A Review of Current Status in Applying Special Radiographic Techniques to Pressure Equipment in China

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Abstract: Special radiographic examination（RT） techniques for the common and special welded joints in pressure equipment are outlined, covering the tube-to-tube sheet joints of heat exchangers and the nozzle and branch joints of various vessels for which the examination procedures are more difficult. The characteristics and attention matters of mega-voltage radiography and the main points and difficulties in radioscopic real-time imaging techniques are pointed out. Finally, the state-of-art and future of digital radiography are described.

Keywords: Radiographic examination; Pressure equipment; T-shaped welded joint; Tube-to-tube sheet joint; Nozzle joint; Real-time imaging ; Digital radiography

For NDE of pressure equipment various welded joints with special structure and shape are involved, such as T-joints, tube-to tube sheet joints, nozzle joints and so on．For the above joints, in general, only performing UT is required for internal flaws and MT or PT for surface flaws (incl. flaws very closed to the surface). However, for those pressure equipment under severe service conditions such as severe-poisonous or erosive/corrosive medium or high temperature or high pressure，the special welded joints in some components or structural members performing all of MT，PT，UT，RT are mostly required． When applying RT, some special procedures even special equipment and techniques are needed．This article will give a review of the current status and the recent development of applying the special techniques of RT to pressures equipment in China.

1. Special RT procedure for special welded joints

T- joints, fillet joints and nozzle joints more often seen in pressure vessels are the rather difficult object for RT．The practicality and reliability of RT for them are determined by many facts including section shape of joints, metal thickness, curvature change of components, usability of equipment and materials, radiographic arrangement for exposure, direction of radiation and accessibility for performance and so on．And observation and interpretation of the completed radiographs, evaluation and acceptance check of the weld quality, are all related to the level of knowledge and experiences of the RT personnel engaged.

1.1 T- joints [1]

For the T-joints (V groove) composed of two components as shown in **Figure 1**, a 45° radiographic technique may be used where the film is placed on the side of component 1 . In this example that the maximum penetrated thickness $T_{max} = \sqrt{2}\,(T_1+T_2)$ and the minimum penetrated thickness $T_{min} = \sqrt{2}\,T_1$, it is not easy to select the proper X-ray energy. Therefore, a piece of plate (whose thickness equals the weld-leg length) with a ready-made bevel (half-V) may be used , placing its oblique face close up to the inspected weld, so that the obtained image quality of the completed radiographs is nearly as same as the one of plate butt-welded joints .Besides, in order to facilitate locating the depth of flaw images, the high-density markers should be placed on both sides of the width of the inspected weld before making radiographs. The IQI wires should be cut shortly and placed between the compensator block and the component 1.

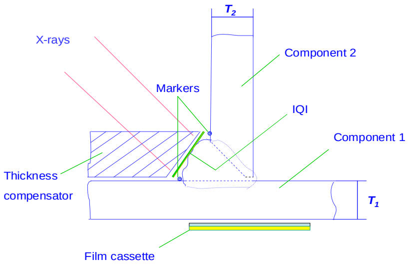

Figure 1. The essentials of RT procedure for T-type joints

(45° radiography + thickness compensator + weld-edge markers)

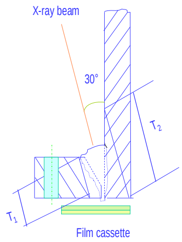

Figure 2. The essentials of RT procedure for Nozzle-to- holey flange combined welds

1.2 Tube (nozzle) to-tube sheet (shell/flange) configuration

1.2.1 Nozzle to holey flange : combined weld **Figure 2** is an example of inspecting the combined weld of a set-in nozzle with a holey flange . The thickness of the flange is 10 mm and the connected nozzle neck is 12 mm in wall thickness and 125 mm in inside diameter. For such a structural component , using a 30°radiographic technique can be considered, where the minimum thickness penetrated $T_1 = 10/\cos 30° = 11.5$ mm and the maximum thickness penetrated $T_2 = 12/\sin 30° = 24$ mm and the thickness difference $\Delta T = 12.5$ mm .

In order to increase the thickness latitude and eliminate the effect of severe "undercut" and overall fog on a film caused by scattered radiation of the flange edge and the holes , an adequate thickness of lead foil (e.g. 0.4 mm in this case) may be used as a filter close to the X-ray tube window to produce a harder beam of radiation . The following combination of radiographic parameters is selected: V = 250kV, I = 10mA , FFD = 800 mm, and making 4 exposures for the whole girth of the combined weld . The IQI wires should be placed to the weld as close as possible.

1.2.2 Heater exchanger : tube-to- tubesheet joints For tube-to-tubesheet joints of a tube-shell type heat exchanger or reactor , generally, tubes are inserted into tubesheets, and tubesheets are welded with tube ends by GTAW . Because of small diameter and thin wall thickness of tubes, making radiographs of such joints usually needs to use a mini-focus rod-anode X-ray tube with 160～320kV or a mini-focus Ir-192 source .

1.2.2.1 Using a mini-focus rod -anode X-ray tube[2] For set-in tube-to-tubesheet joints shown in **Figure 3a**, a rod-anode X-ray tube with a 0.2～0.5 mini-focus (200 kV, 5mA) can be pushed into the tube for some distance , so as with the aid of reflective tungsten target, to make a backward panoramic exposure of the inspected TS joints at one time . However, the completed radiographs cannot be interpreted and evaluated yet because of the severe "undercut" and dense fog caused by such arrangement . For the sake of compensating the thickness change and eliminating "undercut" effect, a special shaped block of thickness compensator has to be designed and fabricated in accordance with the shape and size of the actual TS configuration. After properly compensating thickness, the film density is easy to control in 2.0-3.0. For a titanium tube shown in **Figure 3b** having a bigger diameter (φ25.4 mm) , the one end of the used thickness compensator can be machined in the form of crab pincers and pushed in to clamp the end of the tube . However, for the TS joints of a water-feed heater shown in **Figure 3c**, the tube bore is so small (φ19mm) that it is impossible to use the above shaped compensator block but a circular one with a plane end as shown in this figure . As demonstrated by a series of experimental results , a φ 0.1 mm wire of IQI can be distinguished from the film and a φ 0.1mm gas pore can also be detected in the welds if adopting the above two exposure arrangements .

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(a) Basic setup for radiographic inspection of tube-to-tube sheet joints ; (b) Titanium tube- to-tube sheet joints ;

(c) Water-heater tube- to-tube sheet joints

Figure 3. Setup for mini-focus X-radiographic inspection of tube-to-tubesheet joints in heat exchangers

1. Mini-focus rod anode X-ray tube ; 2. Anode target (plane type) ; 3. Anode handle ; 4. Weld ; 5. Film ; 6. Horn-type

model for placing film； 7. Thickness compensator； 8. φ0.1mm wire of IQI (Al)； 9. Metal wire IQI

1.2.2.2 Using a mini-focus Ir-192 isotope source [3] For tube-to-tubesheet welded joints in accordance with German BASF standard, we use an Ir-192 isotope source with a small focal spot d_f = φ1mm × 0.5mm to perform radiographic examination, adopting ISO Class T2 films sized 100 mm×120mm．Films shall have a center hole suitable to the tube of heat exchangers．The SFD shall be such that the entire weld is imaged with as little distortion as practical. The recommended SFD = 30 mm for D_i≤ 18mm, and SFD≈40mm for D_i > 18～50mm (D_i :tube inside diameter) .The selected exposure time t □ 30 s with film to be exposed so that the optical density D = 2.5-3.5 in the zone to be evaluated (the weld and areas adjacent to the weld)．

In order to obtain an uniform optical density in the evaluated zone, we still use a thickness-compensator block adapted to the tubesheet dimensions as well as to the weld geometry．A test hole has to be drilled into the compensator block which shall be so designed that centering of the radiation source is ensured. Besides, as an auxiliary filter, a tin sheet of 0.5mm thickness has been inserted between the weld and the film．

It is not required to place IQI, because it would increase the weld-to–film distance and result in unsharpness of the image.To verify whether the image quality is adequate or not, a center punch mark can be applied to the weld if welded sample is available．

Figure 4 is a scheme showing a setup for radiographic inspection of tube-to-tubesheet welds with a mini-focus Ir-192 source(high-specific activity) using backward panoramic technique．The source is introduced from the front end of the heat exchanger and it is easy to handle．

1.3 Nozzle seat joints[4-7]

The large diameter of Nozzle joints on a boiler or vessel body have a big curvature variation along the connection line called the mutual- run-through (MRT) line．The whole circle of weld presents a saddle- shape．Generally, such joints will be performed by gas tungsten arc welding on root pass and covered by manual arc welding, starting from the highest point and finishing at the

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Figure 4. Setup for RT of tube-to-tubesheet welds with Ir-192 using backward panoramic technique

lowest point of the MRT line．Both of the two points are the flaw-frequently-occurring areas and the “key points” of RT．

1.3.1 Alignment of beam For set-on nozzle joints, normally, the center beam of radiation shall be approximately along the bisector of two fusion faces of the inspected weld．Because of the big variation of curvature around the weld, making radiographs in some direction may be difficult and even impossible．**Figure 5** illustrates examples of radiographic direction for fusion welded nozzle seat joints, showing proper direction can increase the detectability of flaws．

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Figure 5. Examples of X-ray beam direction involving flaw detectability

In **Figure 5,** □ & □ is better than □ & □.

1.3.2 Number of exposures The number of exposures required for the whole circle of nozzle welds is relevant to the relative sizes of vessels and nozzles:(1) The variation of penetrated thickness in the inspected area depends on the ratio between diameter of nozzles and vessels, the corresponding wall thickness and basic structure (set-on or set-in), and it also depends on the position around the MRT line．The variation of penetrated thickness at both sides of weld is the lowest for a small hole of set-on nozzle and the highest for a large hole of set-in nozzle, especially when the nozzle wall thickness is obviously less than the vessel one．(2) The variation of penetrated thickness around the nozzle weld mainly depends on the nozzle diameter, being the lowest with panoramic exposure, and for a small nozzle, the highest with film-inside and source-outside or with film-outside and offset source- inside．When applying panoramic exposure, frequently, it is not possible that the radiation center beam can inspect along the angle-bisector between both fusion faces around the circle of the weld．Practice has confirmed that a single exposure is permitted as the vessel diameter is 4 times more than the nozzle one, and at least 2 exposures is needed as the vessel diameter is 4 times less than the nozzle one (See **Figure 6**)．

1.3.3 Interpretation of results Interpretation and evaluation of radiographs for nozzle welds involve such problems as image distortion, displacement and magnification due to the oblique projection．To identify whether images are false or true flaws and to judge precisely the nature of flaws, it is important to be familiar with the nozzle structure, fabrication procedure and welding process, moreover, be capable of estimation the real location of flaws in the weld on the principle

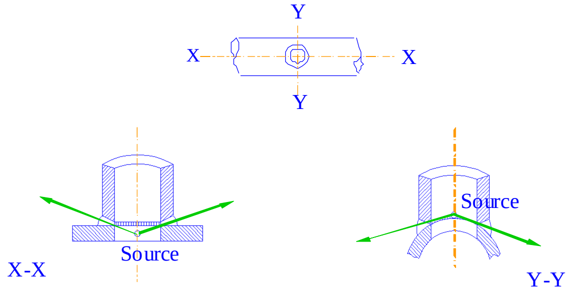

Figure 6. Example illustrating two sections of panoramic exposure for nozzle welds

of projection from a three-dimensional object on to a two-dimensional plane (i.e. the film). For example, on the radiographs, the trace image of drilling or cutting at the opening-to-nozzle connection area in vessels may be misinterpreted as lack of penetration or linear gas pore or lines of slag inclusions .

2. Panoramic exposure procedure for common welded joints [8]

For some small weldments with the same specification but in different wall thickness (e.g. plates or tubes), as batch is large, having need to reducing inspection cycles and increasing inspection efficiency, a panoramic exposure procedure can be employed, in which a ring of specimens is exposed simultaneously, with the source at the center .

For example, using a 300kV X-ray set with a conical anode tube to make panoramic exposure for 8 pieces of welded specimens, arranged at deferent diameters of circles . The sizes of all of the specimens are 300mm×250mm, the thickness is 20, 18, 16 and 14mm respectively . Welding by both sides, with reinforcement h = 4 mm for each welding specimenn . To obtain the same film density using 180kV [half-value thickness (HVT) H= 4.5mm], the panoramic exposure technique can be adopted as shown in **Figure 7,** when No.1 to No.8 specimens are placed separately and orderly at each circle with deferent radius as FFD, according to their thickness . The used FFD can be calculated on the basis of the equivalent values of radiographic HVT, and the equations and results of calculation are presented in **Table 1**.

In addition, the panoramic exposure technique can also be used to inspect the circumferential welds of a number of small pipes arranged at a circle . For example, examining the circumferential welds of 8 pieces of boiler-header-pipes (φ219mm×12mm) can be completed merely by 6 times of exposures for full radiography, but 48 times of exposures will be in need if using a common directional X-ray equipment [9] . Besides, the LPG cylinders (φ400mm×4mm) for civil use can also be inspected with this technique , to remarkably increase efficiency of the inspection .

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Figure 7. Arrangement of the panoramic exposure technique for numbers of welding specimens

Table 1. Determination of FFD using displacement techniques in panoramic exposures

(in correspondence with Figure 7)

Specimen No.	Material thickness T/mm	Established FFD F/mm	The appropriate equations

1, 2	20	500.0	$F_2 = F_1 \times 2^{\Delta T/2H}$ *
3, 4	18	583.3	$F_2 = 500 \times 2^{2/(2\times4.5)} = 583.3$ mm
5, 6	16	680.4	$F_2' = 500 \times 2^{4/(2\times4.5)} = 680.4$ mm
7, 8	14	793.7	$F_2'' = 500 \times 2^{6/(2\times4.5)} = 793.7$ mm

* If F changes，then $I_{02} / I_{01} = F_1^2 / F_2^2$ (I_0 is the incident intensity of radiation)；if T changes，then $I_2 / I_1 = (1/2)^{\Delta T/H}$ (I is the transmitted intensity)．For obtaining the same film density, $(F_2 / F_1)^2 = 2^{\Delta T/H}$ i.e. $F_2/F_1 = 2^{\Delta T/2H}$， so $F_2=F_1\times2^{\Delta T/2H}$.

3 Megavoltage X- radiography[10,11]

For ordinary X-ray sets with common high tension transformers to accelerate the electrons, it is difficult to inspect thick welds of greater than 100mm. Early in the 1940s, 15 - 25 MeV betatrons had been applied abroad．Then in the 1950s, 4 - 25MeV linacs (electro linear accelerators) were introduced in RT application field. In a linac system the electrons are accelerated to the rated high energy by carrying them on a radio-frequency wave traveling along a linear waveguide．The radio-frequency wave is provided by a magnetron or a klystron．In a betatron system, the electrons travel in a circular orbit inside of a toroidal tube and are given an accelerating pulse on each orbit, before being deflected on to a target．

3.1 Comparison of two sorts of accelerators

So far in China, employing mostly linacs (4 - 9MeV systems introduced from U.S. or made in China) but rarely betatrons (from Russia) to inspect boilers and pressure vessels．Linacs are characterized by having a very large X-ray output, for example, 4MeV with 2×2mm focal spot：4Gy/min (400Rad/min) at 1m distance．Betatrons generally have much smaller outputs, for example, 7.5MeV：merely 0.06Gy/min (6Rad/min) at 1m distance, but can have much smaller focal spots, e.g. 0.2×1.0mm． Besides, there are also portable linacs systems introduced from Schonberg Co. of US, offering 3 types of radiation forms by different (bolt-on) collimators, i.e. straight-ahead (0°) beams, 90° port beams and 360° panoramic beams, but they have lower output, e.g. 4MeV and 6MeV: 1 Gy/min and 3 Gy/min, respectively．

3.2 Essentials of the application of linacs

3.2.1 Long FFD plus fine-grain films With the linac, as having the large output of X- ray beams, FFD can be 2-3 m to gain a large field of radiation．In this case, it is better to use ISO T2 or T1 type films, so as to reduce film graininess and increase radiographic contrast . For megavoltage X-ray equipment, the inherent unsharpness Ui will become more important than the geometric unsharpness Ug (e.g. for 8MeV : Ui=0.6mm, and for a 300mm specimen, Ug=0.3mm) in light of crack sensitivity [considering $d \cdot w = \Delta x \cdot \zeta\,(d \sin\theta + w \cos\theta + U)$] .

3.2.2 Using screens of copper or stainless steel For megavoltage X-rays, it is hard to make good radiographs with conventional lead screens . In order to get higher sharpness and contrast and minimize false images, it is preferable to use screens of copper or stainless steel (e.g. 4MeV : 0.25 - 0.7mm front and back screens ; 9MeV : ≤1mm front and back screens), but requiring approximately double of the exposure time . Tantalum screens are generally rarely used due to its expensive cost .

3.2.3 By means of the large thickness latitude technique to make radiographs Employing linacs to inspect a specimen having a large change in shape and thickness, on account of their bigger half –value in steel (e.g. for 4MeV : H=25mm ; for 9MeV : H=31mm), it is possible to reduce the intensity ratio of transmitted radiation through the specimen, thus to decrease the density difference on radiographs, corresponding to the maximum and minimum thickness of the specimen, so one exposure can cover a large thickness range to satisfy the film density range specified in a code (e.g. the maximum thickness range which can be covered by 4MeV and 9MeV on one exposure is 50mm and 65mm, respectively) .

4 Real time radioscopy [12-14]

4.1 Introduction

Real-time Radioscopy (RTR) can real-timely or near real-timely present information concerning the nature, size, location and distribution of inside and surface defects in a specimen to be inspected, thus being able to observe and evaluate on-line, rapidly, timely and dynamically the quality of the inspected specimen . In comparison with the traditional film-based radiography, this method offers a number of advantages, such as saving time, material cost and man power, etc . Because of appearance of X-ray tubes with mini-and micro-focal spots, improvement of television cameras and image intensifier tubes, especially application of computer hardware and software, as well as development of image digitalization and image processing techniques, all of these optimize the performance of RTR and obviously increase the flaw detection sensitivity . So far in certain degree, RTR has become the major competitive method to the conventional film-based radiography in some application fields .

4.2 Application examples

Up till now, there are two groups of RTR equipment extensively used in China：one is X-ray image-intensifier system ; the other is linear-array system (see **Figure 8**) . In the manufacturing field of boilers and pressure vessels, they are mainly to be used to inspect on line the circumferential butt-welds of small diameter of boiler tube with large batch (e.g. tube diameter Φ32-60 mm, wall thickness T = 3.5-8 mm) (see **Figure 9**) and LPG cylinders etc .

4. 3 Some important parameters

4.3.1 Projection magnification M

$$M = 1+(L_2/L_1)$$

Where L_1 is the distance between the focal spot and the focus side of the test object measured along the central axis of the X-ray beam ; L_2 is the distance between the focus side of the test object and film surface measured along the central axis of the X-ray beam .

4.3.2 Optimal projection magnification M_{opt}

$$M_{opt} = 1+ (Us/d_f)^{3/2}$$

where U_s is the screen unsharpness ; d_f is the focal spot size.

4.3.3 Image unsharpness U

$$U = U_0/M$$

where U_0 is the image unsharpness before magnification, and

$$U_0 = (U_s^3+U_g^3)^{1/3} \qquad U_g = d_f \ (M-1)$$

4.3.4 The minimum detectable size of flaws d_{min} $d_{min} = US/M^{2/3}$

4.4 Image processing

Generally, image processing is made by various programs of a computer for static images . For inspection of welds four types of processing programs are widely used, i.e. ① filtering and field flattening to provide the thickness equalization across the relevant part of the weld image ; ② frame integration to reduce quantum noise, over, say 16～32 frames ; ③ Crisping image to improve image sharpness ; ④ Contrast enhancement by contrast adjustor .

4.5 Performance evaluation

At present the achievable level of real-time radioscopic system performance is shown in **Table 2** . In routine inspection these system performance parameters should be determined and monitored regularly, in accordance with the referencing standards, by using the contrast sensitivity gage and the duplex wire (Pt-W) type IQI . The measured results should be recorded in the inspection report . It should be noted that it is not enough merely to use the common IQI for evaluating imaging quality in RTR .

Table 2. Comparison of two groups of RTR system performance

RTR System group	Spatial resolution (lp/mm)	Contrast sensitivity C (%)
Image intensifier system	5	2
Linear-array system	20	5

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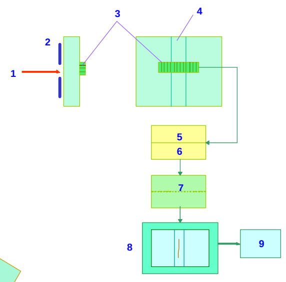
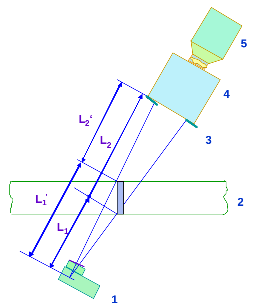
(a)



(b)

Figure 8 Commonly used X-ray real-time imaging system



(a) **Image intensifier system:** 1. X-ray source; 2. Object; 3. Image intensifier tube; 4. TV camera;5. A/D converter; 6. Computer/ Image processing; 7. Optical video disk; 8. Display monitor. (b) **Linear array of detector:** 1. X-rays; 2.Lead marks; 3. Linear array of detector; 4.Weld scan; 5.A/ D converter; 6. Data store; 7. Computer/ Image processing; 8. Display monitor; 9. Optical video disk

Figure 9 RTR arrangement examples for inspecting the butt welded joints of small-diameter boiler tubes

1. X-ray tube; **2.** Small diameter tube; **3.** Lead diaphragm; **4.** Image intensifier tube; **5.** Television camera

5. Digital radiography [15-18]

Digital radiography (DR) can resolve a radiographic picture into lots of micro picture elements (pixels) and store the data included in these elements into the computer .When necessary, the data can be extracted to treat so as to obtain the required picture information.Generally, DR techniques includes two types : one is two-dimensional method, where the detector simulates films and the acquired data represent the two-dimensional projection of a three-dimensional object, and the other is three-dimensional method, where the three-dimensional picture of an object is composed of the information acquired by double separate detectors, in an arrangement being equal to the pupil distance (about 65～75 mm) . So far, there are mainly two following methods for inspection of welded joints．

5.1 Automatic film interpretation by computer

5.1.1 Primary stage The flaw images on a radiograph, by the aid of CCD camera and A-D converter, are turned into digital images storing in a computer, then the digital data can be processed through appropriate image processing system, e.g. reducing noise, flattening, cleaning background and differentiating etc．Finally, the treated results will be displayed in a three-dimensional picture or a color picture so that the defect shape will be clear at a glance without any special skill.

5.1.2 Middle-class stage Those defects hardly discernible due to noise, need to be processed further to make defect shape being clear and distinguishable．

5.1.3 Advanced stage The acquired images should be quantified as far as possible in order to obviously display defect location and shape and, by the aid of automatic distinguishing system, to complete quantitative evaluation, classification and acceptance judgment of defects．

5.1.4 Difficult points To discriminate the root defects from the root geometric indications in welded joints finished by one side and to identify tiny cracks, it is also necessary to set up an artificial intelligence algorithm supported by the expert system．

5.2 Computed radiography (CR) technique

CR technique is one of the new non-film radiographic techniques in DR，where the digital radiograph is created by means of an imaging plate and the resultant image is still a digital radiograph．

5.2.1 Principle and characteristics When X-rays penetrate a specimen, photo quanta hit the grain structure of the phosphor image plate and the energy is absorbed by the atom, creating a latent image．Then this plate is put into a digital converter and scanned by a He-Ne laser, the latent image can be released as visible image, which is detected by a Photo Multiplier Tube and converted to a digital figure．

CR technique has the following features：① The phosphor of imaging plate has a quite wide dynamic range, thus a quite large exposure latitude；② The image processing algorithm is combined in a digital converter and the panel can enhance detail contrast to get the highest image quality；③ Using network transmission can realize long-range evaluation；④ The NDE data can be stored in a Compact Disc, it will not require some special environmental conditions for the storage, and the figure information can be retrieved quickly；⑤ The exposure time required by an imaging plate is shorter than by conventional film method (about 1/2-1/20 of the latter) , and the imaging plate can be reused thousands of times .

5.2.2 Application and evaluation So far, on the basis of the above characteristics, CR technique for inspection of welds is mostly used in detecting flaws in fusion welded branch and nozzle joints, which have the rapid change in thickness both across and along the weld . It is claimed that the flexible type of imaging plate can be used for inspecting circumferential welds . Because of the resolution limited by the phosphor grain of the imaging plate, current CR technique can not yet reach the higher contrast or MTF (Modulation Transfer Function) value (i.e. only some μms for film technique, but 100 μm for CR technique). To the highly-efficient examination of pressure equipment in China, we are researching to apply a high-sensitivity CR technique, where the three key problems have to be solved, i.e. ① Using a highly sensitive digital defector, e.g. CdTe scintillator plate ; ② Using a micro-focus X-ray generator (10-100μm) ; ③ Using the optimum value of projection magnification with $U_g = P$ (P is the pixel pitch)[19] .

6 Conclusion

(1) For the combined butt weld of plate-to-plate T-joints, using thickness compensator method can get the best result of making radiographs .For the combined fillet weld of tube-to-plate joints, if the tube diameter is equal to or more than 120mm, 30°and 45° radiographic methods can be employed respectively in consideration of the two forms of connection, i.e. set in and set on ; if the tube diameter is smaller, a rod-anode X-ray tube with mini-focus or an Ir-192 source with small focus and high specific activity can be adopted, when the radiation source being put into tube from the front end of tubesheet for some distance and making a backward panoramic exposure (where the used films, intensifying screens and cassettes shall be fit to the tube diameter and an appropriate thickness compensator has to be added in) . For the combined weld of tube-to-tube joints (fusion welded nozzle and branch joints in pressure vessels), in accordance with accessibility and the tube diameter, wall thickness and connection form, there are different radiographic arrangements such as source-outside, film-inside method, or source-inside, film-outside method, double wall /single image method, and the radiographic procedure needs to more consider for satisfying the thickness latitude, and viewing and evaluation of defects in welds require some experiences .

(2) Taking account of the necessary radiographic sensitivity, for conventional welded joints, adopting a specific or a special radiographic procedure can increase examination efficiency and shorten inspection cycle . For different diameter and wall thickness of circumferential welds,

special equipment should be employed for panoramic exposure as much as possible． For a mass of small regular test objects arranged in a circle or circles with different diameter, making a panoramic exposure simultaneously is a highly-effective and rapid manner．

(3) To inspect steel welds with thickness T ≥ 100mm, linear electron accelerators (linacs) can offer several advantages such as large thickness latitude, reduced scattered radiation, long focus-to-film distance (FFD) and shorter exposure time etc.．Selecting ISO T2 class of films and stainless or copper intensifying screens can improve detail resolution and flaw sensitivity．Applying a portable linac with changeable direction of radiation (0°, 90°or 360°) can realize highly effective panoramic exposure for circumferential welds with high thickness．

(4) X-ray real-time radioscopy, through the use of mini focal spot, projective magnification, image enhancement and noise reducing, can offer a rapid, on-line, dynamic and multi-directional inspection of circumferential welds for small-diameter tubes and LPG cylinders in large-scale production .Performing RTR techniques for power boiler tubes already have more than 20 years of experiences in China, and two national standards of RTR in fields of boiler and pressure vessel industry have been published since 1999, i.e. *GB 17925-1999 X-ray Real-Time Radioscopic Examination of Butt-Welded Joints for Gas Cylinders*, *GB/T 19293-2003 X-ray Real-Time Radioscopic Examination Technique of Butt-Welded Joints for Boilers and Pressure Vessels*．Their appearance is a symbol of good beginning of advanced RTR technique in China, linking up with the international standards.

(5) CR technique and other digital radiography are still in development at present and have been used in inspection of fusion welded nozzle and branch joints．They can offer plenty of advantages such as wide dynamic range, extensive latitude, shorter exposure time, and inspection results can be conveyed through network and evaluated remotely. Radiograph interpretation by microcomputers is suitable for examination of large quantity of simple and regular specimens．Distinguishing the root geometric indications from the real defects in welding by one side still needs to be with the aid of expert system and intelligent algorithm．The application of digital radiography has wide prospects in the highly efficient examination of pressurized equipment in China．

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