Optical measurement of waviness on specular surfaces by Fringe Reflection Technique, FRT

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Abstract

The need for accurate measurements of long range low amplitude topographic structure of specular (glossy) surfaces has been increased in automotive and aircraft industries. Optical measurement techniques are the most successful techniques to measure different surface structures with high resolution and high accuracy and at high speed. However, for glossy, specular surfaces many commercial techniques based on surface scattering fail. Fringe Reflection Technique (FRT), mimicking the human observation process of specular surfaces, is then a robust and suitable solution for measuring these surfaces. In our research we are interested in measuring waviness in the micron range over cm long spatial wavelengths. The artefact investigated is a flat casted and painted composite surface. By using a simple and non-expensive FRT-setup, combined with image analysis algorithms high resolution data were obtained. The results match well with reference data obtained by a Coherix interferometer with height measures of some ten micrometers over waviness having a lateral structure of several cm.

1 Principle of the method

Figure 1.demonstrates the optical configuration of the measurement system used in Fringe Reflection Technique. The measurement system generates a defined, straight fringe pattern on the glossy sample surface and a camera records the reflected pattern. The distortion of the pattern depends on the height variation of the surface points and on the local slope, i.e. the orientation of the surface normal in each point. This height variation and the local surface slopes can be measured in terms of deviations in the fringe pattern.

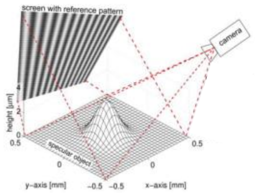

Figure1. Schematic configuration of the measurement system

A matematical model has been developed that reflects the variation of the fringes to the local surface orientation and height variation. This model relates the slope variation ($\delta\gamma$) to the fringe pattern pitch (δx) and the fringe shift in the deformed pattern (d). It also shows the relation between the surface slope variation ($\delta\gamma$) and the derivative of surface height variation (f''), see figure 2. L_0 is the distance between the camera and the sample and d_0 is also the pitch of the fringe pattern.

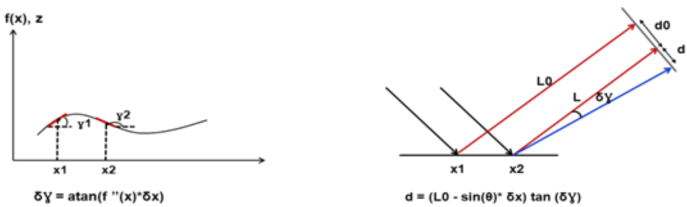

Figure 2. Geometrical configuration and mathematical model

In general the method requires four stages for the measurement process:

1. Set up installation and image acquisition
2. Pre-image processing for noise reduction
3. Image processing for fringe shift measurements
4. Surface slope/height calculation using the mathematical model

1.1 Image processing

To measure the fringe shift in the pattern there are different well-known methods to apply, e.g. phase shift profilometery, Fourier transform profilometery, wavelet transform profilometery etc. In our case we used fringe pattern analysis by using image processing tools to find the position of the edge of each deformed fringe and then calculate the shifted distance. As mentioned above the image processing has two stage. The first stage, pre-image processing or image enhancement, mostly apply different filters for reducing the noise, equalizing the intensity of the background and increasing the contrast of the image. Then the edge detection is initiated. For finding the edge there are several standard methods to use. In our method, the image is smoothed with a 2D Gaussian filter in order to reduce high-frequency noise. A pyramid filter is then applied to equalize the background's intensisty. In the next step a gradient operator is applied to extract the edges of the fringes, and.the edges are finally located by using the zero-crossing of the second derivative.

At the end the height variation is calculated by applying the mathematical model using the measured fringe shifts.

1.1.1 Experimental setup and results

The experimental test bed for the measurement system is shown in figure 3. The three main parts of the setup are the fringe illumination system, sample, and detection system. The illumination part consist of a white LED, a beam expander with the external diameter of 50 mm, a chrome coated glass grid with 1 mm fringe pitch and an angle inclination meter to measure the angle of incident beam. The sample is a flat 100 x100 mm^2 painted composite surface. The detection system is a Canon D500 camera with 15 Mega pixel resolutions and a 75-200 mm zoom lens.

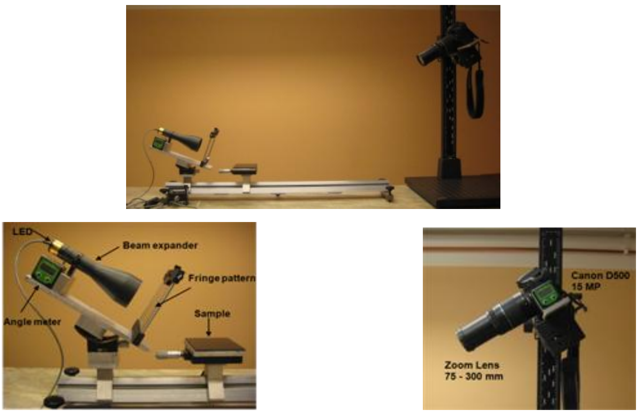

Figure 3. Experimental set up

Results

The measurement was done in a 30 x 30 mm^2 area in the middle of the sample. The height profile determined by our FRT technique in the middle of the measured area is shown in figure. 4. The height profile is in good agreement with the interferometer measurements, shown in figure 5, and done by Nili AB/Coherix European AB on the same sample.

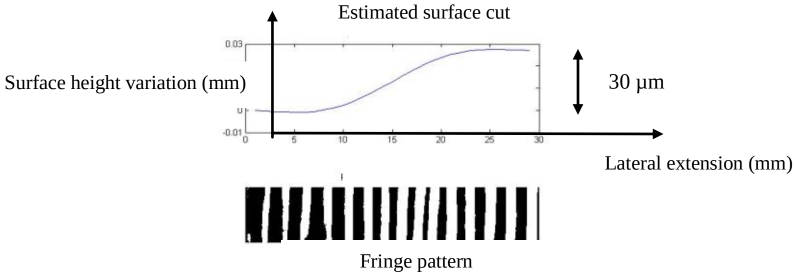

Figure 4. FRT-derived surface profile over 3 cm close to the center of the sample

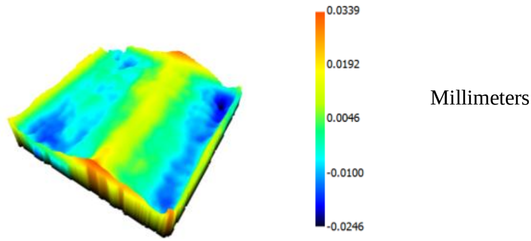

Figure 5. Sample surface topography measured over 10 x 10 cm^2 by a Coherix interferometer

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References:

[1] O A Skydan, M J Lalor, D R Burton, "3D shape measurement of automotive glass by ussing a fringe reflection technique", Meas.Sci.Technol. 18 (2007) 106-114

[2] T Bothe, W Li, C V Kopylow, W Juptner,"High-resolution 3D shape measurement on specular surfaces by frige reflection", Proc. of SPIE Vol. 5457 (2004)

[3] S Zoltan, K Wolfgang, K Andreas, W Konrad, "Detection of surface defects on sheet metal parts by using one-shot deflectometry in the infrared range ", InfraMation 2010 proceedings, ETH Zurich, IWF