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Vision systems for inspection of nuclear fuel components

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Abstract

Nuclear fuel assembly consists of large number of components. In a typical 500 MWe Pressurised Heavy Water (PHWR) fuel assembly consists of 1655 components in form of pellets, tubes, spacer pads , bearing pads, endcaps and endplates. As nuclear fuel has to perform under severe operating conditions, customers insist for 100 % inspection of all these components. Human based visual inspection for such large components is monotonous and expensive. In order to overcome these inherent drawbacks, vision systems were planned and developed indigenously for various visual inspection operations. The paper brings out details of various vision systems used for inspection of pellets, tubes, bearing pads, spacer pads and endcap weld evaluation.

1.0 Introduction

Nuclear Fuel Complex, Hyderabad, a constituent of Department of Atomic energy is sole manufacturer of nuclear fuel in the country. A typical 500 MWe Pressurised Heavy Water (PHWR) fuel consists of UO_2 pellets and various zirconium alloy components viz. tubes, spacer pads, bearing pads, endcaps and endplates. NFC produces around 30,000 PHWR fuel bundles per annum; this requires inspection of 20 million fuel pellets and components.

Human based visual inspection is associated with certain drawbacks when carried out in large –scale. These arise due to limitations of resolution, accessibility, fatigue, improper illumination, environment and absence of quantification ability. In order to overcome these drawbacks and minimise radioactive exposure to the operators, it was decided to automate the visual inspection process. Automated visual inspection systems or machine vision also known as computer vision is a means by which image recognition and analytical capabilities of human brain and eye are simulated by using an image sensing device and microprocessor[1]. It involves acquisition of an image via a lens-camera combination and then digitally processing that image to locate and act upon a desired feature. These systems are advantageous over human eye in cases when large number of similar components have to be inspected with high accuracy and speed, as monotony and fatigue do not have any affect on the machine [2].

2.0 System Design

An automated vision system would essentially consist of handling system to feed the components, imaging system and the image processing software. In order to develop necessary confidence, reliability and to facilitate easy changeover it was decided to carry out the development of the system in two stages. A semiautomatic system where the components will be manually placed would form the first stage and the fully automated version the next. . The equipment had to be rugged and operator friendly as it was required for production shop floor applications. The system design involved following aspects.

- Determining inspection requirements of various components
- Image acquisition and processing

2.1 Inspection Requirements

The inspection requirement differs from component to component. The fuel pellets are cylindrical components whose diameter vary between 12 – 15 mm and length from 15- 19 mm. The surface must be free from defects like pits, chips and cracks. The defect resolution required in this case is 0.05 mm. [Fig 1]

The fuel pellets are loaded in a zircaloy tube having a diameter of 12 or 15mm and thickness of 0.38 mm thickness. The ends of the tube are sealed with end caps by resistance welding process. The inspection involves evaluating lack of fusion line in the weld zone, which is around 3 mm^2 in area.

In order to facilitate proper end closure welding operation, the ends of zircaloy tube used for pellet loading are machined to provide chamfer on the inner and outer surface of tube wall so that the included angle between them is 60^o. The chamfer width must not exceed100 microns [Fig.2]. The end plug, which has similar diameter should have a desired profile and should be free from surface defects.

Spacer pads are small sheet metal punched components of around 9 mm in length with slight curvature [Fig.3]. These are welded on the outer diameter of the fuel element to provide inter element gap for heat transfer from the fuel bundle. The component has two circular projections of 1mm diameter in order to facilitate welding. Absence of the projections or any geometric deviations in these projections can lead to failure of the spacer pad welds.

Bearing pads are also sheet metal punched components that are welded on the outer fuel elements of the fuel bundle to provide bearing surface to the fuel bundle. It has three rectangular projections of 2.5 mm length and 1 mm width. [Fig.4]. Any imperfection in the shape or surface defects on the projection can lead to failure of the welds.

2.2 Image acquisition and processing.

It was decided to develop separate imaging systems for various components due to difference in inspection requirements. It was decided to make four vision systems for following applications.

- Fuel pellet evaluation
- End cap weld evaluation
- Zircaloy tube chamfer
- Zirconium component evaluation

2.2.1 Fuel pellet evaluation vision system

The system consists of a fuel pellet rotating mechanism, where the pellets are placed on rollers to facilitate pellet rotation around its longitudinal axis. A stepper motor with 200 steps/rev was used to provide drive to rollers. A micro-stepping drive with computer interface has been used to control the fuel pellet rotation and to eliminate sudden jerks during rotation. A CCD camera with 1/3inch sensor size and with 410,000 pixels was used for image grabbing. LED white light was used for illumination. Two similar cameras are used to digitize the end faces of the fuel pellet.

CCD camera and fuel pellet rotation is controlled through a software developed in LabView. The fuel pellet is rotated in small angular motion and the CCD camera digitizes the image of the pellet surface directly visible. This process is repeated for complete 360 degrees motion of the pellet. The software processes all the grabbed images to construct a single image of the unwrapped pellet surface. Algorithms are developed to enhance the image quality, determine the region of interest, convert to a binary image subsequently identifies and localizes various predefined defects. The software stores the digitized images along with the analyzed defects in the database. [Fig.5]

2.2.2 Endcap weld evaluation vision system

The system consists of an inverted metallurgical microscope. Image acquisition is carried out using a ½ inch CCD analog camera which is connected to camera port of microscope through a 0.38x video reduction lens. The camera is based on CCIR format with interlaced scanning speed of 25 frames per second. The reduction lens is selected to match the requirements of field of view and sensor size of the camera. The PCI Frame Grabber enables acquisition of data from the camera to the host PC system memory with a maximum resolution of 760x570x24 bits. The industry standard Peripheral Component Interface Bus transfers 32-bit wide data at 33 MHz i.e. with maximum throughput of 132 Megabytes per second. The software is developed using VC++ 6.0 under Windows 98. [Fig.6]

The image acquisition & analysis software is developed in the VC^{++} under windows operating system. The software uses image processing and analysis algorithms to automatically identify the lack of fusion line [Fig.7] . It also has a report generation module that facilitates storage of data and results in MS Access database . The database was connected to the application through ODBC (Open Database Connectivity).

2.2.3 Tube inspection system

The system caters to the inspection needs of both the surface and ID. The system consisting of a standard CCD video camera with 450 TVL Resolution and 'C' mount standard lens, operating on 12 V DC power supply is connected to a 10mm diameter endoscope. A colour camera was chosen over black and white, as defects based on color variations had to be inspected. Quartz halogen lamps based illuminators were used for lighting. For viewing tube end chamfer fibre optic based ring-lighting is being used, keeping in view specular nature of tube chamfer. Such lighting provides 360° of high intensity and uniform shadow-free on-axis lighting. [Fig.7]

A Pentium -IV PC with a video frame grabber card on its PCI slot (Peripheral Component Interface) is used for image capturing. The PCI frame grabber enables acquisition of data from the camera to the host PC system memory with a maximum resolution of 768x576x8 bits.

An imaging software was developed in Visual C++ 6.0 under Widows 98. Microsoft foundation classes provided the framework for programming in Windows including support for Graphical User Interface. The application, when launched, shows live video from the camera on a video window. During this mode the brightness, contrast and sharpness of the image can be adjusted interactively using the controls provided in the dialog box for Video Adjustment. The user has the option to freeze one frame of the video and save it as an image file in the BMP format. The BMP file can be loaded and displayed in the window.

From an image displayed on the video window, interactive measurements can be made. Radio buttons provided in application windows facilitate linear distance measurement, area measurement of regular and irregular shaped regions and radius of curvature measurement. In order to carry out detailed inspection zoom in/out facilities are also provided. It also provides text overlay for adding titles to facilitate report generation.

Before making any measurements calibration has to be carried out which involves relating the pixel based measurements to physical units of measurements.

2.2.4 Components inspection system.

In order to carry out inspection of spacer pads, bearing pads and end caps the vision system consisted of ½ inch CCD camera with an 8X zoom lens. Ring light with fibre optic guide forms the source of illumination. The camera along with zoom lens, ring light was mounted on stand and was vertically placed over the component placement platform.[Fig.8]. A P-IV based PC along with a frame grabber card in the PCI slot formed the basis for transferring the image from the camera to PC. The Integral Technology's PCI Frame Grabber enabled acquisition the data from the camera to the host PC system memory with a maximum resolution of 768x576x8 bits under 4ns pixel jitter.

The software for the image analysis was developed in VC++. The software which windows 98 based has the usual features of image enhancement features like brightness and contrast controls. The image can also be stored as a BMP file. After the image has been acquired, the image processing is carried out. Since the projection on the component does not provide sharp contrast, sobel filter[3] is used for edge detection. Segmentation is carried out based on thresholding to generate blobs.The area of the projection and the other measurements are carried out by blob analysis[4]. The entire software can work in both interactive and automode.

3.0 Conclusions

3.1 Vision system have been successfully developed and implemented for inspection of the fuel pellets and zircaloy components.

3.2 The vision system for zircaloy components and tube chamfer has been working satisfactorily in shopfloor.

3.3 Prototype vision systems for fuel pellet inspection and end cap weld evaluation has been successfully made.

3.4 The new systems have reduced operator strain and permits inspection at a faster rate.

3.5 With the successful implementation in semi automatic system, effort is being made to develop an automated machine vision system for component inspection.

4.0 Acknowledgements

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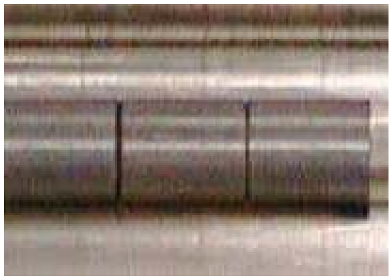

Fig – 1 Tube Chamfer

Fig – 2 Tube Chamfer

Fig 3. Spacer Pads

Fig 4 . Bearing Pads

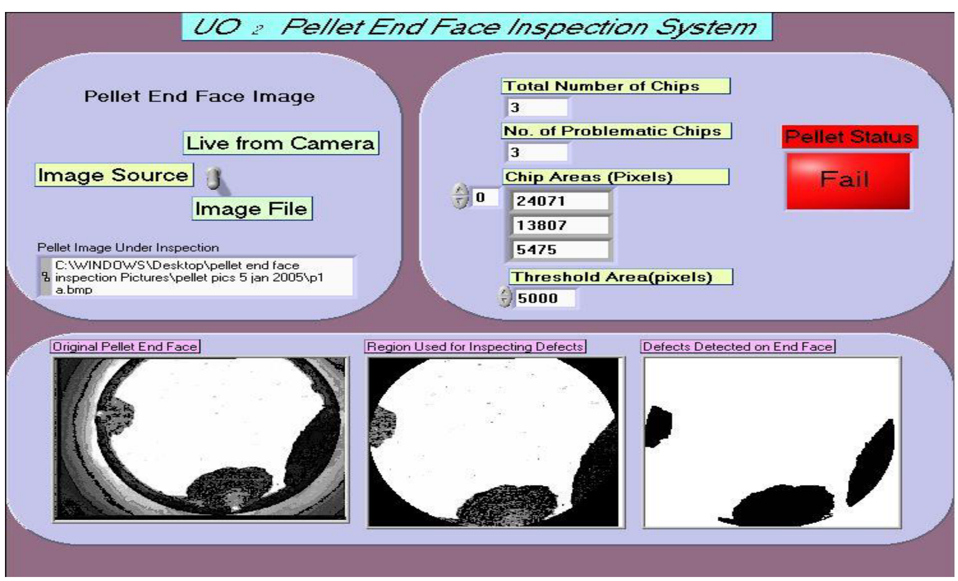

Fig.5 Pellet image from database

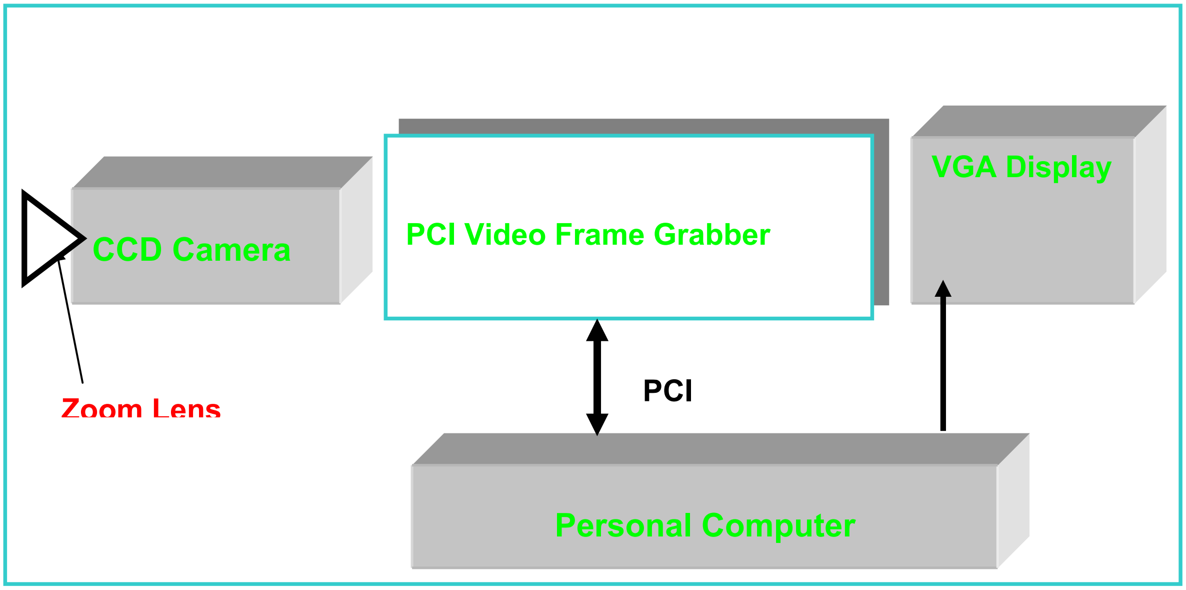

Fig. 6 Schematic Diagram of Vision System showing various components.

Fig.7a Good Weld

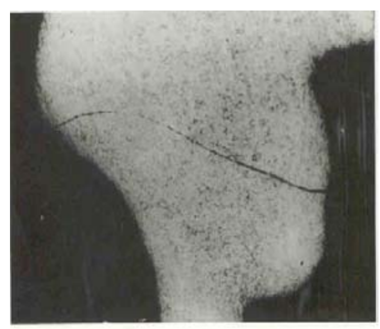

Fig.7b Weld with lack of fusion

Fig.8 Vision system for Tube inspection

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Fig.9 Vision system for components