

A Defect Grading Method for Digital Radiographic Image

Chaoming SUN, Guangping TANG, Qiang LI, Zengyong WANG
(Institute of Machinery Manufacturing Technology, China Academy of Engineering
Physics, Mianyang 621900, China)

Abstract. In this paper, a defect grading method for digital radiographic images from CMOS x-ray linear array detector was put forward, which is based on a standard defect-grading comparison sample and a computer-aided defect interpretation method. A standard defect-grading comparison sample was designed and used to help measuring the distortion and magnification of the images, and to grade the defects in the images by comparison with the standard scale on the comparison sample. Furthermore, a computer-aided defect interpretation method was established by means of digital image defect extraction, labelling, and classification according to characteristic parameters calculated by home-made grading software. With the two tools mentioned above, the grading of overall defects and positioning of critical defects can be easily and effectively implemented.

Introduction

Digital radiography method is finding to have more and more extensive application, and is becoming the development trend of radiographic testing. For example, European joint research project "Film Free"^[1] was carried out to promote digital radiography. Currently, digital radiography techniques such as Direct Radiography (DR) and Computed Radiography (CR) can be better used in production. In CR, Flexible Phosphor Imaging Plates (IP) is used to replace traditional film, and the IP has advantages of flexible, easy to place and can be used to replace film directly, but it has the disadvantage of a middle link that is a laser scanner should be used to read out the latent image in IP. As digital radiography does not require darkroom processing of film, the testing efficiency is higher. CMOS x-ray linear array detector is a new DR detector, in which the detecting elements are lined in a row, and each element has independent readout amplifier, and the electronic elements inside are good shielded, finally the optical signals are converted to digital signals by fibre bundles. The main technical parameters of the detector used are: suitable for 20-320kV X-ray, spatial resolution is 6LP/mm, with 4096 grey level. In the process of radiographic testing, CMOS detector need a relative motion with work piece, thus a full 2D image can be obtained by the scan method. Therefore, digital radiographic testing differ from conventional film radiography (Fig 1).

At present, digital radiography can be partly used as an alternative for conventional film methods in production, but subsequent problems should be solved in practice, such as standardization of the method, grading of defects. With the help of standardization, acquisition of digital images and their analysis and storage can be better specified, and the quality of testing result can be guaranteed. Although digital radiography is convenient and efficient, if a testing is just used to view inside and a conclusion can't obtain, the testing work was not complete obviously.

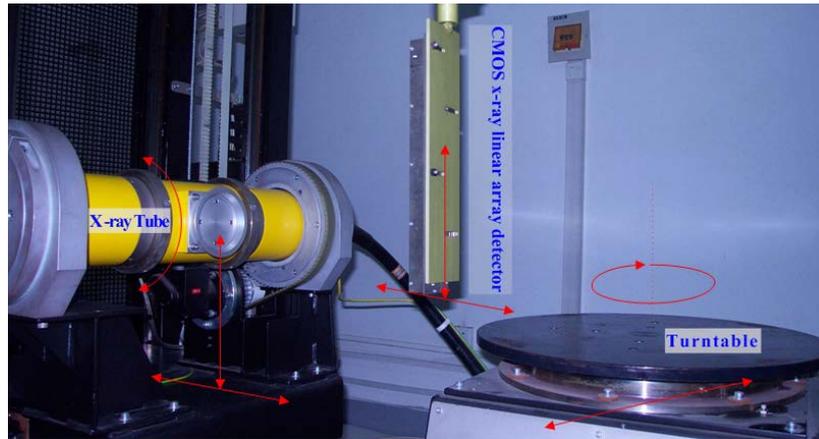


Fig 1. Radiographic testing system with CMOS x-ray linear array detector

In the period of conventional film radiography, how to achieve interpretation of film by computer was a goal pursued by many researchers at home and abroad [2-8]. Recently, there is more research in the area of computer-aided defect interpretation, and also certain progress has been made [9-11]. Egypt scholars have established an expert system for recognition of defects in pipe welds [12], and assessment study on identification accuracy of weld defect was carried out by Brazil scholars [13], while T.Warren Liao from USA also researched on computer-aided film interpretation and how to improve its accuracy [14-15]. Although the technique is in progressing, commercial software to aid defect interpretation is not available up to now. Digital radiographic images can be enhanced with image processing technique, however there are many shortcomings in computer-aided interpretation technique, and this becomes a bottleneck for promotion and application of digital radiography.

In this paper, a defect grading method for digital radiographic images from CMOS x-ray linear array detector was put forward, which is based on a standard defect-grading comparison sample and a computer-aided defect interpretation method.

1 Grading standards for defects in radiographic testing

It is urgently needed to evaluate and classify the testing result according certain standard when the digital radiographic testing is finished. At present, standards such as GB/T 3323-2005^[16] and JB/T 4730-2005^[17] are usually used to grade defects in conventional film radiography.

There are 6 kinds of fusion butt welded joints of pressure equipment made by steel, nickel or copper, aluminium, titanium and titanium alloy etc. can be graded according to standard JB/T 4730-2005. Each class has special requirements, and also has consistent ones, for example evaluation method for linearity flaw. For fusion butt welded joints of pressure equipment made by steel, nickel, or copper, the classification process is approximately as following: classification by general requirement, classification of circular defects, classification of linearity defects and comprehensive evaluation.

1) To evaluate circular defects, grading area should be firstly determined according to thickness of base metal, then equivalent defect points on the basis of defect size can be calculated, so the grading level for the welds can be obtained .The level should be IV if deep hole defects exist.

2) It is relatively troublesome for linearity defect grading, as a maximum length of single linearity defect and accumulation length of a group of linearity defects are needed for the grading. The gaps between linearity defects should be taken into account when calculating the accumulation length of a group of linearity defects. The grading areas are different for

level II and level III according to the thickness of base metal. If two or more linearity defects are located in the same line and their gaps are smaller than or equal to the shorter defect length, then the defects are treated as one defect, and the gaps are also included in the length of the defect.

3) If there are linearity defects in the grading area of circular defects, comprehensive evaluation should be made. The grading level of circular defects and that of linearity defects are summed together, and then the value was subtracted by 1 as the level of comprehensive evaluation.

Compared with JB/T 4730-2005, the standard of GB/T 3323-2005 is simpler in grading of defects, while JB/T 4730 has more detail and strict requirements.

2. Defect grading with standard defect-grading comparison sample

2.1 Problems of defect interpretation in digital radiography

2.1.1 Image enlargement

As a relative motion between CMOS detector and workpiece is needed, the work piece can't reach the surface of the detector, and then the acquisition image is to be magnified from geometry projection principle.

2.1.2 Image distortion

In the testing, a proper relative speed V should be selected to match with the exposure time T of the detector (Formula 1); otherwise the image acquired would be stretched or compressed along movement direction, thus cause image distortion.

$$V = \frac{P}{M \times T \times N} \quad (1)$$

Where, V ——Relative speed (mm/s);

T ——Exposure time of the detector (ms);

P ——Imaging precision (μm);

M ——Magnification;

N ——Number of images to be averaged.

2.1.3 Quantitative evaluation and interpretation of defects

The procedure to evaluate defects in traditional radiographic testing is as following: Firstly, the film is placed upon a view box of which the brightness can be adjusted, the defects can be viewed and classified, the size of defects can be measured by a ruler, then comprehensive analysis can be done by certain standard, finally the grade level of defects can be obtained.

Although measurement function of image processing software for digital radiography can be used to measure the defects, the measurement result varying with the actual defect size thus could affect the grading results, for image scale of the software is set as 1:1 default, while testing image has different magnification due to variety of the structure or position of the work piece actually. Furthermore, inaccurate parameters selected to acquire image in digital radiography will lead to image tension or compression mentioned above, and the defects are distorted, then evaluation of defects will be affected.

To evaluate and quantify the defects accurately, calculation of magnification of the image and control of image distortion are preconditions.

2.2 Design of standard defect-grading comparison sample

To solve the problems in evaluation and interpretation of digital radiographic images, standard defect-grading comparison sample was designed. The sample is made of copper with thickness of 0.5mm or 1mm. Referring to the standard of GB/T 3323-2005 and JB/T 4730-2005, a 10mm×10mm rectangular window and $\phi 0.3$ 、 $\phi 0.5$ 、 $\phi 1$ 、 $\phi 2$ 、 $\phi 3$ 、 $\phi 4$ 、 $\phi 6$ 、 $\phi 8$ circular through holes are made on the sample (Fig 2).

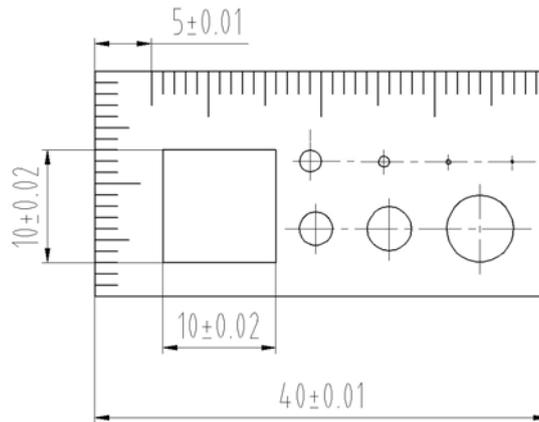
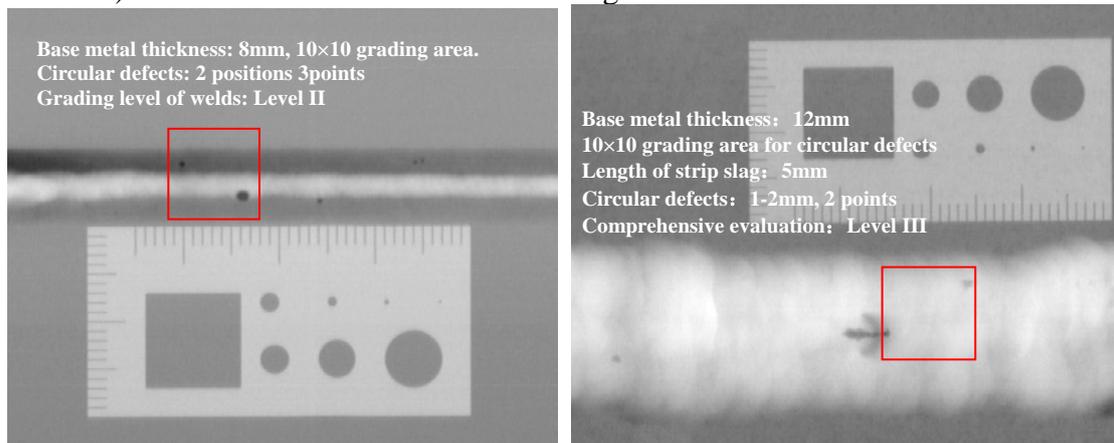


Fig 2: Standard defect-grading comparison sample

2.3 Application of standard defect-grading comparison sample

According to the thickness and material type of workpiece, proper comparison sample is to be used in digital radiography. In the image, the comparison sample should have grey level different from that of the position of workpiece to be tested, and the sample should be thin as possible.

The comparison sample is to be placed closely to the surface of workpiece where to be examined, and the place to be examined can't be covered or blocked by the sample. The sample and workpiece are to be imaged in same image. By means of viewing and measurement of the size of rectangular window or circular hole in the image, it is possible to evaluate the distortion of the image and to judge whether the acquired image is distorted or not. If distortion is detected, it needs to adjust the parameters of image acquisition (Formula 1) until there is no distortion in the image.



a) Evaluation of circular defects

b) Evaluation of strip slag

Fig 3. Standard defect-grading comparison sample and flaw detected

Magnification of the image can be calculated by size ratio of rectangular window or circular hole measured by software and corresponding actual value. The magnification can

be used to set scale settings in the software, and then actual size of defects can be measured by software.

A direct-viewing method to evaluate the defects is comparison approach. The image of small hole on comparison sample can be used to compare with that of defects, the major axis length of defect can be estimated and what size range it belongs to can be determined, then grading of defects can be done according to the standard (Fig 3).

3. Defect grading by computer-aided interpretation method

3.1 Defect extraction

To realize defect interpretation by computer-aided method, it is needed to extract the defects from the image efficiently. Curve fitting method applied to grey value line can be used to extract and segment defects^[11], but there are some short-comings in practice:

- 1) Different distribution features of gray value need different polynomial to fit; it is difficult to use one uniform polynomial to extract defects in a background with different gray value.
- 2) As least square criterion was used in curve fitting, it is likely to get a shadow area at upper and lower parts near defects, especially when many defects are linked together.
- 3) For non-horizontal weld such as annular weld, it is difficult to obtain satisfactory processing result by curve fitting method.

When edge detection operator is applied, false contour lines may arise, and edge line of defects may not close, this brings up a lot of difficulties for following processing.

Threshold segmentation method is an easy method to extract the defects, but it is generally limited to image with distinguishing characteristics on histogram. Actually, background near the object may be variable, it is impossible to extract the defects with a single threshold unless region correlation threshold method is used. After comparing and analysing, image subtraction method is thought to be an efficient method to extract defects, which is independent of specific characteristics of digital radiographic image and has better versatility.

Therefore, strategies for defect extraction are: Firstly, background image is made by smooth convolution with a large template, then original image is used to subtract background image simulated above, the processing flows chart sees Fig 4.

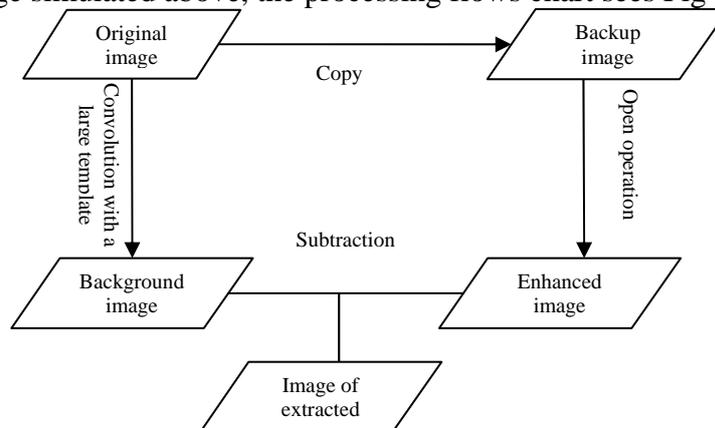


Fig 4. Processing flows chart of defect extraction

3.2 Defects recognition

After extraction of defects, defect object can be segmented by a threshold to form a binary image. In the binary image, different region can be labelled and its characteristic parameters

such as area, length, width, perimeter, aspect ratio, roundness, and angle can be calculated. The defects can be classified and identified according to the characteristic parameters. However, the accuracy of classification by computer-aided method needs to be improved [15, 18].

According to standards mentioned above, defects with aspect ratio smaller than or equal to 3 are defined as circular defects, which have circular, ellipse, conical shape or irregular shape with a tail and which include porosity, slag or tungsten inclusion. Slag defects with aspect ratio greater than 3 are defined as stripy defect. So, the defects can be classified by aspect ratio after calculation of the characteristic parameters. For defects such as lack of penetration, cracks, incomplete fusion etc., the recognition should be carried out by their characteristics and the position where defects located such as outside of the weld, in the centre of the weld [12]. Characterization of this kind defect can be changed and identified by means of manual intervention (Fig 5).

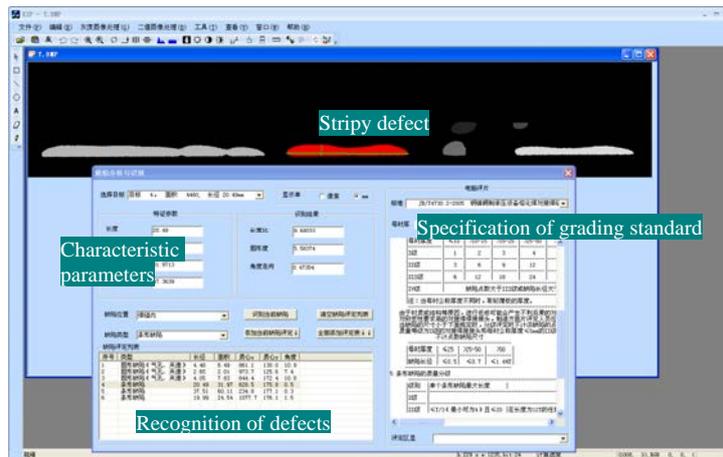


Fig 5. Quantitative evaluation and identification of the defects

3.3 Grading of defects

To realize computer-aided interpretation function according to different standard [7-8], software was developed using object-oriented programming method. Class of defect parameters was designed to record characteristic parameters of the object defect in digital radiographic image; class of defect grading was designed to grade the defects.

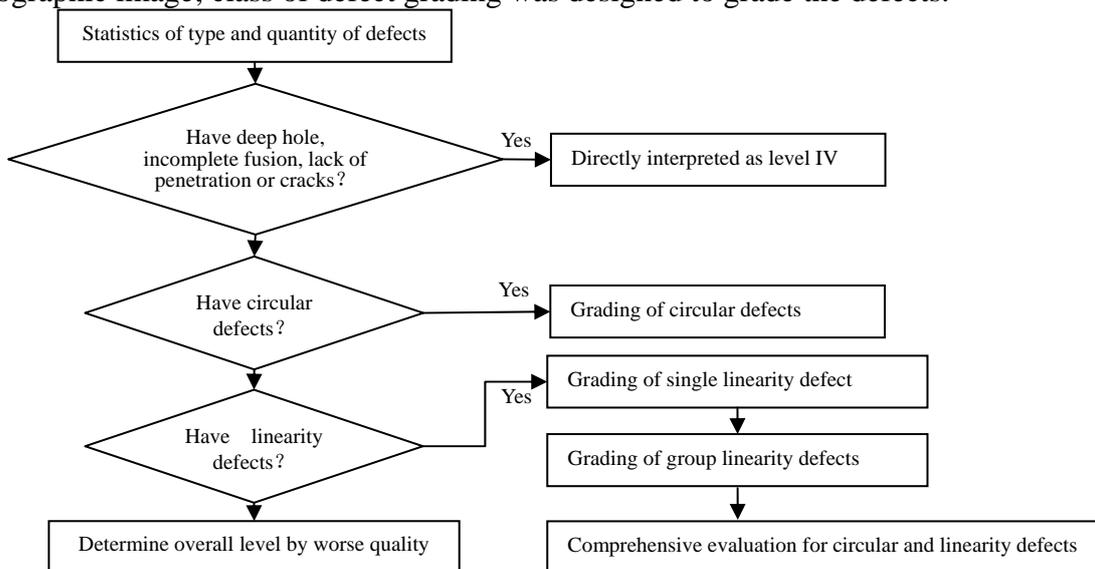


Fig 6. Implementation process of defects grading

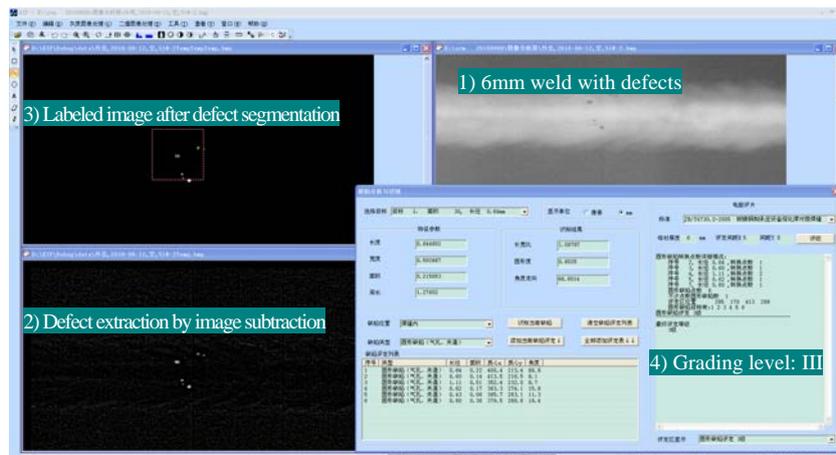
The implementation process to grade the defects in fusion butt welded joints of pressure equipment made by steel, nickel or copper by computer-aided method is shown in Fig 6.

Before quantitative evaluation of defects, calibration for measurement software by standard defect-grading comparison sample is need.

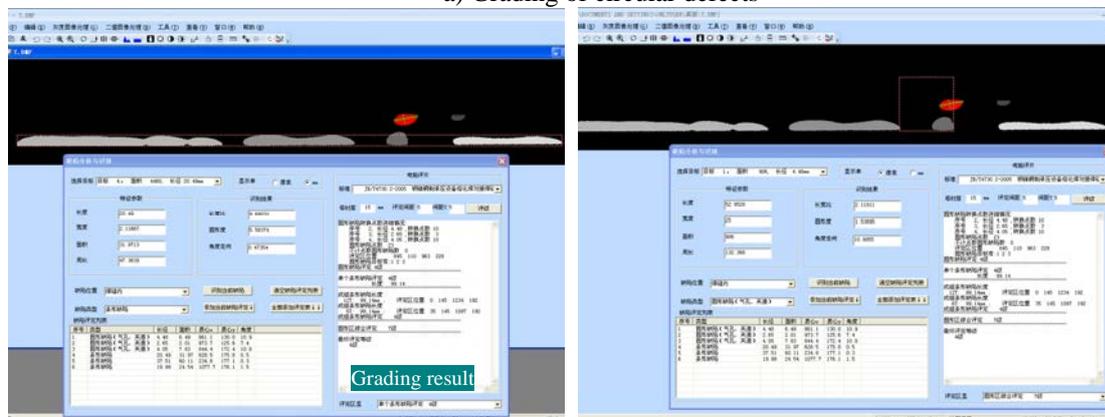
To grade circular defects, the size of grading area, a major axis length below which the circular defect is ignored and the mapping relationship between defects of different size and equivalent points should be determined according to thickness of base metal firstly. Then, traverse on labelled image was carried out according to grading area, the grey value distribution in current grading area was counted, whether there was circular flaw in the area and its characteristic parameter was determined accordingly, the defect points were counted and defects does not count were statistically calculated separately. If defect conversion points counted in current area were bigger than before, then current area was recorded as defect serious region. By this loop operation, the flaw serious region and its equalling conversion points was finally obtained, then the points were converted into the quality level according to the circular flaw grading requirement.

To grade linearity defects based on JB/T4730-2005, whether the defects are in the same line and their gaps are smaller than or equal to the shorter defect length should be analyzed; if the conditions are met, the linearity defects should be combined and regarded as a linearity flaw, whose length is sum of length of separate defects and their gaps.

After the grading completes, the grading result is displayed then, and flaw serious region can be viewed according to grading situation. Grading of overall defects and positioning of critical defects can be implemented by computer-aided defect interpretation method. An implementation on defect grading using computer assistance technique was shown in Fig 7. Grading area wherein serious flaw was marked with dotted line frame.



a) Grading of circular defects



b) Evaluation of single linearity defect and comprehensive evaluation

Fig 7. Example of computer-aided defect grading

Conclusion

- 1) For application of digital radiography, the problems of quantitative evaluation and identification of the defects in digital image should be solved efficiently.
- 2) To solve the problems in evaluation and interpretation of digital radiographic images, standard defect-grading comparison sample was designed. With the sample, it is possible to quantitatively evaluate the defects accurately, conveniently, direct-viewingly and to grade the defects quickly.
- 3) To evaluate the defects accurately and to evaluate the defects comprehensively with computer-assisted technology, computer-aided grading software was developed. With the software, grading of defects can be done according to different standards, and overall defects grade can be evaluated, positioning of critical defects can be implemented.

Future direction

For hazardous defects like crack and incomplete fusion, automated method to extract and classify the defects accurately by computer technology needs further thorough research. Moreover, the accuracy of computer-aided grading software needs to be verified by comparative validation.

Reference

- [1] Uwe Ewert, Uwe Zscherpel, Carsten Bellon etc. Flaw size dependent contrast reduction and additional unsharpness by scattered radiation in radiography- film and digital detectors in comparison -, 17th WCNDT, Shanghai, October 2008.
- [2] Li Yan, Development of film interpretation by computer(in Chinese), *Nondestructive testing*,1997,19(9): 253-257
- [3] Fu Deshen, The study on the model of the computer's distinguishing automatically on the welding defect(in Chinese), *Control and decision*,1998,13(7):469-474
- [4] Gang Tie, Wang Donghu, Defect extraction and segmentation automatically in x-ray inspection images(in Chinese), *Welding&Joining*, 2001(5): 6-9
- [5] Gao Jun, Zhang Xudong, Liu Hongwei etc. Image processing for microcomputer recognition of weld defects on x-ray films(in Chinese), *Nondestructive testing*,1999,21(3): 107-109
- [6] Zhou Zhenggan, Teng Shenghua, Jiang We etc. Research on defect detection and evaluation in welds with x-rays(in Chinese), *Transactions of the china welding institution*,2002,23(6): 85-88
- [7] Ian Songhua, Processing technique for automatic discrimination of defects on films(in Chinese), *Nondestructive testing*,1999,21(6): 251-253
- [8] Li Shaping, Liao Mine, Wu Chennai, Sizing and automatic grading of weld flaws in x-ray negatives with computer(in Chinese), *Nondestructive testing*,1998,20(7): 193-195
- [9] Zhang Dialoguing, Liu Jinee, Lin JeJune , The expert system of x-ray welding seam defects distinguishing(in Chinese), *Coal Mine Machinery*, 2002(11): 22-24
- [10] Zhang Dialoguing, Lin JeJune, Weld defects distinguishing method based on fuzzy neural network(in Chinese), *Journal of China university of mining&technology*, 2003,32(1): 92-95
- [11] Zhang Xiaoguang, Gao Ding, Extraction and automated recognition of weld defects in radiographic testing (in Chinese), *National Defence Industry Press*, 2004,10
- [12] H.I. Shafeek, E.S. Gadelmawla, A.A. Abdel-Shafy, Automatic inspection of gas pipeline welding defects using an expert vision system, *NDT&E International*, 2004,37: 301-307
- [13] Romeu R. da Silva, Marcio H.S. Siqueira, Marcos Paulo Vieira de Souza, Estimated accuracy of classification of defects detected in welded joints by radiographic tests, *NDT&E International*, 2005,38: 335-343
- [14] Gang Wang, T. Warren Liao, Automatic identification of different types of welding defects in radiographic images, *NDT&E International*, 2002, 35: 519-528
- [15] T. Warren Liao, Improving the accuracy of computer-aided radiographic weld inspection by feature selection, *NDT&E International*, 2009 ,42: 229-239
- [16] GB/T 3323-2005, Radiographic examination of fusion welded joints in metallic material (in Chinese)

- [17] JB/T 4730.2-2005, Nondestructive testing of pressure equipments—Part2: Radiographic testing (in Chinese)
- [18] Romeu Ricardo da Silva, Domingo Mery, The state of the art of weld seam radiographic testing: part II, pattern recognition, Materials evaluation, 2007,8: 833-838