In-situ fringe projection using coherent image fibers

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This contribution introduces a new fiber-optic fringe projection system for the fast in-situ inspection of production processes. Using flexible image fibers and gradient index lenses, the system achieves compact dimensions of the sensor head. Followed by a description of the optical setup, results of measurements of features of a calibrated standard are presented.

1 Introduction

Fast in-situ inspection of functional geometries, such as tools, is an essential task in many production processes. An example is the sheet-bulk metal forming process, which allows for the productions of parts with complex geometries, such as gearings, in a single forming step. In-process measurements enable both detailed wear analysis as well as quality control to avoid producing defective parts. However, increasing integration of machinery results in a limited accessibility for measuring systems. The available height in an exemplary forming machine is around 150 mm, with the tool being positioning in the center of the machine. Additionally, with a process cycle time in the order of one second, the time available for inspection is limited. In order to fulfill the requirements, a new measuring device based on fringe projection and endoscopy techniques has been developed.
Fig. 1 shows the sensor head of the fringe projection system positioned inside the sheet-bulk metal forming tool. The sensor head is attached to an extended arm, allowing it to be moved out of the machine in between inspection cycles. A rotation stage enables measuring different parts of the inner tool geometries.

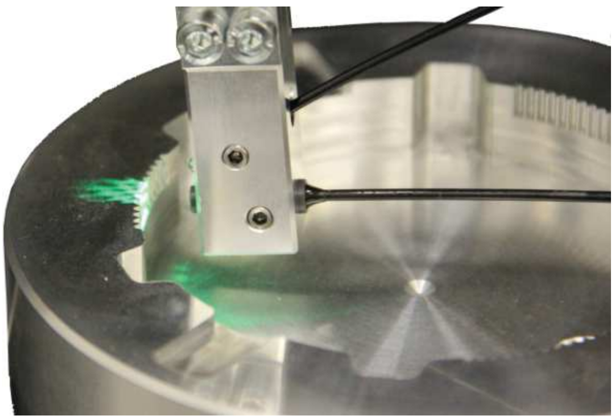

Fig. 1 *Sensor head of the fiber-optic fringe projection system next to forming tool.*

2 Optical setup

Compact dimensions of the sensor head are achieved by employing gradient-index rod lenses by GRINtech with a diameter of 2 mm. Depending on the inspection task, lenses with a working distance of 10 mm or 20 mm may be used. The corresponding measurement volumes result to approximately 5 x 5 x 2.5 mm^3 or 10 x 10 x 4 mm^3. The sensor head is coupled to a base unit, which houses the camera and projector of the system, using flexible image fibers (Fujikura FIGH-100-1500N) with a length of 1000 mm and a diameter of 1.7 mm. Fig. 2 shows a schematic of the base unit, with the camera part on the left and the projector part on the right. To avoid aliasing when imaging through the image fiber, the camera sensor has a resolution of 2 megapixels. For generating the fringe patterns, a digital micro-mirror device (DMD) by Texas Instruments with a resolution of 1024 x 768 pixels is used. By synchronizing the projector to the camera, the system is capable of capturing up to 150 arbitrary grayscale patterns per second. In order to illuminate the patterns, either a LED or a laser light source may be used. While measurements with laser illumination suffer slightly from speckle artifacts in the captured camera images, fiber-coupling efficiency is lower when using the LED light source [1]. Fiber-coupling of the camera and projector fringe images is achieved by using microscopy objectives. Typically, the measurement duration is in the range of 0.5 - 3 s, depending on the optical characteristics of the object's surface.

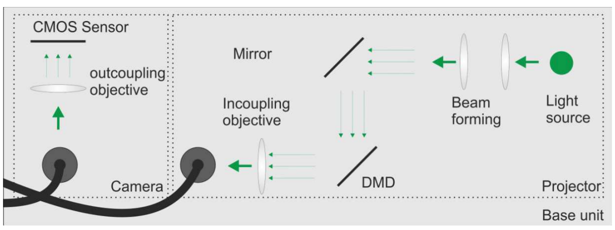

Fig. 2 *Schematic of the base unit of the fringe projection system.*

DGaO Proceedings 2016 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2016-B001-5
submitted: 26.Jul.2016 - published: 15.Aug.2016

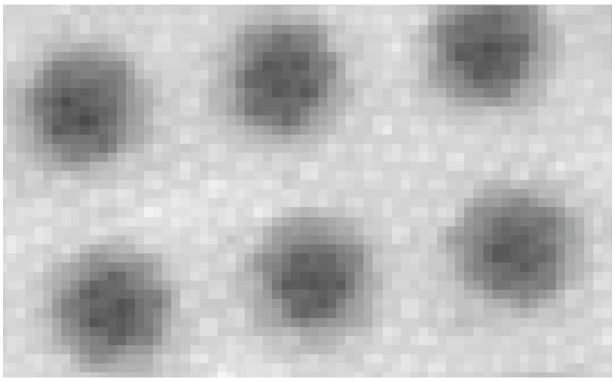

Fig. 3 *Cropped image of a point pattern (point-to-point distance: 125 µm) captured through the image fiber.*

The system is calibrated by a planar point pattern standard, which is positioned automatically in the measurement volume. A detailed description about the calibration models and algorithms can be found in [2]. Measurements of 3-D point clouds are performed using a sequence of phase-shifted cosine patterns. To be able to measure also technical surfaces with highly varying reflectivity, high dynamic range images can be captured via multiple exposures. Artifacts from imaging through the fiber, such as pixilation and cross-talk effects (see Fig. 3), are accounted for in the pattern evaluation algorithm.
To reduce the measurement duration, the inverse fringe projection principle may be used for inspection tasks. By adapting the projected patterns to the reference geometry of the measured object, the required number of projected images can be reduced down to a single pattern.

3 Results

In order to assess the performance of the new measuring device, measurements of a calibrated microcontour standard were performed.

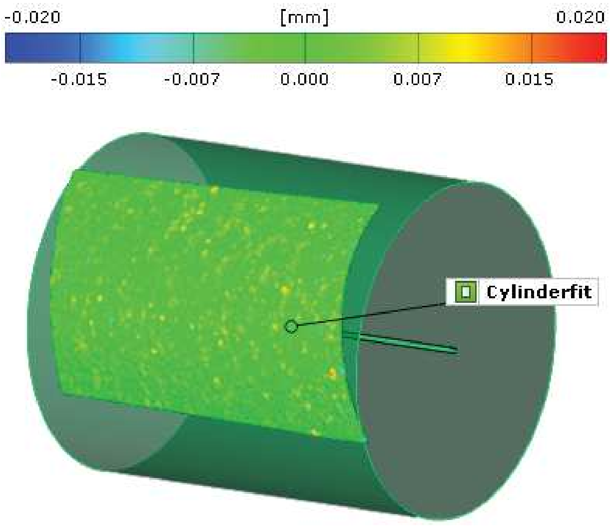

Fig. 4 *Deviation analysis (GOM Inspect) of a measurement of a cylindrical geometry.*

Fig. 4 shows a measurement of a cylindrical element with a calibrated radius of 1001.5 µm. The standard deviation of the distance of the measured points to a fitted cylinder is 4.9 µm. For a constant object-sensor pose, the repeatability for measuring the radius of the cylindrical feature is less than 1 µm, while the systematic error is typically less than 10 µm. Due to the limited resolution of the fibers, the lateral resolution of the fiber-optic system is lower than for non-endoscopic fringe projection systems. However, stochastic and systematic errors are comparable when measuring cylindrical geometries [3].

4 Conclusion

A new fiber-optic fringe projection system and its application for the inspection of industrial manufacturing processes have been presented. By using flexible image fibers and gradient-index lenses, compact sensor heads are designed depending of the measuring task to allow versatile positioning. Artifacts emerging from both fibers and lenses are compensated in the calibration and pattern evaluation algorithms, enabling low noise measurements.

Acknowledgments

The authors would like to thank the German Research Foundation (DFG) for funding the project B6 "Endoscopic geometry inspection" within the Collaborative Research Center (CRC) / TR 73.

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