3D Positioning Method of Defects in Light Alloy Castings Based on Multi-Angle X-Ray Detection Images

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Abstract: The two-dimensional X-ray inspection images of light alloy castings cannot intuitively reflect the depth and size of defects, and the correspondence between image defect coordinates and the three-dimensional body of the casting is unclear. Therefore, manual repeated drilling and inspection are needed to determine defect locations, resulting in low-quality and inefficient welding repairs. To address these problems, we propose a three-dimensional defect positioning method for light alloy castings based on multi-angle X-ray inspection images. First, we collect images of the castings at different inspection angles, and integrate image processing methods such as filtering to extract the contours of defect areas in the images. Next, we establish the relative positions and angles between the radiation source, casting, and imaging plate to construct a coordinate upscaling model from the image to the three-dimensional model, achieving the conversion from two-dimensional image defect coordinates to three-dimensional casting defect coordinates. Finally, we calculate the intersections between the rays and the casting model, establish boundary feature polyhedrons, and develop a defect morphology reconstruction algorithm to achieve three-dimensional defect positioning based on multi-angle inspection images. This method achieves three-dimensional defect positioning of castings by simulating actual DR inspections and has significant engineering application value.

Keywords: defect three-dimensional positioning; multi-angle defect detection; three-dimensional model; X-ray inspection images

1 Introduction

After X-ray inspection imaging of light alloy castings, it is necessary for personnel to manually judge the defect positions on the three-dimensional castings based on the defect information in the DR images. This often requires drilling holes in the castings for positioning and re-imaging. Because the correspondence between the two-dimensional DR images and the three-dimensional castings is unclear, this method often damages the casting body during defect positioning, requiring subsequent welding repairs. Therefore, relying on multiple manual drillings to position defects not only damages the casting body but also severely restricts the quality and efficiency of casting defect welding repairs. Therefore, there is an urgent need to develop an intelligent three-dimensional defect positioning method for light alloy castings.

2 Experimental procedure

(1) The grayscale value of an X-ray inspection image can be calculated based on the light intensity after the X-rays penetrate the medium [1]. The light intensity is related to the attenuation coefficient of the medium and the penetration thickness. Based on this principle, we develop a virtual imaging system that, after inputting the casting model, casting attenuation coefficient, and inspection distance, outputs a virtual inspection image of the casting. We generate holes in the casting model to simulate actual defects, and then put the model into the virtual imaging system to obtain a virtual inspection image with defects. Next, we process the image with median filtering, binarization, and contour searching to obtain a set of two-dimensional coordinates for the defect contours on the virtual inspection image.

(2) In actual inspection, the three-dimensional positions of the radiation source, casting, and imaging plate are correlated [2]. When simulating actual inspection, the generated virtual inspection images are located on the imaging plate. Therefore, the two-dimensional coordinate set of the defect contours needs to be converted into a three-dimensional coordinate set in the world coordinate system. Based on the angular relationship between the radiation source, casting, and imaging plate, the two-dimensional coordinates can be converted into two components in the world coordinate system. The third component can be calculated based on the distance from the imaging plate to the origin of the world coordinate system.

(3) Connect the radiation source to each defect contour point on the imaging plate, and calculate the intersection points of each line with the casting. Use the Delaunay triangulation method to generate a polyhedron that includes all the intersection points. After changing the inspection direction, repeat the above steps. Intersect the two generated polyhedrons to obtain a characteristic polyhedron that represents the defect location, as shown in Figure 1.

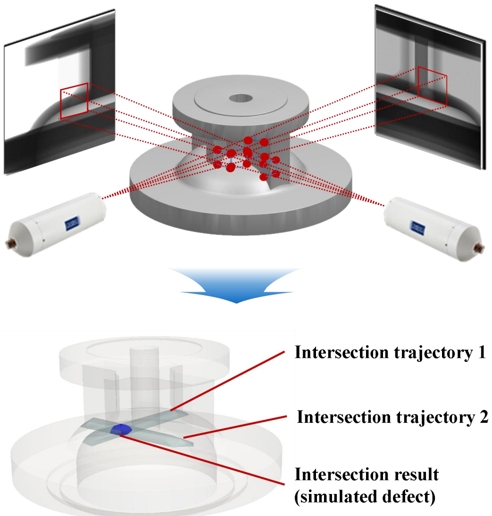

Figure 1 Defect three-dimensional positioning

3 Result and discussion

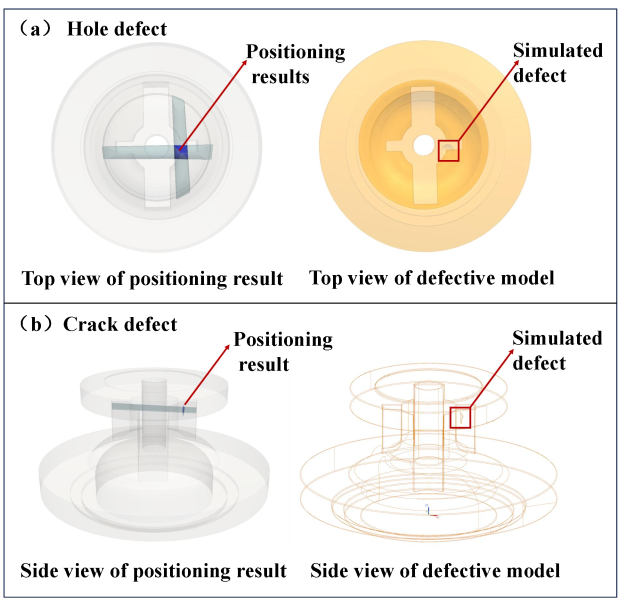

Figure 2 Positioning result comparison

We simulate the three-dimensional positioning of two types of defects: Group A consists of hole defects, and Group B consists of crack defects. The comparison between the defect localization results and the original model is shown in Figure 2. To quantitatively demonstrate the accuracy of defect positioning, we calculate the centroid coordinates of the characteristic polyhedron, the centroid coordinates of the simulated defects in the model, the model dimensions, and the relative positioning error. As shown in Table 1, the three-dimensional defect positioning method based on multi-angle X-ray inspection images achieves a relative positioning error of less than 2% in the *X*, *Y*, and *Z* directions, indicating a high accuracy of defect positioning. In practical applications, the virtual inspection images can be replaced with actual inspection images of the casting, and by inputting the three-dimensional positions of the radiation source, casting, and imaging plate, the three-dimensional positioning results of the defects can be obtained.

Table 1. Defect positioning result quantification table
(CG means the center of gravity)

Object	*X*	*Y*	*Z*
Model size	81.77	81.77	43.81
CG of Defect A	-2.145	-8.776	19.264
CG of Result A	-1.858	-9.085	20.014
Relative error	**0.35%**	**0.38%**	**1.71%**
CG of Defect B	-1.040	10.392	32.471
CG of Result B	-0.828	10.216	32.679
Relative error	**0.26%**	**0.22%**	**0.47%**

4 Conclusion

We propose a three-dimensional defect positioning method for light alloy castings based on multi-angle X-ray inspection images. First, we generate multi-angle virtual inspection images of the casting model using a virtual imaging system, and obtain a set of two-dimensional coordinates for the defect contours on the virtual inspection images. Next, we convert the two-dimensional coordinate set into a three-dimensional coordinate set in the world coordinate system. Finally, we develop a defect morphology reconstruction algorithm to achieve three-dimensional defect positioning based on multi-angle inspection images. The results show that the relative error in three-dimensional defect positioning is less than 2%, indicating that this method has significant engineering application value.

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