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Instrument Transfer Function for Digital Holography System

Tao Sun[1], Anand K. Asundi[2], Yingjie Yu[*1]

1.Dept. of Precision Mechanical Engineering, Shanghai University,
No. 149, Yanchang Rd., Shanghai, China 200072
2. School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore, 639798

ABSTRACT

Digital holography system can quantitatively obtain the microscopic appearance of the measured surface, with non-contact, high precision, large measuring range, etc. Among the varies of characterizing a system, Instrument Transfer Function (ITF) is the most appealing method, which can describe the system response in terms of an input signal's frequency content. In this paper, we proposed a method to calculate the system transfer function of digital holography system for measure a high quality phase step, which contains all spatial frequencies. The ITF can be calculated across all frequencies with a single measurement by comparing the Power spectral Density (PSD) of a measured step to the theoretical PSD. The method is applied to calculate the ITF of digital holography system. Experimental result shows that the ITF of the digital holography system is above 60%.The result shows that the ITF of digital holography system could be kept at acceptable levels within the range of interest.

Key words: Digital holography, Instrument Transfer Function, Power spectral Density.

1. INTRODUCTION

The band error of the optical component, which used in the strong system, is the key to the quality of strong laser focus. The errors can be evaluated using PSD, which was measured by an interferometer. So it is become very important to have a good ITF characteristic, which is most commonly understood to apply to linear systems, which share certain basic properties that lend themselves naturally to frequency analysis. Basically, the PSD method is a powerful Fourier technique for quantifying the contribution of each spatial regime to the total optical error[1]. This method enables us to obtain a clearer comprehension of the magnitude and significance of surface imperfections with different spatial frequencies.

Although many works have described for the height profile of optical surfaces using the PSD method and synchrotron optics by Takacs, Church, Nayak and others in the 1970's and 80's[2][3][4][5][6]. Most of works are still conventionally focus on specified using only figure error and micro-roughness. What we are sure is that the PSD of the surface topography is inversely proportional to spatial frequency raised to the power by studying previous studies of high quality optical surfaces.

Digital holography has been reported as a new method for optical measurement,[7][8][9] such as crystallization, surface errors. In this paper, we assess the suitability of optical surface using PSD by comparing PSDs measured over a wide spatial bandwidth for different grades of mirrors.

2. MATHEMATICAL CONSIDERATIONS

The PSD is mainly a measure of the spatial frequency content of the wave front being analyzed. We may easily determine the ITF of the instrument across any desired spatial frequency range by comparing the PSD of an actual

[*] Corresponding author: yingjieyu@staff.shu.edu.cn

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measurement with the theoretical PSD of the test part. The ITF is actually defined as the ratio of the measured Fourier amplitude to the actual Fourier amplitude of the test piece over all range of spatial frequencies[10]. Since the PSD gives the square of the Fourier amplitude coefficients, the ITF may be calculated as follows:

$$ITF(f)=\sqrt{\frac{PSD_{\text{meas}}(f)}{PSD_{\text{ideal}}(f)}} \qquad (1)$$

According the formula above, samples with known power spectral density characteristic is needed to obtain the ITF. Ideally, we can measure a delta function, which contains all spatial frequencies of equal amplitude. Unfortunately, no such object exists, so other objects with known Fourier spectra have to be used[10].

We describe the mathematical used to generate power spectral density plots from 2-D surface height data. However one usually use the 1-D PSD to calculate in actual measurement calculation[11]. Due to the data we measured is discretization, the PSD may be represented by the following formula:

$$PSD(m)=\frac{\Delta x}{N}\left|\sum_{n=0}^{N-1} z(n)\exp(-j2\pi mn/N)\right|^2, \quad -N/2\le M\le N/2 \qquad (2)$$

Where Δx is the sampling interval. N is the number of samples. z(n) is the data of wave surface. n=0,1,2,…,N-1, the spatial frequency is f, f=m/L=m/NΔx, so the length of step is 1/NΔx. The space coordinates,x=nΔx, can be substituted by n, which is the variable in the equation (2). One can obtain the value of PSD of the samples by using the equation (2) with the data of wave surface.

Another technique which may be used to calculate the system transfer is to measure a high quality phase step. The PSD of height H, measured with N data points over distance L is:

$$PSD(f)=\frac{2}{\pi^2 * L} * W * H^2 * \frac{1}{f^2} \qquad (3)$$

According to the equation above, one can know that a single step contains all spatial frequencies, and the PSD of ideal step phase plate is determined by f^2, PSD$\propto 1/f^2$. The ITF will be calculated across all frequencies with a single measurement by comparing of a measured step to the theoretical PSD. One can also measure data of multi-lines, and calculate a 1-D PSD from each line of height data, then average these 1-D PSDs.

3. EXPERIMENTAL

In this section, digital holography system (see figure 1) will be used to measure the wave surface of a optical flat with the step phase. A suite of metrology instruments are also used to verify conformity to the required specification.

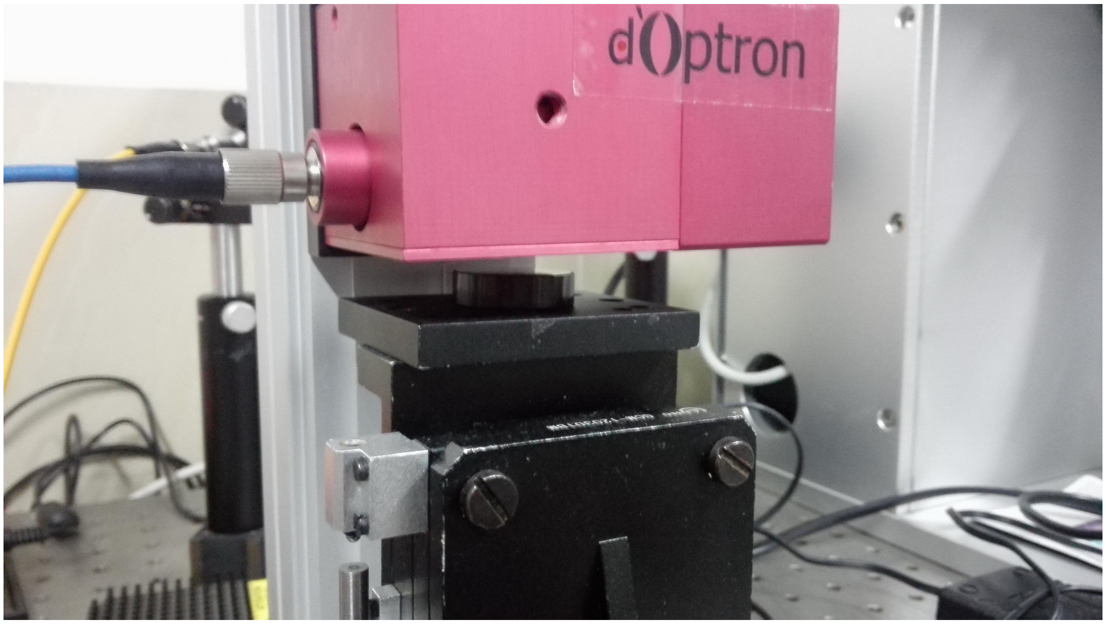

Figure1. The holography system

Holography is a popular method in the field of imaging due to its capability of restoring 3-D volume information from a single hologram acquisition[8].Thus, holography, compared to other imaging techniques, neither encounters the problem of out-of-focus objects, nor does require conversion of measured quantity to size information of surface.

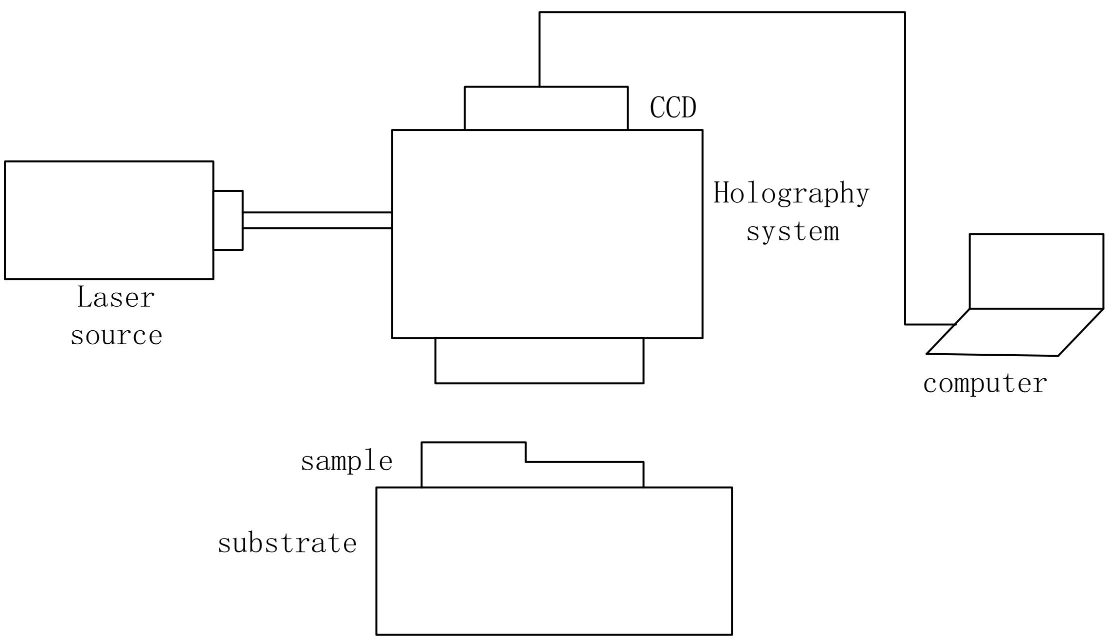

Figure 2. Configuration for testing the PSD of step surface

Sample with step surface was putted in the substrate, while holography records the interference pattern of the simple on the plane of a CCD camera when the simple is illuminated by a laser light source. The recorded interference pattern contains information about the 3D volume of the sample, which can be numerically reconstructed by computer[7].Last, the PSD of the sample can be obtained by using the data of surface.

4. RESULTS

Figure 3 shows the PSD of ideal step surface, which is numerical simulation by MATLAB in the computer. The PSD is dramatic lower as the spatial frequency raised. Figure 4 shows the PSD of measured step surface, which is calculated based on the surface data of sample. Compared with smooth line in figure 3, the PSD of measured step surface is a fluctuation line.

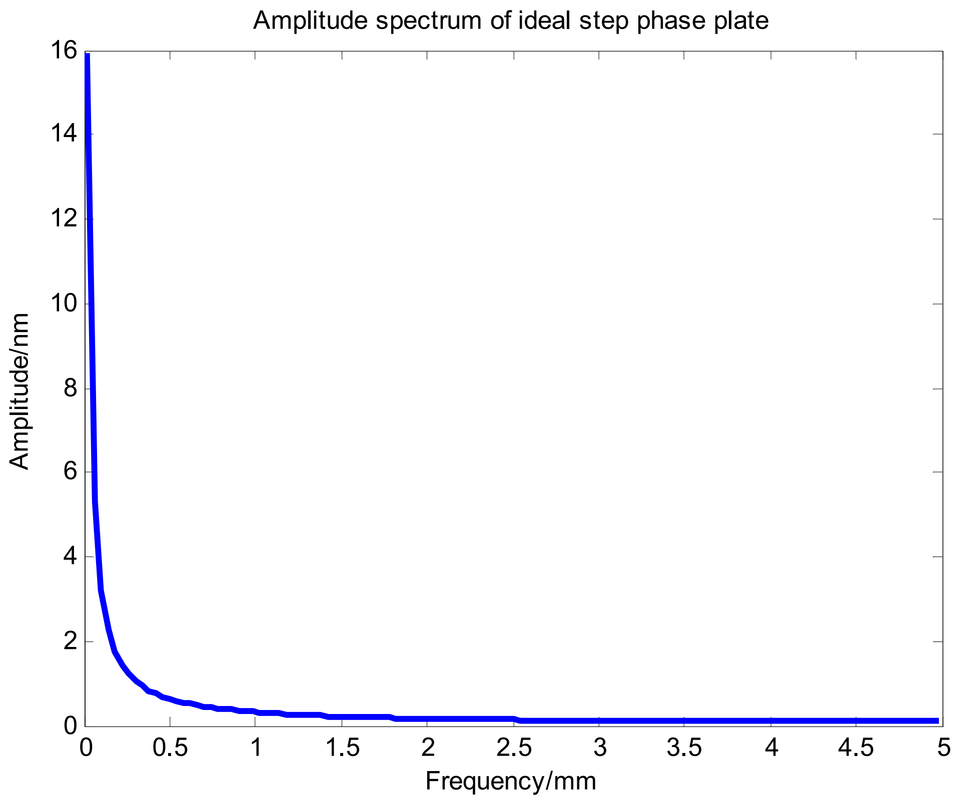

Figure 3. The PSD of the ideal step surface

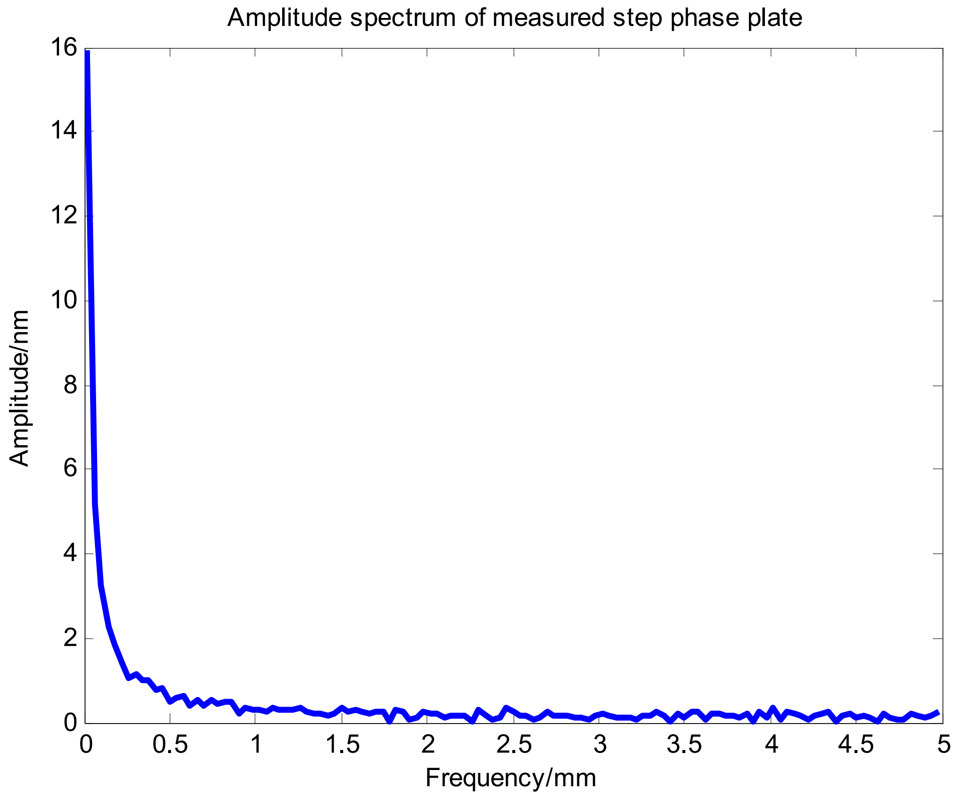

Figure 4. The PSD of measured step surface

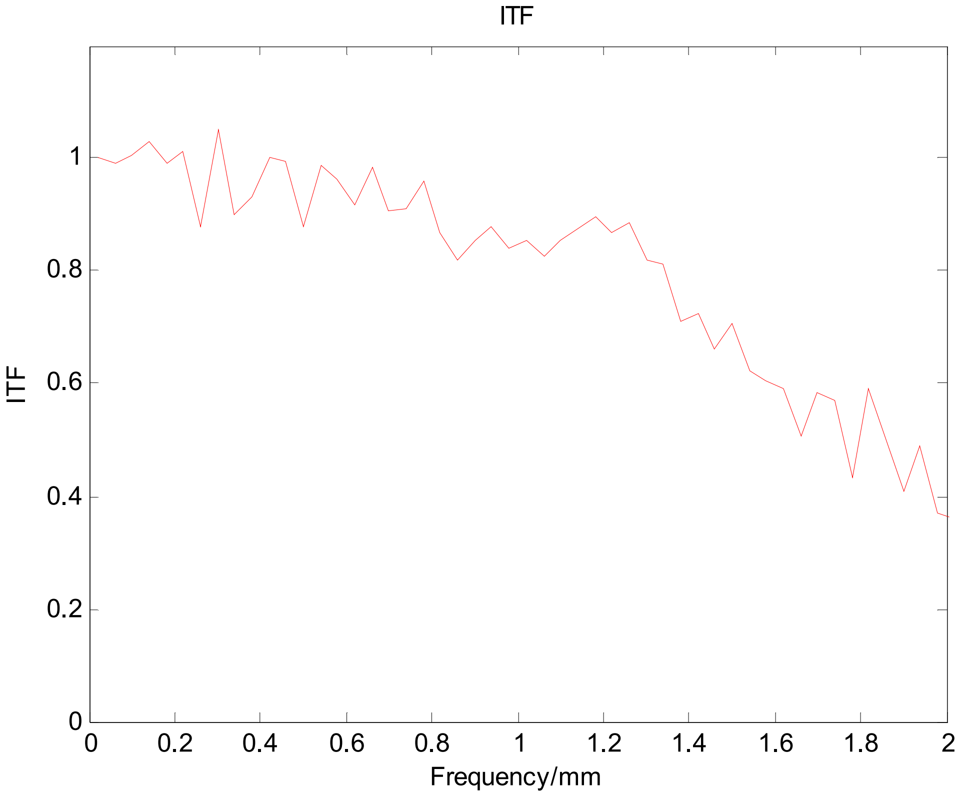

Figure 4. The ITF of digital holography system

As the figure shows above, ITF of digital holography system is about 80% in the frequency of 1/mm, which is an acceptable distortion result for our measurement. As the frequency become higher, the ITF begins to decline.

5. CONCLUSION

In this paper, we use the PSD to measure the ITF of digital holography system. From the result above, digital holography system is a reliable instrument for measuring the surface profile. In order to meet the measurement requirements, the ITF must maintained at a high level out to half the Nyquist frequency of the instrument. Happily, as we have seen above, the ITF of the digital holography system can maintained for 60% in frequency of 1.6/mm, which over the half the Nyquist frequency of the instrument. Thus, with appropriate cautions we can get a good idea of expected performance using the digital holography system as instrument to the measured the surface of object.

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