20 m
51	0.47	0.35	0.43	0.56	0.81 M	0.44	0.18 m
53	0.45	0.35	0.46	0.52	0.72 M	0.36	0.17 m
55	0.47	0.33	0.42	0.49	0.73 M	0.36	0.17 m

calculation results than the magnitude of instrumental error for the most inaccurate machine is high. However when a more control points are used, the probability of mentioned event reduces as well as the point collection process becomes less stochastic.

Thus with some number of control points N_{ref} (for each fitting way: spline 25; second-degree polynomial interpolation 25; third-degree polynomial interpolation 18) this dependence is evident (Table 5): the minimum value of absolute error corresponds to the measurements, simulated for the most precision of all CMMs considered, maximum for the least precision one. Moreover, a certain direct proportionality between the absolute error magnitude and the CMM accuracy is kept between the maximum and minimum absolute error for given number of control points.

It should be noted that when using each of CMMs presented, reliable control of the ring diameter will be achieved at approximately identical number of control points.

That allows drawing that within the field of application instrumental error makes an equivalent contribution to the absolute error regardless of CMMs' precision characteristics.

The influence of instrumental uncertainty on the accuracy of the algorithm: It is known, that the Least-Squares Method eliminates the influence of instrumental uncertainty. For the proposed estimation method of diameter through the perimeter of fitting curve, there was a fear of accumulation of instrumental uncertainty influence and incorrect calculation, respectively, since the method is based on integrating the fitting piecewise functions. For confirmation or refutation of this theory the numerical experiment IV was conducted. The ring with a diameter of 750 mm was simulated on the assumption that rolled ring is processed according to requirements, imposed to contact surfaces of low-pressure compressor ring with dimensional tolerance of 0.1 mm. Consequently, the measurement uncertainty will make 30% of the dimensional tolerance (that corresponds to the characteristic of the normal process) and is equal to 166 μm.

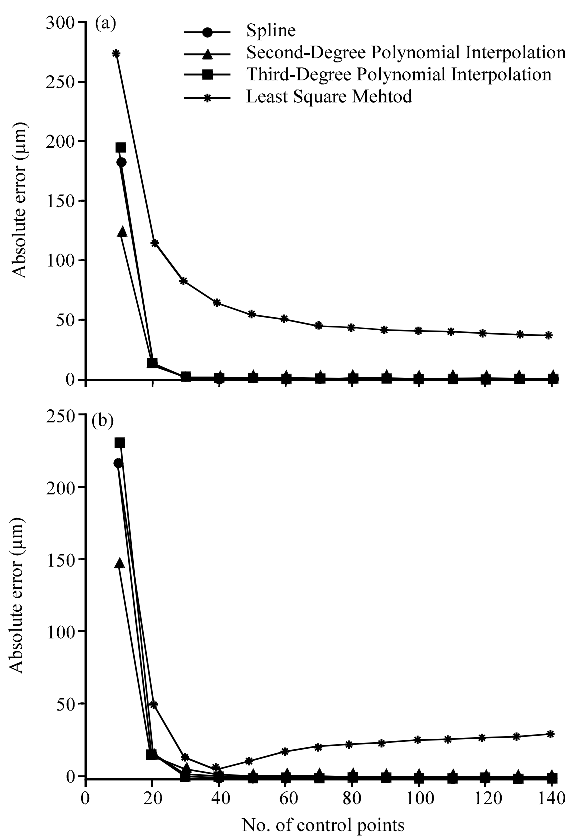

Fig. 2: The graph of absolute error when determining the ring diameter for various ways of fitting: a) the upper limit and b) the lower bound

The experiment was carried out with large design of experiment (the number of control points N = [10:10:140]).

The graphs (Fig. 2) of the estimation of non-rigid ring absolute measurement error against the number of control points were obtained. There are no wavelets of absolute error values, expected with a significant number of control points. Therefore, the proposed method is correct and usable.

CONCLUSION

Mathematical model was tried out in several areas. We can conclude that mathematical model for estimation of the equivalent diameter is stable and this can be used for the diameter calculation for non-rigid stator rings of GTE compressor in case of control using coordinate-measuring machine.

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