NDE Technology of Pressure Equipment in Line with International Standards

Part 1：Radiographic Examination

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Abstract：For the essential requirements of NDE for pressure equipment, this paper compares the Chinese Standard with the current edition（2007）of ASME Code. Combining the production practice in enterprises in China，it presents some of technical pitfalls and remarks in NDE routine operation. The intention is to provide some opinions for reference about NDE technology in connection with the international standards.

Keywords：Pressure equipment；NDE technology；Radiographic examination；ASME Code；Chinese Standard；Areas of confusion；Remarks

Up to now, 260 manufacturing enterprises in China have been certified by ASME and the certified number is increasing at a rate of 11% each year. The ASME Code is not only the statutory basis for the design and manufacture of pressure equipment in the certified companies, but also the quality guideline for the Chinese products of pressure equipment going towards the world markets. The Chinese Industrial Standard JB 4730-2005 *NDE of Pressure Equipment*, in the term of the four basic NDE methods, has adopted a lot of the important requirements of ASME Code. However, there are still certain differences between the standards of China and America such as in selection of some specific parameters and performance of technological procedures. Some of the practices need to be harmonized internationally. Also, there are some areas of confusion in technique and long-standing mistaken concepts exist in routine inspection.

Concerning the essential requirements of NDE for pressure equipment and combining the practice of production in enterprises in China, the author compared the relative clauses of the current edition（2007）of ASME Code and the Chinese Standard, and discussed those problems worthy of remark in NDE technology in order to link up with the international standards.

1 General requirement

There are eight NDE methods (RT, UT, MT, PT, ET, VT, LT and AE) specified in ASME Code， Section Ⅴ, with the acceptance criteria listed in the referencing volumes about design and manufacture (e.g. SectionⅠ Power boilers and Section Ⅷ Pressure vessels).

1.1 NDE personnel

In China, all of the NDE Level Ⅰand Level Ⅱ personnel are qualified and certified by the Province Administration of Quality Supervision, and the NDE Level Ⅲ personnel are qualified and certified by the General Administration of Quality Supervision of China. However, ASME specifies that the NDE personnel shall be qualified and certified in accordance with the employer's written practice which must meet the requirements of SNT-TC-1A (2001) or CP-189 or ACCP given by ASNT or ANSI. The certification work of VT, LT and AE personnel still haven't begun in China.

1.2 NDE procedure

There are two types of NDE procedures specified in ASME Code. One is the general procedures, applicable to most geometric configurations and materials encountered in fabrication under normal conditions. The other is the specific procedures, suitable to special configurations and materials under specific conditions to obtain an acceptable NDE self-quality. The NDE procedures shall be conformed to the requirements of design and manufacture of pressure equipment and NDE shall be performed in accordance with the written procedures.

ASME Code especially emphasizes the requirements of quantities and demonstration of NDE procedures. In the current edition, in terms of the six methods i.e. UT, MT, PT, ET, VT and LT and the related new techniques, ASME has opposed that the necessary variables, established as a single value, or range of values, must be shown in the written procedure. For all of those essential variables, a change of a specified value, or range of values, shall require requalification of the effectiveness of the written procedure. But for the nonessential variables, there is no such a requirement. Both the initial qualification and requalification of the procedure shall be certified by the Authorized Inspector (AI).

In practice, an NDE Specific Procedure Card （SPC）is the working instruction for implementing the general and specific procedure. It has the advantages of concision, precision and practicality as a road sign and the essentials of routine operation of NDE.

In order to verify whether the quantitative parameters in the written procedure are appropriate or not, it is necessary for the NDE Level Ⅲ to try to supervise in making a qualification block(s) and welding specimens with flaws. Flaw nature, location, direction, size, quantity, range and fabricating methods should be meticulously designed in accordance with the requirements of the Code. The successful fabrication of the qualification blocks or welding specimens is very important for the effectiveness of the procedure qualification.

1.3 Problem- area examples of NDE procedure

① After receiving a task assignment, at first, it is not to establish the inspection program and the written procedure or a SPC, but in reverse order to inspect first and provide the SPC later. Therefore, the SPC cannot play a role as a guide, and the operation is not standardized. In order to achieve the specified quality requirement, the inspection has to be performed repeatedly, inversely wasting a lot of time and energy.

② There is no sketch or drawing or diagram in the SPC but merely words description. Or, a map or a diagram is not clear :The structure, shape and the identification of inspected areas are not detailed. For example, in the SPC of ultrasonic examination of butt welded joints, there are no maps showing transducer placement and sound beam path. Another example is the SPC of magnetic examination of nozzle welded joints, being lack of a map showing arrangement of yokes or plods and identification of magnetized areas, or lack of necessary descriptions.

2 Remarks about RT technique

2.1 Major parameters of equipment

Generally, the following parameters of radiation equipment mentioned in ASME Code shall be provided by the equipment manufacturer, and checked by the NDE user and filed as witness data.

① X-ray tube： Focus size, distance from focus to radiation window；

② X-ray out： Exposure per unit time：$C/kg \cdot m^{-1} \cdot min^{-1}$ or $R \cdot m^{-1} \cdot min^{-1}$ (This data is very useful to the calculation of radiation protection in three methods)；

③ Densitometers and step wedge comparison films： Measurable range, measuring deviation and period of validity；

④ Viewing facilities： Maximum brightness, adjustability, heat- remove ability and low noise character；

⑤ Image quality indicators (IQI)：Type, identification, material and deviation of wire diameter.

2.2 Major requirements of equipment calibration

In accordance with ASME Code, densitometers shall be calibrated at least every 90 days during use and step wedge comparison films shall be verified within the last year. However, the calibration period specified in Chinese standard JB 4730 is every 6 months for densitometers and every 2 years for step wedge comparison films. The particular calibration methods of densitometers and step wedge comparison films are detailed in ASME Code.

2.3 Points of radiographic examination procedure

2.3.1 *Choice of radiation energy*

In Subsection A of ASME Code Section Ⅴ there is only one word about the radiation energy employed :To conform the achieved density and IQI image to the specified requirements. However, in subsection B, Article 22, SE-94, the concept of Half-value-thickness (*HVT or H*) used for selection of radiation energy is given. In radiography there is a following relation among the *HVT*, the thickness latitude, and the film latitude：

$$2^{\Delta X / H} = 10^{\Delta lgE} \qquad (1)$$

where ΔX = thickness difference ; ΔlgE = the log difference of relative exposures corresponding to the up- and down- density limits specified in a standard. And H may be read out from an exposure chart：

$E_2 / E_1 = 2^{\Delta X / H}$ where $\Delta X = H$ *if* $E_2 / E_1 = 2$

2.3.2 *Choice of geometric condition*

Related to focus-to-film distance (F), a comparison between the maximum values of geometric unsharpness U_g, for different thickness ranges, specified in ASME Code and Chinese Standard JB 4730 is shown in **Table 1**. Obviously, the permitted values in ASME are much more lenient than those in JB.

Table 1 A comparison between the max. values of U_g specified in ASME Code and JB standard mm

Material Thickness	U_g (**ASME**)	U_g (JB)		
		Class A	Class **AB**	Class B
＜ 50	0.51	0.49	0.36	0.24
≥ 50 ～ 75	0.76	0.49～0.56	0.36～0.42	0.24～0.28
＞ 75 ～ 100	1.02	0.56～0.61	0.42～0.46	0.28～0.30

According to the basic principle of radiography, the adopted value of geometric unsharpness can directly affect the minimum detectable size of cracks in material, i.e.

$$d \cdot W = \Delta x \cdot \zeta \, (d \cdot sin\theta + Wcos\theta + U) \qquad (2)$$

where d = crack height ;W = crack width ;Δx = absolute thickness sensitivity ;ζ= crack form factor （=0.65）; θ = crack angle ; U = unsharpness（ usually $U=U_g$ ）.

It is very important to select an appropriate value of U_g and F when the crack sensitivity and detectability have to be considered. So, it's suggested that the permitted values of max. U_g specified in ASME Code (Section V, Article 2) should be revised based on the above reason. The European countries have the same opinions, too.

2.3.3 *Choice of IQIs*

⑴ *Material of IQIs* : When material of IQIs does not comply with the object to be examined, two solutions are provided by ASME, i.e.

① The material of IQI having smaller absorptive coefficient than the material to be examined may be used. For example, steel (Fe^{56}_{26}) IQI may be used for RT of Nickel (Ni^{58}_{28}) or Copper (Cu^{63}_{29}) but not for RT of Titanium (Ti^{48}_{27}) or Aluminum (Al^{27}_{13}).

② Two blocks of equal thickness, one of the production material and one of the IQI material, shall be radiographed on one film by one exposure at the lowest energy level to be used for production. The density of each image shall be between 2.0 and 4.0. If D_{IQI} = *1-1.15* D_P*, IQI made of that IQI material may be used in radiography of that production material.

*D_{IQI} = the image density of IQI material ; D_p = the image density of production material.

⑵ *Thickness in IQI selection* : The weld quality in RT is evaluated in accordance of the material thickness related to the material strength, and the choice and evaluation of IQI sensitivity related the examination sensitivity of welded joints ought to be based on the *actual* material thickness. For the double-wall penetration single image (DWSI) techniques and the double-wall penetration double image (DWDI) techniques of circumferential welds, the weld areas to be examined and evaluated have an additional material thickness. In ASME Code, for all of the radiographic techniques, no matter DWSI or DWDI, even for inspecting the weld with backing rings or strips, it is specified that the IQI sensitivity shall be selected and evaluated in accordance with the single wall thickness (Backing rings or strips shall not be considered as part of the thickness in IQI selection).It is reasonable. However, in JB, it is specified that with DWSI or DWDI techniques, the choice and evaluation of IQI shall be in accordance with the double walls. In this case, the practical examination sensitivity of the true thickness to be examined will lose the reality due to the additional thickness considered.

It is well known that there is a definite relationship between the IQI sensitivity and the crack sensitivity. The empirical equation in RT is as following：

$$d \cdot W = 0.8\Phi^2 / [1 + (\Phi / U)] \quad (3)$$

where Φ = minimum diameter of IQI wire (mm).

(3) *Placement of IQIs*： Except DWSI techniques, generally，the IQI shall be placed on the source side of part being examined , including DWDI techniques of small diameter tubes. This requirement is relatively stressed in ASME Code. For the DWSI techniques and the special single wall single image techniques (such as panoramic radiography of pipeline by crawler), the IQI on the film side has the inherent limitation, because it can not truly show the effect of the change of focus-to-film distance to sensitivity display. In this case, usually, it is necessary to make a contrast test in advance and then determine the wire diameter that shall be discerned in the radiograph.

2.4 Requirement of image quality

2.4.1 *Density limitations and density variation*

The density of radiograph anywhere through the area of interest, specified by ASME Code, shall meet the following two conditions simultaneously (see **Fig.1**), i.e.

(1) *Density limitations* ：1.8–4.0 for X-radiographs and 2.0-4.0 for γ-radiographs. The permitted deviation of density readings is ± 0.05.

(2) *Density variation* ： $D_i \nless -15\% D_{IQI \cdot min}$ $\quad D_i \ngtr +30\% D_{IQI \cdot max}$

or $\quad 0.85 D_{IQI \cdot min} \leq D_i \leq 1.3 D_{IQI \cdot max}$

where $D_{IQI \cdot min}$= the minimum density adjacent to the designated wire of a wire IQI；

$D_{IQI \cdot max}$= the maximum density adjacent to the designated wire.

Usually, $D_{IQI \cdot min}$ is the density of the weld reinforcement area adjacent to the designated wire, and $D_{IQI \cdot max}$ is the density of the HAZ or base material area adjacent to the designated wire. It is pointed out by ASME that if the density of radiograph varies by the values more than the above, then an additional IQI shall be used in the retaken radiograph.

Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.

Figure 1 Measuring location example of density of a radiograph

1. $D_{IQI\cdot min}$; 2. $D_{IQI\cdot max}$; 3. $D_{i\cdot min}$; 4. $D_{i\cdot max}$

2.4.2 *IQI sensitivity*

As mentioned above, the designated IQI sensitivity required by ASME, no matter which radiographic exposure technique is used, shall be chosen and evaluated uniformly in accordance with the single wall material thickness (plus the weld reinforcement). However, by comparison with ASME Code, it can be found that the specified values of IQI sensitivity in JB standard are better than the one in ASME Code by 25-56% (see **Table.2**). A characteristic may be seen in this table that the required IQI sensitivity values, for source side IQI, for both single wall single image and double wall double image techniques are the same in ASME Code.

Table 2 A comparison between the IQI sensitivity values (the designated minimum diameter of wire) specified in ASME Code and JB standard mm

Material thickness	SWSI* (Source side IQI)		DWSI (Film side IQI)		DWDI (Source side IQI)	
	ASME	JB (Class AB)	ASME	JB (Class AB)	ASME	JB (Class AB)
≤6.4	0.20	0.08 ~ 0.16	0.16	0.10 ~ 0.16	0.20	0.08 ~ 0.16
> 6.4 ~ 9.5	0.25	0.20	0.20	0.16	0.25	0.16 ~ 0.20
> 9.5 ~ 12.7	0.33	0.20 ~ 0.25	0.25	0.16 ~ 0.20	0.33	0.20 ~ 0.25
> 12.7 ~ 19.0	0.41	0.25 ~ 0.32	0.33	0.20 ~ 0.25	0.41	0.25 ~ 0.33
> 19.0 ~ 25.4	0.51	0.32 ~ 0.40	0.41	0.25	0.51	0.32 ~ 0.40
> 25.4 ~ 38.1	0.64	0.40 ~ 0.50	0.51	0.25 ~ 0.31	0.64	0.40 ~ 0.50
> 38.1 ~ 50.8	0.81	0.50 ~ 0.63	0.64	0.40	0.81	0.50 ~ 0.63
> 50.8 ~ 63.5	1.02	0.63 ~ 0.80	0.81	0.40 ~ 0.50	1.02	
> 63.5 ~ 101.6	1.27	0.63 ~ 1.00	1.02	0..5 ~ 0.8	1.27	

*Single wall single image technique

2.5 Problem-area examples of RT procedure

① The densitometer is long shelved in routine work and does not come into use until the quality review by authority. It shall be used with a film-viewing light together.

② The step wedge film is overdue and is still to be used. The maximum measure-permissible density on the step wedge film is 3.8 or 3.9, but the upper limit of density is extended arbitrarily to 4.0 or more in interpretation of radiographs. In fact the measured density is invalid already.

③ It is not to measure the density variation -15% and +30% but the density range only, i.e. 1.8-4.0 for radiographs made with X-rays and 2.0-4.0 for radiographs made with γ-rays, or not to measure the density in HAZ i.e. material areas but the density in weld areas only, or to be aware of nothing about the proper position to be measured.

④ For selection of IQI, the weld reinforcement is excluded from consideration. For exposure of small diameter tubes, IQI is used to be placed on the film side of the tube. And for exposure of welding specimens or samples, IQI is attached to the film cassette for convenience, which causes the displayed IQI sensitivity to lose reality.

3 Non-film radiographic examinations

Up till now, there are mainly three types of non-film radiographic examination technique for pressure equipment：(1) Real-Time Radiography (RTR)；(2) Computed Radiography (CR)；(3) Digital Radiography (DR). The relevant ASME Standards are included in SectionⅤ, Subsection A, Article 2, Mandatory Appendix Ⅱ,Ⅲ,Ⅳ,Ⅵ,Ⅷ and Subsection B, Article 22 (SE-1255, SE-1416 and SE-1647). For more detailed recent standards, EN and ASTM standards may be referenced (such as EN 13068:2001-1,-2,-3, EN 14784-1:2005 etc.). The performance requirements of RTR technology in ASME Code are outlined as following.

3.1 Characteristic parameters of RTR

The typical arrangement of RTR system is shown in **Fig.2**. The requirements of the system performance specified in ASME Code are as following：

① *System resolution* being calibrated with a line pair test pattern, not through any additional absorber.

② *System contrast sensitivity* being calibrated with a step wedge test block, made of 8 thicknesses representing 100%, 99%, 98% and 97% of both the thickest and thinnest material section to be inspected. Also, it may be calibrated by a contrast sensitivity gage given in SE-1647.

③ *Equivalent performance* A system exhibiting a special resolution of 3 line pairs per mm, a thin section contrast sensitivity of 3%, and a thick section contrast sensitivity of 2% has an equivalent performance level of 3% - 2% - 3lp/mm.

3.2 System calibration of RTR

According to ASME Code, the system performance calibration shall be carried out in the static mode by satisfying the line pair test pattern resolution and step wedge contrast sensitivity, and the calibration for welding sample with defects detection shall be in the dynamic mode, being necessary to meet the IQI requirements as same as film radiography. When using wire IQIs, the RTR system may exhibit asymmetrical sensitivity, therefore, it is required especially that the wire diameter axis shall be oriented along the axis of the least sensitivity of the system.

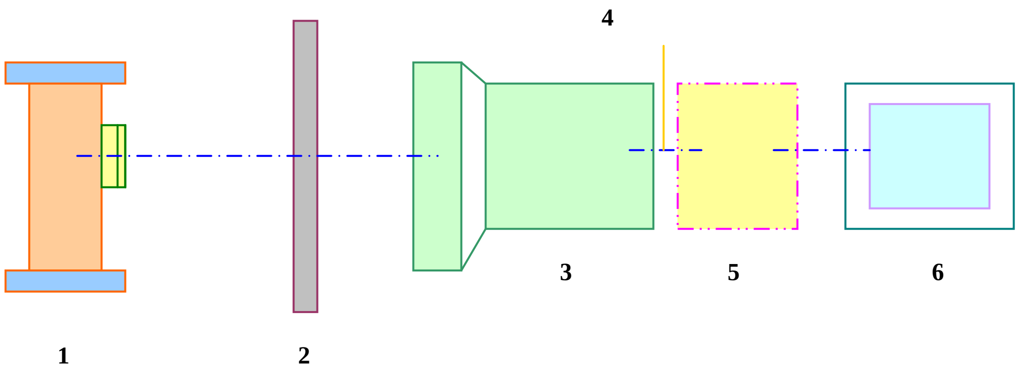

Figure 2 Typical arrangement of radioscopic examination system

1. Radiation source ; 2. Object ; 3. Radiation converting device ;

4. Output signals ; 5. Image processing ; 6. Television monitor

3.3 Written procedure of RTR

Especially, it is emphasized by ASME that a written procedure, established before operation, shall contain as a minimum the following :

① Image digitizing parameters — modulation transfer function(MTF) ,line pair resolution , contrast sensitivity , and dynamic range ; ② Image display parameters — format, contrast , and magnification ; ③ Image processing parameters— noise reduction through image integration or average, contrast enhancement etc. ; ④ Image storage— identification, data compression, media (optical disk or magnetic disk) and precautions to avoid data loss ; ⑤ Analog output formats.

3.4 Quantitative equation of RTR

The essential geometric parameters controlling the sensitivity and resolution of RTR imaging are the following :

① Geometric magnification :$M = F/ f$; ② Geometric unsharpness :$U_g = d_f (F-f) / f$ or $U_g = d_f (M-1)$; ③ Total geometric unsharpness : $U_t = (U_g^2+ U_i^2)^{1/2}$; ④ System resolution : $RP=1 / U_t$; ⑤ Optimum magnification : $M_{opt} = 1+ (U_i / d_f)^2$.

3.5 Problem-area examples of RTR procedure

① For system performance, operators can only use wire IQI to evaluate sensitivity, being familiar neither with evaluation of the system resolution by a line pair test pattern, nor with evaluation of the system contrast sensitivity by a step wedge block or a special contrast sensitivity gage.

② It is not clear how defect image locations displayed on the monitor screen correspond to the practical locations (such as in inspection of small diameter tubes), therefore, it brings some troubles to repair the defect accurately.

③ Both the RTR procedure card and the RTR examination report are lack of complete or proper items or forms in compliance with the relevant standard..

④ Usually, the RTR operators have never received a special training about radioscopic examination, being lack of necessary systematic knowledge and standardizing technical skills.

4 New trend of new RT technology

X-ray sensitive detectors are continually being replaced by new ones , such as amorphous silicon(a-Si), cmos line array ,cmos mini flat-panel detectors etc. The new detectors can be in lieu of the usual image intensifier in X-ray real –time radioscopic (RTR) system for inspecting welds. Experimental results have shown that a suitable new detector can achieve better IQI sensitivity and space resolution than an image intensifier. A comparison of image resolution of the different X-ray sensitive detectors is presented in **Figure 3**.

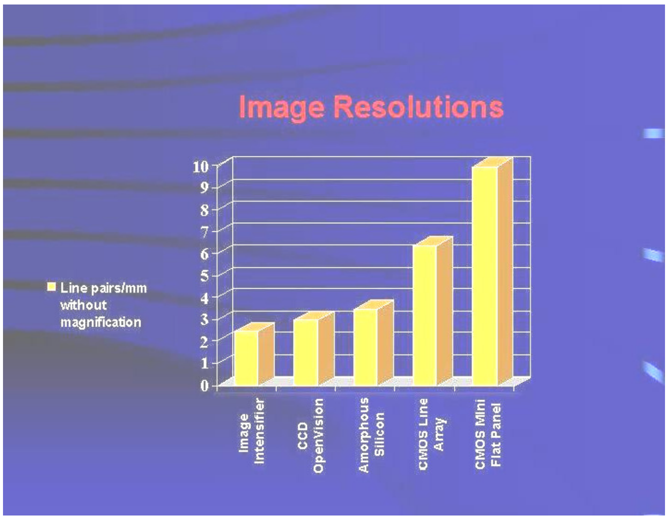

Figure 3 Image resolution of different X-ray sensitive detectors

5 Conclusion

In the above statement, mainly in connection with the requirements of one the conventional NDE methods — radiographic examination for pressure equipment specified in ASME Code, some problem areas and items of attention in routine examination are pointed out, by contrast to those technical parameters given in the Chinese standard and with consideration of industrial production practices.

In this economic globalization era, NDE technology, concerning the product quality of high parameters and high performance and the service reliability of products, has to realize the connection with the international standards in order to be adapted to the high level of industrial development. To make the Chinese pressure equipment take its place on the world market, implementation of ASME Standards is the important channel.

To choose and calibrate NDE requirements, to establish and implement NDE procedure, especially of special objects and with special techniques, and to make and verify calibration blocks and welding samples of RTR, all of these need to be based on the relevant requirements of design and manufacture, or in accordance with the international standards. In the field of RT, UT and other NDE methods for pressure equipment, great changes related to computers have taken place. New technologies such as CR and DR have entered the recent edition of ASME Code. Both of our old and young generations are facing the critical challenge.

References

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