Large vibration-desensitized fiber-optic point-diffraction interferometer for on-machine measurement

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We propose and demonstrate a novel method of vibration-desensitized fiber-optic point-diffraction interferometer for on-machine measurement. The existing point-diffraction interferometers use single mode fiber as a point-diffraction device. But this fiber has practical limitation to large vibration of target. For this reason, two key systems will be supplemented to the interferometer, multi mode fiber with bend loss technique as a point diffraction device and injection locking system to stabilize fiber output intensity. From the 15 times repeated surface profile measurement under 100 μm amplitude axial excitation of target, measurement repeatability of RMS value shows 10 times improved results compared to the previous method.

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1. Introduction

As an optical interferometer has sub-nm measurement resolution, it has been widely used in many application fields of measurement. Especially, in surface profile measurement, optical interferometer is applicable to all kinds of target regardless of its size. For this reason the optical interferometer is the only feasible method of surface profile measurement of large-scale optics. For making large-scale optics, machining and measurement process should be performed repeatedly due to its size. During this process, on-machine measurement is practically mandatory because for target aliment and re-positioning problem. Since ordinary interferometer is sensitive to environment, especially vibration, development of vibration-desensitized interferometer is necessary for this kind of target. In this research, novel methods are proposed to overcome the measurement limitation of fiber point-diffraction optical interferometer [1] under the large vibration environment. First, multi mode fiber (MMF) will be adopted to increase coupling efficiency at the input stage. And to use it as a point-diffraction device, bend loss technique will be applied. Also there are fiber output intensity fluctuation and attenuation due to the target vibration. To improve this drawback, injection locking system is placed at the output stage of MMF to stabilize its output intensity. Stabilized intensity stands for steady visibility of interference fringe, relatively high measurement repeatability is obtainable under large vibration environment. This large vibration desensitized characteristic is verified by related experiments.

2. Principles and Experiment setup

2.1 Principles

To apply bend loss technique to MMF, three parameters should be considered which are core diameter D, bend radius R, fiber length L. The relationship between these parameters and bend loss ratio is determined by eq. (1), where P is input power, ΔP is power output flow per unit length, R is bend radius, a is core diameter of fiber, βg is propagation constant of guided mode, n_1 is refractive index of core, n_2 is refractive index of cladding, Kυ is the modified Henkel function order of υ. [2]

$$\frac{\Delta P}{P} = \frac{\sqrt{\pi}\kappa^2 \exp[-\frac{2\gamma^3}{3\beta_g^2}R]}{e_\nu \gamma^{3/2} V^2 \sqrt{R} K_{\nu-1}(\gamma D) K_{\nu+1}(\gamma D)} \quad (1)$$

$$V = ka\left(n_1^2 - n_2^2\right)^{1/2}, \quad e_v = \begin{cases} 2, v = 0 \\ 1, v \neq 0 \end{cases}, \quad \kappa = \left(n_1^2 k^2 - \beta_g^2\right)^{1/2}, \quad \gamma = \left(\beta_g^2 - n_2^2 k^2\right)^{1/2}$$

2.2 Experiment setup

For measurement target, concave mirror with diameter of 25.4 mm is used. This mirror is set on the PZT stage and excited in the axial direction. The excitation amplitude range is 10 μm~100 μm, waveform is sinusoidal and the frequency is 10 Hz. As a master laser, temperature stabilized semiconductor laser. There are two PBS, a QWP, a BS and bent MMF in this system. The incident light from the master laser passes through the first PBS and reaches the measurement target. After reflection from the target surface containing information of it, the reflected wavefront returns to interferometer. This target reflected wavefront is divided into two part at BS, reference wavefornt and measurement wavefront. Because the first PBS to target section is set as common-path configuration, target vibration affects both wavefronts simultaneously. For this reason, vibration desensitized characteristic of the system is obtained. In the reference path, wavefront is mode filtered by using bent MMF and its intensity is stabilized by using injection locking system. After that, this intensity stabilized reference wavefront is delivered to the second PBS. At the end of this path, PZT stage is installed to perform temporal phase shifting for fringe analysis. As a phase shifting technique, arbitrary-bucket algorithm has been used [3]. Meanwhile, in the measurement path, the target reflected measurement wavefront is delivered to PBS2 intactly. In this path, length adjustment device is necessary to match optical path difference between reference and measurement path. These two wavefornts are interfered at PBS2 and interference fringe is detected by using CCD camera. 3 parameters(D, R, L) should be considered to use the bent MMF as a point diffraction device. To do this, eq. (1) is used to figure out the amount of bend loss related to the parameters.

3. Result and Conclusions

From the result of 15 times repeated measurement, standard deviation of surface profile (RMS) at different excitation amplitude is shown in table 1. As expected, the value of standard deviation of surface profile measurement is increased as excitation amplitude grows up when only SMF is used. Meanwhile, standard deviation of the measurement is stabilized due to its reference intensity stabilization when bent MMF and injection locking are used. The MMF makes the system feasible to large vibration due to its relatively large core size and bend loss induces mode filtering in this fiber. Parameters of bent MMF are determined based on numerical equation. The other is injection locking system placed just after the fiber to amplify and stabilize fiber output intensity for stable visibility of interference fringe. The output intensity fluctuation of injection locked laser under target vibration environment is measured and its stability is verified

These two key systems make the interferometer applicable to the large amplitude vibration circumstance and its vibration immunity is examined by repeatability measurement of target surface profile. In terms of RMS surface profile, the repeatability has been improved 10 times better than the previous method.

Excitation amplitude(㎛)	Standard deviation of surface profile (RMS)	
	SMF without IL (nm)	*Bent MMF with IL* (nm)
0	345±2.03	353±2.47
10	347±2.77	346±2.90
30	351±12.81	352±2.94
50	349±28.40	351±3.04
100	357±34.40	359±3.54

Table. 1 Standard deviation of surface profile (RMS)

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