An Investigation on Optical Measuring Systems using Different Types of Optical Fibre Links and Performance of Optical Sensors

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Abstract: ***One of the most notable characteristics of free-space optical measurement systems is their capability for directly affecting those assessment systems which operate within the context of propagation paths. As the literature attests to, light is dispersed or interfered with as it propagates through an optical fibre, the consequence of which is that the signal at the output end experiences a level of loss. However, the degree to which loss occurs as part of this process can be detected with appropriate technologies, and each error can they be afforded with an uncertainty outcome. Optical measurement systems that operate on this principle of light transmission through fibre optic links prove significant in extracting data that will be pertinent for the mainframe analysis. In view of these considerations, the purpose of the present paper is to investigate and provide an account of the immediate determinations associated with the use of single-multi-mode optical fibres, along with their impacts on the collection of information from high-speed optical measurement instrument links. In addition, the paper gives an overview of several design facets of the design methodology, along with the experimental measurement results of a fibre-optic-based surface topography measurement sensor (with the capability of measuring surface roughness). At the end of the paper, it will be stressed that further research is required to determine whether single- or multi-mode optical fibre sensors are more appropriate with respect to certain categories of instrument, in particular those which are now being utilised heavily in the context of embedded metrology applications.***

Keywords: Optical fibre link, Interferometry, optical instrumentations

1. Introduction

A defining feature of optical interferometric schemes is the way they permit a range of surface measurements of optical elements, including mirrors, with respect to differentiated high-resolution specimens. A myriad of interferometric practices can be applied to analyse interference patterns, and these draw on various light sources paired to the interferometer. Noncontact techniques are increasingly vital in the optoelectronics industry, since these facilitate the rapid and accurate mapping of micromachined surfaces. Although laser interferometry tolerates measurements to a high level of precision, the process merely produces the fractional interference order at every point. Therefore, this can result in discontinuities, which involve an alteration in height (at more than half of the wavelength of the light source).

It is possible to enhance the quality of parts and products by monitoring dimension and roughness. Conventional methods have seen most dimension and surface roughness measurements implemented through touch-triggered probes and stylus-based measuring devices, respectively. Furthermore, due to their operating principles and non-compact structures, researchers have found that these devices are unsuitable for in-line measurements, and they are also inefficient in terms of their speed of operation. It is also noteworthy that dimension and surface roughness monitoring must be applied in an in-line or recurring manner, since this caters for present-day developments in manufacturing processes, most of which lean towards greater speed, precision, and cost-effectiveness. Contrastingly, optical sensors benefit from their greater speed of operation, noncontact, non-destructiveness, and on-line inspection, rather than point-by-point inspection in isolation (which typically occurs in the context of mechanically-based devices). It should also be recognised that optical sensors are characterised by an elevated level of compactness, and owing to these factor, in-line inspection benefits considerably from the use of optical sensors [1, 2]. An examination of the available literature shows that surface roughness measurements carried out with fibre-optic sensors have been on the rise recently. Optical triangulation, light scattering, and intensity- or phase-modulated fibre optic sensing techniques are amongst the various techniques employed to inspect surface roughness [3-5]. There are three broad classifications of sensors used to evaluate surface irregularities; interferometric sensors, polarimetric sensors, and intensity-based sensors. Bradley et. al proposed an interferometric fibre-optic sensor for this purpose [6].

Data derived from practical measurements are related to a range of parameters, where most are established on the basis of the optical fibre type utilised in the present study. Single and multi-mode fibre interferometric sensors demand intricate optical schemes [7, 8]. Hence, almost all interferometric systems are complex and highly receptive to environmental impacts. It is also notable that these systems have the capability to measure surface roughness without contact, similar to the movement of an optical probe into in-on/line measurements.

The condition of in-situ, non-contact examination is most satisfactorily met via optical methods. However, the difficult manufacturing settings (many of which present a challenge for these methods to be adjusted accordingly), as well as the complications of design and cost involved in the creation of the system, frequently deter the application of optical methods. On the other hand, recommendations can be found in the literature which suggest the employment of fibre-optic displacement sensors (FODSs) for non-contact measurement and inspection of surface roughness [9, 10].

The relationship between sensor performance and the parameters of optical fibre links, as well as the diameters of the fibres, have been ascertained through research conducted on the design and principals of fibre-optic sensors. For the most part, research of this kind is conducted in the form of a trial and error procedure. In view of these considerations, research has been conducted to provide insight into utilising straightforward optical fibre links design in optical interferometric measuring systems.

2. A Single-Multi Fibre Optic Investigation

In the research conducted by Krohn [11], a conventional theoretical framework addressing intensity-based fibre optic sensors was provided. Despite the fact that this model had the capacity to explain the correlation between the intensity detected by a receiving fibre and the gap distance at which the detection of the intensity took place, a series of limitations of the framework cannot be overlooked. These are borne from the following suppositions; that the reflecting surface is a perfect specular surface, and that the way in which the light reflects on the surface conforms to the simple law of reflection; that the critical angle of the receiving fibre can be disregarded; that the intensity distribution of incident light is uniform. The measuring surface is used as the surface onto which light from the central fibre is emitted, and this is then reflected and scattered in the direction of the fibre bundle. In general terms, the signals, which are proportionally oriented with respect to the collected light intensities, are primarily dependent on the displacement and the surface roughness. It will be clear to the reader that this includes finish, texture, and reflectivity. Furthermore, when the surface moves away from the focused point more closely, a greater amount of light is gathered by the central fibre; and correspondingly, a lesser amount of light is gathered by the outer fibre. In addition to this, an inversely proportional relationship exists between surface roughness and the degree of the specular reflection of light. Finally, a directly proportional relationship exists between surface roughness and the amount of scattered light.

3. Experimental Results and Discussion

The degree to which the designed optical measurement sensor system is feasible is verified through the investigation of the experimental results acquired. The outcome of the characters of the single and multi-mode optical fibre sensors links are shown in Figure (1). The Optical Spectrum Analyser (OSA/AQ6317B) is an advanced optical device that can be used for a wide range of applications, including light source evaluation, measurement of wavelength loss characteristics in optical devices, and the waveform analysis of signal systems. The spectrometer (Solar Laser System, S 150), with a diffraction grating of 1800 lines/mm, is used at the blaze wavelength of 750 nm. The spectral range of the spectrometer is 799 to 840 nm, which covers the broadband of the SLD light source. The SLD (Exalos EXS8310-8411) is characterised by a smooth spectrum and low magnitude of the ripple, even at the highest power level, and the ripple is equal to 0.11 dB as in the data sheet. In addition to this, it is worth noting that the SLD uses a single mode fibre (Corning HI 780&780C) as a connection link between the SLD light source and the output fibre probe. The SLD has a maximum power of 1.08 mW (at measurement temperature) 25.03 ˚C, as well as a bandwidth amounting to λ =25.144 nm, with central peak wavelength of 820 nm.

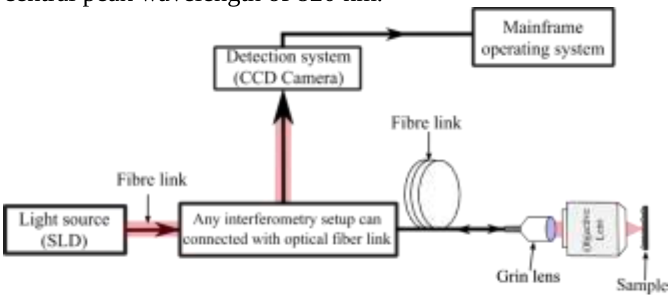
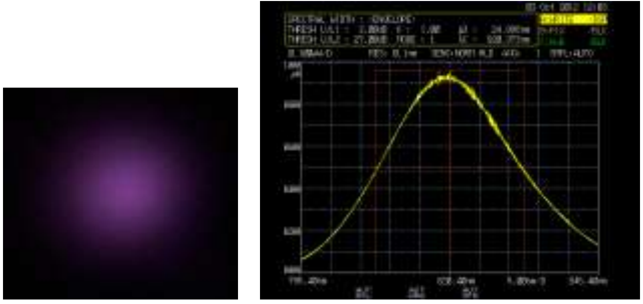


Figure 1: General interferometry optical system

The light source is linked to OSA and spectrometer S150 for the purpose of measuring the impact of the optical fibre type's behavior on the SLD spectrum as shown in Figure (2).

Figure 2: Shows the connection light source with (a) OSA and (b) spectrometer

The SLD beam distribution intensity is given in Figure (3-a), and it is notable that this outcome was examined by way of the OSA device (when the light source was connected with OSA using the single mode fibre type (Corning HI 780&780C).



(a) (b)

Figure 3: Shows (a) SLD beam intensity distribution using single mode optical fiber (Corning HI 780&780C), (b) OSA measurement outcome

The reader will find the potential practical benefits of a single-mode optical fibre in Figure (3-a), where an interferometry system is utilised on the basis of the measurement field, including low transmission, dispersion, and usability regarding the straightforward mechanical stretching of the broad optical fibre sensors. The central limitation associated with this approach is the reduced core size, which gives rise to the possibility that this is solely appropriate under a low-coherence source (since this removes or attenuates the disadvantages related to single wavelength light sources, including lasers in fibre optic sensor systems). As indicated in Figure (3-a), the agreement spectrum conforms to the results of the SLD data sheet.

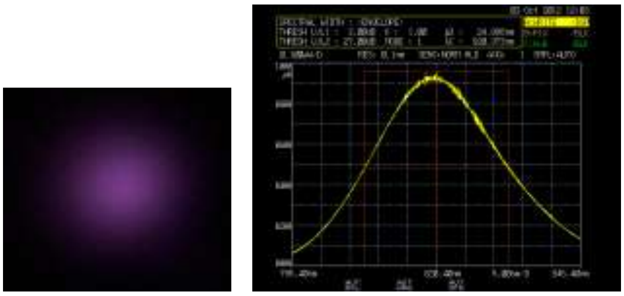

(a) (b)

Figure 4: Shows (a) SLD beam intensity distribution using single mode optical fiber (Corning HI 780&780C), (b) OSA measurement outcome

Contrastingly, SLD with OSA by way of the multi-mode optical fibre type ((M48L01-FC/PC) is given in in Figure 4. Based on the results, major points will be addressed. First of all, it is pertinent to note that weak information is noticed when the interference signal recollects via the optical fibre to the detector, particularly regarding the fringes at the centre of the light source's beam distribution. In addition to this, it is important to address the effect of the central fringes of the set (formed by the sample under test), and to illuminate the impact on sample information following recording. The cumulative loss of information has an effect on the fringe count error's magnitude, which stems from the use of the multi-mode optical fibre (in turn, based on the measurements and the nature of the application). A summary of the experiment is given in Table 1. After examining the table, it is clear that numerous optical fibre types have been examined with an SLD light source, a spectrometer, and OSA devices for the purpose of illuminating the matter of whether the optical fibre interferometric system will lose interference signals (namely, the fringe pattern).

Table 1: SLD connected spectrometer S-150

Fibre type	Wavelength rang (nm)	NA	Core (µm)	Clad (µm)	Centre wavelength (nm)	FWHM (nm)
Thorlab Multimode fibre –M28L02-SMA	400-2200	0.39	400	425	817.1	23.35
Thorlab Multimode fibre – M41L01-SMA	400-2200	0.48	600	630	816.9	21.11
600 µm UV silca –SMA-905-Multimode	400-2200	0.22	600	630	816.1	17.11
SLD connected to a spectrometer	NA	NA	NA	NA	816.1	17.11

Table 2 also indicates the considerable difference between the experimental results and the SLD data sheet. evertheless, the findings do support the notion that the outcome results should relate to the SLD data sheet.

Table 2: SLD connected with OSA

SLD light source	Centre wavelength (nm)
SLD direct connected with OSA using single mode optical fibre	820.373
SLD connected with OSA by using Multimode fibre M48L01-FC-PC	820.017

4. Conclusions

The immediate aim of this paper has been to explore the foundational principles of fibre optic-based surface topography measurement sensors (namely, the single and multi-mode types), and then to establish a theoretical model for these devices. The use of a certain type of optical fibre (e.g., the single or multi-mode types) is a viable way to analyses the data, along with the size of the optical measurement fibre sensor. In this way, the embedded metrology can be conformed to. Moreover, it is possible to use compact sensors of this kind for on-line monitoring over the course of the manufacturing process. This study reveals that it is imperative to consider the nature of the optical fibre link parameters for all optical instrument designs, since this is the key way in which to measure the various categories of surface classification with respect to the relevant application.

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