

ABSOLUTE LENGTH-MEASURING SYSTEM BY AUTOMATIC INTERFERENCE-FRINGE-PEAK DETECTION WITH OPTICAL-COMB FIBER INTERFEROMETER

Hirokazu Matsumoto^{1,2} and Kiyoshi Takamasu²

¹The Univ. of Tokyo, Dep. of Precision Eng. 7-3-1 Hongo Bunkyo Tokyo 113-8656 Japan

E-mail; hi.matsumoto@nanolab.t.u-tokyo.ac.jp

²TOKYO SEIMITSU Co., LTD

Abstract:

Optical frequency comb has various characteristics such as short pulse, broad spectra, many spectral lines, and high temporal coherency. In this present, new absolute length-measuring technique with a high resolution of 0.1 μm is developed by using temporal-coherence interferometry of optical comb and a short translation stage for various length ranges. A new fiber Fabry-Perot etalon of a free spectral range of a frequency of 15 GHz is developed for improving the fine positioning in space. Moreover, interference-fringe-peak is automatically achieved by developing a new analog electric circuit. One position is measured round several milliseconds depending to the SN ratio of the signal detected for various ranges of the lengths measured.

Keywords: Length/distance measurement, High repetition frequency, Optical comb, Absolute metrology

1. INTRODUCTION

In the field of length/distance metrology, precise measurement and then efficient measurements are demanded. In particular, manufacturing industry requires high-grade absolute measurement to produce high-quality products, and moreover it is important to assess the safety in the society. Moreover, non-contact measurement has also become important keywords in metrology. For example, the shape/form measurements of aircraft and engines are very important. In this situation, for a long time, many studies have been carried out using a continuous wave (CW) laser or a pulse laser, but use of the technology is restricted to the special applications. Recently, the significance of ultra-short optical new pulse generation and the utilizing of broad-band spectra are in progress, again. Especially, the development of femtosecond mode-locked laser technology is very fast. In addition, high-speed optical communication technology has been studied separately. Then, with the advent of photonic crystal fiber, the mode-locked pulse laser technology is very attractive for optical metrology, and then the laser is called as "optical frequency comb"(Optical comb), which has various characteristics.

Here, we report the experimental results of new method for measuring absolute length/distance using the pulse interference of the optical frequency comb (optical comb), were experimentally investigated. The technique uses only temporal coherence interferometry of the optical comb, so the measuring system is simple and very accurate. Therefore, it is useful for absolute length/distance measurements with a high accuracy up to several hundreds meters.

2. OPTICAL FREQUENCY COMB

2.1 Outline of optical frequency comb

The optical frequency comb, as shown in Fig.1, in the frequency domain, many narrow spectral lines are arranged in equal frequency interval, but sometimes the carrier envelop offset frequency exists and its control is not easy. On the other hand, in the time domain, the laser is a pulse train with very short pulse width and the intervals are constant. The time interval is stabilized to the frequency standards such as a rubidium optical clock. The stability of the time interval is good as same as an accuracy of 10^{-10} [1]. Moreover, the optical comb with all optical fiber is profitable to industrial metrology in various factories.

The optical comb offers the absolute measuring system using the temporal coherence interferometry, which does not utilize the carrier envelop offset frequency control, and is simple system for in-situ metrology. The measuring range is very wide until several hundred meters.

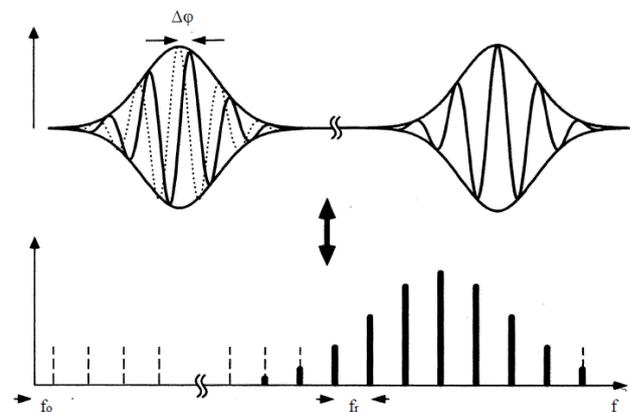


Fig.1 Outline of optical frequency comb: $\Delta\phi$: Phase slip, f_0 : Offset frequency, f_r : Repetition frequency.

2.2 Fast optical frequency comb

In general, the repetition frequency of optical combs that can be produced relatively easily in the frequency range of 40 ~ 150 MHz, because the optical fiber is relatively long to oscillate the laser, and so the temporal coherence interference is generated in the space position longer than 1 m. Thus, the length/distance fields that can be used in the measurement in the industry and the society may be limited to professional measurements. Therefore, it is important to develop the fast optical comb. For this resolution, Fabry-

Perot etalon (etalon) is useful, but it is disturbed by the surrounding conditions. Fortunately, the optical comb, since the discrete spectrum, etalon with high accuracy is not required.

A fiber-optic etalon is developed as shown in Fig.2, because the fiber-optic etalon is not fairly affected by the variation of air temperature and mechanical vibrations. The free spectral range is not accurate. The length of etalon cavity fiber (device) is cut corresponding to the free spectral range required, and sometimes is sandwiched by the optical fibers with the reflection coating and FC connectors. In this case, one optical line should be selected by the etalon of high finesse, but the power of light is reduced as shown in Fig.3 (a). The accuracy of the fast optical comb is the same to the original optical comb which of the repetition frequency is 100 MHz. On the other hand, if we use the etalon of low finesse, the power is not fairly reduced, but several lines are selected similar to multi-mode gas lasers as shown in Fig.3 (b). In this case, the accuracy of the repetition frequency is dependent to the lengths of the etalons used. I can easily suppose that it is less than about 0.5 ppm as well as that of the multi-mode He-Ne laser [2,3].

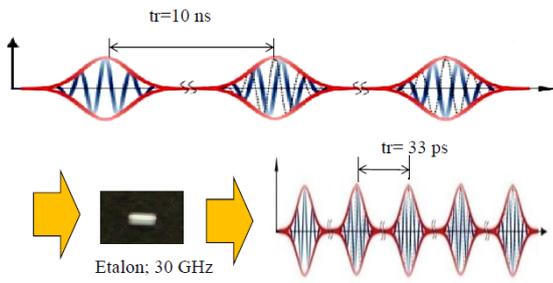


Fig.2 New optical fiber-etalon for in-situ industrial metrology.

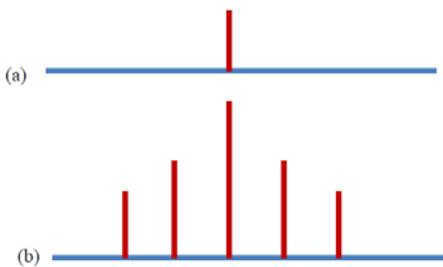


Fig.3 Optical frequency comb through the etalon: (a) high-finesse, and (b) low finesse.

Moreover, the reduced power of the fast optical comb is generally optically amplified for obtaining the high SN-ratio signal though the SN ratio is relatively enlarged, and then the pulse interferometer has a possibility of high accuracy measurement of sub ppm. Therefore, the use of the present system is not restricted to practical measurements in the industry.

3. ABSOLUTE RANGING METHOD

3.1 Pulse interferometry

The principle of position measurement using temporal-coherence interferometry is shown in Fig.4. The interference fringes are generated when the difference between the

measurement path length L_1 and the reference path length L_2 is $mc/2fr$. Here, m is integer, c is the light speed in the air, and fr is the repetition frequency of the optical comb used. The interference is generated in the length range of several tens micrometers in space depending to the pulse width of the optical comb. Therefore, this technique is very useful for various positioning with a high accuracy in space, because the fr is in the accuracy of 10^{-10} . However, the interference fringes are generated to be limited to the distance region of each 1.5 m time m in the case of 100 MHz repetition frequency, and so the translation stage is required to be scanned more than 1.5 m. In generally, the technique is not useful to absolute distance measurement in general industrial fields [4-6].

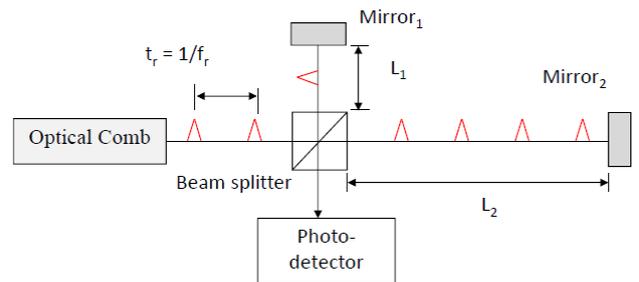


Fig.4 Temporal-coherence interferometry of optical frequency comb.

3.2 The principle of absolute measurement

In pulse interferometry, in order to form an interference fringe pattern, the reference optical path length is required to be scanned over several tens millimeters. In the measurement of the spatial position, the scanning volume was good as long as several tens of μm or more, in absolute distance measurement, that by such a stage, the number of the inverse of the repetition frequency of the comb by scanning is required. For example, in the etalon 1 GHz, optical spacing of the etalon is 150 mm, since the 1.4682 is the group refractive index of the optical fiber, the size of the etalon free spectral range is about 100 mm. Therefore, the amount of scanning required stage is required to be 150 mm or more long.

In this present, the length measurement using the repetition frequency of 15 GHz is discussed and then the scanning range of the stage is about 18 mm long. Figure 5 shows the outline of distance measurement with a scanning

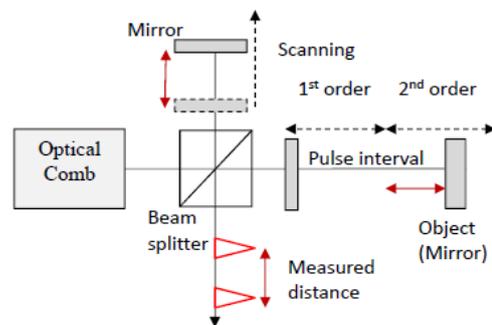


Fig.5 Outline of distance measurement.

stage. For reducing the effect due to the drift of the measurement system, the zero-point of each interference

fringe order is generated by using a window plate and the detected signal is always displayed at each order. The object mirror is at the position under measurement in space.

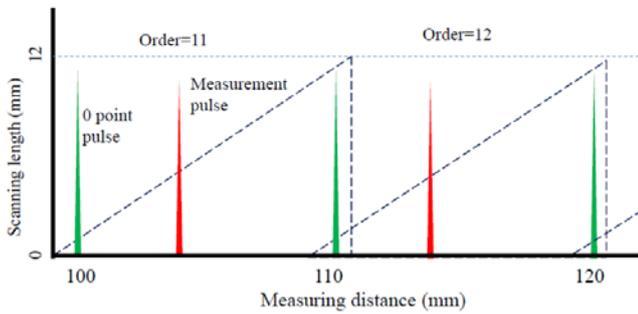


Fig.6 Measurement principle by temporal coherence interferometry with a scanning stage (15 GHz etalon).

Therefore, the measurement is made for the length/distance between zero point and measurement point which is from 0.1 mm to 10.1 mm with the scanning stage as shown in Fig.6. It is very important that it is fast and accurate.

3.3 Automatic measurement

Figure 7(a) shows the outline of automatic processing of interference fringes for determining the length/distances in the range of short distances. In this case, the signal, which shows the peak of fringe pattern, is generated. At first, the photo detection signal is squared, and then is filtered by a low-pass filter, and next is differentiated. Finally, pulse signal is generated at the zero-crossing position for doing the trigger of a short length-measurement sensor. Figure 7(b) shows the interference fringes and the trigger signal obtained.

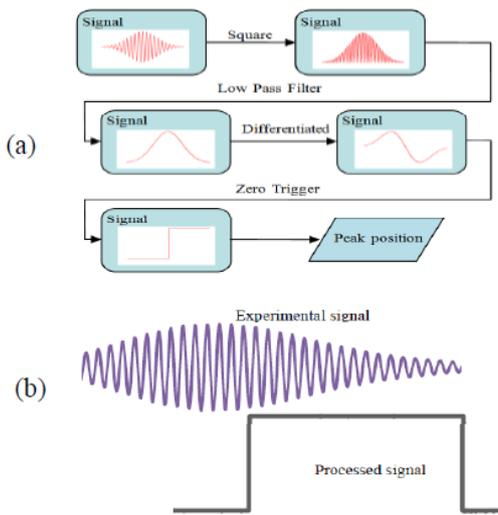


Fig.7 Automatic interference fringe processing; (a) Principle, and (b) Experimental results.

4. 4. EXPERIMENT

4.1 Interferometer and its system

The measurement system developed is shown in Fig.8. The optical comb is incident to two-beam interferometer through an etalon and a fiber circulator. The reference path is scanned by about 12 mm long because the free spectral range of etalon used is 15 GHz which corresponds to about 10 mm in length. The ultrasonic stage is used because it is compact. The measurement path has a window plate (0 point) and a reflecting mirror (target). The generated interference fringes are detected by a photo diode, and are amplified with high SN ratio by a frequency selective amplifier. The SN ratio of the final signal is enough to do automatic measurements.

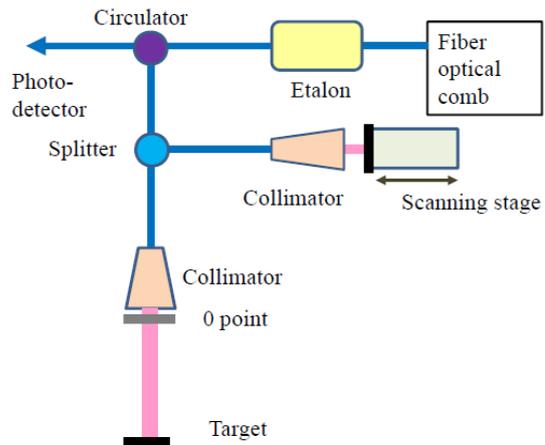


Fig.8 Experimental optical-fiber system for absolute distance measurement.

4.2 Experimental results

Using the new system developed, the measurements on length/distance were preliminary achieved and its experimental result is shown in Fig.9 with complete results. The standard deviation of measured values is less than 0.05 μm and moreover the measurement of higher reliability is achieved by using the average of several measurements. The result shows that the new system has a possibility of measuring the lengths/distances of very wide range up to several hundred meters by utilizing the etalon of different free spectral ranges. The total time of overall measurement of 10 times is fairly less than 10 ms.

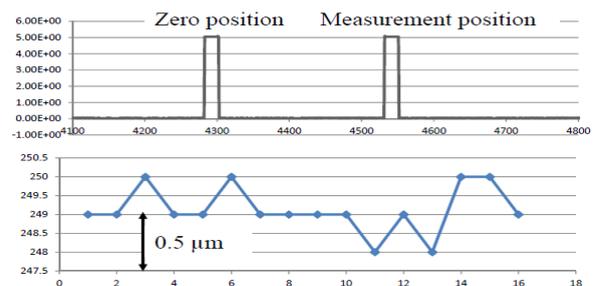


Fig.9 Experimental results of trigger signal and measurement values.

4.3 Discussions

As indicated above, the present measurement system is not fairly affected by air turbulence and mechanical vibration, but the resolution is not small because the peak of the interference fringe pattern is used. If the optical comb of the spectral width 80 nm is used, the half-intensity width of the fringe pattern is about 16 μm . Considering the SN ratio of the pattern; the measurement resolution of 16 nm is expected. Therefore, the present technology may be useful for relatively big-size object which is very difficult and much expensive, though it is also useful for short length/distance measurement.

5. CONCLUSIONS

From theoretical and experimental studies on absolute length/distance metrology, I was able to classify the problem differences between the existing CW laser and the present optical frequency comb, and so the new length-measuring method with optical comb is useful and has efficient metrology.

New absolute distance-measuring technique with a high resolution of 0.05 μm is developed by using temporal-coherence interferometry of optical frequency comb and a short translation stage for various distance ranges. A new fiber Fabry-Perot etalon of the frequency of 15 GHz of the etalon is developed for improving the fine positioning in space. Moreover, interference-fringe-peak is automatically achieved by developing a new analog electric circuit.

Future, it is desirable to develop a new technology that matches the functionality and efficient cost of measuring machine/technique that is acceptable to the user is important, and then the assistance from the government is also important, because metrology is the property and culture of human.

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