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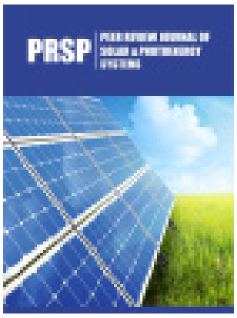
Dimension and Symmetry Inspection Algorithm of Closed Keyseat Based on Grating Principle

Lizhi Gu[1,2], Jinling Song[3]*, Shanping Gao[1], Ehui Huang[1] and Bingzhang Lin[1]

[1]Key Laboratory of Virtual Manufacturing Technology of Fujian Universities, Quanzhou University of Information Engineering, China

[2]College of Mechanical Engineering and Automation, Huaqiao University, China

[3]Quanzhou Normal University, China



***Corresponding author:** Jinling Song, Quanzhou Normal University, China

Submission: February 07, 2023
Published: May 05, 2023

Volume 2 - Issue 3

How to cite this article: Lizhi Gu, Jinling Song, Shanping Gao, Ehui Huang and Bingzhang Lin. Dimension and Symmetry Inspection Algorithm of Closed Keyseat Based on Grating Principle. Peer Rev J Sol Photoen Sys. 2(3). PRSP. 000538. 2023.

Abstract

The closed keyseat on the shaft is an important surface of the shaft, which requires high precision keyseat depth and symmetry. But the closed keyseat on shaft is usually finished by V-block positioning milling on general purpose milling machine or NC machine tool with difficult to meet high precision requirements, especially the high precision inspection. Based on the analysis of the general inspection methods of keyseat depth and symmetry, this paper proposes and uses the parallel beam of grating principle, oblique irradiation, narrow slit scanning and intelligent algorithm. The relevant data are measured online and the error norm is used to determine whether the keyseat is qualified or not, and the rapid inspection of 0.1 micron level is realized, providing technical support for the intelligent manufacturing of components with keyseat.

Keywords: Grating principle; Closed keyseat; Symmetry detection; Parallel beam of light; Error norm

Introduction

The measurement of the symmetry of shaft keyseat is an important but difficult point in machining quality control. No matter by using the traditional way to measure on the inspection platform or by the CNC machine or three coordinate measuring machine, it takes a lot of time, especially for the large diameter of the shaft. Shanshan [1] used the Canny algorithm to extract the two-dimensional contour of the mechanical parts to be tested effectively, and the contour information was refined under the sub-pixel subdivision edge technology. Zhang et al. [2] proposed a new method for precision evaluation of sheet metal forming geometry measurement with statistics theory and combination of the characteristics of 3D optical measurement technology, gaining the accuracy of dimensional inspection. Yun et al. [3] proposed the application of intelligent inspection robot system in sutong GIL comprehensive pipe corridor project. Yong [4] employed laser tracker to achieve faster and more accurate online detection of large workpiece, focusing on how to use the laser tracker to quickly and accurately complete the measurement of shaft keyseat symmetry. Yan Wenping et al. [5] proposed a method to use specially designed process equipment to test keyseat. Su-Mei et al. [6] worked out a machine vision system based on vehicle data recorder and image signal processing to automatically evaluate rail curvature in view of the long distance of railway lines, which makes it difficult to detect track state effectively and accurately. Yong et al. [7] Proposed a detection system for LED press based on machine vision in this study. In this system, two cameras are used to detect epoxy point position and two cameras are used to detect patch status. Mittal et al. [8] described an in-depth survey of problems faced in existing computer vision applications and to present AI on the Edge along with Open VINO toolkit as the solution to those problems. Feng et al. [9] demonstrated a novel application of computer vision technology to solve a challenging vehicle WIM problem. Requiring no sensor installation on the roadway or the vehicle, this cost-effective non-contact computer vision system has demonstrated a great potential to be implemented. Tsotsos et al. [10] examined the distribution of sensor settings in vision datasets, only one potential data set bias, and performance of both classic and deep learning algorithms under various camera settings. The current study will use the grating principle to inspect the closed keyseat with efficiency and ease.

Common Inspection of the Keyseat

The detection of keyseats on the shaft is divided into geometric size detection and position detection. Keyseat geometry size detection is relatively simple, can be directly tested by the meter or gauge. The position detection refers to the offset degree of both sides of the keyseat with respect to the measurement reference, which is difficult to detect because of many complex influencing factors. The commonly used measure of symmetry uses a dial meter or digital instrument to measure the side of the key without gap with the measured keyseat (Figure 1).

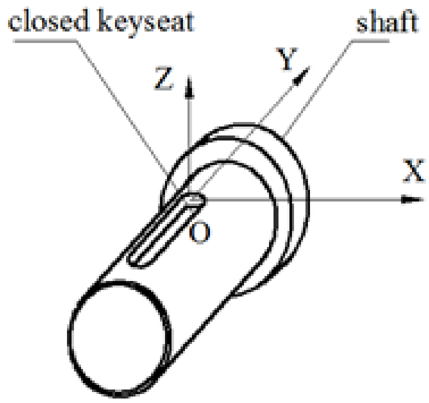


Figure 1: Object to inspect: closed keyseat.

Traditional symmetry inspection

$$e = \left| \frac{t_1(\Delta_1 + \Delta_2)}{d - t_1} + (\Delta_1 - \Delta_2) \right| \quad (1)$$

where d—— shaft diameter

t_1——keyseat depth

Δ_I—— deviation of one working side of standard block from the axis of the shaft

Δ_{II}—— deviation of another working side of standard block from the axis of the shaft

High Precision Inspection On-line Based on Grating Principle

Inspection datum axis—central line of the shaft

In grating field, a beam of parallel laser lights radiate perpendicularly the sensing screen (Figure 2). the shaft with a closed keyseat is laid just in the way. And then on the sensing screen the two longitudinal lines of the shaft contour are obtained. When a third line is put forward orthogonally to the two lines, two intersection points, P_1 and P_2, are known, and the distance between the two points will be obtained in terms of the diameter, d. In order to gain the precision value of the diameter, several pairs of the dual points may be made (Figure 3 & 4).

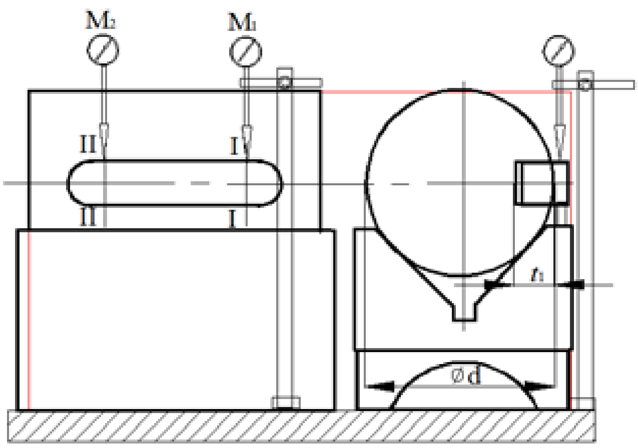


Figure 2: Common inspection of keyseat symmetry.

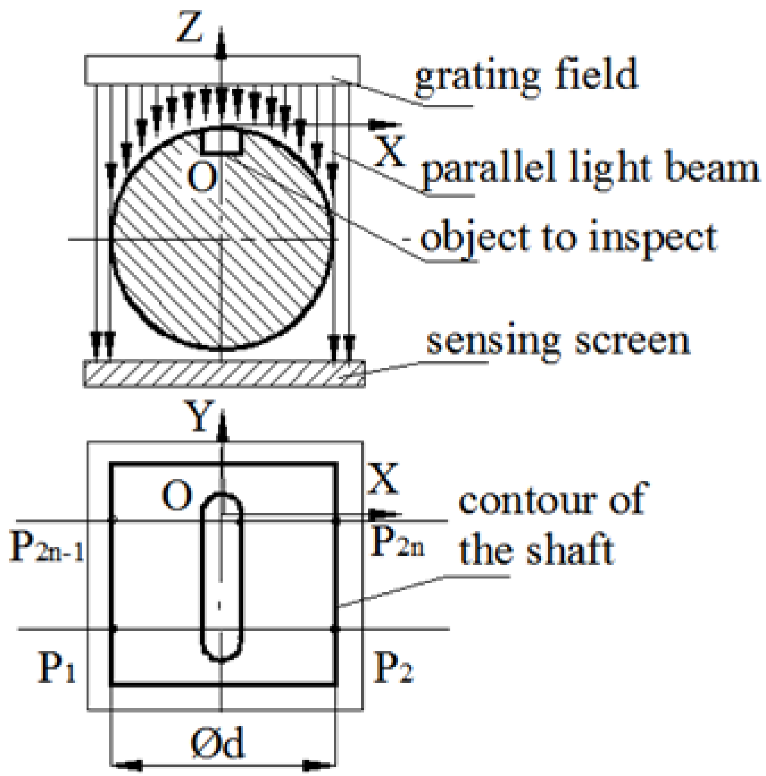


Figure 3: Common inspection of keyseat symmetry.

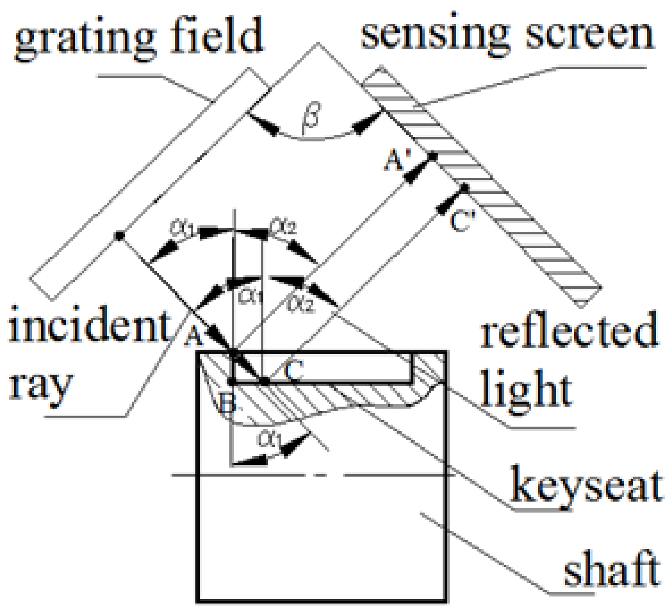


Figure 4: Common inspection of keyseat symmetry.

Then we have the diameter of the shaft

$$d_M = \frac{1}{n}\sum_{i=1}^{2n}\left|(x_1 - x_2)_i\right| \quad (2)$$

The location of the datum axis is l_{datum}

$$l_{datum} : x = \frac{1}{2n}\sum_{i=1}^{2n}(x_1 + x_2)_i \quad (3)$$

Equation (3) provides the datum for symmetry inspection.

Inspection of keyseat depth with oblique parallel light beam

$$t_1 = \overline{AB} = \cos\alpha_1 \times \overline{AC} = \cos\alpha_1 \times \overline{A'C'} \qquad (4)$$

Take

$$\alpha_1 = \alpha_2 = \frac{\pi}{4} \qquad (5)$$

Then on the oblique sensing screen, points and have been obtained, and the concrete depth of the keyseat is calculated. As a result, Equation (4) will be written in terms of

$$t_1 = \frac{\sqrt{2}}{2} \times \overline{A'C'} \qquad (6)$$

Inspection of keyseat width and length with oblique parallel light beam

Inspection of keyseat width and length is done in a similar manner (Figure 5 & 6). with the oblique angle of 45°, on v, ω and π planes, the width remain unchanged, and the point is to express and to calculate it. Here the narrow-oblique projecting method is adopted and the scanning operation is so done that the original points A, D, E, J, F, I, and other points on the v plane are projected by way of ω plane with incident and reflected parallel laser beam onto the π plane with sensor array. Then by the following calculating algorithms the keyseat width will be obtained.

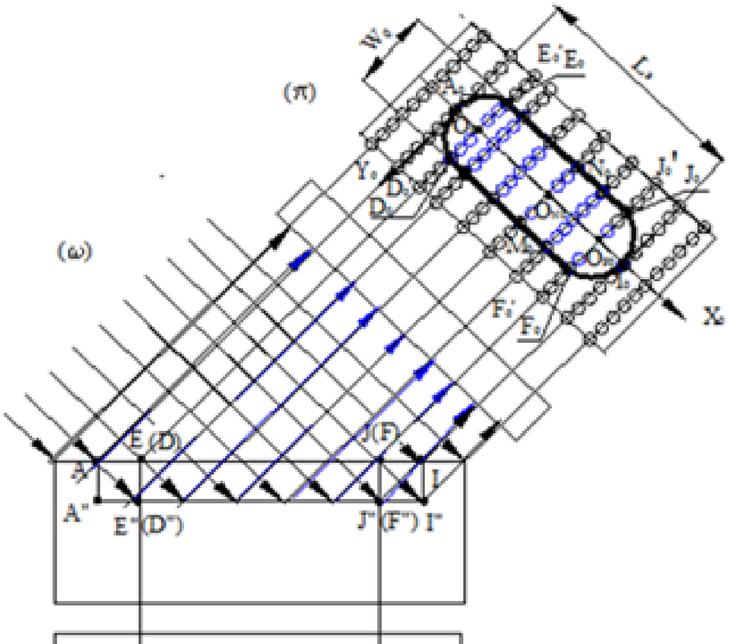


Figure 5: Inspection of the closed keyseat geometry.

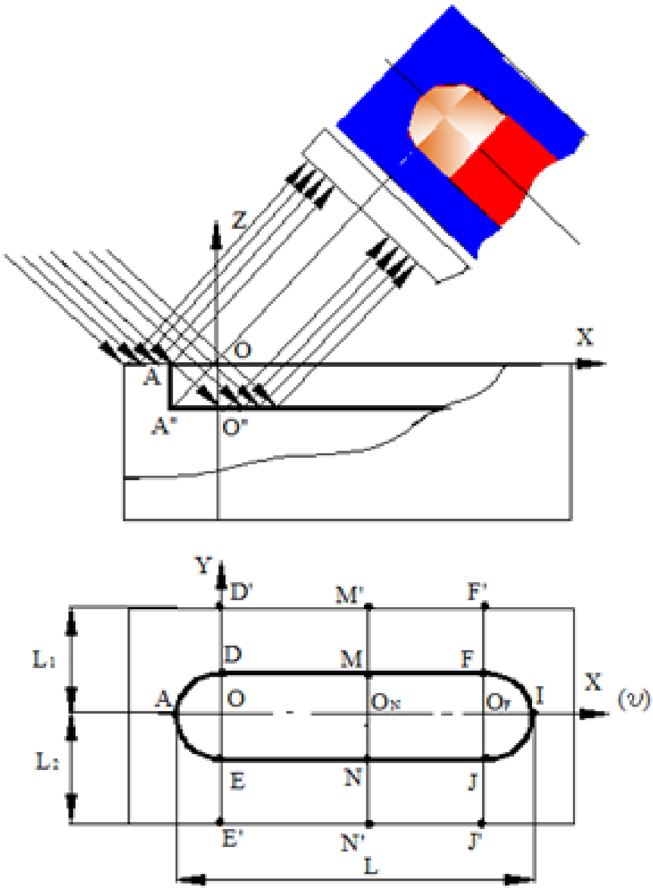


Figure 6: Symmetry inspection.

$$t = \overline{\mathrm{DE}} = \overline{\mathrm{D_0E_0}} = \max\left\{\left|\mathrm{P}_i - \mathrm{P}_{i\text{-}1}\right|,\ \ i = 1,\ 2,\ 3......2\mathrm{n}\right\} \tag{7}$$

In order to gain more accurate value of the width, at least average of five values is employed of five narrow oblique scanning operations at interval of

$$t_e = \frac{1}{5}\sum_{j=1}^{5}\max\{\left|P_i - P_{i-1}\right|, i = 1,2,3.......\}\Delta = L_{est}/n, \text{ and } i = j\times\Delta, j = 1,2,3,4,5 \tag{8}$$

where L_{est}—— pre-estimated value of the real length of the keyseat, L

The edge boundary recognition

$$\left|q_k - q_{k-1}\right| \geq U \tag{9}$$

where q_k—— grey-scale of a point along the line of the narrow scanning

U—— grey-scale difference of any two adjacent points along the line of the narrow scanning

Inspection of Keyseat Symmetry with Oblique Parallel Laser Beam

In the grating field with laser beam by oblique projection to the keyseat (v place), reflected lights on the π plane with the narrow scanning, array of separate points along efficient scanning lines, the symmetry, S, is gained by the following algorithm

$$S_0 = \left|\overline{\mathrm{EO}} - \overline{\mathrm{OD}}\right|,\ \ S_1 = \left|\overline{\mathrm{NO_N}} - \overline{\mathrm{O_NM}}\right|,\ \ S_2 = \left|\overline{\mathrm{JO_F}} - \overline{\mathrm{O_FF}}\right| \tag{10}$$

$$\left|\overline{\mathrm{EO}} - \overline{\mathrm{OD}}\right| = \left|\overline{\mathrm{E_0O_0}} - \overline{\mathrm{O_0M_0}}\right|,\ \left|\overline{\mathrm{NO_N}} - \overline{\mathrm{O_NM}}\right| = \left|\overline{\mathrm{N_0O_N}} - \overline{\mathrm{O_N M_0}}\right|,\ \left|\overline{\mathrm{JO_F}} - \overline{\mathrm{O_FF}}\right| = \left|\overline{\mathrm{J_0O_F}} - \overline{\mathrm{O_F F_0}}\right| \tag{11}$$

$$S = \frac{1}{3}\left|\overline{\mathrm{E_0O_0}} - \overline{\mathrm{O_0M_0}}\right| + \left|\overline{\mathrm{N_0O_N}} - \overline{\mathrm{O_N M_0}}\right| + \left|\overline{\mathrm{J_0O_F}} - \overline{\mathrm{O_F F_0}}\right| \tag{12}$$

Error-Norm Algorithm for Qualification Check

The diameter of tested shaft, width, depth, length, and symmetry of the closed keyseat, with standard values respectively are d_r, t_r, t_{1r}, L_r, and S_r. Now the error-norm of the geometry and symmetry are

$$\left|d - d_r\right| \leq \omega_1; \left|t_e - t_r\right| \leq \omega_2; \left|t_1 - t_{1r}\right| \leq \omega_3; \left|L - L_r\right| \leq \omega_4; \left|S - S_r\right| \leq \omega_5 \tag{13}$$

where ω_1, ω_2, ω_3, ω_4, ω_5—— tolerance of diameter of tested shaft, of width, depth, length, and symmetry of the closed keyseat, respectively, or the allowable values of them. The left side of Equation (13) indicates respectively the error-norms of the diameter, keyseat depth, width, length, and symmetry. All these values calculated from the above may be checked by error-norm test in terms of their tolerances.

Conclusion

Based on the analysis of the general inspection methods of closed key seat depth and symmetry, the current study introduced the parallel beam of grating principle, via oblique irradiation, narrow slit scanning, grey-scale difference to approve the edge of the closed key seat. Error-norm algorithm was applied to check the qualification of the geometry and symmetry. The so-called oblique grating field and data-processing method have created swift on-line inspection of the closed key seat with measurement of 0.1μm accuracy, providing technical support for the intelligent manufacturing of components with keyseat.

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