Optical Absolute Position Measurement on Rough and Unprepared Technical Surfaces

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Abstract

Scattered light speckle techniques enable absolute and high resolution position measurement without the requirement for a special length scale standard. A compact measuring probe set-up and low manufacturing costs qualify it for the integration into machine tools and assembly lines. The contribution focuses on the measuring resolution enhancement and presents the measuring process and first results.

1 Introduction

Varying load and machining speed of machine tools cause thermal instability and dilations of, e.g., ball screw spindles up to 100 µm [1]. Therefore, precision production processes require fast and high resolution position measurements of moving parts. Furthermore, in the case of a production machine failure absolute measurements of the workpiece position enable a faster resumption of the production process. Commercially available non-contacting position measuring instruments are based on optical or magnetic measuring methods. A probe moves along a well known length scale standard, which is a linear grating structure on a glass substrate, a metal substrate or a flexible magnetic material. The position value follows from incremental counts of grating periods. The zero position is arbitrary. Otherwise a reference point, e.g., a special identification mark on the standard or a position switch, is required. Absolute position measuring devices require multiple line pattern standards, i.e. a dual code or a Gray code. The absolute position follows directly from the corresponding code value. A single measurement determines the current position, which is a basic precondition for short machine downtimes and a fast resumption of the production process. Reference positions are not necessary. However, the production of optical or magnetic length scale standards is complex and expensive.

A promising alternative for a new length scale standard is based on the uniqueness of scattered light speckle patterns from an optically rough surface. The resulting speckle intensity distributions depend strongly on the illumination parameters, e.g., the illumination spot diameter and the focal length of the focusing lens [2, 3]. Slight in-plane surface displacements in the nanometer range produce speckle patterns, which are clearly distinguishable by appropriate digital image processing.

2 Measuring set-up and measuring process

Fig. 1 shows the experimental arrangement for the speckle based absolute position measuring system. A lens focuses a laser beam near to the optically rough surface of a linear stage slide. A CCD camera detects the scattered light intensity distribution in the optical far-field. The resulting speckle pattern is unique with respect to the illuminated surface area. Lateral movements of the illuminated surface shift and modulate the far-field speckle intensities. A two frequency laser interferometer measures the position of the slide, which is the reference value for the speckle based position measurement.

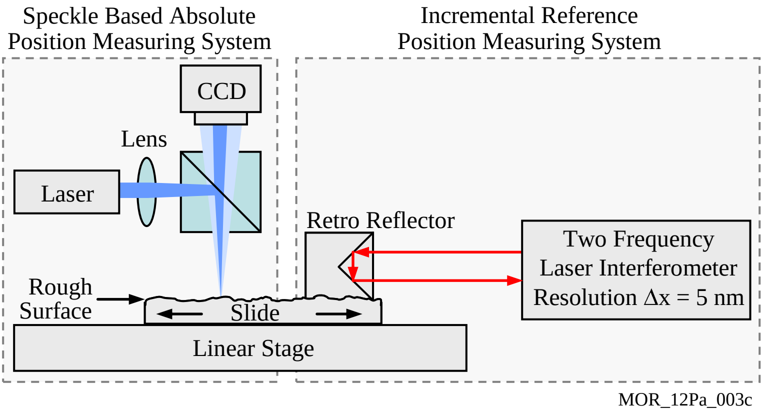

Figure 1: Set-up of the speckle based absolute position measuring system.

Prior to absolute position measurements the measuring device has to be calibrated once only. A piezo actuator moves the linear stage slide. A digital camera continuously records scattered light speckle patterns. As the measuring result strictly depends on the pixel intensities, which is in contrast to former investigations [3], all automatic camera features are turned off. Exposure time, gain and gamma correction are set to constant values. A reference data base contains the digital images and the corresponding position values of the laser interferometer.

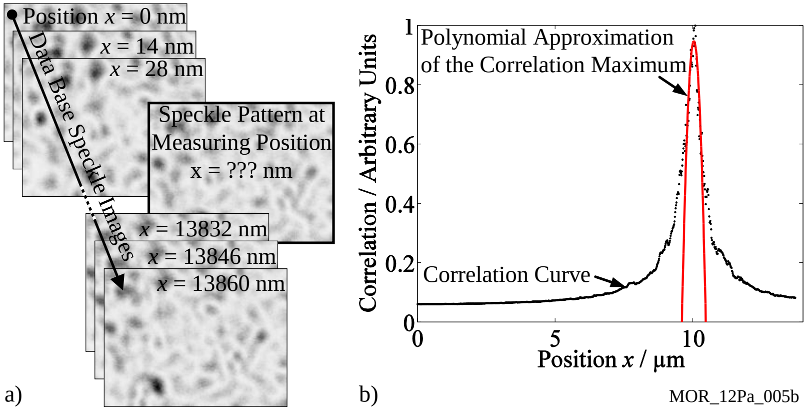

Figure 2: Comparision of a) a measured speckle pattern with digital speckle images of the data base leads to b) a correlation peak and the corresponding absolute position.

Subsequently, the measuring device is ready for fast, absolute position measurements. The piezo actuator moves the slide to an arbitrary position. The resulting unique scattered light speckle pattern is compared with the data base speckle images. Fig. 2.a demonstrates the measuring process schematically. The position *x* of the current speckle pattern follows from a complex comparison with speckle images of the comprehensive data base. The image processing includes local and global digital image filtering and data amount reduction. A median filter removes random pixel intensity noise. Alternatively, timely weighted averaging of a camera sample sequence of the same measuring position or Fourier transform based filters reduce pixel noise. However, due to the uniqueness of scattered light speckle patterns with respect to the illuminated surface area, the laser beam parameters and systematic error sources, the processed speckle pattern is not absolutely identical with a certain data base image. Therefore, a polynomial approximates the correlation curve according to Fig. 2.b. The polynomial maximum indicates the interpolated absolute position measuring result. Multiple measurements at different positions within the full travel path of the piezo driven linear stage lead to a mean deviation of speckle based measuring results from the interferometrical measurements of about ± 20 nm. Currently, the measuring device control, the data acquisition and the data evaluation is implemented in *MATLAB*. A standard PC with dual core processor and 2,4 GHz clock frequency enables about 10 measurements per second. Data amount reduction and the consequent inclusion of CUDA based computer graphics adapters or field programmable gate arrays (FPGA) promise higher clock rates.

3 Summary and Outlook

Image processing of scattered light speckle patterns enables absolute positioning of an illuminated plane, optically rough metal surface with a lateral resolution in two dimensions of less than ± 20 nm. In contrast to commercial measuring instruments the scattered light measuring system requires no grating standard or special preparation of the light scattering surface. A simple ground or beamed rough surface with a nearly Gaussian surface height distribution is adequate to produce the required fully developed speckle patterns. Ideas for fast and efficient imaging processing, concerning the algorithms as well as the computing hardware, are discussed. The expansion of the measuring technique towards a two-dimensional in-plane measurement is straight forward. Furthermore, a three-dimensional absolute position measurement with a single measuring device is possible, if the mean speckle size within a speckle pattern is taken into account.

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