Development of Image Processing and Analyzing Software for Nuclear Fuel Pellet End Faces

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1. Abstract

The fuel pellets used in Pressurized Heavy Water Reactors (PHWR) have cylindrical shape. It is necessary to carry out visual inspection of ground and finished pellets for surface defects like chips, pits, cracks on both cylindrical and end faces of the pellets. These defects can affect the heat transfer characteristics of fuel in the reactor. Every year, around 10 lakh fuel pellets are manufactured at Nuclear Fuel Complex (NFC), Hyderabad, which have to be inspected manually before they are delivered to Nuclear Power Corporation (NPC). The manual visual inspection is monotonous, cumbersome, and leads to operator fatigue. It has been observed that majority of the defects occur on the cylindrical surface of the pellet. In order to automate the job of pellet inspection, in the first phase of development, a prototype machine vision system for inspecting surface defects on cylindrical surface of these pellets was developed and installed in NFC and is in operation for the shop floor. It is now decided to augment this system with end face inspection unit so that the total process is automated.

A lab scale system has been developed for image acquisition and analysis of end faces of fuel pellets. The end faces of pellets have a dished concave shape with an annular flat ring surface at the edge. This system is based Personal Computer, which includes a 2 megapixel digital camera (1626x1236), machine vision lens (Senko ADL make MFA2514), and custom designed illumination (ring light with ultra bright white LED’s). Image acquisition and analysis software has been developed using commercially available imaging software platform. The end face surface image is acquired by the software with a field of view of 24mmx18mm. Working distance of the system is ~70mm to ensure uniform illumination across the end face. The software extracts the circular end face surface from this acquired image. It automatically selects the region of interest (central dished surface) for further processing. Blob analysis which is a fundamental technique of machine vision based analysis of consistent image regions is applied to region of interest. Some of the operations include thresholding, connectivity analysis and noise filtering. Area of each defect is computed and compared with a user defined inspection criteria (~3sq. mm) to generate accept or reject decision.

The performance of the end face image analysis system has been evaluated with a sample lot and found to be satisfactory. The paper brings out the details of the system.

2. Introduction

Nuclear Fuel Complex, (NFC), Hyderabad a constituent unit of Department of Atomic Energy produces and supplies nuclear fuel and structural components for all Pressurized Heavy Water Reactor (PHWR), Boiling Water Reactor (BWR) operating in India. The PHWR fuel pellets have cylindrical geometry with diameter 14.1 mm with length around 17.5mm. The ground pellets are subjected to 100 % visual inspection, prior being loaded into the fuel tubes. Every year, millions of fuel pellets are subjected to visual inspection at NFC. The manual visual inspection is monotonous, cumbersome, subjective and leads to operator fatigue. This may affect throughput over a period of time.
In order to minimize the subjectivity and radiation exposure to operators an automated machine vision system is being developed for use in the shop floor. Machine vision systems score over human based inspection where large numbers of similar components have to be inspected with high accuracy and speed, as machine based systems are independent of factors like monotony and fatigue [1]. These systems have better quantification ability and repeatability when compared to human eye for known type of defects.

It is mandatory to carry out our 100% visual inspection of pellet surface. The pellet being cylindrical in nature (see figure 1), have two different surfaces to be inspected i.e. cylindrical surface and flat surface at two ends. It was planned to develop an inspection system for these pellets in two phases. First phase constitutes machine vision based inspection of cylindrical surface and other phase constitutes end face inspection. The first phase of cylindrical surface inspection system has been completed. It is already installed and commissioned for the shop floor operation [2,3,4,5,6]. This system will be upgraded to incorporate the end face inspection. The end faces of these pellets have a dished concave shape with an annular flat ring surface at the edge. This paper describes a prototype system being developed for end face inspection of these pellets.

### 3. System Design

The PC based system uses two digital cameras for inspecting the two end faces. This inspection of the two end faces is carried out independently. The defect on the end face is usually in the form of missing surface or chip at the edge or body. Layout of the system is as shown in figure 2. After cylindrical surface inspection is complete, the PLC based pellet transport mechanism will pick the pellets and will sequentially place them in the field of view (FOV) of the first end face inspection camera. Once the inspection for the one end face is over, the pellet will be moved to other camera for second end face inspection. The result of the two stations for each pellet will be combined. The pellet is shifted to either “accept tray” or “reject tray” based on decision making made by the system.

![Figure 2: System Layout](image-url)
4. Image Acquisition and Processing System

This inspection system consist of end face image acquisition, Pellet surface extraction from image, Selecting region of interest suitable for defect identification followed by defect detection and categorization.

4.1. Image Acquisition System

LABVIEW [7] based inspection software has been developed on PC to capture each end face images of the pellet (See figure 3). This PC based imaging setup consists of digital camera (Basler make 1600-14gm), machine vision lens (Senko ADL make MFA2514), and custom designed illumination panel. Bright field imaging technique, wherein light is aimed directly on to the surface of interest was chosen for the purpose of illumination. The illumination panel was made from high-intensity white light emitting diodes (LEDs) arranged in a ring topology. The setup provides uniform illumination in the region of interest. The image acquisition setup has a field of view of 24mmx18mm (H x V) to capture end face image of the pellet whose diameter is 14.1mm. The software acquires the end face image after the pellet is placed in its field of view. This image is transferred to PC using GigE interface and is stored internally for further processing.

4.2. Image Processing System

Various image processing algorithms are applied on each end face image to identify actual pellet surface, the defective areas and generate pass/fail type of result based on pre defined inspection criteria.

4.2.1. Extraction of end face surface

The pellet is placed on a set of rollers which is also visible to the camera. The pellet end face surface must be extracted from the image before further processing. A circular edge detection algorithm is used to identify and extract the circular end face surface area.
4.2.2. Selection of region of interest (ROI)

The acquired end face image has two regions viz., an outer thin ring corresponding to the narrow annual flat ring and the central circular area corresponding to the concave dish shape. (See figure 4). The majority of the end face defects are in the form of chips. It has been observed that the large part of these chips is located on the central dished area rather than the outer ring. Hence to minimize the image processing operations, we neglect small area lying on the outer ring and detect and analyze defects present only on the dished surface. From pellet manufacturing process, we know that the outer ring width is ~ 0.5mm. A user settable parameter (ring width) is used to ignore the outer ring and mark the dished surface as ROI for further processing. If the entire defect is on the outer ring, its area is very small and it is acceptable.

4.2.3. Defect detection and analysis

Missing surface or chips appear as dark area in the grayscale image whereas the other surface appears as white. Several blob analysis algorithms are applied to the region of interest. These include thresholding, connectivity analysis and noise filtering. The thresholding operation generates a binary image. Connectivity analysis algorithm is used to detect a group of interconnected pixels which are called particles. A noise filtering algorithm is applied to this image for removing small particles that appear because of surface irregularities. Each particle is treated as a separate defect. Area of these particles is computed by counting number of pixels within the particles. This computed area is compared with a user defined inspection criteria to generate accept / reject decision.

Figure 4: Images of end faces at various stages during inspection

5. Conclusion

A cylindrical surface inspection system was earlier installed and commissioned at NFC, Hyderabad. A prototype system has been developed for end face inspection of PHWR fuel pellets. The system acquires two end face images using two different digital cameras and processes the image to generate accept / reject result. The performance of the end face inspection system has been evaluated with a sample lot and has been found to be satisfactorily.
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7. References

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