The Research of Screw Thread Parameter Measurement Based on Position Sensitive Detector and Laser

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Abstract. A technique and system of measuring screw thread parameter based on the theory of laser measurement is presented in this paper, which can be carried out the automated measurement of screw thread parameter. An inspection instrument was designed and produced, which included exterior imaging system of optical path, transverse displacement measurement system, axial displacement measurement system, and a module to deal with, control and assess the data in the upper system. The inspection and estimate of the screw thread contour curve were completed by using position sensitive device (PSD) as photoelectric detector to measure the coordinate data of the screw thread contour curve in the transverse section, and using precise raster to measure the axial displacement of the precision worktable under the screw thread test criterion., computer can gives a measured result according to coordinate data of the screw thread obtained by PSD. The relation between measured spot and image is established, and optimum design of the system organization are introduced, including the image length of receiving lens. focal length. optical system and the choice of PSD , and some main factor affected measuring precision are analyzed. The experimental results show that the measurement uncertainty of screw thread minor diameter can reach 0. 5μm, which can meet most requests for the measurement of screw thread parameter.

1. Introduction

Thread pieces as a connecting are commonly used in manufacturing and aerospace industries, particularly in the case of some aircraft systems, many components are connected to a thread. With the development of modern technology, requires high reliability and interchangeability to thread, and the accurate detection of thread parameters for improving interchangeability and thread reliability is of great significance.

The measurement of screw thread parameter in traditional method is the use of thread gauge by contact-type or the use powerful tools microscopes by men, big workload, low efficiency, and it is vulnerable to the result of measurements by man-made factors [1]; for complex screw thread parts in the shape of geometry, traditional testing methods were not applied. Therefore, the principle and implementing method of non-contact thread parameter inspection based on laser measurement principle were presented, which can eliminate contact-induced measurement errors in measurement, can increase detection accuracy and achieve thread parameters automatic measurements.
2. Laser measurement principles

Figure 1 shows the principle of measuring the screw thread parameter based on the laser-optical method [2]. The laser origin from the semiconductor LD goes through the aperture, the polarizing beamsplitter, the \( \lambda/4 \) wave-plate, the receiving lens, and then spread on the surface of screw thread, then some of the dispersion ray of the incidence ray is pool by the receiver lens and focus on the PSD. When the incidence spot has a displacement \( l \) along the optical axis, it causes a displacement \( l' \) of

![Figure 1](image)

**Figure 1.** The basic principle of laser-optical triangulation method.

1. the semiconductor LD  2. the aperture  3. the polarizing beam splitter  4. the \( \lambda/4 \) wave-plate  5. the receiving lens  6. the receiver lens  7. position sensitive detector (PSD)

image point on the sensitization surface, which causes the change of the signal coming from PSD. We can detect the change of the signal to get the value of \( l' \), according to the relationship of image and object in geometry optics:

\[
\frac{1}{a} + \frac{1}{b} = \frac{1}{f}
\]

(1)

Where \( f \) is the focus of receive lens, \( a \) is the distance of the receiving lens and the reference point; \( b \) is the distance of the receiving lens and the center of PSD. The relationship of \( l \) and \( l' \) can be described in such a formula:

\[
l = \frac{al' \sin \beta}{b \sin \alpha - l' \sin(\alpha + \beta)}
\]

(2)

Where \( \alpha \) is the angle of the incidence axis and receiving axis; \( \beta \) is the angle of receiving axis and PSD device. When the image point of the incidence ray is on the center of optoelectronic detector PSD, the incidence point becomes the measurement datum mark. The selection of \( \beta \) must satisfy the condition of constant focus.

When the point was just to throw the photosensitive surface of PSD, it outputs two routes of current, the quantity of which is according to the intense and position of the light spot on the photosensitive surface. The relationship of \( l' \) and the two routes of current \( I_1, I_2 \) is described in the following [3]:

\[
l' = \frac{L}{2} \frac{I_1 - I_2}{I_1 + I_2}
\]

(3)

Where \( L \) is the photosensitive length of PSD.
3. Systems design optimization analysis

3.1. Light path and PSD design optimization analysis
As showed in the figure 1, according to laser measuring principle, optics distortion of light source spot on the energy center of gravity change have a great impact on the measurement accuracy. Tapering incident beam is an effective way to reduce the optics distortion, where an diaphragm and converging lens is added in the light path to taper the light beam, and to eliminate stray light. Polarizer and $\lambda/4$ wave plate prevent light source fluctuating from the device’s return light. According to the optimum design scheme of the measurement system, PSD that is picked is S3979 device and produced by HAMAMATSU, Japan. Its effective area of receiving light is 1mm×3mm, position resolution is 0.1μm, the maximal dark-current is 10nA.

3.2. The determination of receiving lens’s imagine distance and focal distance\[4\].
The change of light from the laser measuring system is small on the surface of the screw thread, so can make $b=90^\circ$ and by formula (2) and seek its differential coefficient, get the following equation from the formula (2):

$$\frac{dl}{dl'} = \frac{ab \sin \alpha}{(b \sin \alpha - l \cos \alpha)^2}$$

(4)

Usually $b \sin \alpha >> l \cos \alpha$, so Eq-2 and Eq-6 can be expressed respectively as:

$$l = \frac{a' l}{b \sin \alpha}$$

(5)

According to the Eq-5, the input and output of the measuring system is approximate linearity. The maximal measurement range $l_{max}$ is direct ratio to the size $l'_{max}$ of the PSD’s sensitive plate. When the resolution of the PSD is fixed value, the larger value of $b$ can enhance the measurement resolution, but reduce the measurement range corresponding.

In the condition that working range is less than $\pm5$mm, maximal working distance is 220mm, measurement resolution is 2μm, the resolution of the preferred PSD is 0.1μm, the size of the sensitive plate is 3×1mm, from the Eq-4, we can know that measurement resolution is the minimum when the incident light is the negative brim $l'=5$mm of the measurement range. Introduce known parameters into Eq-4 and get:

$$\Delta l = \frac{100b \sin \alpha}{(b \sin \alpha + 6 \cos \alpha)^2} \leq 2 \times 10^{-3}$$

(6)

According to the Eq-1, when $l'=-5$mm, the measurement range $l_{max}$ should meet flowing equation:

$$l_{max} = \frac{100 \times 5}{b \sin \alpha - 5 \cos \alpha} \geq 2$$

(7)

According to the Eq-6 and Eq-7, the range of the parameter $b$ can be determined when one of parameters, such as parameter $a$ is known and $f$ can be gained from Eq-1.

4. Performance Experiment and analysis of influencing factors

4.1. Experimental system and measuring results
The geometric information of screw thread parameter was obtained according to the principle of measurement, and then, acquired various screw thread parameters by definition and datum processing. Figure 2 shows the measuring principle of the screw thread parameter. Measurement systems was designed and produced, which included transverse displacement measurement module, axial displacement measurement module, and a module to deal with, control and assess the data in the upper
system. Figure 2 shows the system of experiment. The use of position sensitive device (PSD) as photovoltaic detector along the axis cross-section must scanning thread teeth shaped contours, photoelectric detectors detected teeth-shaped contours of the radial coordinates, and axis coordinates of screw thread (axial displacement of sensor) must be given by precise raster sensor. Two coordinates sensors controlled by the computer clock simultaneously surveys the sampling according to the certain time-gap, constitutes the group coordinates, can acquire two-dimensional coordinates data of section contour in the measurement of screw thread. The data can be used to calculate the half-angle of screw thread and thread pitch. To obtain measuring information about radius, required to measure the two axis coordinates data of cross section of teeth-shaped contours in the location of diameter. To this end, after the completion of the side teeth is measured, photovoltaic detectors must be rotated with 180° around optical axis to acquire the measuring information about radius using same method, then the value of half diameter about screw thread can be calculated thread by the two sets of data and definition.

The top-computer process the two dimensions of longitudinal and lateral displacement datum, it can paints the conjugate surface of screw thread. And then whether the measured screw is qualified or not can be evaluated referring to certain parameter standard of screw thread.
Figure 3 shows the contours curve after curve fitting by test system for measurements of the screw thread, the experimental results indicate that the uncertainty of the measuring system is up to 0.5 μm.

4.2 Analysis of influencing factors influencing for test system

4.2.1 The influence of the spot size for the objective surface. Through the experiment we found that when the light incident power is constant, the spot size has significantly influence on the measurement precision. Generally, the less size of the incident facula has higher precision of the measuring result, the received power of PSD is in proportion to $I_0$. When the incident facula size is a constant, $I_0$ is in proportion to the square of the diameter. Therefore, when the size of the incident facula increases, the power received by the PSD will decrease, and weak photoelectrical signal and low signal-to-noise ratio, this will make the precision of the measuring system to decrease. For improve measuring precision, we can solve this problem through increasing the diameter of the lens or reducing optical parameter $a$ and so on to increase receiving optical power to PSD.

4.2.2 The influence comes from the incline of the measured surface. According to analyzing the experiment results, we find out that the measured surface’s incline has much influence on the result. The measuring error caused by the surface’s incline mainly comes from these two aspects: firstly, the incline of the measured surface can change the power received by PSD; secondly, the equivalent energy center of the image facula displaces. Object plane leaning make the equivalent center displacement of image facula produce leaning error on the PSD. The changing law of the leaning error can be summarized as: leaning error increases as the $|l|$ and $|\gamma|$ increases. The range of the measured device leaning angel has been known, so we can use software to revise the measurement error.

5. Conclusion

The principle and implementing method of non-contact internal and external thread parameter inspection based on laser measurement principle are presented in this article, which can carry out the automated measurement of thread parameter, and to avoid friction and edge deformation and other factors, help to improve the precision. The two-dimensional coordinate data obtained by scanning the axis section of thread teeth shaped contours can reflect the geometrical shape error of screw thread completely. Experiment result shows that measuring resolution is 0.5 μm, nonlinear indicating error of laser sensor is 0.04%. The technology provides a new technology approach for solving the distortion problem caused by contact measurement, and real-time control of thread processing quality, increase testing accuracy and efficiency of testing.

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