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Calibration of an on-board positioning correction system for micro-EDM machines

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Abstract
The work presented in this article focuses on a positioning and inspection contactless system aiming at improving the accuracy of the micro-EDM machining of film-cooling channels in turbine blades. These components are freeform and characterized by relatively high levels of uncertainty, which leads to a difficult on-machine positioning relying on traditional methods such as precision mechanical jigs and mechanical touch probes. The presented system is based on the 3D acquisition of the work piece via a laser triangulation sensor integrated in the micro-EDM machine tool. This system allows the acquisition of millions of data points and so to correct the work piece position inside the machine tool reference frame by means of dedicated algorithms based on surface fitting principles. Furthermore, the capabilities of the chosen senor allow for the after work inspection of the machined work piece.
The system has been developed in close collaboration with SARIX SA, a Swiss machine tool manufacturer, and the experimental campaign is hereby included.

On-board positioning, on-board inspection, micro edm, system calibration

1. Introduction

Over the past few years, there has been a continuous growth of gas turbines efficiency, leading to an even more demanding request for the blades and vanes cooling technology, enabled by channels on the blade surface. These channels are micro-features characterized by small size diameters, in the range from 0.08 mm to 0.3 mm, and length up to 30 times the diameter. Studies on the effects of the manufacturing of these cooling channels show that deviations from nominal positioning have a significant impact on the overall turbine efficiency ([1], [2]).

Traditional positioning techniques ([3], [4], [5]) provide accurate and repeatable positioning, but cannot take into account for the work piece geometrical variability and presence of local defects. Moreover, a common practice with these components is the product repair, which obviously faces even higher geometrical variations. A few machine tool producers have developed on-board contact based systems [6] using touch probes, which leads to relatively high cycle times and to a lack of robustness, due mainly to the small number of data points acquired.

The present paper describes the structure and the calibration procedure of an experimental system for automatically correcting the position of freeform shaped work pieces in the machine tool workspace, compensating for machine fixture errors and minimizing effects of work piece geometrical deviations with unprecedented accuracy, repeatability and cycle time. The method has been implemented, tested and industrialized on a high precision industrial micro-Electro Discharge Machining (EDM) machine tool from a Swiss manufacturer (SARIX SA – www.sarix.com).

2. Positioning method and setup

This article will focus on the calibration of the developed on-board positioning system based on laser triangulation principle. This calibration procedure is necessary to express the measurements performed by the sensor into the machine tool reference frame, which requires to define the transformation matrixes between the sensor and the machine tool reference systems, in terms of offset angles and translations.

The machine tool used for this experiment is the "sarix SX200 aero" which is specifically designed for aerospace applications. The machine carries an electrode which functions both as a tool and as a tactile measurement probe. The basic principle is to mesure a set of reference points on a calibration artefact with both the proposed system and the machine tool built-in probe.

2.1. Integration solution

A mechanical actuated arm (Figure 1) has been developed for the specific use in order to satisfy all requirements in terms of precision, workspace loss and sensor protection.

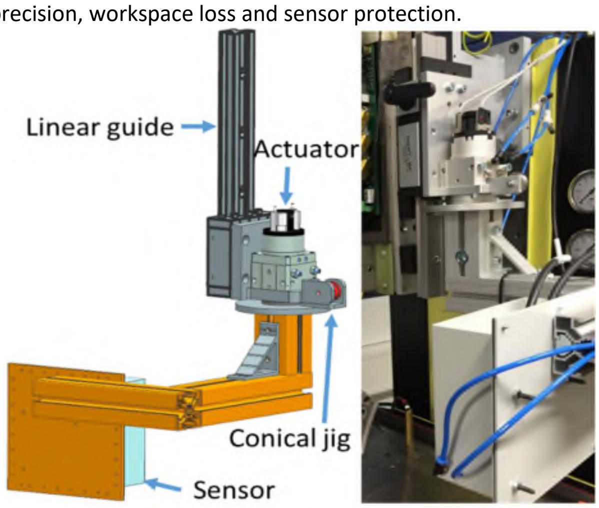

Figure 1 Sensor integration schema

The sensor is moved in and out of the workspace thanks to a rotary actuator and the arm geometry and position are adjustable so to adapt to different machine heads, work pieces and machine tool configurations. During measuring operations the rotary movement places the sensor within the machine tool workspace allowing to minimize the distance between sensor and tool head and consequently minimizing the workspace loss, while during machining operations allows to move the sensor out of the way, freeing of any impediment the machine and protecting the sensor. The repeatability of the movement is guaranteed by a precision conical adjustable jig mounted on the arm.

2.2. Calibration artefact

A calibration artefact (Figure 2) has been developed to allow the calculation of the aforementioned matrixes. The artefact is specifically designed to allow the extraction of reference points with both measurement systems: tactile (using the machine tool probe) and optical (with the integrated laser triangulation sensor). The former requires regular fine grinded geometries and a highly electrically conductive material, while the latter sufficiently large reference surfaces and adequately reflective material and surface finish.

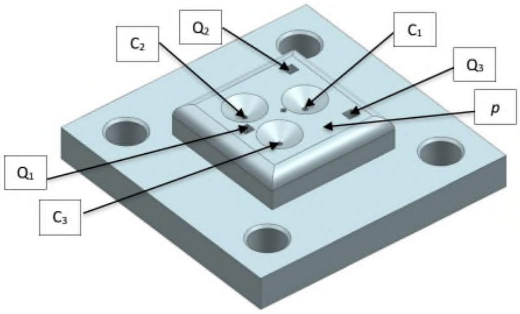

Figure 2 Calibration artefact

The calibration algorithm relies only on relative measurements; subsequently the calibration of the artefact itself is not required.

2.3. Calibration procedure

The artefact is mounted on the machine tool work plate, and the reference points are measured by both the laser triangulation sensor and the machine tool touch probe. The transformation matrixes are then calculated by comparing the coordinates of these reference points in the two reference systems. Specifically, the cones/holes (C_1, C_2, C_3) centres are used to measure the translation vector that expresses the translation between the machine tool end effector and the sensor reference frame, while the inclinations of the calibrated planes are used to calculate the rotation matrix that expresses the rotation between the two reference systems. Squares slot centres (Q_1, Q_2, Q_3) are used as reference at the end of the process to double-check the calculated transformation matrixes.

3. Calibration results

Summary table of data representing maximum, minimum and average values relative to the X-Y coordinates measured 17 consecutive times of the three reference points on the calibration artefact.

Table 1

		Min [mm]	Max [mm]	Average [mm]
Point C1	X coordinate [mm]	201,4181	201,4207	201,4189
	Y coordinate [mm]	136,7083	136,7199	136,7101
Point C2	X coordinate [mm]	208,4199	208,4229	208,4209
	Y coordinate [mm]	140,2061	140,2091	140,2078
Point C3	X coordinate [mm]	208,4168	208,4179	208,4172
	Y coordinate [mm]	133,2073	133,2089	133,2081

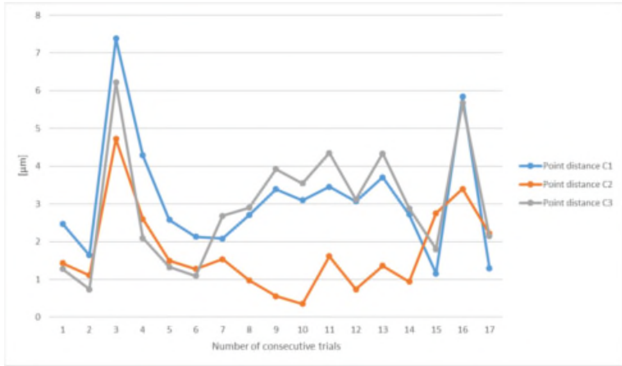

Figure 3 Error (point-to-point distance) between cones centres of the calibration artefact (C1, C2 and C3) measured with touch probing and laser triangulation sensor

The fact that the trends of the three point coordinates measured (i.e. C1, C2 and C3) are similar along the 17 trials, indicates residual rotations/displacements caused by the uncertainty in the best-fit algorithm, and by the residual deformation caused by the single compensation iteration applied. However, these results can be considered satisfactorily, for the application.

4. Conclusions

In conclusion, the designed system demonstrated to be a valid method for the positioning and the on-board inspection of freeform shaped parts in high precision machine tools. The amount of information on each single machined component enabled by the adoption of this method paves the way for further developments, which have already started in the form of new research projects involving also other European universities and large gas turbine industries.

At the present moment, we are working with our partner Sarix sa in order to industrialize the system, which will become soon a product sold as an accessory on their machine tools.

References

[1] «R. S. Bunker, "The Effect of Manufacturing Tolerances on Gas Turbine Cooling", Journal of Turbomachinery, vol. 131, pp. 1-11, October 2009.».

[2] «K. Bammert, H. Sandstede, "Influences of Manufacturing Tolerances and Surface Roughness of Blades on the Performance of Turbines" Journal of Engineering for Power, vol. 98, issue 1, pp. 29-36.».

[3] «US 6844515 B2, "Method and apparatus for turbine blade machining"».

[4] «US 7334331 B2, "Methods and apparatus for machining components"».

[5] «Y. Wang, X. Chen, Q. Liu, N. Gindy "Optimisation of machining fixture layout under multi-constraints", International Journal of Machine Tools and Manufacture", Volume 46, Issues 12–13, October 2006, Pages 1291–1300».

[6] «Patent US6611731: machining aerofoil components».

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[8] «M. Konter, M. Thumann, "Materials and manufacturing of advanced industrial gas turbine components", Journal of Materials Processing Technology, Volume 117, Issue 3, 23 November 2001, Pages 386–390».

[9] «S.A.M. Rezavand, A.H. Behravesh, "An experimental investigation on dimensional stability of injected wax patterns of gas turbine blades", Journal of Materials Processing Technology, vol. 182, issues 1–3, 2 February 2007, pp. 580–587».

Reviewer's comments

1. The English needs improving throughout the manuscript.

2. They have a very long inyrodcution and little detail about the measurement methods employed. They should decrease the intro to a single paragraph (and maybe reference other docs) and add much more detail about how the measurement mthods works, results and uncertaintes.

3. The references format should follow the euspen guidelines and the details (e.g. title) can be reduced to save space.

4. Only one paragraph should be used for the Abstract.

5. Units should be on the same line as the number. List should be e.g. 0.08 mm to 0.3 mm.

6. They completely lack any literature review of current optical techniques used for EDM, e.g. focus variation (Alicona) and laser lines (e.g. Marposs).

7. What does "out of bounds" mean - do they mean "tolerance"?

8. Fig 1 is way too small and needs labels. Again, reduce the intro and increase the size of the figs.

9. There are two sections with the same name and number (2.2).

10. How is the artefact calibrated?

11. Text in the table is far too small to read.