Optica Applicata, Vol. XXVII, No. 4, 1997

Two-frequency laser interferometer with phase shift measurement

J. Rzepka, J. Pieńkowski, H. Pawolka, S. Sambor

Institute of Telecommunication and Acoustics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50–370 Wrocław, Poland.

We present a two-frequency laser interferometer with high measurement resolution. The interferometer relies on the use of a two-frequency Zeeman effect laser. The He-Ne laser uses magnetic field to create a Zeeman energy level splitting. The two laser lines frequency difference, *i.e.*, Zeeman frequency, is about 1.8 MHz. The principle of displacement measurement in the interferometer is based on the counting of the frequency and the phase of the Zeeman frequency changes due to the retroreflector translation. The measurement resolution up to $\lambda/1024$ (0.64 nm) was achieved.

1. Introduction

The two-frequency laser interferometry is a well known technique for easy and precise measurement of displacement. Most of the commercial interferometers use the He-Ne Zeeman laser. The laser uses magnetic field to create a Zeeman energy level splitting. This permits two different laser lines to lase simultaneously. The frequency difference is usually 1.8 MHz. The basic measurement resolution is $\lambda/2$ and can be electronically increased up to $\lambda/1024$. There are two principal methods to increase the measurement resolution; by the Zeeman frequency multiplication and by interpolation of sine signal of the Zeeman frequency [1], [2]. The first method uses electronical multiplication of the Zeeman frequency in the measurement and in the reference channels. The principal resolution of $\lambda/2$ can be increased by the rate of the frequency multiplication. In the second method, the sine signal A and, shifted by $\pi/2$, the sine signal B from the measurement photodetectors are interpolated in the system of comparators. The resolution of the measurement depends on the number of levels of comparison. The accuracy of interpolation strongly depends on stability of the amplitude of the signal and its curvature. We present the interferometer which provides the resolution of $\lambda/1024$ for static measurements and $\lambda/4$ – for dynamic ones. The principle of the method increasing the resolution is based on the measurement of the interference signal phase at the beginning and at the end of the measurement.

2. Two-frequency laser interferometer

The two-frequency interferometer LSP-30 [3], the block diagram of which is presented in Fig. 1, uses the wavelength of light from a low power He-Ne 633 nm

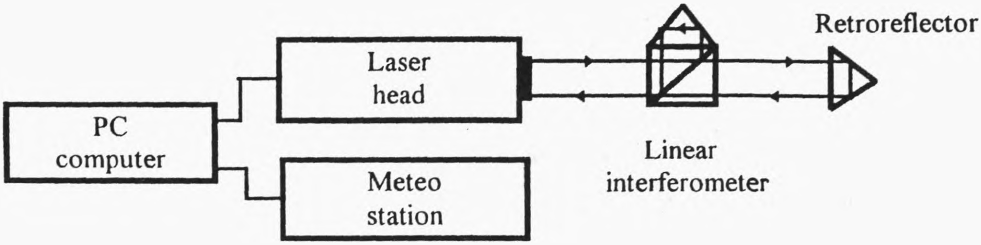

Fig. 1. Block diagram of the laser interferometer LSP-30

frequency stabilized laser as a length standard. The interferometer consists of the laser head, the meteo station, the PC computer and optics. Although, the optical frequency of the laser output is constant, the wavelength is constant only in a vacuum. In the air the wavelength decreases as a refractive index increases. The refractive index is affected by air temperature, pressure and humidity. The automatic wavelength compensation unit – the meteo station is used for continuous collection of the data on air temperature, pressure and humidity and corrections of the laser wavelength. The PC computer is used to compute, display, store and analyze results of measurements. Different optical elements are used for distance, velocity, angle and straightness measurements.

The laser head (Fig. 2) incorporates the internal mirror Ne-Ne 633 nm laser tube placed in an axial magnetic field. The Zeeman frequency of the laser is about 1.8 MHz and its output power reaches 1 mW. The frequency of the laser radiation is actively stabilized by a digital Zeeman beat method [4]. The laser frequency stability is better than 10^{-8}. The laser output is composed of two slightly different optical frequencies f_1 and f_2 with circularly opposed sense polarization. After passing through the quarter-wave and half-wave plates they display linear polarizations mutually perpendicular to each other. A small portion of the beam is used to generate a reference frequency F.R. (Zeeman frequency) and provide an error singal to the laser stabilization system. The major portion of the beam passes out of the laser head.

The beam f_1 passes through the linear interferometer when the beam f_2 is reflected to the reference retroreflector. The frequency of the beam f_1 reflected by the moving retroreflector is changed by Δf (Doppler effect). The interference of the f_2 beam and the $f_1+\Delta f$ beam give the measure signal F.M., where frequency is $f_1-f_2+\Delta f$. The frequencies of F.R. and F.M. signals are multiplied electronically by 2 after amplification and pass to the counters. The phase detector provides analogue signal, which is proportional to the phase shift between F.R. and F.M. signals. This analogue signal is then converted to digital signal and is stored in the microprocessor system. The initial phase shift is measured and stored before starting the measurement. The difference between frequencies of F.M. and F.R. signals is measured by the microprocessor system. This difference, multiplied by $\lambda/4$, is a major part of translation. The phase shift between the F.R. and F.M. signals is measured by microprocessor and the initial phase shift is subtracted. Then the mirror part of

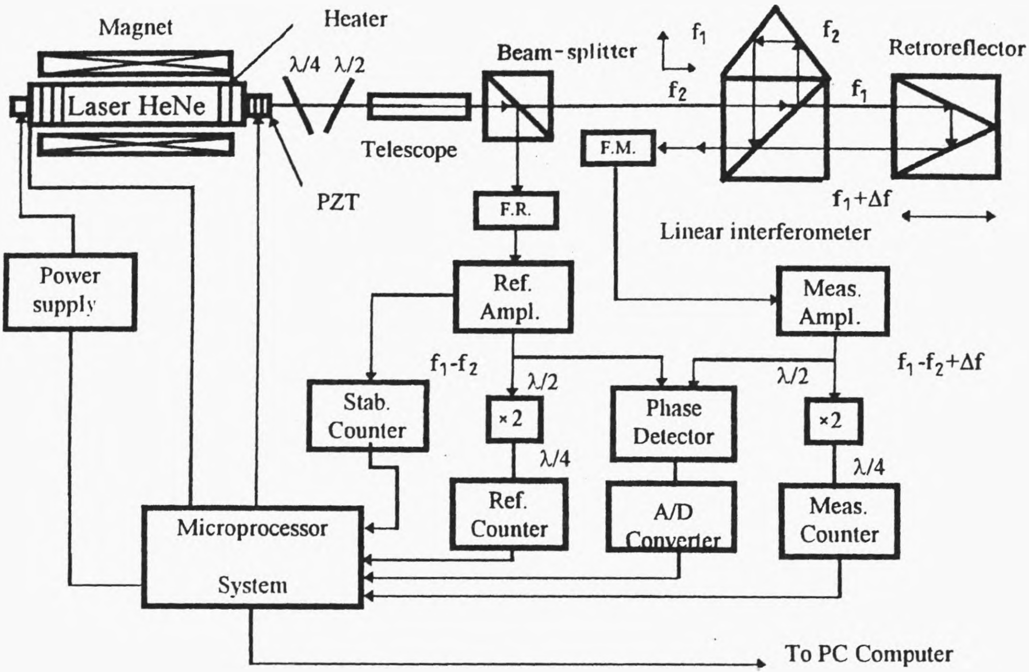

Fig. 2. Block diagram of laser head. $\lambda/4$ — quarter-wave plate, $\lambda/2$ — half-wave plate, F.M. — measurement photodetector, F.R. — reference photodetector, $\times 2$ — multiplier by 2, PZT — piezoceramic

translation, due to phase shift difference, is added to the result. The phase detector time constant $\tau = 0.03$ s limits the speed of the phase changes which can be measured. The translation with the speed up to several μm/s can be measured with high resolution $\lambda/1024$. For higher speeds the resolution of the system decreases to $\lambda/4$.

3. Conclusion

In most industrial interferometric measurements, the resolution equal $\lambda/4$ is satisfied, specially for dynamic measurements. In the static position uncertainty measurements, static angular straightness, squareness and flatness measurements much higher resolution is demanded. The presented system can measure a distance of up to 30 m with resolution 0.1 μm and accuracy 1.5 μm/m for dynamic measurements and with resolution of $\lambda/1024$ for static measurements. The resolution of the measurements can be changed via the sofware of the system. Due to mechanical vibration, air fluctuation and temperature instabilities, the measurements with highest resolution are possible only in laboratory conditions.

References

[1] *Laser Interferometer ZLI150*, Spindler & Hoyer Catalogue, 1989.
[2] *HP5529A Dynamic Calibrator*, Hewlett Packard Catalogue, 1993.
[3] PIEŃKOWSKI J., RZEPKA J., Proc. 3rd Mideuropean Symposium and Exhibition on *Semiconductor Engineering and Materials*, Warszawa 1992.
[4] PIEŃKOWSKI J., RZEPKA J., *Technical Digest Quantum Electronics* Conference, Edinburgh 1991.

Received September 16, 1997