A non-contact gear measurement method based on laser vision*

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In order to classify the gears and achieve high precision measurement results, a non-contact gear measurement system based on the laser vision is developed in this paper. The laser vision precision measurement method (LVPMM) is proposed to ensure the accuracy. Experimental results indicate that the gear measuring uncertainty is 2.1 μm. The precision can satisfy the gear measurement requirements for two-grade or under two-grade standard gears in industry, and can classify the gears very well.

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Gear measuring process is complicated[1,2], and the precision of gear measuring instrument is very important. The research on gear detection methods can be divided into two categories: the contact measurement[3-7] and the non-contact measurement[8-10]. However, these methods have high demands on the measurement environment, so can not be widely used. The non-contact gear measurement mainly includes image analysis method[11,12] and laser ranging method. The image analysis method is difficult to detect the gear lead surface defects, especially for helical gear lead surface. Zhang xinghua[13] and others designed gear chamfering profile measurement system based on laser ranging and achieved the measurement of gear chamfering section. But the system did not meet the accuracy requirement of gear lead detection, because of the complexity of the gear shaping and a lot of test items.

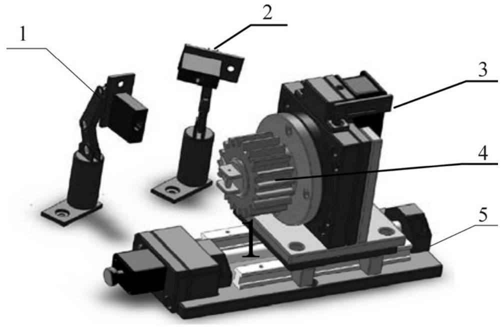
Based on the former researches of our laboratory[14,15], the laser vision precision measurement method (LVPMM) is proposed. The method uses laser vision measuring principle and combines the accurate positioning movement of the rotating table and linear guideway. It is able to get reliable data, meet the demand of nondestructive testing of gears, and realize the comprehensive measurement of gear lead. The corresponding measuring devices are developed and have been successfully applied.

The measurement system of gear lead is shown in Fig.1. It is mainly composed of two laser vision sensors, a microcomputer, a control box, a linear guideway, a precision electronic rotating table, an optical table and gear positioning components. The measuring process consists of the following three parts:

1) The two laser vision sensors collect the data of the gear lead, and then laser visual sensors convert the data into electrical signals and send the electrical signals to the data processor. The data processor connects and communicates with the computer through RS232 serial bus.

2) The linear guideway and the precision electronic rotating table connect through two adapter plates. Grating ruler is the position detecting element of linear guideway and rotating table. It feedbacks the workbench's motion state and location information to the control system in real time. According to the feedback information, the control system realizes the closed-loop control of linear guideway and rotating table using the servo motor.

3) The measuring modules are integrated by upper computer system. Computer communicates with control system through RS232 serial port.



1. Laser vision sensor a; 2. Laser vision sensor b; 3. Precision electronic rotating table; 4. Cylindrical gear; 5. Precision electronic translation table

Fig.1 Gear-line measurement system

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Laser vision sensors as the main measuring tool of measurement system, combine with the linear guideway and the precision electronic rotating table to realize the measurement of the related parameters. Two laser visual sensors are installed to the measured workpiece installation position of the optical table and are fixed with a universal rotating support. The linear guideway moves at a constant speed back and forth on the *x* axis. The precision electronic translation table moves in forward or reverse direction at a constant speed around the *x* axis. During measurement, the position of the laser vision sensors must be firstly adjusted to make workpiece in measurement range. Then the straightness of the workbench and the alignment of jig should be calibrated to complete the system calibration. According to the system calibration, the parameters of workbench can be set, and then a work command will be issued to computer through software system. After receiving the command, computer issues a control command to drive the servo motor control system. The motor drives the bench to work and laser visual sensors scan the workpiece on the bench simultaneously. In a sampling interval, the two laser vision sensors a and b complete a collection action at the same time, then the collected data is converted into digital quantity and transferred to the computer, then a sampling period ends. After the completion of the measurement, the computer reads data from the acquisition card, then stores and displays the information collected by the two laser vision sensors. The system is able to achieve accuracy testing of gear lead, gear ring radial runout, etc, and classify gears.

As shown in Fig.2, sensors adopt the laser vision ranging principle[16]. The beam emitted by the laser incidences vertically on the object surface after the converging lens focus. Object moving or surface changes will lead to the incident light spot moving along the incident optical axis. The receive lens receives scattered light from the incident light, and then its image is formed on the photoelectric receiving sensitivity surface. When the distance of the object surface changes *D*, the position of image on the photoelectric receiving sensitivity surface will change *a*. Then the actual displacement of the object can be calculated by the relationship between the image displacement and the actual displacement.

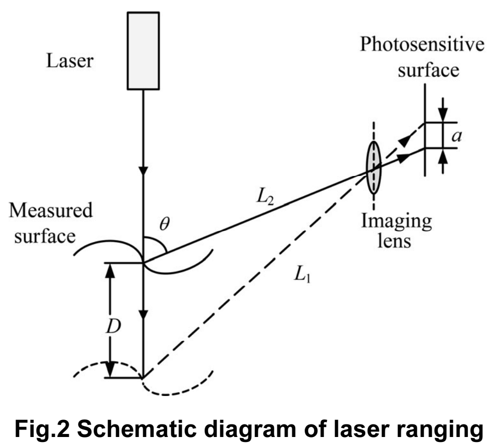

Fig.2 Schematic diagram of laser ranging

Two laser vision sensors are used to measure the left and right tooth surfaces in measurement system respectively. They work at the same time. Before measurement, the parameters of measured workpiece are input, and then a work command is sent to the system if the parameter is set correctly. The measurement adopts multi-tooth surface measurement model and is able to ensure the continuity and integrity of the measurement.

Many factors have a significant impact on the result of the measurement, for example, the measuring accuracy of the laser vision sensor, the straightness of jig, the concentricity of jig and rotating table. Thereby the measurement system calibration must be done before measuring the workpiece. Standard gauge blocks manufactured by Harbin Measuring Tool Company are used to the accurate calibration of laser vision sensors. In the calibration process, the standard gauge blocks 20, 1, 1.005, 1.05, 1.1, 2 and 10 are used. In order to make the results more accurately, the laser should irradiate vertically to the optical surface of gauge blocks as far as possible. Calibration results are shown in Tab.1.

Tab.1 The checking results of the sensor (Unit: mm)

The total thickness of the engagement block	The ideal value	The measured value	The absolute error
20.0000	\	39.2304	\
21.0000	38.2304	38.2302	-0.0002
22.0050	37.2209	37.2208	-0.0001
23.0550	36.1709	36.1801	0.0002
24.1550	35.0709	35.0708	-0.0001
26.1550	33.0709	33.0707	-0.0002
36.1550	23.0709	23.0800	0.0001

It can be derived from Tab.1 that the error value of laser visual sensor used in the system is 0.00015 mm. It conforms the requirements of the system.

As we know, the gear measurement is usually in the place of pitch circle. This circle is intersecting lines of transverse plane and indexing cylindrical surface of cylindrical gear. It is the size standard of computing gear parts. In the process of calibration, addendum circle and dedendum circle of the gear are replaced by two fine grinding cylinders, as shown in Fig.3. The two fine grinding cylinder diameter sizes are decided by addendum circle and dedendum circle of the gear. The pitch circle location is determined by the geometric relationship.

In Fig.4, M1 is laser vision sensor, M2 is fine grinding cylinder, *AB* is the distance between the sensor and the addendum circle, and *AC* is the distance between the sensor and the dedendum circle. Assume that $OA=S$, $AB=d_1$, $AC=d_2$, $BC=l$, $DC=p$, $OD=q$, $OB=r_1$, $OC=r_2$.

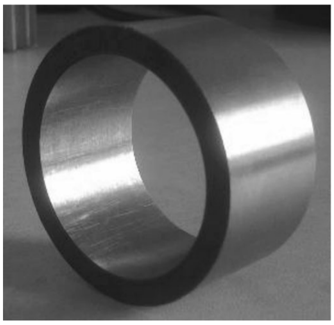

Fig.3 The cylindrical grinding for calibration

By the figure, the following relationship can be obtained:

$$q^2 + p^2 = r_2^2 , \tag{1}$$

$$r_1^2 = q^2 + [p + (d_2 - d_1)]^2 . \tag{2}$$

Then we can get

$$q = \sqrt{r_2^2 - p^2} , \tag{3}$$

$$p = \frac{r_2^2 - r_1^2 - (d_2 - d_1)^2}{2(d_2 - d_1)} . \tag{4}$$

From the above formula, we can know

$$S = \sqrt{q^2 + (p + d_2)^2} . \tag{5}$$

By the triangular relationship, we have

$$\alpha = \arcsin(q/S) . \tag{6}$$

As we know, the position of sensor does not change in the testing process, therefore, the distance S of the sensor to the center of the gear is a fixed value, and α is also a fixed value. Thereby the relationship between d detected by sensors and the radius R of gear can be obtained from cosine theorem

$$R = \sqrt{S^2 + d^2 - 2Sd\cos\alpha} . \tag{7}$$

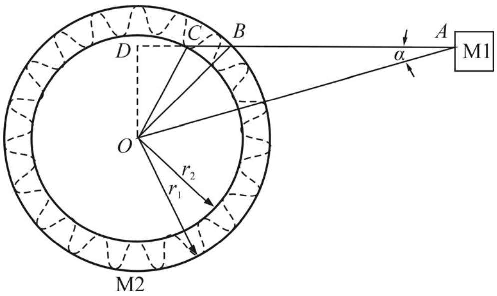

Fig.4 Model diagram of the relationship between sensor and gear position

The establishment of the mathematical model is to find the location of gear pitch circle. As the pitch circle on the gear does not have a distinct geometric position, only to find out pitch circle by the relative position of the dedendum circle, the addendum circle and sensors. Therefore, the above described calculation method was derived. Experiments show that this method is easy to find the gear pitch circle and has good effect of calibration. When the system space position calibration is completed, the measurement of gear can be started.

The system interface is shown in Fig.5. The four groups of data in the left and right display bars are the measurement results of two laser vision sensors respectively. The measured gear is the cylindrical spur gear with m=4.1, α=22.5 and z=19.

Each gear only needs to detect 4 teeth, and measure two tooth surfaces. Each lead line measures 3 groups of data, and 14 measured values are selected from every group of data. The measurement results are shown in Fig.6.

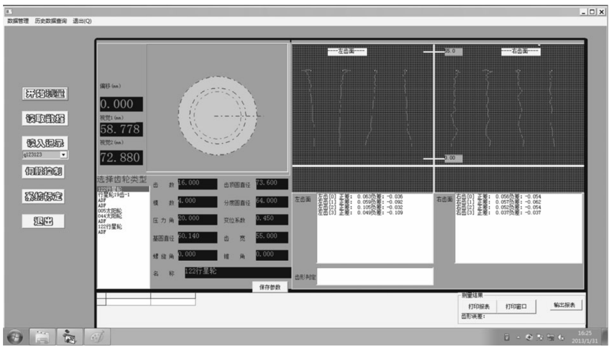

Fig.5 System operation interface

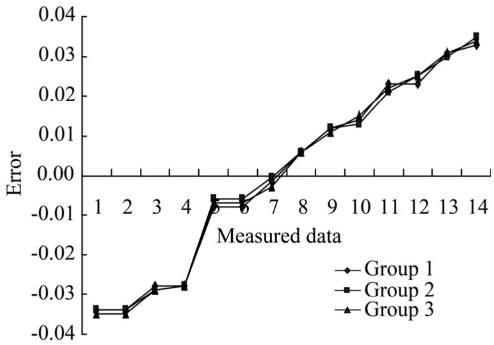

Fig.6 Measurement errors of 3 groups

Uncertainty evaluation of the measurement results is measured by national metrology technical specification. It can be known from the measurement results that the average distance measured by the vision sensor is 37.619 mm, measurement uncertainty is 0.0021 mm, and the maximum helix deviation value is 0.035 mm.

The LVPMM for gear is proposed in this paper and the high precision, fast, non-contact measurement of cylindrical gear lead is achieved. The system uses laser vision ranging principle and combines accurate positioning of the linear guideway and the rotating table controlled by servo motor. The system software is designed by VB. The repeated measurements show that the measurement uncertainty of the system is 0.0021 mm.

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