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Determination of Optical Path Difference of White Light Fibre Interferometer Using Peak Tracking Method

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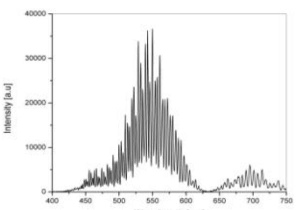
Graphical abstract



Interference spectrum from Mach-Zehnder fibre interferometer

Abstract

The aim of this paper is to evaluate the peak tracking method for determination of optical path difference of a fibre interferometer. This study narros the scope for Mach-Zehnder configuration with neutral white LED as its light source. The peak tracking method is then applied on the interference spectrum recorded from the output port of the interferometer using a spectrometer, allowing the optical path difference to be computed. Accuracy of this method is greatly affected by the wavelength resolution of the detector, where the uncertainty of the result is smaller with higher wavelength resolution and the maximum measurable path difference was found to be about 0.6 mm.

Keywords: Fibre interferometer; Mach-Zehnder; peak tracking method; white light

Abstrak

Kajian ini bertujuan mengkaji kemampuan kaedah pengesanan puncak untuk beza lintasan optik pada interferometer gentian optik. Skop kajian difokuskan terhadap konfigurasi interferometer Mach-Zehnder dengan LED putih sebagai punca cahaya. Kaedah pengesanan puncak diaplikasikan pada spektrum interferens yang dicatatkan oleh spectrometer pada output interferometer tersebut. Kejituan kaedah ini dipengaruhi oleh resolusi panjang gelombang spectrometer manakala ketidakpastian nilai beza lintasan optik didapati adalah lebih kecil untuk resolusi panjang gelombang yang tinggi. Beza lintasan optik maksima yang boleh ditentukan melalui sistem ini adalah kira-kira 0.6 mm.

Kata kunci: Interferometer gentian optik; Mach-Zehnder; kaedah pengesanan puncak; cahaya putih

1.0 INTRODUCTION

The primary concern in the field of interferometry is to extract the information of phase change which is closely related to the optical path difference. Fibre interferometer offers the versatility to an interferometer in terms of optical alignment ease, less susceptible to ambient fluctuations, and portability compared to its bulk interferometer counterpart. Data acquisition method for fibre interferometer allows the convenient use of a spectrometer to measure the output spectrum whereas the conventional setup requires one to employ an image processing technique in order to obtain the interferogram. Owing to these differences, the analysis method for extracting the phase information from the interferogram may differs despite based on the same principle.

Common phase measurement methods such as fringe shift counting, Fourier transform and phase shifting are applicable for fibre and bulk interferometer system. Each of these methods requires different optical component to be incorporated into the interferometer system which may in turn introduces unwanted noise to the result. The use of a spectrum analyser, in this case a spectrometer, offers the peak tracking method to be employ as a tool for determining the optical path difference from the spectrum. However, this method suffers from its accuracy limited by the spectral resolution of the detector use as pointed out it[1-3]. For that matter, this study narrows the scope and objective to evaluate the results obtained by the peak tracking method in terms of its accuracy, repeatability and the possible usage as a sensing principle suggested[4].

2.0 THEORY

The principle of peak tracking method is based on the condition for the formation of bright or dark fringes. For a neighbouring bright or dark fringes, the phase difference is 2π. Unlike the bulk interferometer where one can physically observe the bright and dark fringes, these fringes manifest as peaks and trough for bright and dark fringes respectively in a spectrum recorded by the spectrometer. Hence, by measuring the corresponding wavelength values for two consecutive peaks in the spectrum would imply a phase difference $\Delta\varphi$ of 2π such that the optical path difference D is given by Eq. 1;

$$D = \frac{\lambda_1 \lambda_2}{|\lambda_1 - \lambda_2|} \tag{1}$$

In reference [4], the author suggested the measurement average fringe period shift as a sensing method, where the fringe period Λ is related to the optical path difference D by Eq. 2.

$$\Lambda = \frac{2\pi\lambda}{(\Delta\beta)D} \quad (2)$$

Where $\Delta\beta$ is the difference of propagation modes. As suggested by the author, the change in average fringe period allows for the change in optical path difference to be measured. From Eq. 2, the fringe period Λ varies inversely with the optical path difference *D*.

■3.0 METHODOLOGY

The fibre Mach-Zehnder interferometer schematic is shown in Figure 1.

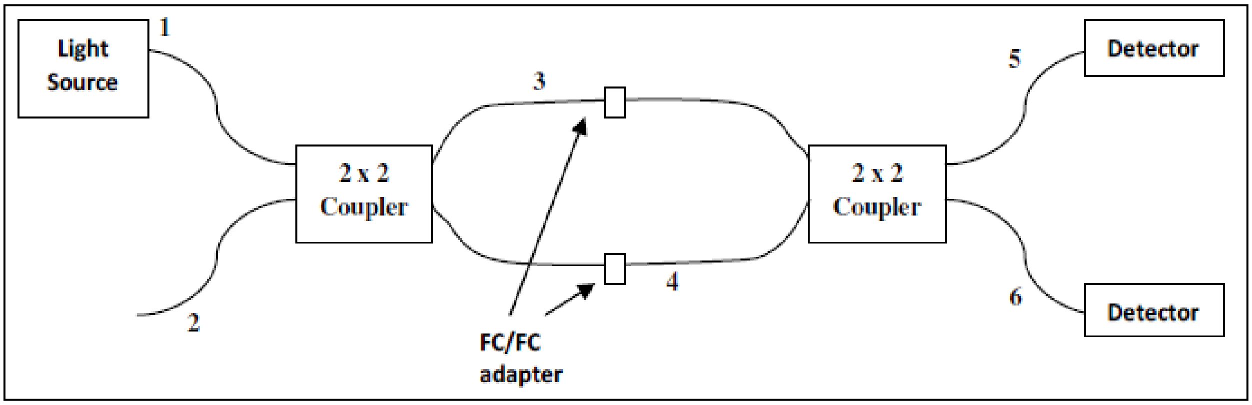


Figure 1 Mach-Zehnder fibre interferometer

Both simulation and experimental work are conducted for this study. The theoretical construct for the simulation of the Mach-Zehnder interferometer output spectrum are outlined in our previous work[5]. By decreasing the wavelength interval value from 0.30 *nm* to 0.05 *nm*, the output spectra are obtained for optical path difference between 84 μm to 92 μm with a 1 μm increment. The peak tracking method is then employed on these simulated spectra to determine the optical path difference. Whereas for experimental work, neutral white LED is employed as the light source for the interferometer and a spectrometer model Ocean Optic's USB4000 with the integration time of 500 *ms* and dark corrected settings.

■4.0 RESULTS AND DISCUSSION

The simulated and experimental interference spectra from output port 6 of the Mach-Zehnder interferometer are shown in Figure 2. The neighbouring peaks of the interference spectrum are selected for wavelength values ranging from 500–600 nm. For each pair of consecutive wavelength peaks value, the optical path difference is obtained via Eq.1 and the average path difference value is taken from a set of 20 pairs of the interference peaks and the uncertainty are reflected in the standard deviations. Simulated results of the optical path difference determined by peak tracking method for various wavelength intervals are presented in Table 1.

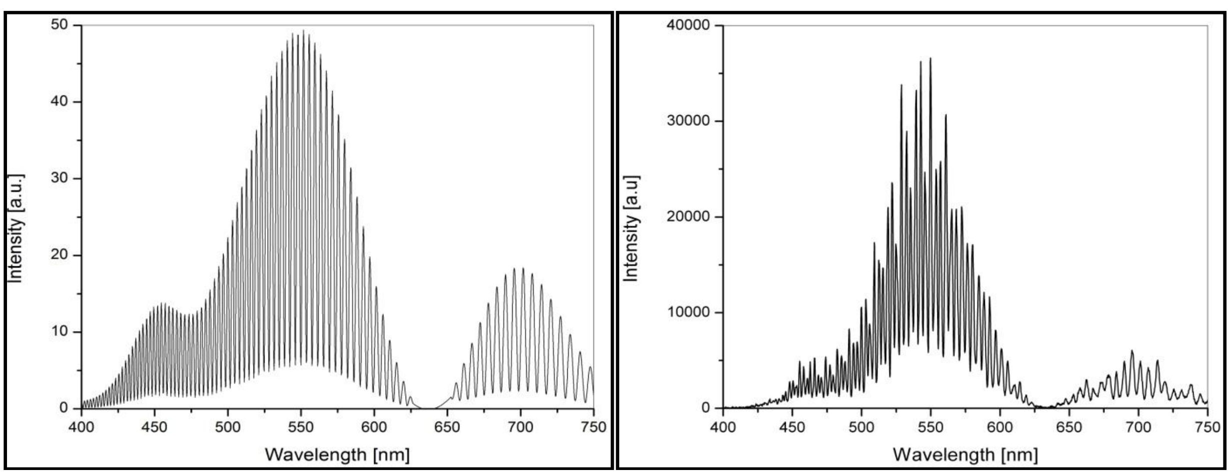


Figure 2 Simulated (left) and experimental (right) interference spectrum

Table 1 Results obtained for output spectrum simulated with 84μm path difference.

Wavelength Interval [nm]	Optical Path Difference $[nm]$	Standard Deviation $[nm]$
0.30	84143.91	2519.40
0.20	84173.91	1661.22
0.10	84060.77	1326.98
0.05	84042.93	449.81

The standard deviation of the optical path difference determined via peak tracking method decreases with lower wavelength interval values used in the simulation. This suggest that the use of detector with higher resolution can improve the result obtain by this method in terms of accuracy and consistency however, most commercial spectrometers have the wavelength interval values ranging from 0.1 nm to 0.3 nm such that idea of using high spectral resolution detector is limited.

From Eq.2, the fringe period is inversely proportional to the optical path difference. Hence, the linear plot is achieved by plotting the fringe period against the inverse of optical path difference ($1/d$) as illustrated in Figure 3. Sensitivity of this method is measured by the gradient of the linear plot and the x-intercept represents the maximum limit of optical path difference measurable. The simulation and experimental values shows the same gradient for the linear plot which suggest the same sensitivity regardless of wavelength resolution used, however the x-intercept of experimental result is larger that implies a lower maximum optical path difference that can be measured by the spectrometer.

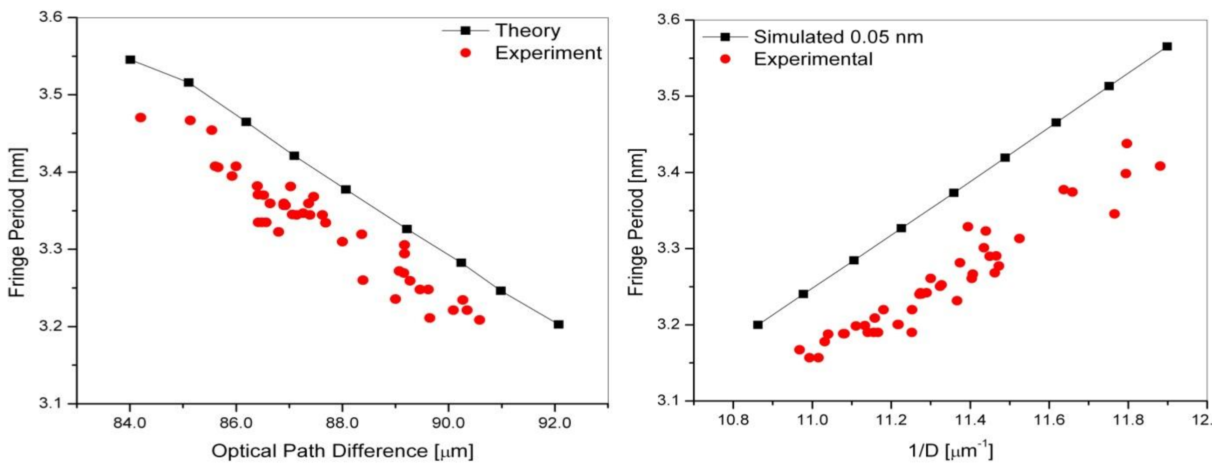


Figure 3 Plot of average fringe period versus optical path difference (left) and the linear plot (right) for experimental and simulated data.

Sensitivity of the change in fringe period was found to be 0.34 nm for a change of 1 μm, where as the maximum measurable optical path difference was found to be about 0.7 mm and 0.6 mm for simulated and experimental results respectively. The repeatability of the results in this study is presented as the standard deviation of the data. Simulated results for the average fringe period and its average optical path difference computed via peak tracking method are summarised in Table 2.

Table 2 Variation of fringe period with average optical path difference

Optical Path Difference $[nm]$	Computed Average Optical Path Difference $[nm]$	Standard Deviation	Average Fringe Period $[nm]$
84000	84173.91	2229.35	3.562
85000	85103.86	2186.65	3.515
86000	86232.35	2372.45	3.462
87000	87213.63	2268.64	3.415
88000	87991.76	2262.25	3.380
89000	89035.56	2406.19	3.331
90000	90084.10	2028.69	3.285
91000	91209.09	2620.00	3.238
92000	92104.04	1661.22	3.200

From the data presented in Table 2, the average fringe period shows an inverse relationship with the average optical path difference computed. The first column of Table 2 is the input value of the optical path difference in the simulation with the wavelength interval of 0.2 nm. Notice that the optical path difference value recovered shows an error of about 0.3% or less, although the standard deviation shows an unsatisfactory value if this principle were to be used as sensing method. This weakness however can be overcome by building a calibration curve by using a detector with higher resolution.

Other factors that contribute to the error in the peak tracking method besides limitation by wavelength resolution are the noise from the detector which may cause in false peak being detected or causing inaccurate determination of the peaks. In addition, the concept of this method is based on the assumption that two neighbouring peak has a phase difference of exactly 2π which may not be the case in reality.

■5.0 CONCLUSION

In short, this study evaluated thoroughly the peak tracking method for determination of optical path difference from an interference spectrum. This method can be improved by using a detector with higher spectral resolution and taking the average value of the optical path difference computed from an interference spectrum. As for the use of fringe period shift as sensing principle, this method may not be suitable to provide the corresponding optical path difference value unless the detector used have a spectral resolution of 0.1 nm or lower.

Further work on the improvement for this method may employ the use of phase shift interferometry concept to determine the phase change as a function of wavelength to overcome the basic assumption of the 2π phase change between the two neighbouring peaks.

Acknowledgement

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