- Super-heterodyne interferometer using the beat signals of one optical comb and three laser diodes –

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Abstract A super-heterodyne interference system is developed for absolute distance measurement up to several meters based on multiple-wavelength interferometric method. Three laser diodes and an optical frequency comb are used as the light sources. The repetition frequency of the optical comb is 58.418 MHz with a frequency stability of 10^-11, and the wavelengths of the laser diodes are 1542 nm, 1542 nm and 1573 nm. There is a frequency difference of 20 GHz between the two laser diodes with the wavelength of 1542 nm. Therefore, two synthetic wavelengths, \( \lambda_{s1} = 80.5 \mu m \) and \( \lambda_{s2} = 15 \mu m \), are obtained by changing different laser sources using an optical switch, and the interferometer has different measurement ranges. A distance of about 3 m is measured and the stability of the results are 0.32 μm for \( \lambda_{s1} \) and 17 μm for \( \lambda_{s2} \). Since only two of the laser diodes are phased locked to the optical comb, the stability of the carrier envelope offset frequency will influence the measurement stability.

1 Introduction
When multiple-wavelength interferometric method is used for absolute distance measurement, it is necessary to stabilize each wavelength to a standard for precision measurement, which makes the measurement method traceable, and the measurement stability and accuracy can be proved. In the developed super-heterodyne interference system, a stabilized optical frequency comb (frequency comb) is used as the frequency standard of three laser diodes (LD), and two synthetic wavelengths are obtained for the absolute distance measurement. A distance of about 3 m is measured and the measurement stability is 0.32 μm.

2 Principles
Figure 1 shows the frequencies of laser diodes and the spectrum of the optical comb. The frequency \( f \) of any mode within an optical comb can be expressed as \( f = N f_c + f_{com} \), where \( f_c \) is the repetition frequency, \( f_{com} \) is the carrier envelop offset frequency and \( N \) is an integer. The repetition frequency \( f_c \) of the optical comb (Neoark Co.) in the experimental system is stabilized to a rubidium frequency standard and the relative uncertainty is 10^-11.

The frequencies of LD1 and LD2 are \( f_1, f_2 \), and the frequency of LD3 is much closed to \( f_1 \). The wavelengths are 1.54 μm, 1.57 μm and 1.542 μm. The frequency difference of LD1 and LD3 is 20 GHz, so the synthetic wavelengths \( \lambda_{s1} = 15 \mu m \) and \( \lambda_{s2} = 80.5 \mu m \) are obtained.

Fig. 1 Frequencies of the laser diodes and the optical comb.

Figure 2 shows the interference system using three laser diodes as the light sources. The frequencies of LD1 and LD2 are phase-locked to different modes of the optical comb. The beat signals of the laser diodes and the optical comb are \( \Delta f_1 \) and \( \Delta f_2 \), which are also stabilized to the rubidium frequency standard. Therefore the stability and the accuracy of \( \lambda_{s2} \) are the same with the stability and the accuracy of \( f_c \). For the precision measurement, LD3 should also be phase-locked to the optical comb with a certain offset frequency. The stability and accuracy of \( \lambda_{s1} \) could be improved, and the frequency standard of the interference system can be unified. In this case, the beat signals of the LDs and the optical comb can be used as the heterodyne signal, when the optical comb is used as both the frequency standard and the light source of the interference system.

Since we do not have the third LD which can be phase-locked to the optical comb, extra measurement error has to be introduced by the frequency instability, and the optical comb is only used as the frequency standard. The frequency modulator is necessary to generate the heterodyne signals.

Fig. 2 Super-heterodyne interference system using three CW LDs and an optical comb

In the developed super-heterodyne interference system, an acousto-optic modulator (AOM) is set in the reference arm and the heterodyne frequency is \( \Delta f_c \). The target mirror is moved by a piezo-electric transducer (PZT), so the optical path difference under measurement can be adjusted with an accuracy of tens of nanometers.

Two optical filters before the photo detectors select the light from different LDs. The center wavelength of the filter1 is 1.54 μm, which works for LD1 and LD3, and the center wavelength of the filter2 is 1.57 μm, which works for LD2. The frequencies of LD1 and LD 3 are too close to be separated by the optical filters, so an optical switch is used to select the laser sources between LD1 and LD3. Therefore, there are two super-heterodyne interferences in the system, each of which has two LDs as the light sources, one has LD1 & LD2 and the other has LD2 & LD3. The heterodyne signal of LD2 is sent to the reference input of the lock-in amplifier, and the heterodyne signal of LD1 or LD3 is sent to the signal input.

The synthetic wavelengths of the two interferometers are almost the same, which is 80.6 μm. Since there is a frequency difference of 20 GHz between LD1 and LD3, the detected phases of the two super-heterodyne signals are different. This difference shows the information of the synthetic wavelength \( \lambda_{s1} \).

3 Experiments and Results
Figure 3 shows the measurement stability (3 m, 50 s) of the developed super-heterodyne interference system. Since the laser beams of all the three laser diodes go through the same optical path, the measurement stability of each interferometer is better than the stability of the system using two AOMs.
The measurement stability is 0.2 μm and 0.7 μm. But the LD2 is better than the result of LD1 and LD3 because these two laser diodes are phase locked to the optical comb, and the stability of the synthetic wavelength is the same as the stability of the repetition frequency of the optical comb. LD3 is a standard stabilized laser diode, and the relative stability of the wavelength is 10⁻⁶. But the fceo of the optical comb is not stabilized, so the stability of the synthetic wavelengths of LD1 & LD3 is not very good.

The measurement stability of LD1 & LD2 is better than the result of LD2 & LD3 because these two laser diodes are phase locked to the optical comb, and the stability of the synthetic wavelength is the same as the stability of the repetition frequency of the optical comb. LD3 is a standard stabilized laser diode, and the relative stability of the wavelength is 10⁻⁶. But the fceo of the optical comb is not stabilized, so the stability of the synthetic wavelengths of LD1 & LD3 is not very good.

The measurement stability is better than the system with two AOMs, but it is no good enough. The drift is considered to be due to the drift of the carrier envelope offset frequency of the optical comb, which is 2 MHz in 10 min and the maximum drift could be 6 MHz in 30 min. Since the length under measurement is 3 m, and the difference frequency between LD1 and LD3 is 20 GHz, a drift of 2 MHz will cause a change of 14 degree in phase.

Table 1 Phase difference between the two interferometers.

<table>
<thead>
<tr>
<th>Displacement/μm</th>
<th>0</th>
<th>25.16</th>
<th>94.36</th>
<th>142.96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase difference/degree</td>
<td>93.3</td>
<td>117.6</td>
<td>121.9</td>
<td>95.2</td>
</tr>
</tbody>
</table>

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4 Conclusions

The super-heterodyne interference system using three laser diodes and an optical comb is developed. An optical switch is used to change the light sources, and there are two super-heterodyne interferometers with a synthetic wavelength of 80.6 μm (LD1 & LD2, LD3 & LD2). The measurement stability is 0.2 μm and 0.7 μm for the distance of 3 m in 50 s. The interference phase of the synthetic wavelength of 15 mm (LD1 & LD3) is calculated by the measurement results of these two interferometers. A stability of 27 μm in 50 s and 140 μm in 5 min is realized. The drift is mainly caused by the change of carrier envelope offset frequency of the optical comb. Better measurement stability and accuracy is expected if all the LDs can be phased locked to the optical comb.

5 Acknowledgements

This research work was financially supported by the Development of System and Technology for Advanced Measurement and Analysis Industrial Innovation Program at the Japan Science and Technology Agency (JST). The laser sources are developed by Dr. C. Ishibashi, NEOARK Corporation.

6 Reference