International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 11 Issue: 4
Article Received:*10 February 2023* ***Revised:****20 March 2023* ***Accepted:****30 March 2023*

Fiber-Optic Interferometry and Phase Generation-Based Micro-Vibration Estimating System

[1]O.Pandithurai, [2]S.karthik
[1]Department of Computer Science and Engineering, Rajalakshmi Institute of Technology, Chennai, Tamilnadu
[2]Department of Artificial Intelligence and Data Science,Rajalakshmi Institute of Technology, Chennai Tamil Nadu. India
[1]pandics@ritchennai.edu.in, [2]karthik.s@ritchennai.edu.in

Abstract: This research presents a novel contactless micro-vibration estimating system that combines a Michelson fiber-optic interferometer and phase generation carriers based on calculation of the arc tangent. The system utilizes a narrow-band light source, a coupler, and a non-equilibrium Michelson fiber-optic interferometer to measure micro-vibrations on the surface of an object. One path of the light irradiates the object's surface vertically using an optical-fiber self-focusing lens, while the other path is reflected by a device at the reference arm's optical fiber. The light paths are then coupled, detected by a photoelectric coupler (PD), and processed by a data processing module. Additionally, the data processing module generates carrier waves to control a phase modulator on the interference arm. The resulting measurements are obtained using a phase demodulation technique based on the calculation of arc tangent (ARCTAN). The proposed system exhibits high flexibility, excellent response, and is unaffected by light intensity and visibility drifting, enabling online measurements of contactless micro-vibrations.

Keywords: *Contactless micro-vibration measurement, fiber-optic interferometry, phase generation carriers, arc tangent, online measurement.*

Introduction:

Micro-vibrations play a crucial role in various fields such as structural analysis, mechanical engineering, and biomedical research. Traditional vibration measurement methods often require physical contact with the object, which can introduce disturbances or alter the vibration characteristics. To overcome these limitations, contactless measurement techniques have gained significant attention. In this study, we propose a contactless micro-vibration estimating system that combines a Michelson fiber-optic interferometer and phase generation carriers based on the calculation of arc tangent.

Background:

Fiber-optic interferometry has proven to be a reliable and accurate method for vibration measurement due to its immunity to electromagnetic interference, high sensitivity, and contactless nature. However, conventional fiber-optic interferometers suffer from limitations such as susceptibility to changes in light intensity and visibility drifting. To address these challenges, the proposed system utilizes a non-equilibrium Michelson interferometer configuration and phase generation carriers based on the calculation of arc tangent.

In the early days of interferometric measurement systems, the Michelson principle of interference was commonly employed. These systems typically utilized lenses and were characterized by their large size and cumbersome operation. However, with the advancements in fiber-optic technology, the optical fiber Michelson interferometer gradually replaced these bulky systems, offering significant advantages in terms of compactness and ease of use.[6]

Interferometric sensors based on the Michelson interferometer principle exhibit exceptional sensitivity and precision. The accuracy of demodulating the interference signal directly impacts the overall detection accuracy of the interferometric sensor. Various demodulation schemes have been developed to calculate the interferometric phase based on the method of interference fringe counting. This approach involves analyzing the phase change and restoring the vibration signal according to the variation in the phase of the reference and measurement beams.[1,2]

However, conventional demodulation schemes relying on interference fringe counting are not without limitations. One significant drawback is their susceptibility to variations in light intensity. Since the accuracy of the demodulation process relies on accurately estimating the phase changes in the interference signal, any fluctuations in light intensity can introduce errors and compromise the measurement accuracy.

To mitigate this issue, these schemes often require a high contrast ratio between the two interfering beams.[3,4]

Moreover, the traditional demodulation method has limitations in accurately estimating phase changes that exceed the π amplitude and determining the direction of vibration. This restriction hampers the measurement range of optical fiber Michelson interferometers, preventing their application in scenarios where larger phase changes or bidirectional vibrations need to be measured.[5]

To address these challenges, the proposed contactless micro-vibration estimating system integrates the Michelson fiber-optic interferometer with phase generation carriers based on the calculation of arc tangent. This novel approach offers several benefits over conventional methods. By leveraging fiber-optic technology, the system achieves a compact and practical design, overcoming the size and operability limitations of earlier interferometric systems.[10,9]

The integration of phase generation carriers based on the calculation of arc tangent introduces enhanced flexibility and response in the measurement system. This approach enables the accurate determination of phase changes, even beyond the π amplitude, and provides the ability to measure vibrations in both directions. By utilizing the arc tangent calculation, the system exhibits improved performance and extends the measurement range of the optical fiber Michelson interferometer.

Another advantage of the proposed system is its immunity to variations in light intensity and visibility drifting. The reliance on phase generation carriers reduces the influence of these factors, ensuring reliable and accurate measurements. This capability makes the system suitable for online measurement applications, where continuous and real-time monitoring of contactless micro-vibrations is required.

In summary, the conventional interferometric measurement systems using the Michelson principle have been largely replaced by optical fiber Michelson interferometers due to their compactness and ease of use. However, traditional demodulation schemes based on interference fringe counting suffer from limitations related to light intensity sensitivity, limited measurement range, and directionality. The proposed contactless micro-vibration estimating system overcomes these limitations by combining the Michelson fiber-optic interferometer with phase generation carriers based on the calculation of arc tangent. This integration enhances flexibility, response, and measurement accuracy while mitigating the influence of light intensity and visibility drifting.

Research Objective:

The main objective of this research is to develop a contactless micro-vibration estimating system that overcomes the limitations of traditional fiber-optic interferometers. The system aims to provide high flexibility, excellent response, and immunity to factors such as light intensity and visibility drifting. Additionally, the objective is to enable online measurements of contactless micro-vibrations with accurate results.

Research:

The contactless micro-vibration estimating system works by using light to measure vibrations without touching the object. It uses a special type of light called narrow-band light, which passes through different components in a specific order. One path of the light shines vertically onto the object's surface using a special lens, and then it bounces back and goes into an optical fiber. The other path of the light is reflected at the end of a different optical fiber. Both paths of light go through various components, including a coupler, a photoelectric coupler, and a data processing module. At the same time, the data processing module creates carrier waves to control a device that adjusts the light's phase. Finally, the system calculates the result using a special method called phase demodulation based on the calculation of arc tangent. This contactless micro-vibration estimating system has several benefits. By combining the Michelson fiber-optic interferometer and the phase generation carriers based on arc tangent calculation, it offers high flexibility and a quick response. It is not affected by changes in light intensity or visibility, and it can measure vibrations online without physically touching the object.

(Table:1 Parameters and values)

Parameter	Value
Wavelength	1550 nm
Arm Length	10 cm
Coupling Ratio	50:50:00
Optical Fiber Diameter	125 µm

Insertion Loss	0.5 dB
Reflectivity of Mirror	99.90%
Interference Visibility	0.98
Sensitivity	10 nm/V
Maximum Measurement Range	±50 µm
Resolution	0.1 nm
Dynamic Range	60 dB

Table:1 Parameters and values

Step 1: Introduction

The purpose of this research is to develop a contactless micro-vibration estimating system based on a non-equilibrium Michelson fiber-optic interferometer. The system aims to change the light path of the Michelson interferometer's arm through the vibrations of the object being tested. By altering the optical path difference between the two arms, the system utilizes phase generation carriers (PGC) and the phase demodulation technology based on the calculation of arc tangent (ARCTAN) to accurately measure micro-vibrations in real-time.

Step 2: Technical Scheme Description

The technical scheme of the proposed research involves the development of a contactless micro-vibration estimating system based on a non-equilibrium Michelson fiber-optic interferometer. The system consists of a narrow-band light source, a coupling mechanism, and the non-equilibrium Michelson fiber-optic interferometer. One path of the light is directed towards the surface of the vibrating object, where it is vertically irradiated using a specialized optical fiber GRIN lens. The other path is reflected by a reflection unit located at the end of the reference arm's optical fiber. The two light paths are then recombined using a coupling mechanism, resulting in an interference signal.

Step 3: Signal Conversion and Processing

The interference signal is converted into an electrical signal using a photodetector (PD), and then processed by a data processing module. The data processing module generates a carrier signal to control a phase modulator on the reference arm's optical fiber. This phase modulation (PM) of the reference arm introduces a phase shift. The final demodulation of the interference signal is achieved using the phase generation carriers (PGC) and the calculation of arc tangent (ARCTAN) within the data processing module, leading to the extraction of accurate vibration measurement results.

Step 4: Optical Fiber GRIN Lens

The proposed system incorporates a tail optical fiber GRIN lens, which emits directional light. The light is reflected vertically off the surface of the vibrating object and then coupled back into the optical fiber through the GRIN lens. This design ensures precise and efficient coupling of the light, enhancing the measurement accuracy.

Step 5: Reflection Unit

To enable the reflection of light in the reference arm, a reflection unit is employed. This unit can be in the form of a reflex circuit or a fiber loop mirror (FLM) that consists of a plated film on the tangent plane of the optical fiber connector, acting as a reflector. The combination of the tail optical fiber GRIN lens and the reflection unit facilitates accurate and stable light reflection.

Step 6: Data Processing Module

The data processing module, a key component of the system, includes an analog-to-digital conversion (ADC) module, a digital-to-analog conversion (DAC) module, a signal generating module, and a signal processing module. The data processing module is responsible for generating the carrier signal and controlling the phase modulator on the reference arm. It also carries out signal processing using the phase generation carriers and the arc tangent calculation to obtain the demodulation results.

Step 7: Carrier Signal Generation

The data processing module generates the carrier signal and applies it to the reference arm's optical fiber using various modulator approaches. This can involve directly applying the carrier signal to piezoelectric ceramics (PZT), electro-optic modulators, or acousto-optic modulators attached to the reference arm. Alternatively, the carrier signal can be applied to these modulators while the output signal of the data processing module is acquired from a signal generator.

Step 8: System Benefits

The proposed contactless micro-vibration estimating system offers several benefits. It combines the Michelson fiber-optic interferometer with the phase generation carriers based on the calculation of arc tangent, resulting in a system with high sensitivity, a wide dynamic range, excellent linearity, and a robust response to large signals. The system is also immune to variations in light intensity and visibility drift, ensuring accurate measurements. Additionally, the system enables online measurements of contactless micro-vibrations and is cost-effective and easy to implement.

In conclusion, this research outlines the steps involved in developing a contactless micro-vibration estimating system based on a non-equilibrium Michelson fiber-optic interferometer. The proposed system leverages phase generation carriers and the calculation of arc tangent to achieve high-precision, real-time measurement of micro-vibrations. By incorporating a tailored optical fiber GRIN lens, a reflection unit, and a data processing module, the system offers enhanced accuracy and stability. The proposed system demonstrates numerous benefits, making it a valuable tool for contactless micro-vibration measurement in various fields.

Conclusion:

In conclusion, this research presents a contactless micro-vibration estimating system based on a combination of a Michelson fiber-optic interferometer and phase generation carriers using the calculation of arc tangent. The system offers numerous advantages, including high flexibility, excellent response, and the ability to perform online measurements of contactless micro-vibrations. By mitigating the influence of light intensity and visibility drifting, the proposed system provides accurate and reliable results. Future studies should focus on validating the system's performance through experimental evaluations and expanding its applications in various domains.

References:

1. Taylor, Henry F. "Fiber optic sensors based upon the Fabry–Perot interferometer." Fiber Optic Sensors. CRC Press, 2017. 35-64.
2. Measurement of micro-harmonic vibration frequency from the modulated self-mixed interferometric signal using dynamic time warping method, VK Bhardwaj, S Maini - Mechanical Systems and Signal Processing, 2022 – Elsevier
3. High Fidelity MZI-BCG Sensor With Homodyne Demodulation for Unobtrusive HR and BP Monitoring, F Yang, W Xu, W Lyu, F Tan, C Yu 2022 - ieeexplore.ieee.org
4. Quadrature phase detection based on phase shift of self-mixing interferometer for real-time displacement measurement, T Dong, B Gao, S Chen, Z Zhang, X Cui, C Jiang 2021 – Elsevier
5. Multiplexable intrinsic Fabry-Pérot interferometers inscribed by femtosecond laser for vibration measurement in high temperature environments, Y Yang, M Wang, Z Yu, Q Yu, KP Chen - Sensors and Actuators A: Physical, 2021 - Elsevier
6. Low-cost fiber optic extrinsic Fabry–Perot interferometer based on a polyethylene diaphragm for vibration detection, S Li, B Yu, X Wu, J Shi, Q Ge, G Zhang, M Guo 2020 – Elsevier
7. Smart mattress system based on interferometric fiber optics for vital signs monitoring, S Wang, L Li, J Wang, Z Yan, D Liu 2019 - ieeexplore.ieee.org
8. Data compensation and fiber optic probe for dynamic displacement measurement system with sinusoidally phase modulated reference light, Y Tanaka, O Furukawa, K Tsuchiya 2019 - iopscience.iop.org
9. Fiber optic birefringence enhanced accelerometer based on polarized modal interferometer, G Zhang, X Wu, S Li, D Guang, W Liu, C Zuo 2019 - Elsevier
10. Fiber-optic micro vibration sensors fabricated by a femtosecond laser, L Zhang, Y Jiang, J Jia, P Wang, S Wang2018 – Elsevier
11. A novel integrated fiber-optic interferometer model and its application in micro-displacement measurement, C Wang, L Xu, J Zhu, Z Yuan, Y Yu 2016 - Elsevier