A New Method for Auto-Inspecting Both Opposite Surfaces of Tec Components Based on Equal-Optical-Path Imaging System

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Abstract. An new optical method for simultaneously inspecting opposite surfaces defects of thermoelectric cooler (TEC) components that meets condition of equal optical paths for both surfaces imaging has been proposed. The optical apparatus for surfaces defects inspection has been designed and established with “confocal” imaging system consisting of two trapezoid reflection prisms and one optical images combiner. Experimental investigations on defects inspection with the “confocal” imaging system have been carried out. The results showed that the proposed optical method can be used to simultaneously inspect the defects of opposite surfaces of TEC components without need to employ a tele-centric imaging lens with large depth of focus. It was concluded that the optical inspection method can meet the technical requirements for inspecting opposite surfaces (both side surfaces, or both top and bottom surfaces) defects of TEC components and has advantages of equal good imaging quality, increased inspection accuracy and throughput, simplified system configuration and improved system reliability etc.

1. Introduction

In recent years, the combination of the optical imaging technology and the artificial intelligence has become a very active research field of optical engineering technology [1-7]. The traditional machine vision automatic optical inspection apparatus uses one set of optical imaging device to inspect one surface of the object. In order to improve the efficiency, the optical apparatus with several sets of optical imaging device are required for the inspection of large-size objects [8, 9]. In some applications, multiple surfaces of the object are required to be inspected simultaneously. Today, it has become necessary to employ machine vision automatic optical inspection in the intelligent manufacturing of thermo-electric cooler (TEC) components. However there exists a considerable amount of optical path difference between the images of two adjacent surfaces. A telecentric imaging lens with corresponding large depth of field needs to be employed in order to achieve equally reasonable good-resolution imaging of two opposite surfaces of TEC components [10].

Recently, an optical apparatus with quasi-confocal imaging has been proposed and experimentally demonstrated for simultaneously inspecting adjacent surfaces defects of thermo-electric cooler (TEC)
components [11]. The optical path difference ($\Delta$) of the adjacent surfaces in the apparatus is not related to the structure parameters of the optical imaging system, but only related to the distance between the center of the adjacent sides of the TEC component. Although the optical inspection apparatus allows us to obtain the "quasi" equal-optical-path imaging inspection of two adjacent surfaces of TEC components, there still exists an optical path difference $\Delta$ between the adjacent surfaces of TEC components. In this paper, a new method for simultaneously inspecting two opposite surfaces of TEC components is proposed. It can simultaneously inspect the defects of the opposite sides (such as the top and the bottom) of the TEC components, and the optical path of two opposite sides of TEC components allows us to obtain the condition of equal-optical-path imaging, hence the confocal-imaging inspection of two opposite sides of TEC components. The new inspection method has the advantage of equally good imaging performance of two opposite surfaces of TEC components which can improve the defects inspection accuracy and increase the inspection speed of the apparatus. It is expected to be found potentially applications in the automatic optical inspection of TEC components defects.

2. Principle of Inspection Apparatus

Figure 1 shows the schematic diagram of an optical apparatus for simultaneously inspecting two opposite surfaces defects of TEC components with confocal imaging that meets condition of equal optical path for both surfaces of TEC components. It is composed of CMOS camera 1, telecentric lens 2, image-combining optical element 3, TEC component 4, glass plate 5, trapezoidal image relay prism 6a and 6b, and lighting source 7, etc. The system imaging principle is described as follows: two beams from two identical illumination sources 7a and 7b are incident at a certain angle on the upper surfaces of two identical trapezoidal prisms 6a and 6b, respectively and then exit from their lower surfaces to illuminate the opposite sides of the TEC component.

The imaging optical paths of the illuminated opposite sides of the TEC component propagate through the trapezoidal prism 6a and 6b, respectively, then relays by 180° and finally incident on the sides of image-combining optical element 3a and 3b, respectively. The imaging beams turn 90° into the telecentric imaging lens 2, and finally reach the sensors of CMOS camera 1 to form two separate images of two opposite surfaces of TEC components. The central spacing $\delta$ between the images of two opposite surfaces of TEC components depends on the relative positions of the image-combining optical element and the trapezoidal prisms along the optical axis. Now that the imaging optical system of the two opposite surfaces of TEC components is exactly the same and symmetrically located on both sides of the optical axis of the telecentric imaging lens and TEC components, the imaging of the two opposite surfaces of TEC component can meet the condition of equal-optical-path confocal imaging. Without need using a telecentric imaging lens with large depth of field the clear images of both opposite surfaces of TEC components can be obtained. On the other hand, two independent lighting sources 5a and 5b are used for the illumination of the opposite surfaces of the TEC components, the apparatus can also allow us to achieve the imaging of the double side of the TEC components with equal illumination. Therefore simultaneously inspecting two opposite surfaces of TEC components with equal-optical-path, confocal imaging and equal-irradiance illumination can all be obtained with this new apparatus.
3. Experimental Verification of Defects Inspection

3.1. Design of Inspection Apparatus

Based on the above described principle for simultaneously inspecting two opposite surfaces of TEC components with equal-optical-path confocal imaging, an inspection apparatus of TEC components was set up with confocal imaging and equal-irradiance illumination. The pre-prismatic image relay subsystem for the imaging inspection apparatus for two opposite surfaces of TEC components are shown in figure 2. The defects on two opposite surfaces of TEC components can be inspected simultaneously using this apparatus. The TEC component is of rectangular shape with the typical size of 2.10mm×1.32mm×1.32mm. According to the requirements, the sizes of the trapezoidal right-angle image prism is 25mmx25mmx20mm (thickness) and the image-combining optical element is 20mmx10mmx20mm (thickness). In this experiment, Hikvision’s CMOS camera of CA050-10GM was employed. The camera’s CMOS sensors was 2/3” with the pixel size of 3.45μm and the pixels of 2448 *2048. Dehong’s 1.5x telecentric imaging lens WTL110-1520 was also used.

3.2. Experimental Results and Discussion

Figure 2. Illustration of prism relay system for the optical apparatus for simultaneously inspecting two side surfaces defects of TEC component. (a) optical relay prism layout, (b) mechanical housing.
The imaging inspection results of two opposite surfaces of TEC components are shown in figure 3. Figure 3a, 3b, 3c and 3d show the simultaneously inspection of two opposite surfaces of several various TEC components under slightly different conditions. The spacing d=0.3~1.0mm is the separation between the edges of adjacent relay images of two opposite side surfaces of the TEC components. From figure 3, images of both sides of the TEC components are equally clear without any difference, which is due to the fact that the inspection apparatus has the characteristics of equal-optical-path confocal imaging completely for both opposite surfaces. In addition, the spacing between two images of the TEC components can be adjustable by fine-tuning the image-combining optical element upward and downward along the optical axis direction. The advantage of the apparatus is that the spacing d can be selected independent on the depth of the field of telecentric imaging lens and without need for a specially designed telecentric imaging lens with large depth of field. The results show that this method allow us to obtain the images of two opposite surfaces of the TEC components which can meet the requirements of machine vision image processing. The image quality of two opposite surfaces obtained by this methods is better than those by others [10, 11].

![Simultaneously inspecting two side surfaces defects of TEC component with confocal imaging system and equal optical paths. d=0.3—1.0mm is the separation between the adjacent edges of relay images of two opposite side surfaces.](image)

**Figure 3.** Simultaneously inspecting two side surfaces defects of TEC component with confocal imaging system and equal optical paths. d=0.3—1.0mm is the separation between the adjacent edges of relay images of two opposite side surfaces.

### 4. Conclusions
A method is presented for simultaneously inspection of two opposite surfaces of TEC components with confocal imaging. An optical apparatus for confocal imaging inspection of two opposite surfaces of TEC component with equal-optical-path was demonstrated by using a image-combining optical element based on total internal reflection and a relaying trapezoidal prism. The experimental results show that the proposed method can effectively inspect defects on the opposite surfaces of TEC component with equal optical path and confocal imaging. The spacing between two images of the
opposite surfaces of TEC component can be fine-adjusted by moving the image-combining optical element along the optical axis. The optical inspection apparatus has the advantages of good imaging performance, compact and reliable system configuration. Usually four (or more) surfaces of a TEC component need to be inspected. Only two (or three) sets of the proposed apparatus are required to complete inspection on four faces with confocal imaging. This method can be found applications in the automatic optical inspection and screening system of TEC components with improved inspection efficiency and accuracy.

References
[1] Lu R S, Wu A, Zhang T D and Wang Y H. 2018 Review on Automated Optical (Visual) Inspection and Its Applications in Defect Detection [J] ACTA OPTICA SINICA. 380815002G1-35
[2] Tang B, Kong J Y and Wu S L Review of surface defect detection based on machine vision 2017 Journal of Image and Graphics 22 1640-1663.
[3] Mar N S S, Yarlagadda P K D V and Fookes C Design and development of automatic visual inspection system for PCB manufacturing 2011 Robotics and Computer Integrated Manufacturing 27 949-962.
[4] Neogi N and Mohanta D K and Dutta P K Review of vision-based steel surface inspection systems [J].EURASIP Journal on Image and Video Processing 2014 EURASIP Journal on Image and Video Processing 2014 50.
[5] Yang S W, Lin C S, Lin S K and Chiang H T Automatic defect recognition of TFT array process using gray level co-occurrence matrix 2014 Optik 125 2671-76.
[6] Liu Y and Yu F H Automatic inspection system of surface defects on optical IR-CUT filter based on machine vision 2014 Optics and Lasers in Engineering 55 243-57
[7] Mao C L, Lu R S, Dong J T and Zhang Y Z Overview of the 3D Profilometry of Phase Shifting Fringe Projection 2018 ACTA METROLOGICA SINIC. 39 628-40.
[8] Shi Y Q, Lu R S and Zhang T D Defect Inspection System Design Based on the Automated Optical Inspection Technique for LCD Backlight Modules 2015 CHINESE JOURNAL OF SENSORS AND ACTUATORS 28 768-73.
[9] Hu H B, Xu T, Zhang B, Xu D J, Jin S Q and Lu R S Application of Open MP and Ring Buffer Technology in Defects Detection of Glass Substrate 2019 COMPUTER SCIENCE 46 563-66
[10] Su L L, Wu P H, Guo Z W, Pan S F and Liao T D An optical apparatus for machine vision inspecting both top and bottom surfaces of the TEC components 2019 Proc. SPIE AOPC: Optical Sensing and Imaging Technology 113383.
[11] Liao T D, Yan S B, Chen W Z et al, A novel method for inspecting both opposite surfaces of TEC components based on confocal imaging system, 2021 Optical Instruments, Accepted.