High-Speed Optoelectronic System for Surface Inspection of Fuel Pellets

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Abstract: *Two high-speed optoelectronic methods and computer vision system for surface inspection of nuclear reactor fuel pellets are considered. In the proposed methods the reflected images of pellet surfaces are taken by digital cameras, which provide high contrast of defective areas against the frame background. Image processing algorithms for identification of defective products are given. A system with productivity of up to 10 pellets per second was designed. Results of real time processing of the obtained images show that the probability of defective pellets detection is not less than 95%.*

Key words: Computer Vision System (Technical Vision), Fuel Pellet, Surface Defects, Image Processing

1. Introduction

Fuel pellets of UO_2 are one of the main components of nuclear reactor fuel elements. In this connection high demands are required as for the quality of pellets, especially their surface. In the production process, many defects may appear on the cylindrical pellet surface. They usually occur in the most strained parts of pellets such as edge chips and cracks on the side surface [1].

In case of visual inspection by operators the probability of false solution by operator may be unacceptable, namely defective fuel pellets are considered as fit production. The above-mentioned drawbacks determine the urgency of the problem of automating the detection of defective pellets. Moreover, it is important that the productivity of visual inspection system must be very high: from 4 to 10 pellets/sec. To solve this problem, we have proposed to use optoelectronic methods and computer vision system combined with a mathematical apparatus for image processing.

In this report two high-speed methods and automatic system for side and edge surfaces inspection are presented. The experimental results of the system testing are given.

2. High-Speed Method for Inspection of the Pellets Side Surface

To solve the problem of fast inspection of fuel pellets' side surfaces the authors have developed an original method based on four parallel channel registration of optical information by the specialized lens. The principle underlying the inspection of the side surface is explained in Fig. 1.

The fuel pellet (1) is being transported along a hole prism (not depicted) along the pellet's axis. The fragment of the image is being formed by the specialized lens (2) and the standard camera lens (5). Then the fragment is being recorded by the linear camera (6). As a light source we used a laser diode (3) which illuminates the side surface of the pellet through a translucent plate (4).

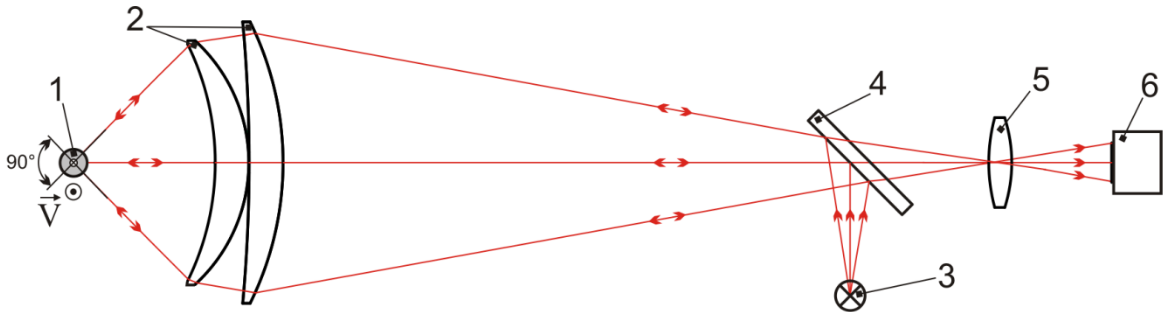

Fig. 1. Principle of image acquisition of the pellet side surface.

The observation and illumination of each point of the product is performed along the normal to the surface, providing high contrast of defects. A full image of the side surface of the pellet moving in the technological flow can be acquired by localization four such optical channels in the same plane.

The image processing algorithm for the side surface [2] determines the boundaries of the side surface, rejects images according to the width and sliding, selects dark and bright defects, determines defect size, and eliminates small, false, and embedded defects. A decision on rejection of cracked pellets of products with other defects is made in accordance with the logical rule

$$\textit{If } (s_i > s_0), \textit{ or } (S > S_0), \textit{ or } (l_j > l_0), \textit{ or } (L > L_0), \textit{ then (Reject)}, \quad (1)$$

where s_i is the area of an individual defect, s_0 is the permissible area of an individual defect, S is the sum of the areas of the defects, and S_0 is the permissible total area of all defects, l_j is the length of the *j*th crack, l_0 is the permissible length of an individual crack, L is the total length of all cracks, and L_0 is the total permissible length of all cracks.

The industrial version of system was developed and produced (Fig. 2). The inspection speed is up to 100 mm/s (10 pellets/s). The tests showed stable operation of the system with a probability of detection of defective pellets not less than 95%. The processed images of the side surface of real pellets are shown in Fig. 3.

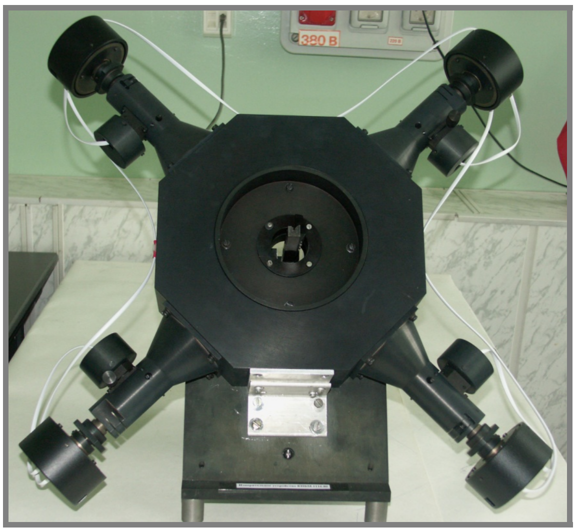

Fig. 2. Four-channel high-speed system for side surface inspection.

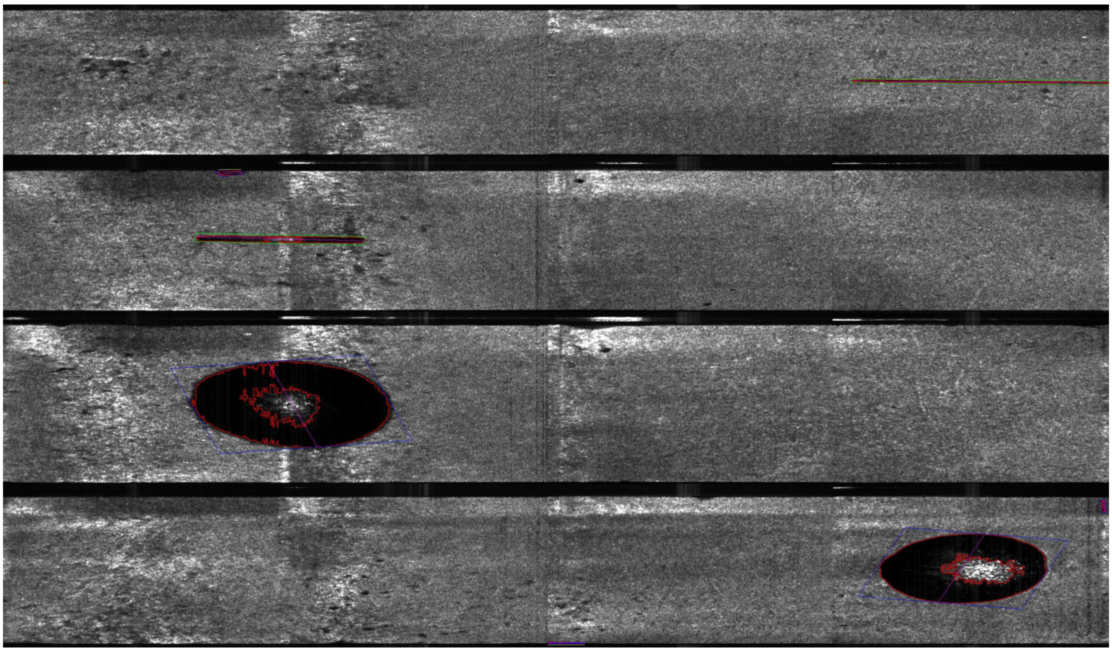

Fig. 3. Examples of processed images of real pellets with characteristic defects like as crakes and cavities. The resolution is 25 μm/pixel in both directions.

3. High-Speed Method for Inspection of the Pellets Edge Surface

The existing engineering solutions [3, 4], which involve detection of the radiation scattered along the pellet surface, failed in under obtaining high-contrast images. Positive results were reached with the scheme where the surface was illuminated and the image was recorded at the same angle with respect to the normal to the surface inspected (reflective require).

In case one is taking an image of the end face of a pellet (Fig. 4), the light source (1) illuminates the face end of the pellet (2) at the angle φ to the normal. The light reflected from the flat part of the end face is recorded by the camera (3). High-performance inspection of the edge surfaces of pellets during their movement was achieved through a new technical implementation of the previously described method, particularly using a focused pulsed light and modern computer technology based on multi-core processors.

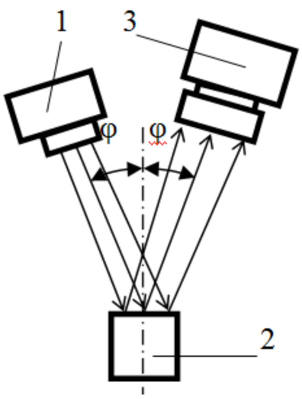

Fig. 4.Diagram of the pellet edge imaging.

Fig. 5. Image recording unit for the edge surfaces inspection.

The edge image processing algorithm comprises the following steps: search for the external contours of white areas, construction of the boundary of white areas, correction of the boundary of the flat part of the edge, search for opening boundaries, search for defects, and rejection. A decision to reject a product is made using pattern recognition methods based on the logical decision rule

$$If\ (s_i > s_0),\ or\ (S > S_0),\ then\ (Reject), \tag{2}$$

where s_i is the area of an individual defect, s_0 is the permissible area of an individual defect, S is the sum of the areas of the defects, and S_0 is the permissible total area of all defects.

Example of images of the edge surfaces of tablets obtained by the new recording system (Fig. 5) are shown in Fig. 6.

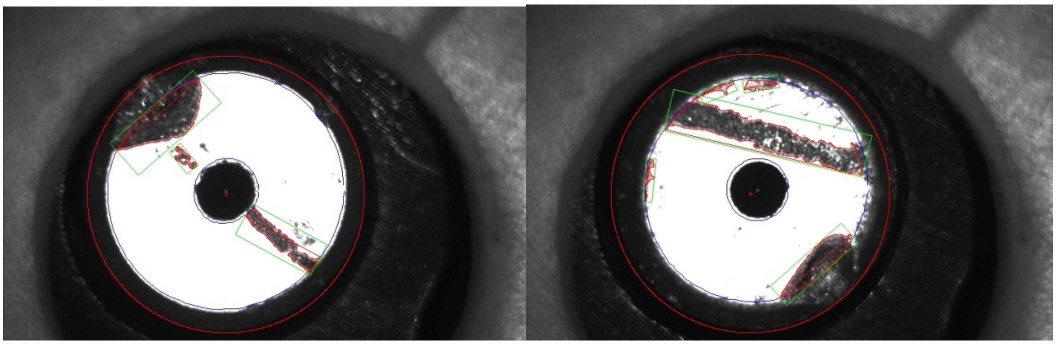

Fig. 6. Processed images of real edge surfaces of tablets with defects like as cavities (productivity is 10 pellets/s, resolution is 18 μm/pixel).

The images of the pellet edge surface have an average contrast of 0.62. This contrast allows using the previously described algorithms to detect the defects on the edge surface with a good relativity.

4. Conclusions

In this paper two high-speed optoelectronic methods and inspection system for side and edge surfaces of nuclear reactor fuel pellets are considered. Image processing algorithms for identifying the defective products were described. The system with productivity of 10 pellets/s was designed. Technical solutions implementing fast image registration of pellet surfaces with a productivity of up to 10 pellets/s were tested on both simulators and real products. The results of real time image processing showed a probability of defective pellets detection not less than 95%.

At the present time the high-speed system for surface pallets inspection is under preliminary exploitation at the technological line in atomic industry (JSC «Novosibirsk Chemical Concentrates Plant»).

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