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3D optical sensor in continuous motion

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Abstract
Surface metrology can provide information about the properties and performance of the measured object through surface parameters. Optical surface profilers inspect the sample without causing any damage during the measurement. The most used technologies are Coherence Scanning Interferometry (CSI), Imaging Confocal Microscopy (ICM) and Focus Variation (FV) because of their capability of reaching nanometer vertical resolution when measuring at the micrometer scale. However, they need to perform a mechanical scan along the optical axis of the whole sensor or some parts of it for a few hundreds of frames, which takes a certain amount of time.
The evolution to industry 4.0 creates the demand of faster and smaller sensors to minimize the costs associated to the quality control inspection, especially when it needs to be in-line and sample inspection is required to be made in less than 1 s. In this context, there is an interest in reducing the downtime between measurements, which includes the accelerations before and after the measurement and the repositioning of the sensor with respect to the next sample to be within the measurement range.
In this paper we analyze the metrological characteristics of replacing the linear movement scanning by a sinusoidal movement profile. This specific type of movement profile has the benefit of reducing the downtime between consecutive measurements and extending the lifetime of the stage by enhancing the acceleration dynamics. Nevertheless, it causes some errors in terms of accuracy, which, for a 1 mm travel range measured in 1 s, are observed to be less than 0.5 µm when measuring structures up to 150 µm in height.

Keywords: In-process measurement, Metrology, Microscope, Surface

1. Introduction

Manufacturing processes are becoming more complex, precise and digitized in which quality control acquires even more relevance, with its penalty to the throughput. In this context, there is a demand of integrating in-line sensors to provide accurate and fast results used for close-loop manufacturing in surface engineering.

When measuring samples at the micrometer level, the most common surface characterization techniques are Imaging Confocal Microscopy (ICM), Coherence Scanning Interferomety (CSI) and Focus Variation (FV), with CSI providing the best vertical resolution. These techniques inspect the sample optically, causing no damage to it while being capable of obtaning sub-micrometer vertical resolution.

With these techniques the sample must be scanned through the optical axis, which is time-consuming and may lead to errors in the final measurement result. The component performing the scan suffers from wear over time.

Additionally, the most common way to measure a sample is starting the movement in the position where the sample is in the best focus position of the sensor. Then it moves downwards half of the travel range, starts the acquisition upwards and finally returns to the original position. These positioning movements are done at high speed to minimize the measurement downtime, but at the expense of increasing the dynamics and furthermore, the wear of the stage.

In quality control applications, where the sample is usually located at the same axial position and fast acquisition rates are required, the lifetime of the stage is heavily decreased due to the dynamics of the sensor.

In this paper we have evaluated sinusoidal movement profiles to avoid sudden accelerations of the typical movement profiles of a measurement. This will reduce the wear of the stage and extend the overall system's lifetime maintaining the performance.

2. Methodology

The accuracy of scanning-based optical profilometers relies mostly on the performance of the Z stage. The non-linearities of the linear stage are the primary source of error that affects the final output of the measurement of the sample surface [1]. If the different images grabbed by the camera are not from equidistant positions some errors appear in the final measurement. The use of a very precise linear brushless motor will minimize the errors due to a mispositioning from the commanded position [2].

A sinusoidal movement profile has very smooth dynamics, without sudden acceleration changes, which is very beneficial for minimizing the wear of the scanning components over time. However, accuracy errors increase due to inherent non-linearities.

The aim of this study is to determine how a sinusoidal movement profile affects the measurements instead of a typical linear movement profile. In order to compare both movement profiles, identical measurement range in the same time frame will be performed. It entails that the sinusoidal profile will have an oscillation amplitude equal to half the travel range, and the period of the oscillation will be set to match the measurement time of the linear movement profile.

The camera frame rate is the main limiting factor as to the sensor's scanning speed. Therefore, our setup includes a camera with a frame rate of 1000 fps to maximize the speed and thus minimize the measurement time. Figure 1 shows our sensor.

Figure 1. Optical profilometer sensor. It was designed to minimize dimensions and weight.

The aim of this study is to obtain a full measurement within 1 s. We analyzed the profiles with two scanning ranges: 1 mm and 500 µm, meaning that the scanning speeds will also be different. For CSI the optimal measuring speed using our setup would be around 65 µm/s, which is too slow for industrial applications. We increased it to be 15 times higher (984 µm/s) for the 1 mm travel range, and 7 times higher (459 µm/s) for the 500 µm travel range. The noise associated to the speed increase is still acceptable for industrial applications [3].

3. Results

We measured two different step height standards: SHS 50.0 Q (VLSI Standards, USA) and VS20 (Simetrics, Germany) with nominal values of 48.643 µm and 21.702 µm, respectively. They were placed in different axial positions of the scanning range (each 15 µm) and then the step height was evaluated.

In Figure 2 we show the comparison of measuring both step heights between the linear movement profile and its equivalent sinusoidal movement profile. The sample was scanned through a full 1 mm range in 1 s.

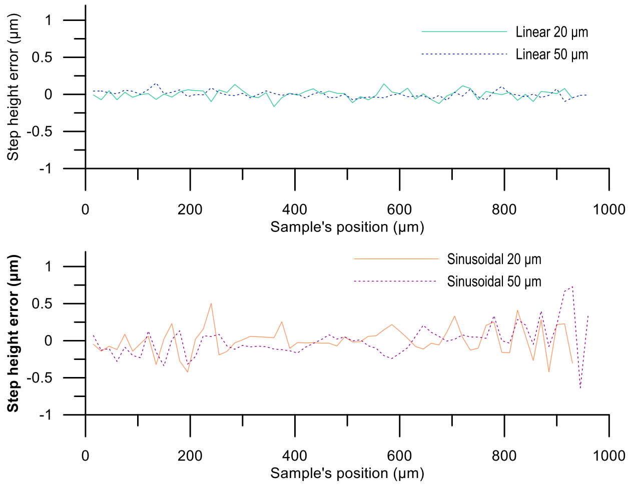

Figure 2. Step height error obtained from measuring a step placed in different positions along the scanning range (1 mm), using a linear movement profile (top) and a sinusoidal profile (bottom).

For the 20 and 50 µm steps, the root mean square (rms) error is, while using the linear profile, 0.061 µm and 0.047 µm respectively. Analogously, using the sinusoidal profiles, we obtain a rms of 0.199 µm and 0.195 µm. Sinusoidal profile's central region shows better performance as it resembles more a linear profile. Additionally, we do not appreciate a clear difference in the rms error depending on the step height.

We repeated the measurements with a 500 µm scanning range, while reducing the speed by half to meet the requirement of measuring the sample in 1 s. The results are shown in Figure 3.

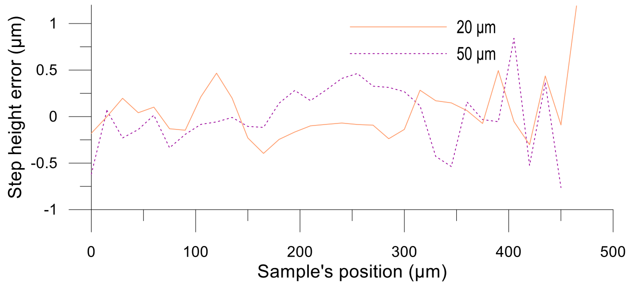

Figure 3. Step height error obtained from measuring a step placed in different positions along the scanning range (500 µm), moving with a sinusoidal profile.

We can see that the magnitude of the error does not decrease when the sensor's speed and range are reduced. The first and last positions of the scan are more likely to have higher error variability, reproducing the same behaviour as in the last experiment.

Last, we simulated the conditions of the first experiment with the focus on the step height values, in order to determine the dependance on the accuracy error with respect to the vertical dimensions of the sample feature. Figure 4 shows the results of simulating step height values from 10 to 150 µm.

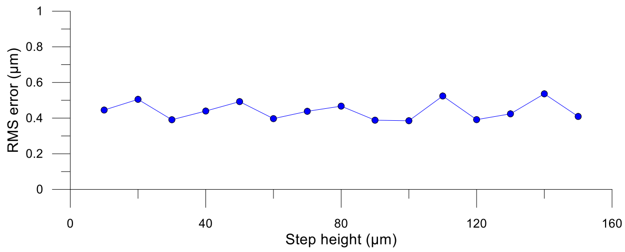

Figure 4. RMS of the step height error through different positions of the axial scan with different values of step height when using a sinusoidal movement profile.

The simulation shows that step height error is not dependant on the height dimensions of the sample, meaning that the error is systematic to the shape of the sinusoidal profile.

4. Conclusions

Using a sinsusoidal movement profile instead of a linear profile reduces the sudden accelerations between successive measurements, decreasing the wear of the scanning component and extending its lifetime. Although its performance is not as good as measuring with a linear profile, the associated errors have the same order of magnitude independently of the velocities analyzed and the height of the sample.

For those industrial applications where an accuracy error of ±0.5 µm is acceptable, the extension of the sensor's lifetime by using a sinusoidal movement profile can be very beneficial to reduce system downtime due to maintenance.

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