7th Research/Expert Conference with International Participations
"QUALITY 2011", Neum, B&H, June 01 – 04, 2011

IN-LINE METROLOGY OF SEMI-FINISHED PRODUCTS BY THE OPTICAL BI-SENSOR-METHOD

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SUMMARY
Optical coordinate metrology offers advantages for in-line manufacturing processes. Today, the performance of one unique optical principle cannot deal with all requirements of fast in-line applications under rough external conditions like the extruding. For synchronistic high measurement speeds and contact-less data acquisition the combination of two optical principles is achieved to ensure concave profile measurements with uncertainties better 0.1 mm for diameters up to 100 mm. Therefore, a prototype was built-up and the experimental measurement uncertainty analysis was carried out according to metrological guidelines. A couple of profiles from brass have been measured after a repeatability test and under constant conditions to the measurement. The uncertainty was examined to four specific influences with Design of Experiments. Therein the interactions for typical environmental influences like dust, vibration, pitch errors or extraneous light, are analyzed. The discrete uncertainty budgets were examined and the results show that the novel optical method is always better than 10 µm for Gaussian form elements. Furthermore, measurements for other sizes and concave shapes are carried out. Based on the positive results in the laboratory an evaluation in the shop was made. For the high temperatures a fluid based cooling device was applied and the evaluation was finished successfully. The reduced uncertainties of 0.01 mm can be used for optimizing the quality of semi-finished parts and to safe costs.

Keywords: Data Fusion, Multi-Sensor-Metrology, Measurement Uncertainty

1. INTRODUCTION
Because of economic reasons many technical parts are finished based on semi finished products, e.g. synchronizing disks in automotive gearboxes. The rising requirements of these products are attended with rising demands for their dimensional accuracy what cannot be dealt today with one single optical measurement system. Nowadays only two methods are available for the described measuring task. The combination of these two technologies can combine the benefits [1]. Therefore a prototypic bi-sensor measurement method was set up and tested under laboratory conditions at the Chair Quality Management and Manufacturing Metrology and afterwards in the shop floor. The extruded profiles are produced in the temperature region nearly below the fusion point with forces of up to 10^7 N. The area around

the extruder is process-related afflicted with powdered graphite and scales. Because of the high forces the movement shocks and lateral vibrations (1 Hz – 5 Hz frequencies) are occurring, hence the moving profiles swing laterally and non-harmonically.

2. FUNDAMENTALS AND MOCK-UP

For achieving in-line measurement results for the quality control only the area some meters behind the extruder seems to be suitable because in the place after the cooling application and storage begins. That is essential for observing all complex profiles' characteristics and must play a role for a realistic measurement uncertainty analysis. For reliable results the running profiles (with speeds over 10 m/s) have to be measured high frequently and holistically in profiles' measurement ranges from 10 mm to 100 mm (Fig. 1). However, the system has to cover a 360°-view around the profiles' cross-section (Fig. 2, left: prototypic mock-up, right: principle of the optical bi-sensor-method).

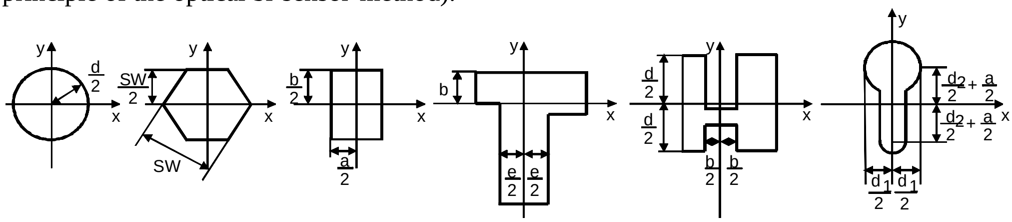

Figure 1. Profile types for the measurement tasks for the optical bi-sensor-method, from left to right: round, hexagonal, square, T-, H-, L-, door lock

Light section systems operate with light sources which project a laser fan on the surface. A camera system observes the distorted line from a stationary position and re-calculates the real form of the section by a coordinate transformation. The advantages are the ability of form measurements in the field of view (up to 120° - 180°). But the singular systems cannot measure holistically. Multi-systems equally contain the critics of low rates (max. 30 frames per second) at sufficient physical resolutions as well as the measurement uncertainty of about 100 µm and the influence by movements of the profile [1]. Those technical constraints are non-sufficient for the industrial requirements. Shadow systems for that purposes usually work with constant moving parallel light rays which are analyzed by the time measurement of the shadow arising on the other side of the light curtain by the device under test.

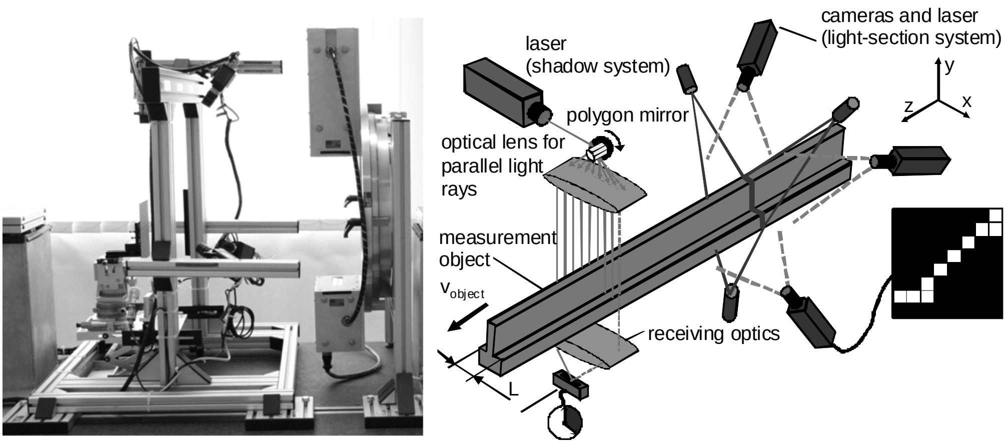

Figure 2. Design of the optical bi-sensor-prototype, left: mock-up of the optical-bi-sensor-method in the Chair Quality Management and Manufacturing Metrology (QFM) at the University Erlangen-Nuremberg; right: schematic diagram of the measurement principle

So, they deal with uncertainties of about 10 µm and as well higher speeds with 600 Hz rate in the mentioned measuring range. In exchange they can only measure one distance between the widest boundary points of the measurement gauge. Consequently, they are not suitable for concave shapes and additionally not for form measurements (data are scalar two-point information, no fix coordinate system). Herein, three light-section system and one shadow system for geometrical fastness and accuracy are used isochronously by data fusion according to an agreement of effort and benefit. A weighted parameter combines the information of shadow system and light-section system for better accuracy and data density for measuring of concave zones. The "Random Sample Consensus" method (RANSAC) or "Iterative closest points" – algorithm (ICP) as well as classical linear regressions or criteria for circle fit analysis are the most common prospects for positively combining and analyzing the overlapping datasets with particular fast response times. The algorithms used here have to be optimized on fastness and robustness against external light, miss-use, shocks or non-perfect calibration parameters (Figure 2). The challenge for combining different data types (like 2-D and 1-D information) is taken in the presented bi-sensor-method (Table 1).

Table 1. Comparison of different possibilities for the in-line measurement of extrudings

	light-section system	shadow system	offline metrology	multi-sensor system
measurement speed	**medium, up to 20 Hz**	high, up to 600 Hz	**very low**	high, up to 600 Hz
measurement uncertainty	**medium, up to 0.2 mm**	low, better 0.1 mm	low, better 0.1 mm	low, better 0.1 mm
application efforts	medium	low	**very high**	medium
time for additional handling	no	no	yes	no
form measurement	yes, sectionally	**no**	yes	yes
ability to concave shapes	**particulate**	**no**	yes	yes

3. MEASUREMENTS AND RESULTS

Every measurement is influenced by several factors from different types of groups [2]. The Ishikawa-diagram presents five main factor groups of influences to explain, describe and deal with for further expectations [3]. Measurement uncertainty is a quality parameter for the measurement according to the result and is dedicated to a specific environment of one operator with a concrete measurement instrument and analysis method as well as many partly unknown factors [4]. The couple of influences lead to the extended measurement result with the uncertainty u and k_p. The simulative constraints and the results had been acquired according to the "Guide to the Expression of Uncertainty in Measurement (GUM)" and the experimental setup was proceed and valued strictly according to the guideline VDI 2617-8 what is adequate terminology of the vocabulary in measurement [5]. The measurement software is intrinsic designed on a Basic .NET program according to the ergonomic standard EN ISO 9241-1, -11, -17. The shadow system and the light-section systems are calibrated itself under use of correction factors. The measuring chain is described and implemented clearly for the model with the value Y (1) and pre-processing simulation of the measurement can theoretically done with the software GUM Workbench. The standard deviation $u(x_i)$ is the calculation base for the uncertainty with the expectation x_0 (2), (3).

$$Y = f(x_1, x_2, \ldots, x_n) \tag{1}$$

The number of measurements N should as well be repeated to N of more than 125 times for a solid x_0 as a result of best estimation [6].

$$u(x_i) = \sqrt{\frac{\sum_{i=1}^{N}(x_i - x_0)^2}{N-1}} \tag{2}$$

Over a series of measurements the best estimate of the value (the truth value is indeed unknown) for x_0 is given (3). The combination of different uncertainties can be accumulated to u_C (4).

$$x_0 = \frac{1}{N}\sum_{i=1}^{N} x_i = \mu \tag{3}$$

It is influenced from a high number of mostly unknown systematic and stochastic values and takes part in the measurement value, see [3] and [4].

$$u^2{}_c = \sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) \tag{4}$$

The calibration of the cameras follows basically the method of Tsai for calibrating 2-D systems with multiple observers [1], [4]. The lasers of the light section system work with 58 mW and 652 nm light for high lifecycle and deal lengthwise with rectangular light distributions for first-grade illumination as well as high contrast in the boundary areas [7]. The most lasers work with Gaussian light distributions what affects negatively for 2-D laser triangulation in multi-systems with overlapping zones. The impact is supplementary higher on strongly shaped parts. The grabbed image data is reconstructed to world-coordinates and the unit of length (Fig. 2). For the calibration of the light-section system a plate with specimen is used, 225 black uniformly distributed circles are grabbed, used for corrections of the distortions and the transformation in world-coordinates of all light-section system equally.

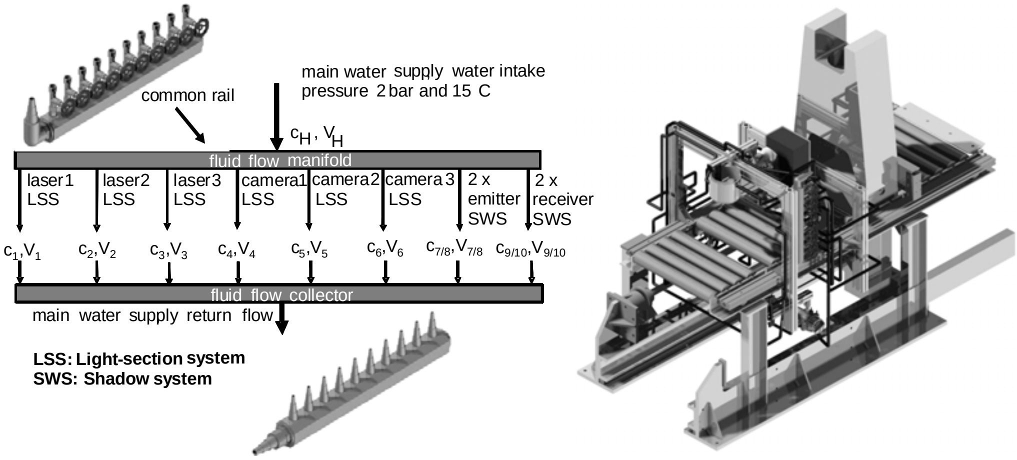

Figure 3. Cooling method; left: fluid flow principle, right: integrated cooling devices

Therefore a 100 cm^2 plate (100 mm · 100 mm) embodies the measurement range which is used for all three systems. The repeatability examinations were made under reduction to a minimum of the variations with the same measurement procedure by the same observer and constant measuring conditions at the same location, by repetition over a short period of time. The measurement speed is one very critic aspect in the analysis of the method [8]. So, sorting algorithms, filtering and the data processing has to state times per dataset of definitely under 50 ms to enable the data rate of in at least 20 frames per second (fps) definitely [9]. The examinations brought out that the „quicksort algorithm“ is the best one for confident termination of calculations during point registration and analysing time, where alternatives like the „heap sort“ or the „bubble sort“ as well as the „line sort“ fail. In Figure 4 there is illustrated the case of simulated point clouds with 2000 points (one dataset) and the case for fitting elements for analysing critria and conformity control afterwards what is then no time critic partition. The ICP-algorithm, surely very interesting in a couple of other metrology areas of metrology especially for 3-D applications, does not deal with enough performance with respect to the processing time. The RANSAC-algortihm and the straight line regression are comparable in time and deviation results. On the right in Figure 4 the results for the two best alternatives in real measurement with noise and additionally disturbed data are given.

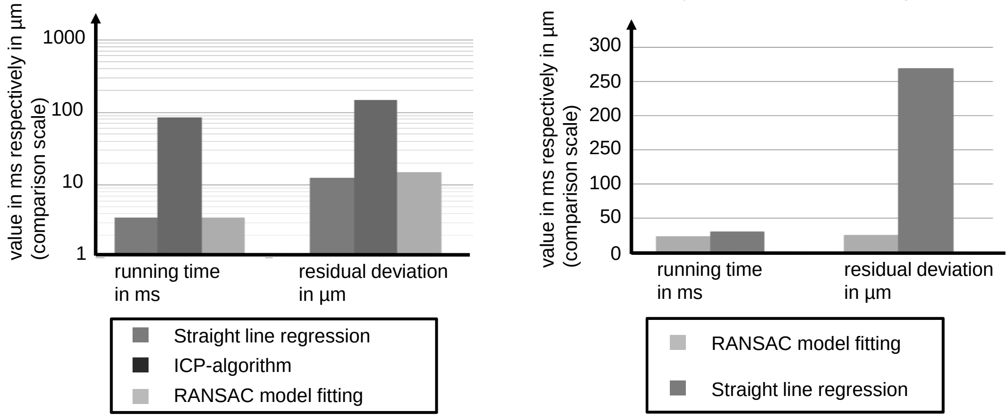

Figure 4. Comparison of analysis methods for noised data points, left: simulated with Gaussian noise distribution of 150 µm range for fitting flanks of the dataset (e.g. lines); right: real measured data for fitting flanks (ICP not examined because of the disadvantages)

Therefore results brought out, that RANSAC can be the best alternative if the data is more noisy and non gaussian distributed with resulting running times of 5 ms to 25 ms. Furthermore the optimal hardware and software combining several other parameters like point density per grab and binning of parts of the shuttered image 100 % by the sensors, enable real evaluation test in the shop with applicated fluid based cooling devices.

4. EVALUATION OF THE METHOD IN THE SHOP

The method has been evaluated in the shop in the field of brass extruding manufacturing (Figure 5). So, the prototypic system had to be installed in short time of some less hours and directly in the assembly line of the profiles. The cooling device had to be leak-proof up and be applicable for measuring ranges up to 100 mm. The main focus of attention laid on the reachable contrast of the cameras, the robustness against disturbances, vibrations, external light, the infrared light of the heat of the measurement objects as well as low uncertainties during measurements over a long period of time of more than 100 hours without failure.

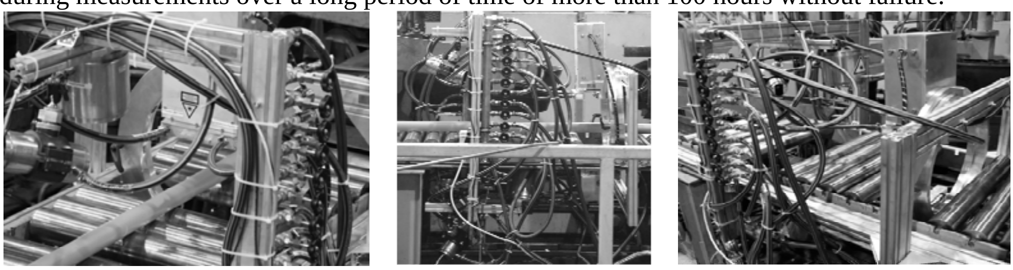

Figure 5. In-line measurement of extruding with the optical multi-sensor-method in the shop during the evaluation; left: isometric close-up view, middle: side view, right: isometric view

The contraction of the profile moving in z-direction in two different measuring planes is corrected during the self-calibration procedure [10]. The uncertainties for the Gaussian criteria are better 12 µm for profiles up to 80 mm (Fig. 6, right). The influence of dirt is not to be defined as a critic. The lasers' pitch error up to a typical tilt of 0.6 ° (examined in pre-tests to be currently determined by human eye) is not significant. The extraneous light influence is fairly significant with an optimum in dark areas.

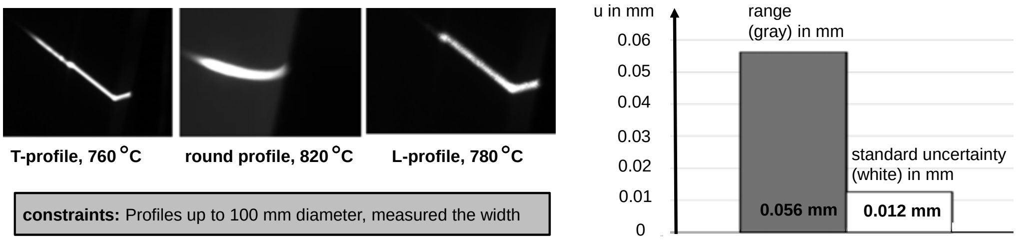

Figure 6. Contrast on profile surfaces realized in the evaluation experiments in the shop floor

5. CONCLUSION AND OUTLOOK

In this contribution an optical multi-sensor-measurement method for extruding and other semi-finished parts was presented. The prototype for in-line applications was tested in laboratory and a realistic evaluation was carried out in the shop for brass extruding. The analysis showed that the method deals with accuracies about 10 µm. The included influences of implemented cooling practices brought out that the results can actually be achieved in the shop floor. Furthermore they should be even more precise for enhanced methods of post-processing. The method could as well be adapted to other in-line measurement objects like e.g. plates with high aspect ratios or fibre-tapes for the aircraft industry what is present purpose and as well part of further research.

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7. ACKNOWLEDGEMENTS

The research was gratefully funded by the Bavarian Research Foundation (BFS) in the project “Optical Bi-Sensor-Measurement System for the Production Control of Extruded Profiles”.