Line-profiling white-light interferometers for in-line industrial inspection

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A new interferometer can measure even non-planar, rough surfaces with high accuracy, as well as being insensitive to vibration.

There is a strong demand for fast non-contact surface inspection techniques in industry. The main driver for this is increasing quality demands, which often require the measurement and evaluation of the critical surfaces of every single part produced (in-line inspection). A typical example of such a critical surface is a laser weld that has to resist large temperature gradients or high pressure. Under these conditions, even very small defects and distortions, such as a hole a few µm in diameter, can cause the weld to fail. Detecting such small defects, especially on rough surfaces, requires both high lateral resolution and a height resolution of better than 1 µm.

White light interferometers are well established for such inspection tasks. They are commercially available, and allow three-dimensional sensing of rough surfaces. A drawback of white light interferometers, however, is their limited field of view, which means that extended or round objects, such as rotary welds, must be measured in multiple steps. To provide higher angular range or resolution, several measurement results must be ‘stitched’ together.

A more convenient way to scan large objects is to use a line profiler, which is able to fulfill the requirements for high-precision in-line inspection by offering continuous scanning of moving objects.

Reducing the field of view from three dimensions to two introduces the possibility of replacing the mechanical phase shifting of conventional white-light interferometers with spatial phase shifting. A variety of point sensors based on white light interferometry with a spatial phase shift have been experimentally demonstrated, and there have been suggestions for a corresponding line profiler. To our knowledge, however, the technique has so far not been adapted to optically rough surfaces.

Our line profiler (Figure 1) is based on a Mach-Zehnder interferometer, since the separation and recombination of the beams occurs at different beam splitters (BS). With the aid of cylindrical lenses CL₁ and CL₂, light from a superluminescence diode is spatially filtered (SF) and focused as a stripe onto the object. The scattered light is collimated by the microscope objective MO₁, however, the technique has so far not been adapted to optically rough surfaces.

Figure 1. Two orthogonal views of the line-profiling interferometer. BS: Beam splitter. CP: Compensation plate. CL₁, CL₂: Cylindrical lenses. SF: Spatial filter. M: Mirror. MO₁, MO₂: Microscope objectives. ND: Neutral density filter.

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and propagates as a plane wave towards the sensor array. The reference beam is treated in the same way. The compensation plate (CP) in the object beam is used to allow for the effects of dispersion introduced by the neutral density filter (ND) in the reference beam.

Mirror M has a slight tilt with respect to the optical axis, so the phase shift between the object and reference waves has a linear dependence on the spatial coordinate. Due to this phase shift, the appearance of the typical white light fringes that show up at zero optical path difference will vary along the x-axis, according to the distance from the object to the sensor head. As Figure 1(b) shows, the object is imaged by a telescope onto the sensor array along the y-axis. The positions of the fringes in each row therefore yield the cross-sectional topography of the object (see Figure 2).

A crucial feature of optically rough surfaces is the appearance of speckle\(^8\) due to the coherent illumination. While for a conventional white light interferometer the size of the speckles is isotropic in the plane of observation, in our setup we have to handle strong anisotropy introduced by the anamorphic optics. With respect to optically rough objects, different constraints on the shape of the speckle arise.

As in conventional white light interferometry, the extent of the speckle in the imaging direction is restricted to the pixel pitch of the sensor array in order to improve the interference contrast. In the direction of the phase shift, the grainy intensity distribution of the speckle pattern implies a disturbance of the sensor signal and hence reduced accuracy.

To address this problem, the optical design has to ensure that the influence of speckle can be well separated in frequency space from the measurement signal itself. Since the spectral contribution of the speckle is determined mainly by the focal length of the microscope objective and the width of the illuminating stripe, a tradeoff between speckle size, measuring range, and magnification can be made. Even though the current setup covers a measuring range of more than 200 µm, it is also capable of measuring rough surfaces, as demonstrated by the profile of a ceramic object shown in Figure 3.

By eliminating the need for mechanical components for phase shifting, our suggested sensor design has an accuracy comparable to that of conventional white light interferometers, but with less noise and reduced sensitivity to vibration. These features make it a promising tool for high-quality in-line inspection. Further efforts will focus on the illumination of the object: alternate light sources should enable higher measuring frequencies and improved accuracy to be achieved.

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References