IMPROVING of the PRODUCTIVITY USING REAL-TIME X-RAY

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***ABSTRACT** - Until now, old-fashioned industrial x-ray technology providers didn't solve their customer's real problem: increasing productivity by preventing defects instead of finding defects that were produced. The idea to build quality by inspection is wrong and the results are poor quality and high costs. Dr. W. Edwards Deming is best known for his work in Japan, which commenced in 1950, and created a revolution in quality and economic production. In Jacobsen we adopted his approach - build quality by prevention of defects - by understanding and tuning up the manufacturing process, and focusing on the cause of the defects. Using feedback from the X-ray machine, casting machines are tuned up to produce fewer defects, the main objective of any casting plant.*

***Keywords:** Real-time X-ray, production, casting, automatic defect recognition*

1. INTRODUCTION

This paper presents a new approach to fully automatic defect recognition (ADR) using real-time x-ray images: multistage modified median filtering as well as defect prevention using x-ray in the loop, and casting process tune-up. This new image analysis method makes it possible to use digital image processing in the very complex field of pattern recognition. X-ray ADR systems replace human observers, work non-stop and don't get tired. We also focus on improving x-ray image quality. And finally we propose simple standards related to semi and fully automated real-time on-line x-ray inspection systems.

2. REAL-TIME X-RAY

In comparison to other NDT methods real-time X-ray shows up well, particularly for defects that do not occur on the surface. Flow parameters using the real-time X-ray method based on available information is good. Additionally, other aspects are important for the factory floor, such as automation, real-time defect presentation and evaluation, handling ease and implementation in the manufacturing process.

ADR (Automatic Defect Recognition) in finding defects in wheels is used for two reasons:

1. To automatically find defects in wheels and sort good and bad wheels (reduce costs and improve quality).

2. Using feedback from the x-ray machine, casting machines can be tuned so that fewer defects are produced because x-ray images of failed wheel are sent to casting machine terminal where casting machine operator analyzes the image. Based on observed defects and their trends, casting parameters can be tuned up.

Here are some difficulties associated with finding defects in the x-ray images:

<u>Defect position</u>: The defects can superimpose upon each other.

<u>Defect contrast</u>: defect detection methods are based on the detection of local density differences. The image input system (The CCD camera in the Image Intensifier chain) must deliver sufficient local contrast, a contrast-rich image, in other words.

Defect types: the large number of different defects and their varying representations in the images prevent a direct search with predefined references.

In simplified form, a radioscopic X-ray image is created in a sequence of two steps:

- Generation of the attenuated image
- Transformation into a visible radio scopic image followed by image transfer

Attenuation of x-rays through material is given as (1):

$$I(E,x) = I_0(E) \cdot \exp(-\mu(E) \cdot x);$$

Where:

- I Transmission intensity
- I_0 Intensity of the incident radiation
- μ Attenuation coefficient
- x Length of x-ray penetration

The attenuation coefficient, μ, depends on:

- E Energy
- Z Material atomic number
- ρ Density

The relationship between the Focus to Detector Distance (FDD) and Focus-to-Object Distance (FOD) determines the geometric magnification of the image. The X-ray image intensifier transforms the attenuated image into a visible x-ray radioscopic image. The transfer chain (lens + CCD camera + monitor) renders a visible image on the screen so that an operator may view it. Digitization enables the transfer of the image to an image processor for processing and evaluation (ADR software).

Before work is started, the following question must be answered: What size of internal defect should be found? Based on application requirements a proper imaging chain can be built.

Determining Sensitivity

IQI wire sensitivity is specified as a percentage value, see below (2), and has values 1.5 – 2.0% in aluminum thickness ranging from 10 to 50mm.

$$S = \frac{\text{diameter of thinnest discernible wire}}{\text{penetreted thickness of specimen}} \text{x100\%} \qquad (2)$$

If we compare radiographic methods with radioscopic methods the wire sensitivity for radioscopy is inferior by factor 2. But with the correct selection of test parameters and optimization of the imaging chain, an IQI wire sensitivity of 1% can be obtained. Additional methods to improve sensitivity include:

- Geometric magnification
- Electronic magnification
- Optical magnification
- Image processing

Geometric magnification

The relation between the focus-to-detector distance (b) and the focus-to-object distance (a) determines the geometric magnification of the image. The optimum magnification factor for any application is determined by the size of the x-ray tube focal spot and the inspection capacity being reduced with the square of the magnification. It makes sense to arrange the x-ray tube at a small angle (5-9°) against the optical axis resulting in a smaller anode angle with respect to the input screen of image intensifier. The stated focal spot of 0.4 x 0.4 mm can be reduced to 0.2 x 0.4 mm in the central beam axis without loss of radiation intensity

Electronic magnification

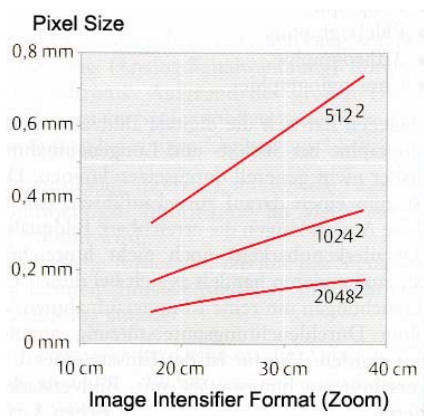

Figure 1 *Relationship between pixel size and zoom*

Optical magnification

The optical coupling between the image intensifier and the CCD camera allows an adaptation of the resolving power of the image intensifier output screen to the resolving power of the CCD camera input lens. Improvement of the resolving power has negative consequences with respect to inspection performance, image brightness and image noise.

Limitations of the Image Intensifier System

What is the smallest defect size that can be seen? First, the blowhole should produce a visible contrast. Second, the total unsharpness of the system must be smaller than the defect size. With all these limitations, the use of a properly optimized image intensifier chain is enough for automotive applications where defect sizes exceed 1mm^2.

Image processing

All aforementioned resolution and contrast improvements are not visible without the use of digital image processing. But image processing is not magic – it can only make visible information that is available in the digital image. In this application, real-time image processing is done in three dynamic stages to generate a high quality x-ray image.

Stage 1

At the first stage of the processing, the input image is treated to remove noise or unwanted artifacts. This stage consists of the following steps:

Shading Correction

High-resolution sensors produce non-uniform response when exposed to radiation. The correction of the sensor output is done so that resulting pixel values cover the entire dynamic range of the sensor. This is accomplished by applying offset (dark value) and gain (bias) values to each pixel individually.

Lens Correction and Alignment

Images generated by a camera can also be influenced by lens characteristics. Left uncorrected, lens distortion can undermine measurement and defect accuracy.

Stage 2

In the second stage motion compensated noise reduction is completed. The conventional method to reduce noise in X-ray images involves averaging several consecutive frames. However this technique is ineffective when capturing images of object that are moving. When the object is in motion averaging frames over time can cause ghosting, smear or streaking. The algorithm utilizes a temporal filter to estimate motion in the input image.

Stage 3

In the third stage image rotation and/or flip along with image enhancement (digital filter) and masking is completed. The digital filter kernel can be used to perform convolution functions such as edge enhancement or removing high or low frequency components from the images. Pixel masking is a process to remove the unwanted gray values from the output image. This is completed in real-time to improve visual attributes of the output images and assists the operator's ability to focus in the area of interest.

3. STANDARDS PROPOSALS

Minimum requirements for semi-automated radioscopic on-line systems in aluminium

Table 1 *Minimum requirements for the visibility of the wire Image Quality Indicators (IQI) according to ASTM E 747 and ASTM E 2002*

Penetrated Aluminum thickness (mm)	ASTM E 747 (Rev. 1997) Wire No. IQI (02B 11)	ASTM E 2002-98 Wire IQI
5	6	8
10	7	7
15	8	7
25	9	7
35	10	7
45	11	7

Minimum requirements for semi-automated radioscopic on-line system are given for the following conditions:

Operator decision, 30 or 25fps, X-ray tube focal spot 0.1-1 mm according to EN 12453 (new standard) or 0.1-0.5 mm according to IEC 336 (old standard)

The Image Quality Indicators (ASTM E 747 and ASTM E 2002 – 98) are fixed on the source side of the object The plates are under the optimum conditions. In Table 1 shows the wire numbers that should be seen depending on penetrated thickness.

Minimum requirements for fully automated ADR radioscopic on-line system

The requirements stated here only concern the image processing capabilities of the ADR system.

1. Detection

The system should be able to detect all critical defects starting at a size of five connected pixels which all must have a minimum contrast of 10 gray values in a 8 bit digitized image in comparison to the gray values of the surrounding material.ADR software reacts to pixels and contrast of the image only. The ratio between pixel size and real defect size depends on geometry and x-ray equipment (x-ray tube and imaging system).

2. Reproducibility

To evaluate the reproducibility of an ADR system, 10 to 20 images of a defect should be taken in the exact same position. Depending on the type of the defect, the measured area should be converted to linear units to minimize quantization errors. For blowholes, a conversion from area for averaged radius should be calculated. The converted results have to be analyzed for standard deviation. Limits for the maximum allowed deviation should be defined according to size of the defect

3. False negative rate should be as small as possible.

4. The system availability should be better than 99%.

5. Automatic self-test starts periodically to ensure that the machine and imaging chain are running properly.

6. Number of peaces inspected in fully automatic mode should be greater than the number inspected in semi-automated mode using inspectors, averaged over ten years.

7. The X-ray image should be of high quality (low noise, contrast rich image).

4. REQUIREMENTS OF A GOOD ADR SYSTEM

Requirements for a fully automatic real-time x-ray inspection system:

- Short inspection time, fast throughput
- System availability better than 99%
- Easy to setup and operation.
- Ability to integrate into the control loop
- Ability to identify defects and their cause, and feed that data back into the control loop (defect prevention).
- Flexibility through modular design
- Built in database of manufacturing processes that is available to the factory network.
- Terminals that display data from the machine in key location such as quality control
- Ability to interface with other machines, databases, processes in the plant. Open architecture that can be accessed by other machines
- Ability to store important inspection data on digital media
- Self verification of image quality

5. STRUCTURE OF AN ADR SYSTEM

This is four stage image processing system:

1. Preprocessing: segmentation and noise reduction.
2. Defect detection: detection of all possible defects.
3. Plausibility check: distinction between real defects and artifacts.
4. Quality criteria check: compare defects to user defined quality criteria.

6. DIFFERENT APPROACHES TO ADR

<u>Filtering with prior knowledge</u>

Template matching / Reference position method

During setup a reference position for the good part must be defined and run. An inspection or filter window must be specified, and different filters for every part section, if necessary, must be applied. Inspection parameters and must be taught, and finally the tuning data must be stored. In inspection mode, a predefined part position is chosen, the stored inspection parameters recalled, part position is checked and finally the scored reference image is compared to the image acquired during inspection to find all the differences - i.e. the defects.

Disadvantages of this method are:

- Precise handling system necessary
- Time-consuming setup process
- Limited re-use of already learned parameters

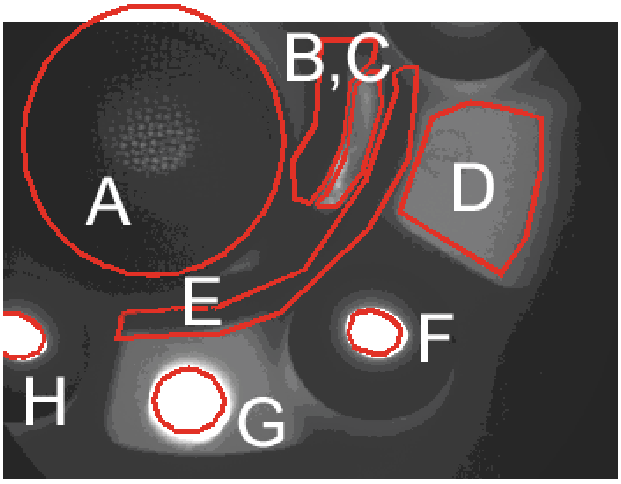

Figure 2 *Filtering according to pre-defined areas*

This method requires high precision positioning of the inspected part and doesn't work well on the plant floor, but does work in a lab environment.

<u>Adaptive matching</u>

Adaptive matching is characterized by producing reference images that are adapted to the shape of the inspected part. This model assumes the flawless mould part is composed from areas of relatively smooth intensity separated by edges. The defects are described as local deviations from the smooth intensity surface.

Often defects cannot be identified in the edge regions due to high noise levels. The actual image evaluation relating to actual position and orientation is stored and optimized as follows: edge detection, region of interest network, adaptive reference subtraction, region of interest masking, defect identification based on Hopfield-Tank neural network and finally quality estimation.

<u>Multiple filter usage</u>

A flawless reference image is produced for every inspection image by use of a special filter process. This filter process suppresses all structures beyond a predefined threshold value. After comparing this image with the object under inspection all defects are identified and evaluated.

Additionally all filters are adapted to the structure of the inspected part in order to distinguish regular and irregular structures.

The actual image evaluation depends on the position and orientation of the part. Only qualified people can perform setup, which often takes a long time.

Multistage-modified median filtering without prior knowledge and reference positioning

WHEELinspector™ (ADR) is a simple solution:

1. Generate a flawless reference image (Figure 4) from the original X-ray image (Figure 3).
2. Subtract the created reference from the original X-ray image (Figure 5).
3. Compare every pixel value with a given threshold
4. Group pixels in a neighborhood into defect regions
5. Measure size and density of defects regions and compare these values to user-defined quality criteria (specs).

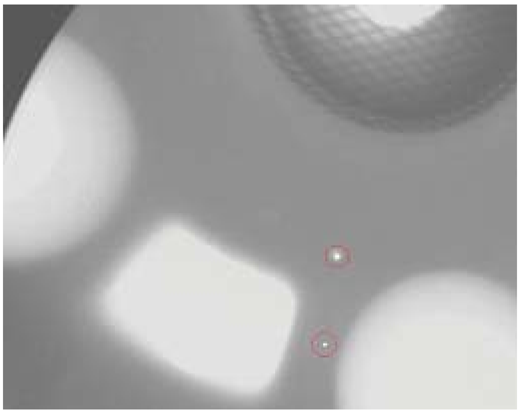

Figure 3 *Original x-ray image of the wheel*

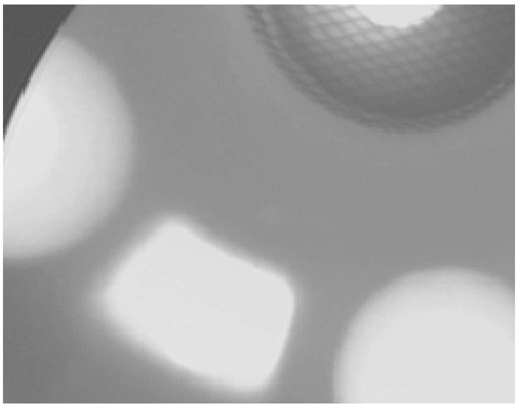

Figure 4 *Reference (defect free) X-ray image*

Figure 5 *Original x-ray image of the wheel*

WHEELinspector™ (ADR) creates a flawless reference image from the actual image without any a priori information by using a self-adapting algorithm.

The self-adaptation of this operator has several advantages for use in inline inspection. Filter parameters can be set easily for new parts to inspect, because there is no need for a priori information. Inline real-time X-ray systems have a need for the highest speed possible, so the possibility to compute an algorithm on more than one processor is important.

Figure 6 *Defect detection and defect size measurements*

CONCLUSION

Using this new technology cast wheel plants will improve quality and reduce costs of manufacturing, eliminate scrap and rework. The ultimate goal to have only safe, good quality wheels on our highways can be achieved.

After producing quality wheels, plants will sell more and more wheels for less money, and will employ more people who contribute for more prosperity and happiness for everyone.

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