

Dual-Wavelength Interferometer for Surface Profile Measurements

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Abstract

The design and first experimental results of a dual-wavelength heterodyne interferometer (DWHI) for precise surface profile measurements are presented. The DWHI is based on a Mach-Zehnder type interferometer with the surface to be measured in the sensing arm of the interferometer. Two adjacent wavelengths are simultaneously used in the interferometer; the range information is gained from the beat frequency of both heterodyne interferometer signals. Thus, the extreme range ambiguity of classical interferometers and their sensitivity to mechanical distortions are reduced by the ratio of laser frequency to beat frequency. The DWHI is expected to have the good S/N performance of a coherent detection system but also the capability of measuring diffusely scattering targets. The main features of the system presented here are:

- use of a single diode laser in combination with a high frequency Bragg cell to generate two adjacent wavelengths
- use of an all-fiber concept for the optomechanical build-up

Introduction

The need of remote sensors in manufacturing processes and in robotics has stimulated the development of refined techniques for 3-D mapping. The most frequently used techniques are: focused beam probing, triangulation, time-of-flight radar, and interferometry. Interferometry - without doubt - is the most sensitive one, but in general it requires smooth surfaces and a very stable build-up. To get rid of these restrictions dual-wavelength techniques can be applied¹. Although dual-wavelength interferometry is known since years a novel approach using a Michelson type interferometer was presented by R. Dändliker et al.². Two adjacent laser wavelengths are frequency shifted by acousto-optic modulators and are simultaneously passed through the interferometer. The heterodyne signals of both laser lines are electrically mixed and the resulting beat frequency is taken for the range evaluation.

In our approach the two adjacent laser lines for the DWHI are produced from a single laser source by passing the collimated beam through a high frequency Bragg cell. The diffracted beam is frequency shifted with respect to the undiffracted beam by the Bragg cell drive frequency. In another step we reduce alignment and backreflection criticalities and strive for a rugged and compact configuration by using an all-fiber optical concept.

Principle of Operation

The basic operation scheme of our DWHI is shown in Fig.1. Two laser beams of frequency ν_1 and frequency ν_2 are passed through the acousto-optic modulators AOM1 and AOM2. The diffracted beams are frequency shifted by f_1 and f_2 . The four beams are distributed by mirrors and beamsplitters in a way that interferometric signals can be gained from ν_1 and ν_1+f_1 and from ν_2 and ν_2+f_2 , ν_1 and ν_2 travelling via the target arm z and ν_1+f_1 and ν_2+f_2 travelling via the reference arm l . Photodetector D1 will provide the following signal:

$$I(t) = [a_1 + a_2 + a_3 + a_4]^2 \quad (1)$$

$$\text{with } a_1 = A_1 \exp i(2\pi\nu_1 t - 4\pi\nu_1 z/c) \quad (2a)$$

$$a_2 = A_2 \exp i(2\pi\nu_2 t - 4\pi\nu_2 z/c) \quad (2b)$$

$$a_3 = A_3 \exp i[2\pi(\nu_1+f_1)t - 4\pi(\nu_1+f_1)l/c] \quad (2c)$$

$$a_4 = A_4 \exp i[2\pi(\nu_2+f_2)t - 4\pi(\nu_2+f_2)l/c] \quad (2d)$$

z is the target arm length, l is the reference arm length

By filtering the heterodyne signals of frequency f_1 and f_2 we get

$$I'(t) = 2A_1 A_3 \cos(2\pi f_1 t + 4\pi\nu_1 z/c) + 2A_2 A_4 \cos(2\pi f_2 t + 4\pi\nu_2 z/c) \quad (3)$$

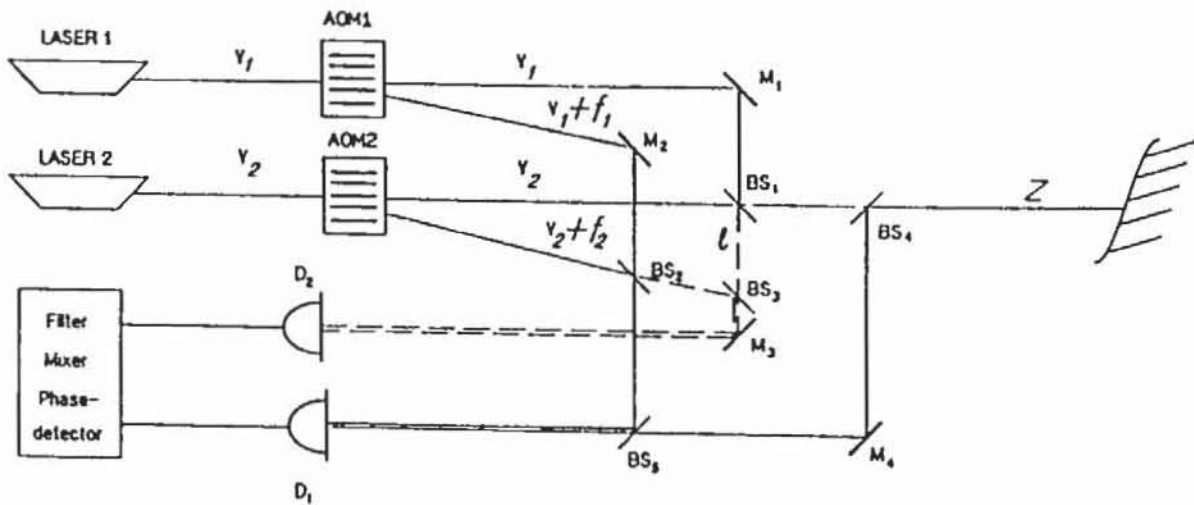


Fig. 1 Scheme of the Dual-Wavelength Heterodyne Interferometer

Both heterodyne signal are phase sensitive according to the laser wavelength.

Mixing both heterodyne signals and filtering the beat frequency yields

$$I''(t) = A'' \cos[2\pi(f_1 - f_2)t + 4\pi(v_1 - v_2)z/c] \quad (4)$$

The phase sensitivity of the beat signal now is no longer related to the laser wavelengths but to a synthetic wavelength of

$$\Lambda = \frac{\lambda_1 \cdot \lambda_2}{|\lambda_1 - \lambda_2|} \quad (5)$$

Photodetector D2 provides the phase reference signal.

The main problems in realizing a DWHI system are:

- 1) the coherence lengths of the laser lines and the mutual wavelength stability
- 2) the alignment of the laser beams
- 3) parasitic backreflections and straylight

Laser Source

Out of a large variety of possible laser sources² diode lasers are most attractive for a future DWHI because they are small, rugged, and low power consuming. It is however obvious that two independent laser diodes hardly can fulfil the mutual stability requirements for accurate measurements. If, for example, a range resolution of $dz = 0.1$ mm is strived for and a phasemeter resolution of $d\phi/2\pi = 3 \cdot 10^{-4}$ is assumed the difference frequency of both laser lines should be $v_1 - v_2 = 500$ MHz to have the maximum of range unambiguity. The mutual stability of both laser lines then has to be better than

$$\begin{aligned} dv &= (v_1 - v_2) \cdot dz / \Lambda z & (6) \\ dv &= 150 \text{ kHz} & \text{for } \Lambda z = 300 \text{ mm} \quad \text{measuring range} \end{aligned}$$

In consideration that the frequency walk of a single mode GaAlAs laser diode with temperature and injection current is approximately:

$$dv/dT = 26 \text{ GHz/K} \quad (d\lambda/dT = 0.06 \text{ nm/K}) \quad (7)$$

$$dv/dI = 3 \text{ GHz/mA} \quad (d\lambda/dI = 0.007 \text{ nm/mA}) \quad (8)$$

it is evident that it would be extremely difficult to control two individual diodes to the mutual frequency stability required for a DWHI as described above. Therefore the more promising approach is to use only a single laser diode in combination with a high frequency Bragg cell. If, after passing the laser beam through the Bragg cell, the diffracted beam and the undiffracted beam are

used for the DWHI both laser lines are correlated in frequency and phase.

Modern monomode laser diodes (e.g. Hitachi HLP 1400 or HL 8314) show stable single frequency emission at dc operation conditions. Fig.2 and Fig.3 show the spectral changes with temperature and injection current. Single frequency emission is obtained over a wide range of temperature and injection current.

Fig.4 shows the linewidth of the HL 8314 at its nominal injection current of 125 mA measured by a scanning Fabry Perot interferometer. Since the FP resolution was only 10 MHz it can be derived from Fig.4 that the laser linewidth is smaller than 10 MHz. A self-heterodyning experiment (Fig.5) gives a better resolution of the laser linewidth. It could be shown that the linewidth is about 2 MHz at 125 mA injection current (30 mW optical power output); it increases to 5 MHz when the injection current is decreased to 90 mA (15 mW output power). During the linewidth measurements the laser diode was stabilized within 10 mK in temperature and within 10 μ A in injection current. Fig.6 shows the spectrum of the self-heterodyne signals at 125 mA and 90 mA laser diode injection current.

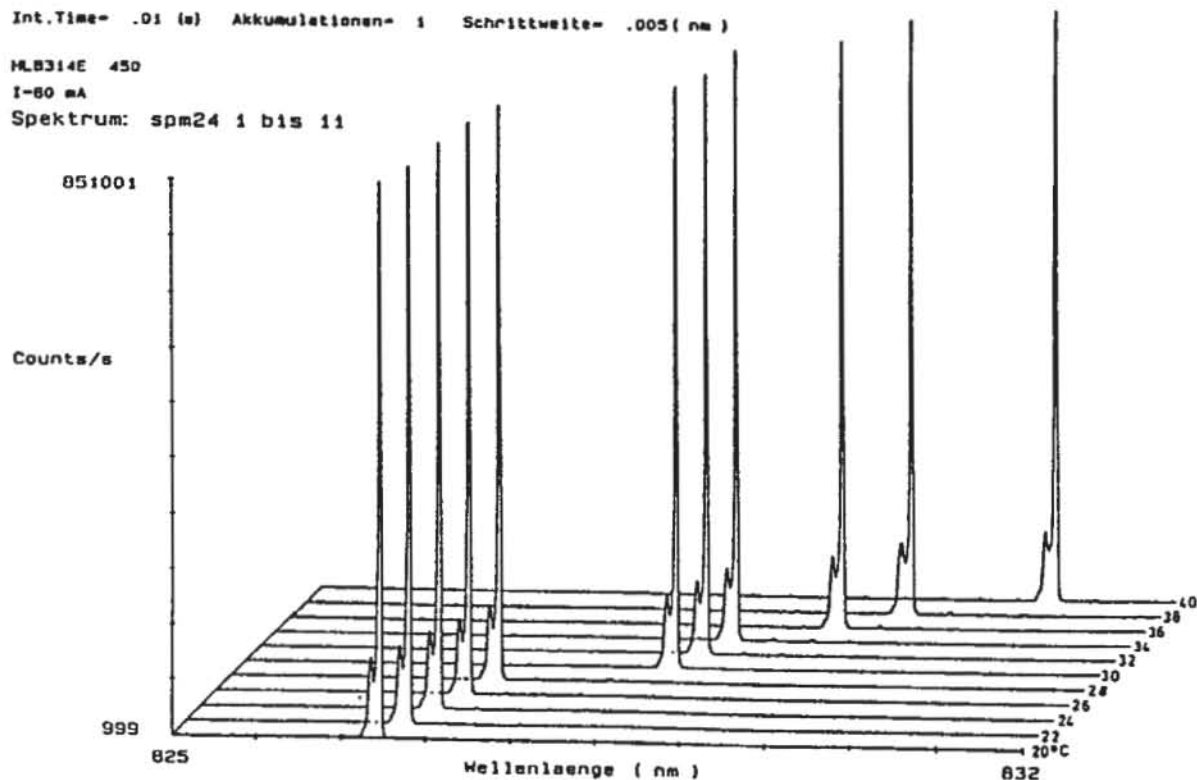


Fig. 2 Laser Diode Single Mode Operation and Spectral Walk with Temperature (Hitachi HL 8314)

Int.Time= 01 (s) Akkumulationen= 1 Schrittweite= .005 (nm)

HL8314E 450

T= 25 deg.

Spektrum. spm22 1 bis 11

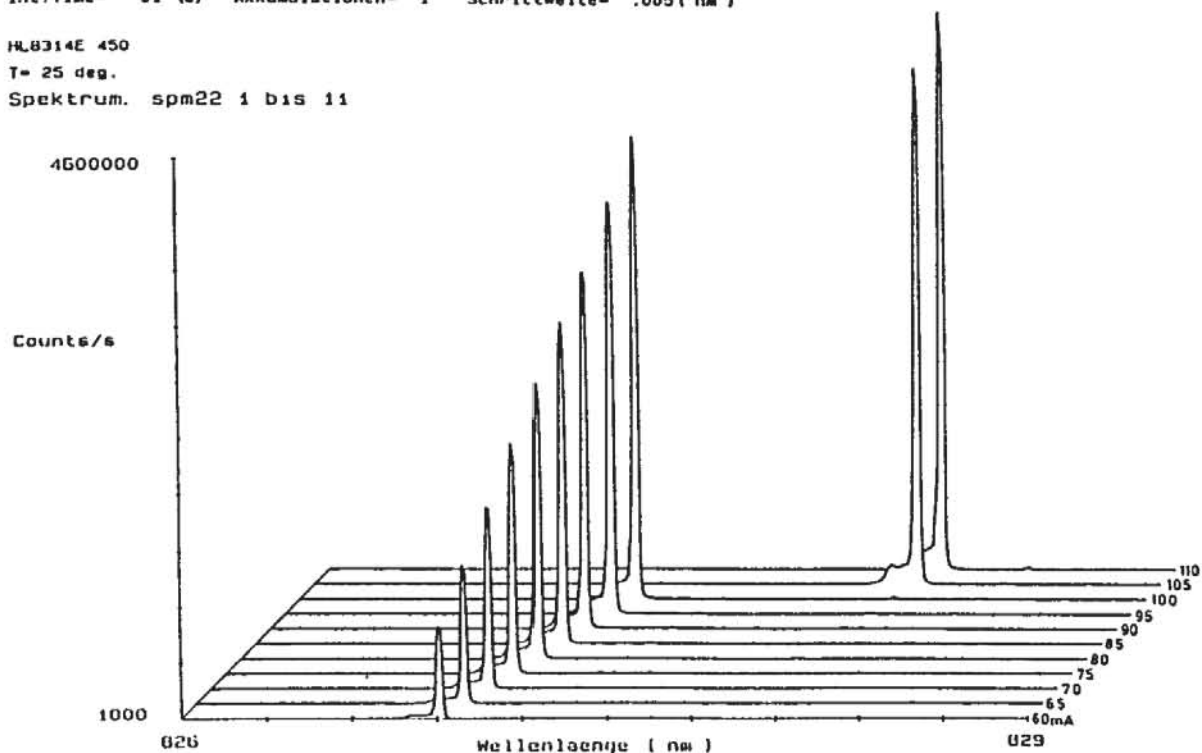
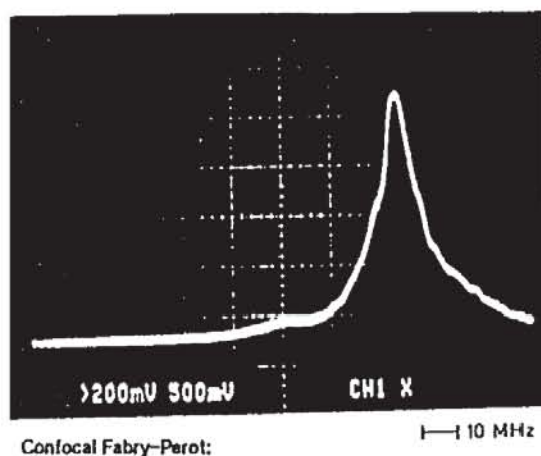


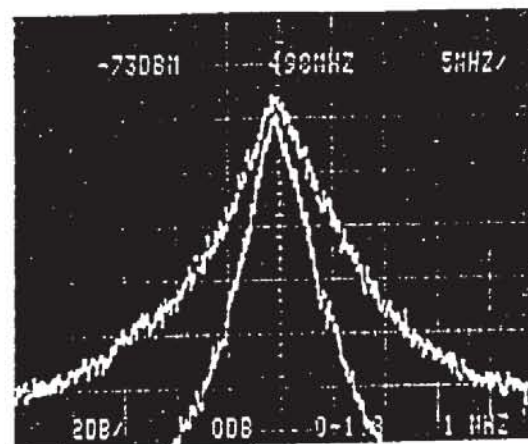
Fig. 3 Laser Diode Single Mode Operation and Spectral Walk with Injection Current (Hitachi HL 8314)



Confocal Fabry-Perot:

- Free Spectral Range 2 GHz
- Finesse 200
- Scan time 0.01 s

Fig. 4 Linewidth Measurement by a Scanning Fabry Perot Interferometer



horizontal: 5 MHz/Div.

vertical: 2 dB/Div.

Fig. 6 Linewidth Measurement by a Self-Heterodyning Experiment

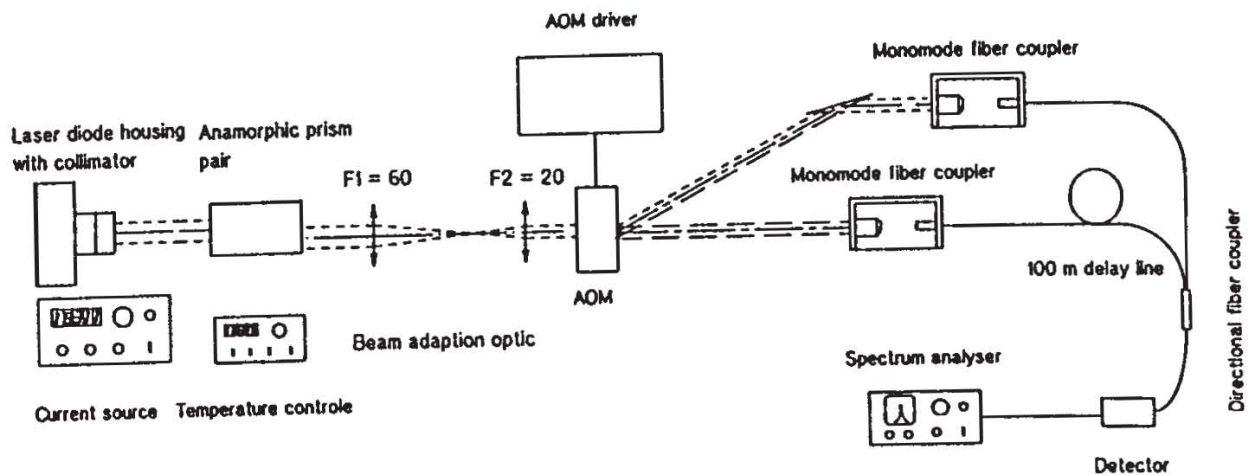


Fig. 5 Experimental Set-up for the Self-Heterodyning Linewidth Measurements

It can be summarized:

- Modern single frequency laser diodes are well-suited for interferometry up to several tens of meters of path difference between target and reference arm.
- For dual-wavelength interferometry it is more convenient to generate both wavelengths by passing one laser beam through a Bragg cell instead of controlling two independent sources.

Optical Configuration

Single optical elements, e.g. beam splitters or quarter wave plates, as used in former dual-wavelength interferometer set-ups, introduce the risks of non-perfect beam alignment and of parasitic straylight and backreflections.

Non-perfect beam alignment causes the speckle phases from rough surfaces in both beams to vary in an undefined way³. Thus, phase measurements to rough surfaces will be extremely critical. Reflections from optical surfaces can cause light to propagate from the reference arm to the target arm or vice versa. Thus, phase errors are introduced in the detector beat signal which strongly affect the ranging accuracy.

In our approach an all-fiber concept was chosen which is expected to remove the above risks. Fig.7 schematically shows the set-up. A single diode laser in combination with a 500 MHz Bragg cell provides two adjacent laser lines ν_1 and ν_2 in the diffracted and the undiffracted beam. Both beams again are passed through AOM's of $f_1 = 40.0$ MHz and $f_2 = 40.1$ MHz. The resulting beams are fed into monomode fibers. The directional fiber couplers DC1 and DC2 combine ν_1 and ν_2 in a target arm signal, and $\nu_1 + f_1$ and $\nu_2 + f_2$ in a reference arm signal. Part of the target signal and part of the reference signal are fed to detector D2 to provide the phase reference. A variable fiber delay line DL2 makes it possible to

Literature

1. H.J. Tiziani, "Real-time measurement in optical metrology", 5th Int. Congr. LASER'81, Munich 1981 (Conf. Proc. p.127)
2. R. Dändliker, R. Thalmann and D. Prongué, "Two-wavelength laser interferometer using super-heterodyne detection", 14th Congr. of the Int. Commission for Optics, Aug. 24-28, 1987, Quebec (Canada), B1.2 (SPIE Vol. 813)
3. A.F. Fercher, H.Z. Hu and U. Vry, "Rough surface interferometry with a two-wavelength heterodyne speckle interferometer, Appl Optics 24 (1985), 2181