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A Precision Dual-Frequency Laser Interferometer for High Speed Target

[1]Sheng-Hua Lee, [2]Tian-Syung Lan, [1]Yu-Tang Chen and [1]Shand-Dad Liaw
[1]Department of Mechanical Engineering, De Lin Institute of Technology,
Taiwan 236, Republic of China
[2]Department of Information Management, Yu Da College of Business,
Miaoli County, Taiwan 361, Republic of China

Abstract: This study summarizes several different methods that may be used to obtain the high frequency difference that is required in high-speed laser interferometers to support the advances made in mechanical manufacture and measurement techniques. A design for a dual-frequency interferometer with a frequency difference of 5 MHz and a bi-reflecting film cavity mirror is proposed, which satisfies application requirements and the need for reducing cost solutions. The characters of its frequency stabilization and polarization properties are tested. The theoretical performance is confirmed through experimentation. Finally, a laser interferometer is successfully constructed using this type of laser tube and is tested at a movement speed of 1 m sec^{-1}.

Key words: Dual-frequency interferometer, bi-reflecting film, refractive index, resonant cavity

INTRODUCTION

The dual-frequency laser interferometer has become an indispensable instrument in the fields of manufacturing, assembly and measurement in the years. It has been moved out of the laboratory for the purpose of finding many practical applications in the real machining world. The dual-frequency laser interferometer has yielded tremendous benefits to the mechanical industry due to its ability to measure over a long distance, its longevity, its ability to realize multiple axis measurement simultaneously, its tolerance to changes in ambient light intensity, its ability to work in a vibration environment and its capability of measuring variations in both length and angles. In short, it may be regarded as a mobile measurement laboratory.

Nowadays, the mechanical industry is attempting to make improvements in productivity as well as in quality. For this reason the feed and return speeds of workbenches have increased to 1 m sec^{-1}. It is obvious that the functional speed of the dual-frequency laser interferometer should match this requirement.

It is straightforward to stabilize frequency using the ZEEMAN method and its gain curve character. However, it is a contradiction to increase the frequency difference while simultaneously assuring the necessary output power. The frequency difference is typically no more than 3 MHz, which gives an allowable measuring speed of no more than 700 mm sec^{-1}. This falls short of the required high-speed machining requirement of 1 m sec^{-1} discussed previously.

Although optical theory imposes no particular limits for single frequency interferometers, this type of instrument is very sensitive to changes in light intensity. For example, its performance would be disturbed by the flash of a visitor's camera flash. Additionally, it is not possible to realize multiple axis measurement simultaneously with a single laser head. For these reasons, it is accepted that a single frequency laser interferometer is not a perfect device. Since the early 1980's much work has been done for developing more convenient ways of realizing high frequency differences. Thus, this has led to the development and improvement of dual-frequency techniques.

The use of an acoustic-optic modulator to obtain a high frequency difference is a long established technique and may be used to generate a 20-40 MHz difference. However, using this technique, it is necessary to stabilize the frequency by means of an equal light power method and to obtain two orthogonal polarization beams of light with a frequency difference of 20-40 MHz. Furthermore, a crystal wedge is required to ensure that the beams are parallel. It will be appreciated that this method is, therefore, rather more complicated and obviously, the cost is higher than the Zeeman method. However, the advantages of the method are clear: a Quartz oscillator

Corresponding Author: Tian-Syung Lan, Department of Information Management, Yu Da College of Business, Miaoli County, Taiwan 361, Republic of China

determines the beat frequency and the frequency change is only several Hz. In contrast that of the Zeeman method is several thousand Hz. Of course several thousand Hz also meets most application requirements.

Another solution is to insert a bi-refraction retardation piece into the cavity. Several researches (Zhang and Li, 1988; Zhang *et al*., 1998) have inserted a quartz wedge into the cavity to create orthogonally polarized dual frequency beams. The resulting frequency difference was found to be proportional to the path differences between the two main axes of the refractive index.

$$\Delta\nu = \nu_e - \nu_o = (n_e - n_o)\ell\nu / L \qquad (1)$$

where, n_e is the extraordinary refractive index of the crystal, n_o is the ordinary light refractive index, l is the geometric thickness, v is the light frequency and L is the length of the resonant cavity.

Due to the large change in beat frequency that occurs when the crystal moves, it can be used to create a highly sensitive (10 nm) micro-displacement transducer. Using this technique it is possible to develop a dual-frequency laser interferometer which has a frequency difference of 40 MHz. However, this instrument is not ideal for length measurement due to the high cost of the electronic elements required for signal processing and the difficulties associated with the technologies involved.

The intention of this research project was to develop a more straightforward solution which would use standard, commercially available electronic components, but which would still meet the beat frequency requirements. This project developed a 5 MHz beat frequency laser using a stressed film cavity mirror rather than a bi-refraction crystal wedge. This solution simplifies the structure of the instrument and the technology required, with the result that it is possible to meet application requirements at a lower cost.

CALCULATION ANALYSIS

In developing a solution it is first necessary to determine the frequency difference required and the corresponding light path difference. If these are small, then using the aspect of a film layer may provide the solution.

The number of fringes corresponding to a speed of 1 m sec^{-1} is a little over 3 MHz.

Use of a heterodyne interferometer avoids low frequency noise, but it will nevertheless remove about 1 MHz at the lower end of the range. Therefore if a 3 MHz difference is the output required, then the actual difference generated should be 4 MHz. In order to meet the increased movement speeds anticipated within the machining world in the future, this project aimed for a frequency difference of 5 MHz.

The path difference of quartz can be calculated and converted by the light path difference to give a phase difference, namely:

$$\Delta\phi_{quartz} = 2\pi\frac{(n_e - n_o)\ell}{\lambda/2} = 4\pi\frac{(n_e - n_o)\ell}{\lambda} = 4\pi Ln\Delta\nu / c \qquad (2)$$

The cavity length of the single node He-Ne laser, L = 150 mm and v = c/λ, c = 299792458 m sec^{-1}, $\lambda \approx 0.6328$ μm, $n \approx 1$.

Substituting the frequency difference of 5 MHz into Eq. 2 gives:

$$\Delta\phi_{quartz} = 0.0314 rad \qquad (3)$$

It is necessary to generate the same phase difference using the film layer bi-reflection effect. The reflected light at the two main axes of the stressed cavity film is represented by:

$$R_o = r_o e^{-i\phi_o} \qquad R_e = r_e e^{-i\phi_e} \qquad (4)$$

As noted above, a precondition of substituting a stressed bi-reflection mirror for the quartz plate is that:

$$\Delta\phi_{Mirros} = \Delta\phi_{quartz} \qquad (5)$$

It is found that the performance of the film layer is no longer homogenous when it is stressed and that the reflective index difference is proportional to the stress applied.

For many years, there have been reports of a sudden phase change phenomenon observable in absorbable reflecting films (Ward, 1995, 2000). Under certain conditions, dielectric films may also be used to generate a similar sudden phase change. This allows for the creation of a sufficiently large phase change by applying only small forces. Since the issue of film layer design and techniques are well documented in other papers, they will not be discussed further in this particular paper.

CHARACTERISTICS OF THE LASER

The experimental procedure and results are outlined below (Gao *et al*., 2002).

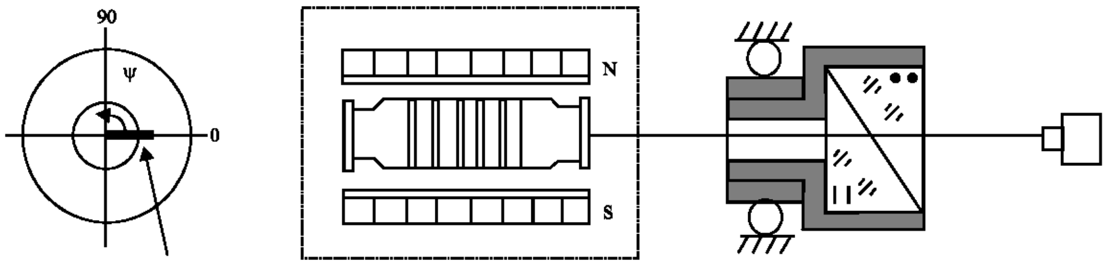

Fig. 1: Experimental setup of V_{min}/V_{max}

Table 1: Vanish ratio results

Ψ°	75	80	85	90	95	100
V_{min}/V_{max}	1/58	1/117	1/175	1/175	1/175	1/60

- Five laser tubes were designed using a stressed film cavity mirror. The frequency differences were 5.38, 4.10, 5.90, 5.58 and 4.87 MHz.
- Two orthogonal polarized beams were output directly. The direction and power of the beams depend on the direction and value of the main stress, rather than upon the direction and value of the transverse magnetic field. The direction of the magnetic field should be parallel with that of the main stress. The magnetic field affects only the variable range of the beat frequency.
- The Beat Frequency Vanish Ratio of the output beams was defined as the ratio of the minimum and the maximum signal (V_{min}/V_{max}) which was recorded as the polarizer was rotated through one cycle. The minimum value of this ratio occurred when the axis of the magnetic field was parallel or perpendicular to that of the main stress.

The experiment equipment is shown as Fig. 1. We made a mark on the laser tube, the rotate angle of the laser tube is **Ψ**. Then measured the V_{min} and V_{max} as the polarizer is rotated. The Vanish Ratio results are shown in Table 1.

From these results it will be observed that the value of the Beat Frequency Vanish Ratio is as low as 1/175 when the laser tube is correctly installed. This result is as good as that achieved using the conventional Zeeman laser.

- Calibration by the Chinese National Institute of Metrology gives that the wavelength λ = 632.9071 nm and that the extending uncertainty of average wave length $U(\lambda) = 3\times10^{-8}$ (k = 3).

MEASURING LENGTH EXPERIMENT

The basic elements of the instrument are shown in Fig. 2. It is necessary to explain the function of the half-wave plate. As described earlier, the direction of the magnetic field should be parallel to the direction of main stress. In the mechanical design, the direction of the magnetic field is fixed first and the laser tube is rotated until it is approximately parallel to the orientation of magnetic field. When the process of frequency stabilization is complete, it is possible that the orientation of polarization does not match the polarization beam splitter. In this case, a half wave plate can easily be used to adjust the direction. The other parts of the instrument are identical to those used in conventional dual frequency interferometers

- Repeatability Experiment. On a long rail of length 3 m, the location was ascertained by using an indicator of 0.1 μm. Measurement was carried out 8 times in the direction of increasing beat frequency and 9 times in the opposite direction. The process movement speed was maintained at about 1 m sec^{-1}. Deceleration was applied as the indicator was approached. The interferometer counter was recorded when the indicator showed zero. The standard deviation of the measurements obtained was 0.82 μm.

This is bigger than the standard deviation for a conventional interferometer. This is because the optical parts used in this study were taken from a conventional interferometer. Ideally, they would be specifically designed for high-speed movement processes.

- In September 2000, this instrument was used in a high-speed three coordinate measuring machine at the Braun and Shap Company in Qingdao City, China. It was found that the interferometer worked well under real world, high-speed conditions.

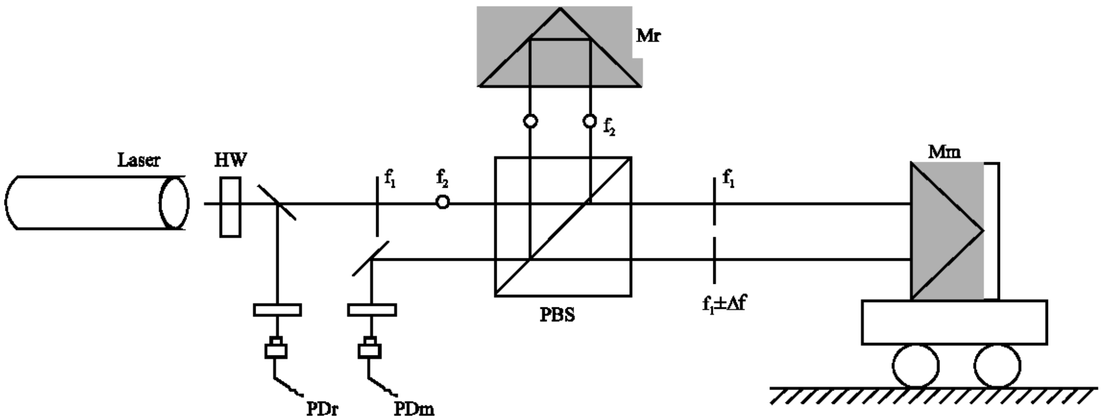

Fig. 2: Interferometer for high-speed measurement. HW: Half wave plate PBS: polarization beam splitter Mr: Retroreflector of reference arm Mm: Retroreflector of measuring arm PDr: Photodetector of reference signal PDm: Photodetector of measuring signal

CONCLUSION

In line with developments in mechanical manufacture and measurement requirements, it is necessary to increase the functional speed of dual-frequency laser interferometers. This study has presented an approach to the design of such an instrument, which has a frequency difference of 5 MHz generated using a bi-reflecting film cavity mirror. This interferometer meets all application requirements and does so at a reduced cost. The project has analyzed and calibrated the character of the frequency stabilization ad the properties of polarization. The results predicted by theory have been confirmed by experimental work. A laser interferometer has been successfully constructed using this type of laser tube and has been applied at movement speeds of 1 m sec^{-1} in both the laboratory and factory environments.

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NOMENCLATURE

L = Length of resonant cavity
l = Geometric thickness of the crystal
n_e = Extraordinary refractive index
n_o = Ordinary refractive index
R = Reflective coefficient
V = Signal voltage of the detector
V_{min}/V_{max} = Beat frequency vanish ratio
v = Light frequency
Δv = Frequency difference
λ = Wavelength of the laser
Δϕ = Phase difference
Ψ = Rotate angle of the laser tube

REFERENCES

Gao, S., C.Y. Yin and J.H. Guo, 2002. A 5 MHz beat frequency He-Ne Laser equipped with bi-reflectance cavity mirror. Acta Metrol. China, 6 (3): 118-126.

Ward, L., 1995. The geometric forms of the equation for reflectance and transmittance for radiation incident on very thin films. Optics Laser Technol., 27 (2): 125-129.

Ward, L., 2000. Further observation on the variation with dielectric constant and thickness of the reflectance and phase change on reflection of film. Optics Laser Technol., 3 2(1): 165-170.

Zhang, S. and D. Li, 1988.Using beat frequency laser to measure micro-displacement and gravity. An Discussion Applied Optics, 27 (1): 57-63.

Zhang, S., J. Li, Y. Han, Y. Li and Y. Zhang, 1998. Study of displacement sensing based on laser mode splitting by interacavity quartz crystal wedges oh He-Ne laser. Optics Eng., 37 (6): 1800-1803.