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Endoscopic Fringeprojection with Laser Light Sources

Adaption of Beamshaping Techniques for a new kind of Laser Illumination of Micro Fringe Projection Systems

Dipl.-Ing.(FH) **C.Ohrt**, Dr.-Ing. Dipl.-Phys. **M. Kästner**,
Prof. **E. Reithmeier,** Institut für Mess- und Regelungstechnik,
Leibniz Universität Hannover

Abstract:

Inspection of assembly parts and tool surfaces based on geometric measurement still states an increasing and essential part in quality management. Suited measurement techniques thereto should be, above all, flexible and fast in order to keep up with the production process. Large area analysis of topographies nowadays can be realised by commercially available fringe projection systems which carry a satisfying and sufficient accuracy. However, these systems reach their limits for assemblies with a high geometric complexity, because of shading effects in the area of measurement. Within the scope of different research projects containing these difficulties, a new kind of micro fringe projection system has been developed at the institute of Measurement & Automatic Control. A fairly small laser illuminated flexible fibre bundle endoscope is used to carry out structured light measurements particularly for tiny details in shaded or difficult to reach regions. Due to the high measuring speed of comparatively large measuring volumes the generated data can immediately give online-feedback to the running manufacturing process and can be used for in situ optimization in the fabrication line to avoid high reject rates. Information and experimental results on measuring speed, accuracy and flexibility in certain fabrication processes will be presented in this work.

Introduction:

Bulk Sheet Metal Forming states combination of different techniques in engineering at a high technological level. Starting with material science going to bulk forming processes and multidimensional force directions, it also requires the newest results of sheet forming in the respect of new biometric nanostructured surfaces on tools that define and improve glide directions and minimize the necessary forces for the forming procedure. In addition to that, new, comparably small complex details, were applied in the mould, which are later to be filled in the final bulk sheet metal forming process [1, 2, 3]

The goals of the developed technology shall be the functional integration and extension of sheet metal parts, increase in workpiece complexity, the shortening of process chains and increase of robustness and reliability, the improvement of economic efficiency and new product development / lot size and its ability to adapt novel variations.

In order to guarantee all these features in an industrial manufacturing process, a sophisticated quality inspection is necessary. For the optimization of process and erosion parameters the workpiece and tool should be measured on regular time intervals within the fabrication line. Our demonstrator workpiece under consideration is shown in Fig. 1. Invetigations of that kind require new measuring strategies.

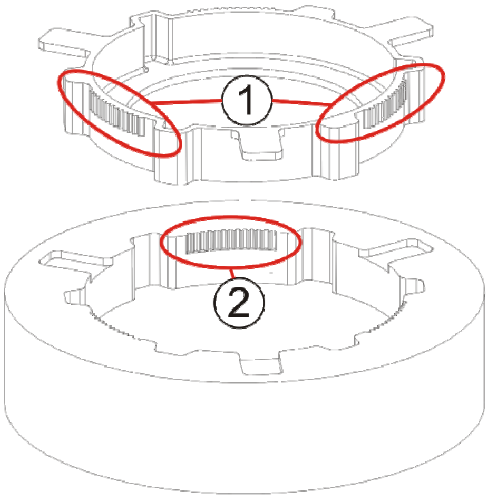

Fig. 1: Demonstrator part of the Transregio 73 tool and workpiece; 1,2 critical areas

The used measuring device needs to be capable of handling the environment of a production chain such as

- temperature variations,
- dust and dirt in the surrounding area,
- and vibrations.

Common high accuracy measurement devices such as Coordinate Measurement Machines (CMM) or roughness measurement devices do not allow the inspections for several reasons: They are comparatively slow to the speed of the production cycle, they cannot be installed in the production line due to dirt and they cannot handle temperature changes that may occur within the measuring process. A new measurement device, together with a measuring strategy are main part of this work. The requirements from above guide to a fast measuring process with a high number of measured data for geometry and roughness analysis.

In the last decades and years the importance of optical measurements techniques in the dimensional field is steadily growing. Reasons for that are not only the advantages of a contact-free and non-destructive measuring system. Also the speed per measurement increases immensely with certain methods. One of those methods is the fringe projection. It is capable to grab more than 1000 measuring points per second in a defined measuring volume. By projection of different light patterns on a specimen and detection of the reflected pattern under a defined angle a conclusion about the geometry of a measuring object can be made. The technology is well known and ready to use for many technical applications. It is mainly employed for fast and precise measurements of complex geometries and often quality assurance applications [4].

Disadvantages of the technology are the low scalability within the designated measuring volume as well as difficulties in measuring of undercuts shaded areas in complex design.

To tackle these problems mentioned above, the project targets on a very small flexible fringe projection system, that is able to measure in areas with comparatively small and complex geometries with high accuracy.

Conventional image generators and detection cameras with high resections are too large, therefore it was not easily possible to reduce the size of the whole system, only by the usage of micro devices, such as micro cameras and micro projectors, because their resolutions and with it the targeted precisions would not have been achievable. For that reason the well-known technology of endoscopy widely used in medical applications has been tailored to the project.

Laboratory setup

Fig. 2 shows a schematic diagram of the endoscopic fringe projection system. A despeckled laser light source is used to illuminate a high resolution digital mirror device (DMD). The collimated laser beam runs through a telescope with a rotating diffuser in its focus. That removes partly the coherence of the laser light and thereby the speckle effects that would appear in the optical path otherwise. Afterwards a beamshaper assembly expands the beam to the diameter of the DMD and at the time changes the intensity profile of the beam from Gaussian to a rectangular distribution (Fi3) with a micro lens array. The pattern is generated by the positions of

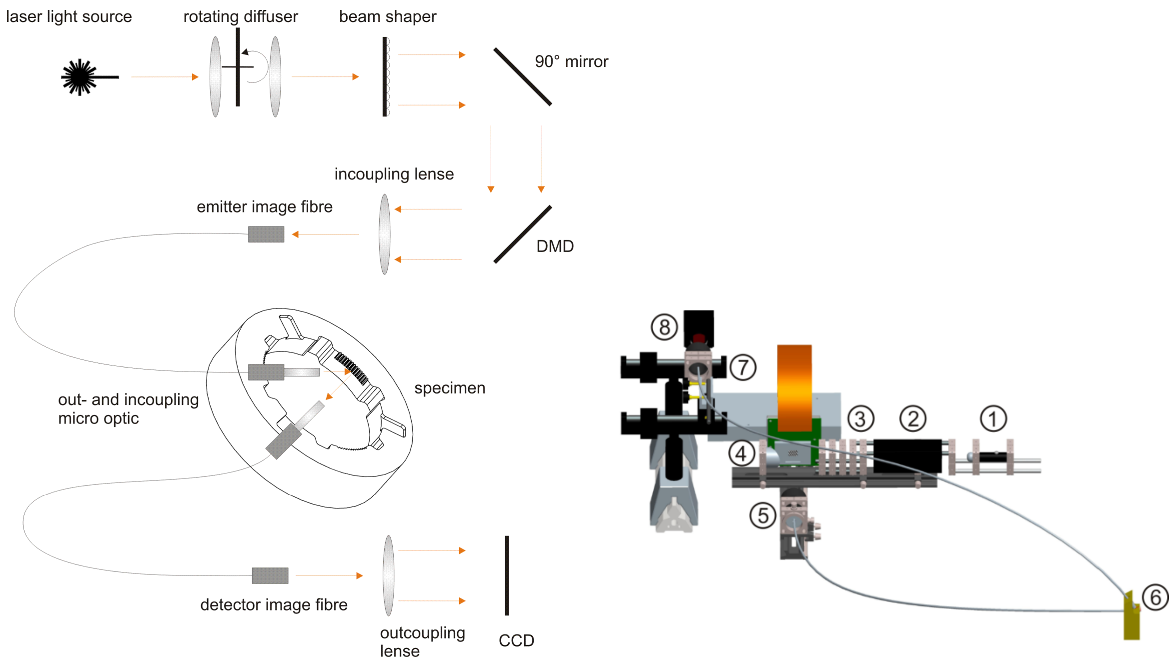

Fig. 2: Endoscopic fringe projection system schematic (top) and CAD-Model (bottom):
1: Illumination laser; 2: rotating diffuser; 3: Beam shaper and Flat-Top Generator;
4: Digital Mirror Array; 5: In coupling objective with fibre bundle; 6: Sensor head;
7: Out coupling objective; 8: CCD-Camera

computer controlled mirrors of the DMD, which either reflect a pixel in or out the beam path [5]. Using an incoupling lens in form of a high numerical aperture (NA) microscope objective the fringe pattern is focused to a 2 mm diameter image fibre bundle with 100.000 fibres and transmitted via a gradient index (GRIN) micro lens to the specimen. The reflection of the geometry is then guided through another GRIN optic to the detector fibre and focused with another microscope objective on a high resolution CCD. Emitter and detector GRIN lens are aligned in a well-defined triangulation value. With the camera and projector calibration to this certain angle, later the 3D coordinates of each single point of the measured geometry can be calculated. Resolutions strongly depend on alignment, quality of optics and optical design and the used post processing software.

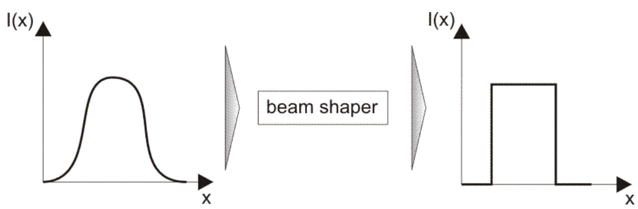

Fig. 3: Beam shaper intensity profile

Calibration and Results

For the transformation in a 3D model of the specimen it is necessary to transform the reflected picture into coordinates. By the projection of a stack of a black and white stripe patterns in order of a Gray-Code (Fig. 4) projector and camera are aligned on the specimen and corresponding pixels of both devices identified. With the information of the triangulation and the beforehand made camera coordinate calibration the exact geometry of the sample can be calculated to compare its shape to the CAD model with the accurate measures. To increase the resolution of the system four phase shift cosine patterns are projected to the specimen's surface. Added to the before taken Gray-Code pattern it creates a highly accurate and well defined scatter plot (Fig. 5) for high resolution 3D measurements.

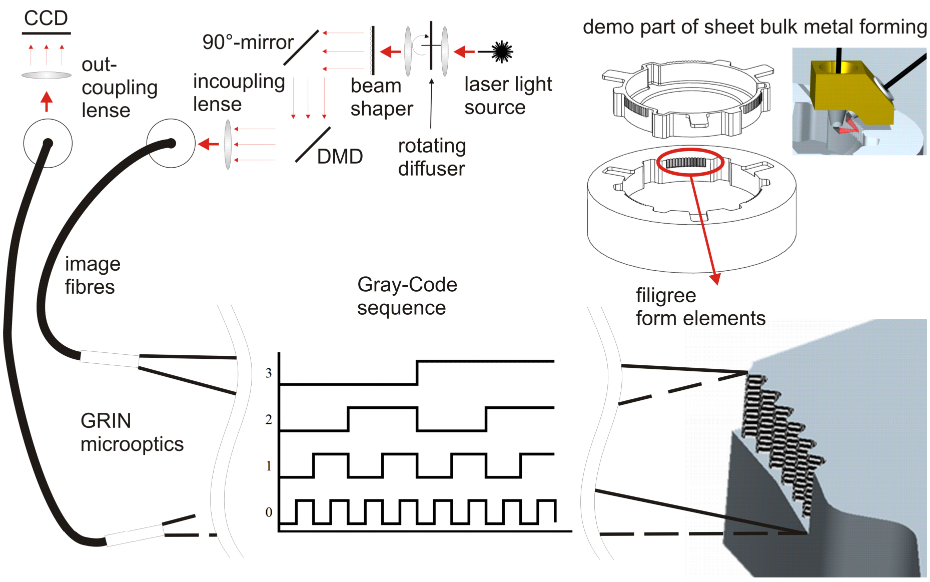

Fig. 4: Projected Gray-Code Sequence by the endoscopic fringe projector

The results of the first calibration [6, 7] with a plane test geometry with high optical cooperativeness are promising in respect of measuring speed and depth of focus to fulfil the requirements of a measuring system in the production cycle. The complete time that is needed to take one scatterplot of a sensitive area takes about 6 seconds, including projection and calculation of the corresponding 3D-Computer model. The top part of Fig. 6 shows the gearing of the demonstrator mould with an module of 0,5. The height of a single tooth is about 1,5 mm. The measured depth of focus of the system, after installing the highly collimated and specklefree lightsource in form of a beamshaped laser increased from 400 µm to about 3 mm compared to a common halogen white light source. That mainly results from the high collimation of the laser and the missing colour dispersion of a monochromatic light source. The spot diameter on the screen is 7 mm. The bottom part of Fig. 6 shows the results of a projected fringe pattern on a comparable plastic geometry.

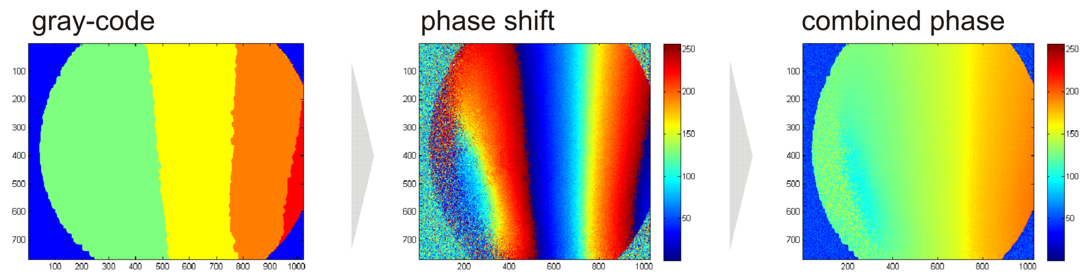

Fig. 5: Phase Algorithm on a flap surface (Grey Code – top, Phase shift – middle, combined phase - bottom)

One of the main problems in measuring metallic, highly finished tools or workpieces with optical methods is their low "optical cooperativeness".

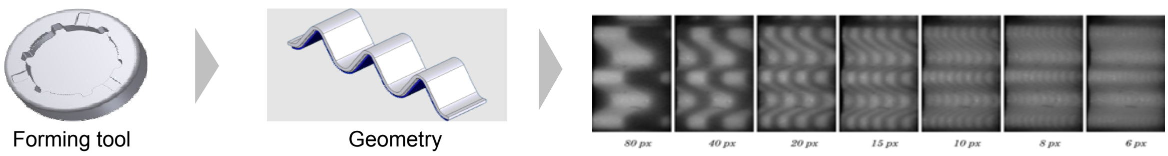

Fig. 6: Acquisition pictures of a plastic gear with a module of 1,5 and a diameter of 5 mm

That can be overcome by new methods of creating a very thin optically cooperative layer in the measuring area [8, 9].Optical cooperativeness is mainly defined by the properties of the material and the direction of the reflection of an incoming light ray from the specimen [4, 10]. A smooth white surface creates a Lambert reflection in many directions, which is best for fringe projection properties, because it avoids over illumination of the CCD Camera in high light spots. So far successful experiments with thin white paint layers were made.

Depth of focus

With f being the focal length of the lens, Δx the current distance to the lens and k the aperture number, the depth of focus ΔS can be described with (1).

$$\Delta S = \frac{g \cdot f^2}{k \cdot \Delta x}\left(\frac{1}{\frac{f^2}{k \cdot \Delta x} + f - g} - \frac{1}{\frac{f^2}{k \cdot \Delta x} - f + g} \right) \qquad (1)$$

It shows an increase of ΔS with decreasing apertures.

That happens because of the higher percentage of collimated light that passes through narrow apertures (Fig. 8).

However, coming along with that also there is also a large decrease of intensity that complicates the image interpretation and by that decreases the accuracy of the whole system. (Fig. 7).

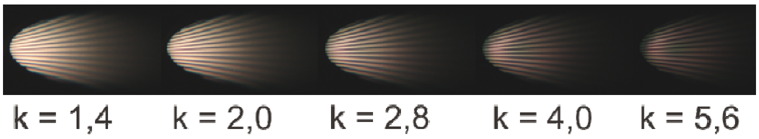

Fig. 7: Relation of intensity and aperture

By using a despeckled laser light source as described above a significant increase of depth of focus from less about 600 µm to 4 mm can be shown (Fig. 8). Taking that as a base it proves that endoscopic micro fringe projection is possible and further developments lead to promising results.

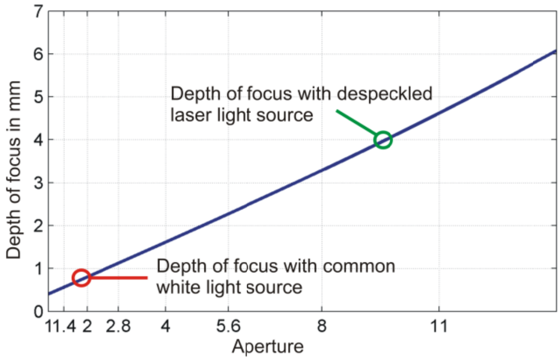

Fig. 8: Relation of depth of focus and aperture

Summary and Outlook

We have shown a new method of measuring small and complex geometries with fringe projection. A newly developed laser based fringe projection system was used to scale down fringe patterns and transmit it through a 100.000 pixel image fibre to a specimen.

After the calibration of new endoscopic fringe projection system is finished, the achievable resolution will be determined by the calibration with standards. Main limitations in resolutions could be the reduction of the image resolution to 100.000 pixels in the image fibre. Since 100.000 pixels is the maximum that is available on the market an increase of resolution can only be achieved by first improvement of the optical system and second software improvement of the system. For the software common algorithm will be tried in order to create a sub pixel resolution. For the optical part highly sophisticated simulation and optimization software shall be used to find fitted optics and alignment parameters. On that way a resolution in the low micrometer range for the measurement results is aimed at.

Acknowledgement
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