

High-Precision Dimension Measurement of Large Scale Workpiece by Laser

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Introduction

The dimension accuracy of a large scale workpiece is one of the most important parameters to assure the quality of heavy machines such as 60MW steam turbine rotors and fixers, however, there are not available methods to meet the needs of high-precision measurements for such machines. The most difficult problem with large dimension measurement is how to aim at and position to the measured points in a large-scale workpiece. This problem has not been solved properly up to now.

A new method of aiming at the points of a large workpiece is developed by using a laser beam from a host-built mono-mode fiber laser collimator, which is a Chinese Invent Patent^[1]. The high-precision dimension measurement of large workpieces is realized by using a heterodyne interferometer such as a Hewlett-Packard laser interferometer. The experiment results on a 1000mm block gage and on a 500mm diameter workpiece show that uncertainty (three sigma) within 5 micrometers is obtained.

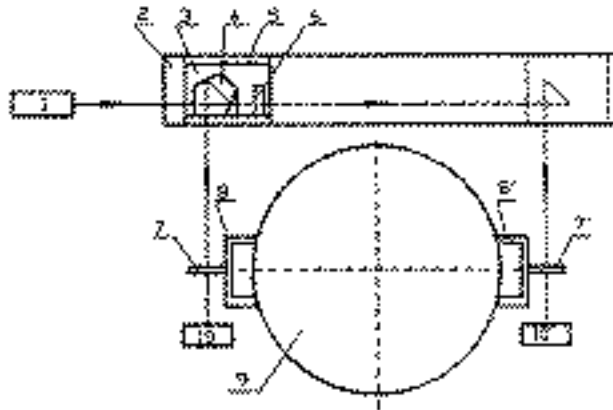
Principle of Aiming and Positioning

It is well known that a heterodyne laser interferometer is one of the most accurate length measurement methods. Typically, such a laser interferometer has a resolution of several nanometers with the relative measurement accuracy of about 10^{-7} within a measurement range of up to 60 meters. So, how to directly use a heterodyne laser interferometer for large dimension measurements, especially large diameter measurement is a target to be pursued. Unfortunately, this problem has not been solved up to now due to the fact that aiming at and positioning the measured points of a large diameter is very difficulty. A novel method of aiming at and positioning the measured points of a large diameter is put forward in this paper and high precise measurement of large workpiece is realized by using a laser interferometer.

There are some current optical methods to aim at and to position the measured points of a diameter. A light gauging method^[2] by which a laser beam is used to aim at the two diametrically opposite points of a diameter is one of examples. In this measurement principle, the point of the measured workpiece diameter to be considered is aimed at correctly when 50 percent of laser energy is blocked by the edge of the workpiece. The dimension of the diameter can be measured by comparing it with a known size diameter, which makes it very inconvenient for this method to be used for large diameter in site. In addition, the positioning by a long mechanical arm limits greatly the measurement range of diameter.

Fig.1 shows a method of aiming at and positioning the measured points of a large diameter by a laser beam. The laser beam from a single-mode fiber laser collimator is divided into two parts by a beam splitter when it passes through a pentagonal prism in the measurement head. One part of the laser beam, which is reflected by the pentagonal prism at an angle of 90 degrees with respect to the incident ray, forms a datum line for aiming at the workpiece. When the measurement head is moved along a slideway,

the reflected ray successively aims at centers of two quadrant silicon photodiodes on the magnetic positioning chocks attached on the two end points of the measured workpiece. With the coincidence of the incident ray into the chock and the ray reflected from it, the correct positions of two chocks are ensured. In this way, the two diametrically opposite points are correctly aimed at. The another part of the laser beam, which passes through directly the pentagonal prism and is received by another quadrant photodiode fixed with the pentagonal prism, forms a datum line for adjusting the position of the measurement head. With this datum line as a reference for adjusting, the positions of the measurement head can be kept to be fixed when the reflected laser beam successively aims at two points of the measured workpiece, thus eliminating influences of the straightness error and the position error of the sildeway on the measurement results.



1 Single-mode fiber laser collimator, 2 Slideway, 3 Measurement head, 4 Pentagonal prism, 5 Carriage, 6.7.7' Quadrant photodiode, 8.8' Positioning Chock, 9 Workipece, 10.10' Signal processor.

Fig.1 Schematic Diagram of Aiming and Positioning

The theoretical analyses and experiments show that the Abbe error is greatly decreased even though there exists a large Abbe offset in the case of measurement of large outer diameters. The only source for Abbe error is from laser beam direction drift, but it decreases largely as the laser beam from a single-mode fiber laser collimator is very stable.

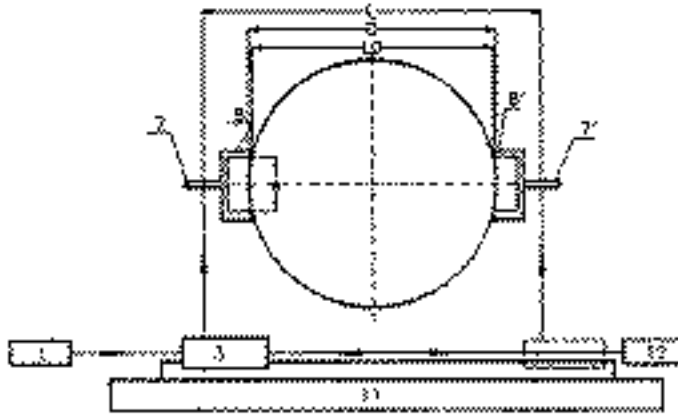
Measurement Principles

A schematic block diagram for high-precision measurement of large workpieces is shown in Fig.2. A Hewlett-Packard laser interferometer is used as a high accurate length measurement instrument. Before the measurement, it is necessary to make the measurement direction be perpendicular to the axis of the measured workpiece in order to reduce the Cosine error. It is also necessary to adjust the positions of the positioning chocks on the workpiece in order to ensure the correct measurement position of the chocks. When all these adjustments are correctly done, the distance between centers of two quadrant silicon photodiodes on the chocks can be measured directly by a laser interferometer when the measurement head is moved along the guideway to make the reflected laser beam from the single mode laser collimator aims at the two centers successively.

If the system is used to measure dimension between two parallel planes of a large scale workpiece, its size or dimension can be easily obtained by

$$L_0 = L - C \quad (1)$$

where L_0 is the length of the measured workpiece, L the distance between centers of the two quadrant photodiodes, C the distances between two centers when the two chocks are put together. All these parameters are shown in Fig.2.



1 Single-mode fiber laser collimator, 3 Measurement head, 7,7' Quadrant photodiode,8,8' Positioning chock,
11 Chassis of a lathe, 12 Hewlett-Packard laser interferometer

Fig.2 Schematic diagram of measurement of large diameters

If the system is used for measuring both external and internal diameters, the equation for getting the dimension becomes

$$D = \sqrt{(L \mp C)^2 + S^2} \quad (2)$$

where S is the slot width of the chock. The signs of negative “-” and positive “+” are used when the system is used to measure external and internal diameters respectively.

Other high precise length measurement systems such as grating length measurement system etc. can be used as a substitute for a laser interferometer. In addition, a dual frequency wavelength beat wave interferometer can be used to measure absolutely diameters of extremely large workpieces without a guide^[3], as in this case, uses of a guide can be very difficult or inconvenient in practice.

When the measurement chocks are positioned correctly, the whole measurement is completed automatically as there are several step motors and a computer installed on this system and it is now used in a steam turbine factory to measure large diameters of rotors.

Experiments

The experiments on a 1000mm gauge and on a 500mm diameter were made by the system on a laboratory not temperature-controlled with the correction of temperature errors for both the material and laser wavelength. A HP5528 laser interferometer is used in the measurement system. The two chocks are placed on the two end planes of the gauge, its dimension can be measured by using Equation (1). Table 1

shows four groups of experiment data with each group of resulting taken from 11 times of measurements. The gauge size measured by a 1000mm measurement machine is 1000.0035mm.

Table 1 The Experiment Results on a 1000mm Gauge (in mm)

<u>Group Number</u>	<u>Results(with three sigma)</u>
1	1000.0025±0.0019
2	1000.0025±0.0033
3	1000.0037±0.0050
4	1000.0041±0.0020

Table 2 shows the experiment results on a 500mm external diameter obtained by the system using the Equation (2). The result taken from a model MERLIN II coordinate measuring machine is 499.8775±0.004mm.

Table 2 The Experiment Results on a 500mm Diameter (in mm)

<u>Group Number</u>	<u>Results(with three sigma)</u>
1	499.8748±0.0028
2	499.8749±0.0021
3	499.8753±0.0018

The major error resources include: the error produced by the system, the fluctuation of the temperature and the temperature gradient existing in the measurement direction etc. as the experiments were conducted in a not-temperature-controlled laboratory. The uncertainty(three sigma) within 5 micrometers in measuring a 1000 diameter can be ensured if the temperature error can be corrected.

Conclusions

In this system, the application of a single-mode fiber laser collimation technology decreases greatly the Abbe error caused by the laser drift. The use of one pentagonal prism instead of two pentagonal prisms^[2] to aim at two points of the diameters eliminates the Abbe error produced by angle manufacturing errors of the prisms and reduces the influences of the straightness error and position error of the carriage on the measurement results. The use of magnetic positioning chocks extends greatly the measurement ranges and makes it convenient to be used in practice. By using this aiming system together with a heterodyne interferometer, high-precision dimension measurements of large inner, outer diameters and lengths up to 10 meters can be realized. The experiment results on a 1000mm gage block and on a 500mm outer diameter show the three sigma uncertainty to be within 5 micrometers.

References

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3. Qibo Feng, Qinwen Liang, *Study on absolute measurement method of a large diameter by a 3.39 μm dual frequency wavelength beat wave interferometer*, Chinese Journal of Lasers, 1994, A15 (11).