

Development of Image Inspection System for CVT Steel Belt Element

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ABSTRACT

An image inspection system has been developed to reduce the time expended on product inspection. This system has been designed for inspection of the elements utilized in CVT steel belts. Images from a CCD camera are automatically inspected on the basis of a quantified grading standard. In addition, a new element transport system, which automatically sorts and arranges the elements according to the results of inspection of the images, has been developed to specific elements to be sorted out. The use of this system for inspection of CVT elements has reduced the time required for inspection by more than half against the visual product inspection method.

1. Introduction

Honda has developed a steel belt as a structural element of CVT systems, which are designed to contribute to driving comfort and increased fuel economy. The unit has been in mass production since 2001⁽¹⁾. As shown in Fig. 1, the steel belt is composed of 400 elements and two rows of layered metal rings. The quality of the elements and metal rings affects the ability of the belt to transmit traction. Therefore high reliability is demanded⁽²⁾.

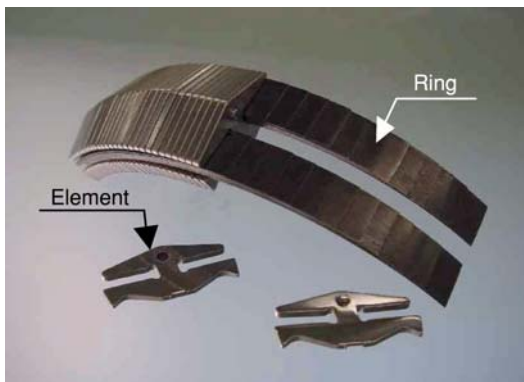


Fig. 1 CVT steel belt

Figure 2 shows a chip-off on an element saddle surface that will make contact with the metal rings. Inspection of the saddle surfaces and detection of these chip-offs takes time. The authors developed an inspection system that employs image processing technology that enables inspection time to be reduced.

This paper discusses the application of the new image inspection system to CVT elements.

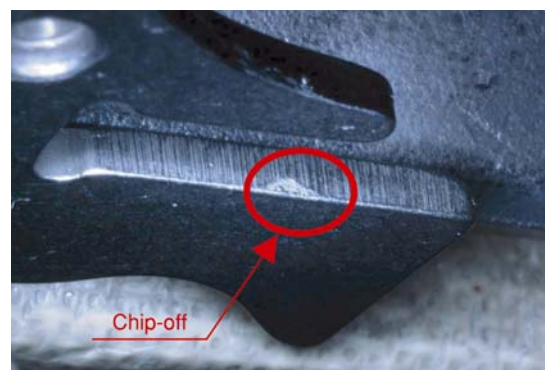


Fig. 2 Chip-off on saddle surface

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2. Development Goals

Figure 3 shows the configuration of an element, and Fig. 4 shows an example of a chip-off on a saddle surface. The aim of the project discussed here was to develop an image inspection system that would detect such chip-offs on the saddle surface and quantify their size.

The following were required in the course of development of this system:

- (1) Imaging of the entire saddle surface including the R section of the neck
- (2) Establishment of an inspection standard for image processing
- (3) Development of a system that enables automatic transport of the elements, and sorting and separation on the basis of the results of the image inspection

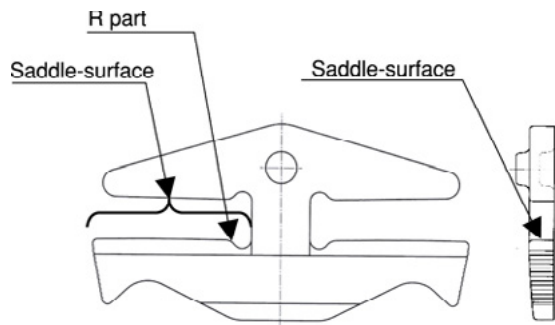


Fig. 3 Configuration of element

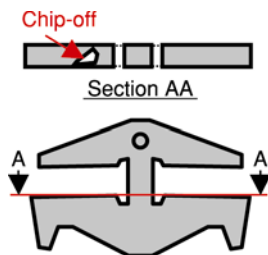


Fig. 4 Sample of chip-off on element

3. CVT Element Image Inspection System

3.1. System Overview

Figure 5 shows the image inspection system. As Fig. 6 shows, the system is composed of three sections: A carrier section that transports individual elements to the imaging processing section and sets them in position, the image processing section that takes and processes images of the saddle surfaces to detect chip-offs, and the selector section that sorts and separates the elements on the basis of the results of image inspection. Each section is controlled by a system control unit and the PC in the image processing section.



Fig. 5 Image inspection system for CVT element

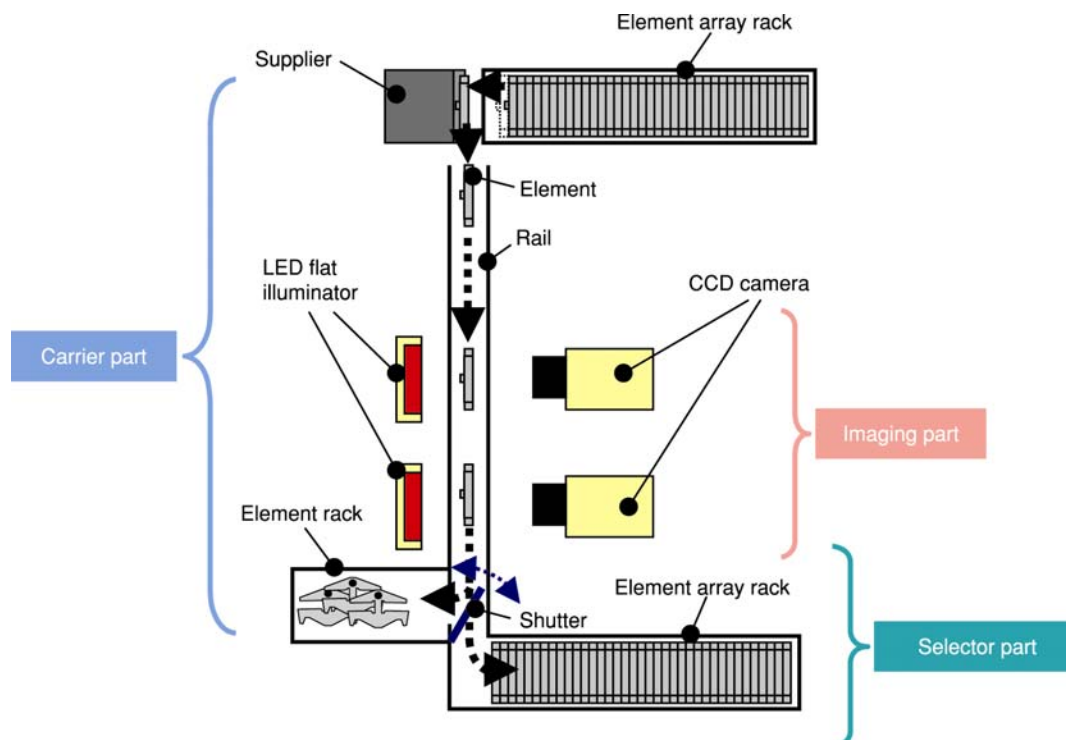


Fig. 6 System configuration

3.2. Carrier Section

The carrier section is made up of a supply unit that provides the elements to the carrier unit and the carrier unit that transports the elements to the imaging position and sets them in place.

As shown in Fig. 7, the supply unit is composed of an element array rack, which arranges the elements in a row and stores them until required, and a supplier mechanism that enables the elements to be individually sent to the carrier unit. If there are no elements in the carrier unit, a command is output from the system control unit, and the supplier mechanism, which is positioned coaxially with the element array rack, moves towards the front element in the element array rack. The selection mechanism is provided with a suction function, and can draw in the front element. After this element has been sent to the carrier unit, the supplier mechanism returns to its original coaxial position with the element array rack.

Figure 8 shows an external view of the carrier unit, Fig. 9 shows one of the imaging positions, and Fig. 10 shows the configuration of the imaging positions. The carrier unit consists of a rail to transport the elements, an optical sensor to detect the presence of elements on the rail, an air blower to assist in sliding the elements along the rail, a piston and a stopper to set the elements in the imaging position, and an optical sensor to determine that elements are in the imaging position.

Elements sent from the supply unit are slid along the rail until they are set in the imaging position. The elements are sent down the transport rail at an oblique angle. The air from the air blower assists the elements in moving down the rail.

When the element reaches the first imaging position, it hits a stopper. The optical sensor detects the position of the element. On the basis of that information, a piston receives a command from the system control unit to press down from above the element and hold it in place in the imaging position. When imaging is completed, the piston is removed and the stopper is simultaneously retracted to the underside of the transport rail, enabling the element to move to the second imaging position. After the identical procedure is carried out in the second imaging position, the element is transported to the selector section.

3.3. Image Processing Section

The image processing section is made up of an imaging unit, which takes images of the element saddle surfaces, and an image processing unit.

To enable the CCD cameras and LED flat illuminators to be set up with an adequate degree of freedom, the image processing section in this system enables right and left images of the element saddle surfaces to be processed

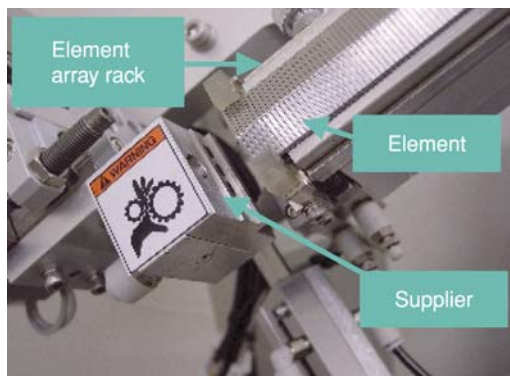


Fig. 7 Supply unit

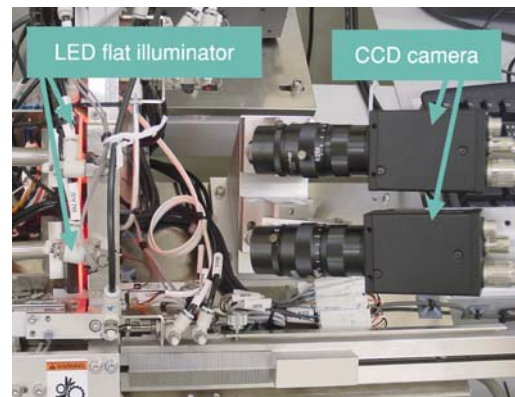


Fig. 9 Imaging position

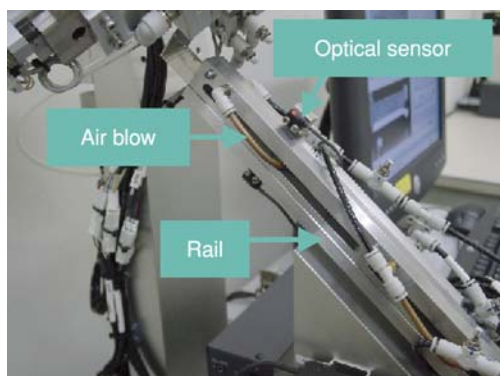


Fig. 8 Carrier unit

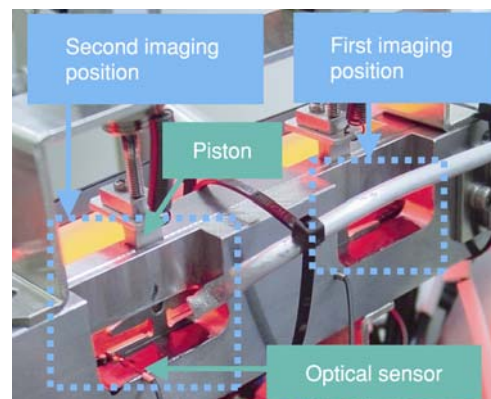


Fig. 10 Configuration of imaging positions

independently. This allows an image of the saddle surface on the left side of the element (as seen from the front; refer to Fig. 3) to be processed in the first imaging position, and permits an image of the saddle surface on the right side to be processed in the second imaging position.

The imaging unit is comprised of red LED flat illuminators and CCD cameras. The illuminators were chosen with the ability to project a uniform illumination over the entire saddle surface with no shadow at the R section of the neck. This criterion led to the adoption of red LED flat illuminators with numerous parallel optical elements. When normal halogen illuminators are utilized, the numerous scattered optical elements cause shadows to occur on target objects with surface irregularities, making it difficult to detect chip-offs over the entire saddle surface, including the R section of the neck. Figure 11 shows a comparison of images produced using red LED and halogen flat illuminators. The image taken using the LED flat illuminator shows uniform brightness with no shadow across the entire saddle surface including the R section of the neck.

Figure 12 shows the relative positions of the red LED flat illuminator, the CCD camera and the element being imaged. The light from the illuminator is reflected off of the element saddle surface, and retrieved by the CCD camera. The illuminator and the camera are set in position so that the optic angle θ_c of the camera to the front of the element, and the vertical angle θ_l of the illuminator to the front of the element are symmetrical.

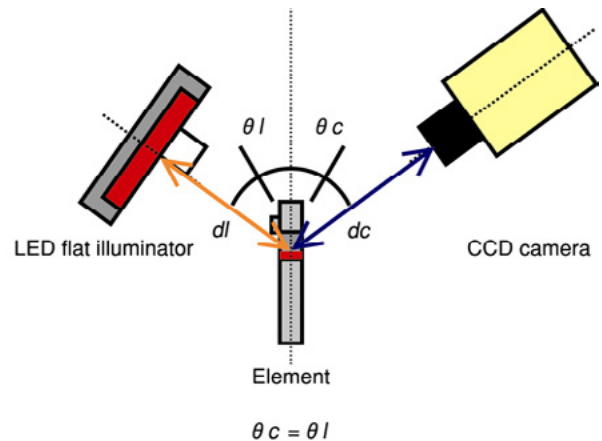
As Fig. 13 shows, the image processing unit is made up of an image processing PC, an image capture board, a digital I/O board, and image processing software. The images taken by the CCD camera are input to the image processing computer RAM by the image capture board. The image processing software quantifies the quality of the element saddle surface using the input images. The results are transmitted to the system control unit via the digital I/O board.

The program employed in the image processing software to quantify the quality of the saddle surface was designed as a multi-thread application capable of simultaneously monitoring the control signals from the system control unit, operating programs, and processing images.

Image inspection is carried out with cooperation between the system control unit and the image processing unit. The system control unit ensures that the element reaches the imaging position; the image processing unit takes an image of the element in position and conducts image processing.

Illuminator	Image
Halogen flat illuminator	
LED flat illuminator	

Fig. 11 Images using each illuminator



θ_c : Optic angle of CCD camera

θ_l : Vertical angle of LED flat illuminator

dc : Distance between CCD camera lens and element

dl : Distance between LED flat illuminator and element

Fig. 12 Layout of CCD camera and LED flat illuminator

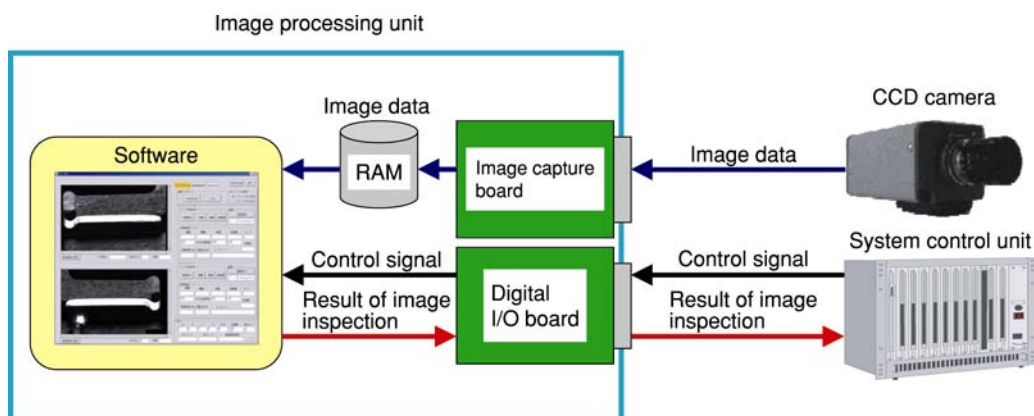


Fig. 13 Configuration of image processing unit

Figure 14 shows a flow chart of the operation of the system control unit and image processing unit in image inspection. When the element reaches the first imaging position, an imaging trigger is sent from the system control unit to the image processing unit. Immediately after receiving the imaging trigger, the image processing unit takes an image of the saddle surface and subjects it to image processing. The results are sent to the system control unit. When image processing at the first imaging position is completed, the element is transported to the second imaging position, where the identical image processing procedures are conducted.

3.4. Selector Section

The selector section is made up of an inspected element selector unit located at the lower end of the transport rail, and a specific element selector unit.

The inspected element selector unit shown in Fig. 15 comprises a pushing mechanism, an optic sensor to detect elements sent to the unit by the rail, an element array rack, and a stopper. The optic sensor detects the presence of an inspected element sliding along the rail. After this, a command is sent to the pushing mechanism from the system control unit, which pushes the elements onto the element



Fig. 14 Flow chart of image inspection

array rack set at right angles to the rail. Movable stoppers on the element array rack enable the elements to be consecutively aligned.

The specific element selector unit shown in Fig. 16 is made up of a discharge shutter, a sensor to detect discharged elements, and a specific element array rack. The shutter is positioned on the underside of the lower end of the transport rail, and opens and closes in response to commands from the system control unit. When specific elements are judged, the inspected elements are sent down the transport rail, the shutter opens and they drop into a specific element array rack. The optical sensor detects the element dropping into the rack, and as a result the system control unit closes the shutter.

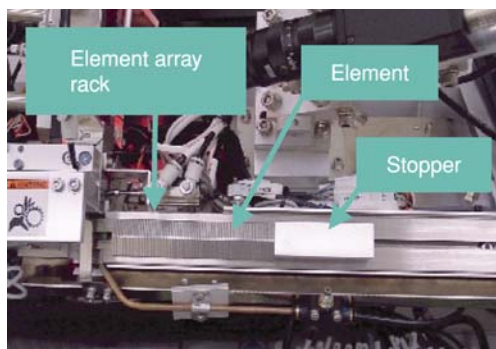


Fig. 15 Inspected element selector unit



Fig. 16 Specific element selector unit

4. Establishing a Standard for Element Inspection

To inspect elements using the image inspection system, it was essential to establish a standard for the judgment of deviations. The area of the chip-off, the total area of multiple chip-offs, and the length of chip-offs in the direction of the thickness of the element were therefore established as criteria for specific elements. The following sections discuss the method by which chip-offs are detected from the images and the standard used in judgment.

4.1. Method of Detecting Chip-offs from Images

Figure 17 shows the procedure for detecting chip-offs on the element saddle surface by image processing. The different levels of brightness in the outline of the section with the chip-off and the other sections (i.e. the sections with no chip-offs) were focused on to enable the detection of chip-offs. Figure 18 shows the original image of an element with a chip-off on the saddle surface taken by a CCD camera, and Fig. 19 shows the results of an analysis of the distribution of brightness using that image. This figure demonstrates that the brightness drops significantly in the outline area of the chip-off in comparison with areas with no chip-offs.

The procedure for detection of chip-offs shown in Fig. 17 is discussed below.

The original image shown in Fig. 18 contains more information than an image of the saddle surface, which will be the focus of image processing. The image is therefore first binarized on the basis of brightness values to enable the saddle surface to be extracted. The saddle surface is highly reflective of light from the illuminators and its brightness is therefore high in the image. The largest area of high brightness in the original image can therefore be extracted as the saddle surface. Figure 20 shows an example of an extracted saddle surface after binarization. Next, the edge section, which shows the greatest modulation in brightness, is extracted from the area previously extracted by binarization. The edge area is extracted using a Kirsch operator⁽³⁾. This enables an image of the edge of the saddle surface to be obtained, as shown in Fig. 21. The saddle surface edge area can be extracted from this image of the edge. This image of the edge area is subjected to a closing operation, enabling the chip-off section, the outline area, and the edge of the saddle surface to be extracted. Figure 22 shows the result of this extraction superimposed on the extraction of the saddle surface shown in Fig. 20. Next, the image resulting from the

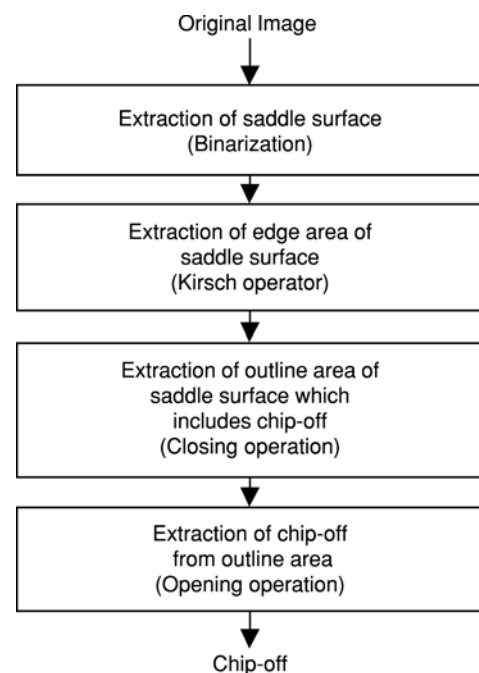


Fig. 17 Image processing for extraction of chip-off

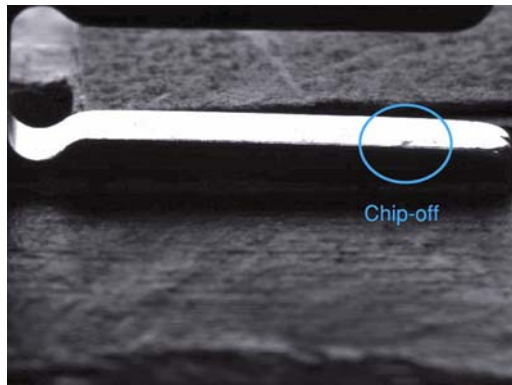


Fig. 18 Original image

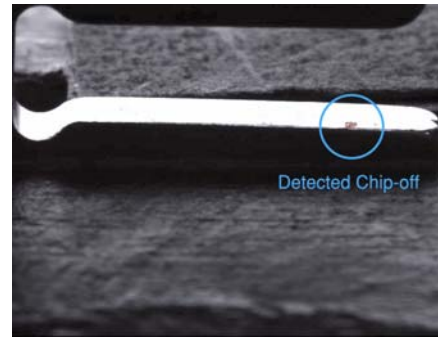


Fig. 24 Result of image processing

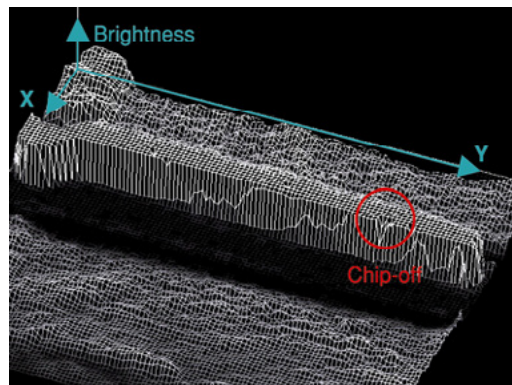


Fig. 19 Distribution map of brightness



Fig. 20 Result of extraction of saddle surface

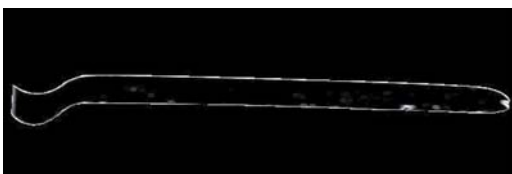


Fig. 21 Edge image



Fig. 22 Result of closing operation



Fig. 23 Result of opening operation

closing operation shown in Fig. 22 is subjected to an opening operation to eliminate the outline area. The result is shown in Fig. 23. The edge shown here will not make contact with the rings, and is therefore not judged as a deviation.

The processing described above enables detection of chip-offs on the element saddle surface. Figure 24 shows the image at the completion of processing superimposed on the original image. The area in which the chip-off was detected is shown as red in Fig. 24. This image demonstrates that the method described here was able to correctly detect a chip-off in the element saddle surface.

4.2. Inspection Standard

The image processing described in 4.1 has made it possible to detect chip-offs on the element saddle surface. Values for the size of chip-offs have been quantified for use in the image processing system.

These quantified values were correlated with the standards utilized in visual inspections, and the three quantified standards for inspection shown in Fig. 25 were developed.

- (1) The area of a single chip-off
- (2) The total area of multiple chip-offs
- (3) The length of a chip-off in the direction of element thickness

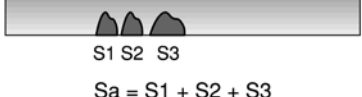
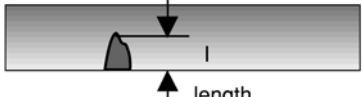
Standard	Chip-off
Area: S	
Total area of all chip-offs : Sa	 $S_a = S_1 + S_2 + S_3$
Length: l	

Fig. 25 Standard for inspection

Multiple samples of each type of chip-off were utilized in deciding on these standards, and the minimum values for the standards utilized in visual inspections were set as the standard values for image inspection. Because the depth of the chip-off is a factor in establishing the standard value for the area of chip-offs, the edge extraction parameters were optimized at the stage of generation of the image of the edge, to make the area of the chip-offs detected by image processing match the area detected by visual inspection.

5. Employment of Image Inspection System

This section compares the time required for inspection using the image inspection system described here and for visual inspection. Figure 26 shows the results of inspection of the length of chip-offs in the direction of element thickness of the 400 elements used in a vehicle with a CVT employing the image inspection system. This figure shows the ratio of the time required for inspection by the system to the time required for visual inspection considered as 100%. The image inspection system required less than half the time required for visual inspection.

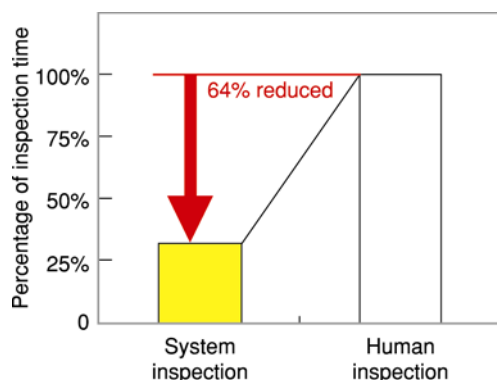


Fig. 26 Inspection time

6. Conclusion

A system that employs image inspection has been developed for the inspection of the saddle surfaces of CVT elements. The following three technological considerations were basic in the development of this system:

- (1) Red LED flat illuminators are employed to illuminate the element saddle surface. Light is reflected from the mirror surface. An image of the elements is captured by CCD cameras, enabling the entire saddle surface, including the R section of the neck, to be imaged. Chip-offs on the saddle surface can then be detected using image processing.
- (2) The size of chip-offs is quantified by image processing, and three inspection standards have been established.
- (3) The system automatically transports the elements and sorts and separates them on the basis of the results of the image inspection.

These features of the system have enabled it to reduce the time required for inspection by more than half against visual

inspection.

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