POLAR γ-RAY MODE FOR TESTING WELD QUALITY OF NATURAL GAS PIPELINE

A. M. Shahout, And A. Sh. Mahmood*

Physics Department, Faculty of Arts and Science, Mergib University, Khoms, Libya

Physics Department, College of Science, Baghdad University, Baghdad, Iraq.

** Physics Department, Faculty of Arts and Science, Mergib University, Khoms, Libya*

The polar γ-ray radiography method was studied extensively, γ-ray from Ir^{192} source was used to detect weld defects in the main gas pipeline extending from Khoms to Tripoli. γ-ray radiographic inspections were carried out according to the ASTM(1) standards, and the radiographs were analyzed according to the quality specifications API(2) standard-1104. The polar γ-ray mode has been applied to specimens of weld joints of pipes used in this pipeline in the regions [the kilometer 118(3)] and [the kilometer 123], and weld joints in the SLR 7 station in the region [the kilometer 125]. The results obtained from γ-rays have been discussed and analyzed.

Keywords: *Gamma-ray radiography, radiographic inspections, polar radiography, weld defects.*

INTRODUCTION

Radiography today is one of the most important, most versatile, of all the nondestructive test methods used by modern industry. Employing highly penetrating x-rays, gamma-rays, and other forms of radiation that do not damage the part itself, radiography provides a permanent visible film record of internal conditions, containing the basic information by which soundness can be determined. Radiography is important in the detection of the weld joints, such as the cooling pipes in the nuclear reactors, pipes of airplanes fuel, and pumping pipes of petroleum and natural gas, where the pressure is very high and the flowing materials are too dangerous, that necessitate a high degree of accuracy in the welding processes.

Radiography with gamma-rays has the advantages of simplicity of the apparatus used, compactness of the radiation source, and independence from outside power.

The present work is intended to study gamma-ray polar radiography for detection of welding defects in the natural gas pipeline extending from Khoms city to Tripoli. The length of the pipeline is 150.8 km and made of pipes each 12 m long [diameter 86.36 cm and 9.52 $\frac{1}{N}$ 14.27 mm thick], this requires 83 $\frac{1}{N}$ 100 weld joints for each kilometer, and more than of weld joints for the whole project. Defects appeared in some of these weld joints, in some selected regions will be discussed.

---

(1) American Society for Testing and Materials.

(2) American Petroleum Institute.

(3) [The kilometer zero] region is considered as the starting point that is located at Khoms city.

INSPECTION OF WELD JOINTS

For the radiographic inspection of weld joints, three main exposure geometries are used depending on the pipe diameter [1].

(1) Panoramic sight radiography "single wall exposure-single wall viewing" to detect weld joints in pipes with diameter larger than 50.80 cm.
(2) Polar radiography "double wall exposure-single wall viewing" for pipes with diameter smaller than 25.40 cm.
(3) Elliptical radiography "double wall exposure-double wall viewing" for pipes with diameter smaller than 25.40 cm.

In this research the second geometric mode was studied, (the diameter pipe is 20.32 cm), where three exposures are required to radiograph the whole weld joint, in each one, an arc of 120° is irradiated and an image of only one third of the pipe circumference in the weld region can be obtained. In each stage of exposure a film strip (70 mm wide) is placed outside on the weld joint along the whole arc, while the radiation source is installed outside the pipe (i.e., the focus distance F = D where D is the pipe outer diameters) at one of the three poles ["ex:" at poles 12, 4, 8 (Figure 1)] so the film subtends a central radiation angle of 120° in each stage, provided the angle between radiation direction and the weld seam plane dose not exceed 5°. Also two metal strips (penetrameters) are placed on each film, one is at the center of the film, the other at one of its ends, in order to measure the ability of gamma-ray to penetrate the pipe material. These penetrameters [2] are used as a basic reference to test the quality of the radiograph on the film (after development) according to the specifications API-standard 1104.

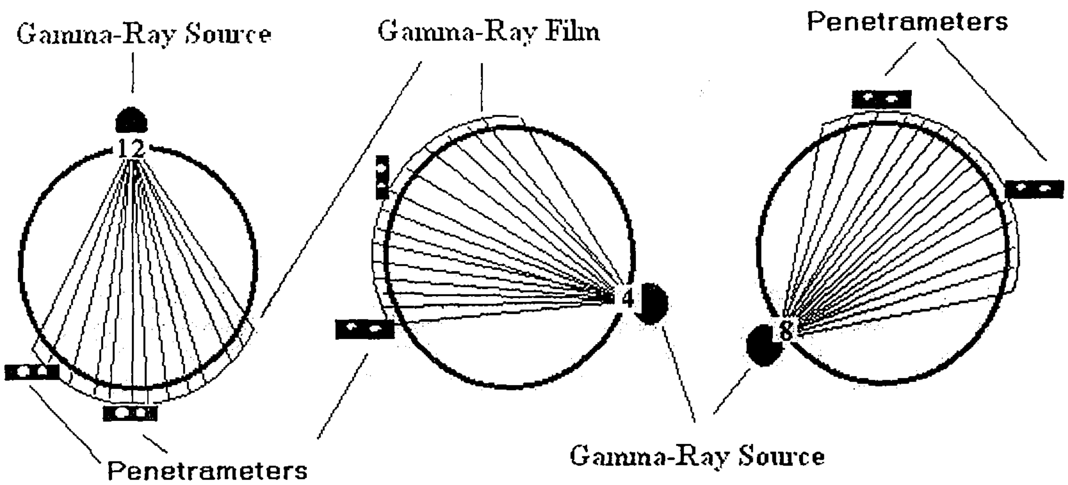


Fig. 1. The three stages of polar radiography for one weld joint.

CONDITIONS OF DETECTION

The process of nondestructive tests for weld joints of natural gas pipeline using gamma-ray polar radiography (see, 2,) needs to put specified conditions in order to get an image that could be analyzed so that it reflects all the points of detection, these conditions are

(1) gamma-ray source should be chosen such that it is suitable for the pipe thickness and its material;
(2) the exposure time should be proper, so that it is suitable for the thickness of the pipe and the activity of gamma-ray source;
(3) the distance between gamma-ray source and the detection point should give optimal sensitivity and must be kept constant for a given isotope;
(4) radiographic film type D4 must be used;
(5) the range of optical density is from 2 to 4.

1- Gamma- Ray Source:

It is difficult to give specific recommendations or the choices of gamma-ray emitter and source strength. These choices depend on several factors, among which are the type of specimen radiographed, allowable exposure time, storage facilities available, protective measures required, and convenience of source replacement. Table 1 gives the radioactive sources used in industrial radiography, the half-life of the source and gamma-rays energy are also included [2, 3].

Table 1. Radioactive sources used in industrial radiography.

Radioactive source	Half-life	energy of gamma-rays (MeV)	applications and approximate practical thickness limits (mm)
Ir^{192}	73.83 days	0.137 to 0.651*	6.35 to 76.2 steel or equivalent
Ce^{137}	33 years	0.66	25.4 to 76.2 steel or equivalent
Co^{60}	5.3 years	1.17 and 1.33	25.4 to 177.8 steel or equivalent

* Twelve gamma rays.

From this table, it is noticed that gamma-rays from Co^{60} have relatively great penetrating power and can be used, under some conditions, to radiograph sections of steel 177.8 mm thick, or the equivalent. Radiations from other radioactive sources have lower energies; for example, Ir^{192} can be used to radiograph sections of steel with thickness 6.35 to 76.2 mm, or the equivalent, so it is suitable for pipes used in the natural gas pipeline with thickness in the range 3.91-14.27mm.

2. Exposure Time:

It is well known that gamma-ray sources gradually lose activity with time, the rate of decrease of activity, depend on the kind of radioactive material (see Table 1). This decrease in emission necessitates more or less frequent revision of exposures and replacement of sources. The exposure calculations necessitated by the gradual decrease in the radiation output of gamma-ray source can be facilitated by the use of the decay curves.

The half-life time of Ir^{192} isotopes is 73.83 days, therefore every 1-2 weeks, exposure time must be increased by dividing the initial value by Ir^{192} correction factors, K (Table 2). The initial value of the exposure time can be determined by control photographs, where maximum radiograph sensitivity indicates optimum exposure time, it is found to be 15 in this project.

Table 2. Values of Ir^{192} factor (K) and exposure times for successive weeks of radiography[1].

Time (weeks)	Ir^{192} factor value K	Exposure time (sec)	w)	Ir^{192} factor value K	Exposure time (sec)
0	1	15	11	0.486	31
1	0.937	16	12	0.455	33
2	0.877	17	13	0.426	35
3	0.821	18	14	0.399	38
4	0.769	20	15	0.374	40
5	0.720	21	16	0.350	43
6	0.675	22	17	0.328	46
7	0.632	24	18	0.307	49
8	0.592	25	19	0.288	52
9	0.554	27	20	0.269	56
10	0.519	29	21	0.252	60

Thus the gamma-ray output is directly proportional to both activity of the source and exposure time, and hence is directly proportional to their product. The gamma-ray exposure E may be stated as E = At, where A is the activity in curies and t is the exposure time, the amount of gamma-radiation remains constant long as E remains constant. This permits specifying gamma-ray exposures in curie-hours without stating specific values for source activity or time. So the only way to change the penetrating power of gamma-ray is to change the source.

3. Source Film Distance:

The density of any radiographic image depends on the amount of radiation absorbed by the sensitive emulsion of the film. This amount of radiation depends on the total amount of radiation emitted from gamma-ray source which is expressed by the exposure (E) and the amount of radiation reaching the specimen which is governed by the distance between the source and the specimen, varying inversely with the square of the distance. The exposure factor [2] is a quantity that combines source activity, time, and distance. Numerically the exposure factor equals $\frac{curies' \; time}{distance^2}$. Radioactive techniques are sometimes given in radioactive isotope and exposure factor. In such a case, it is necessary merely to multiply the exposure factor by the square of the distance to be used in order to find the curie hours required.

It is important to mention that the amount of radiation absorbed by the film depends also on the proportion of this radiation that passes through the specimen which absorbs some of gamma-ray, the absorption depends on the thickness of the specimen, density, and atomic number.

4. Selection of the Film:

The selection of a film for the radiography of any particular part depends on the following factors [2]:

(1) the thickness and material of the specimen;

(2) the type of radiation used whether x-rays from an x-ray machine or gamma-rays from a radioactive material;
(3) the kilovoltages available with the x-ray equipment.
(4) the intensity of the gamma radiation;

The film used in this work was of kind D4 (Agfa Gevart).

5. Optical Density:

Optical density [2] refers to the quantitative measure of the film blackening, it is defined by the equation $d = \log\frac{I_0}{I_t}$ where d is the optical density, I_0 is the light intensity incident on the film, and I_t is the light intensity transmitted. As mentioned above the optical density must be from 2 to 4.

EQUIPMENTS, MATERIALS AND, ACCESSORIES FOR RADIOGRAPHIC INSPECTION

The equipments for testing the welding qualities used for the detection of the weld defects in the project of gas pipeline Khoms-Tripoli differ according to the kind of detection which depends in the first place upon the diameter of the pipe. For this reason, we shall mention the tools and test equipments that are used in the polar detection method, which is the subject of this research, these are [1]

(1) Gamma-ray flaw detector 660/693 with Ir^{192} isotope of initial activity(1) 100.6 Ci at 09/07/2001.
(2) Radiographic films kind D4 (Agfa Gevart) for shooting by Ir^{192}.
(3) Laboratory containers for manual and automatic radiographic film development.
(4) Negatiscope (film viewer) for radiographic films interpretation.
(5) Densitometer of type Radix-D [4] for determination of radiographic films optical density. It gives digital readings directly from the film viewer, with density range 0.00 – 4.00 and resolution 0.01.
(6) Identification symbols (numbers and letters) and measuring tape, made from lead or graphite placed in contact with the film, for marking and coding of weld joints. For this reason, when giving numbers or letters to the gamma-ray film, data they must be written from left to right according to the following [1]:
    - Code of the company responsible for the project SC(1)
    - Date of inspection dd/mm/yy
    - Pipe diameter (inches)(2)
    - Wall thickness (mm)
    - Steel grade of the pipe
    - Code of the main gas pipeline EKT(3)
    - Reference kilometer or reference station of the joint (SAZ)
    - Code of the joint's type and number of the joint
    - Codes of a tie-in, repair (R), or cut-out (N1).

(In this work, the activity of the source was 2.636 Ci during the radiographic inspection (date 31/07/2002).(
(1) Sirt Company.
(2) This system of units is used by the company, so it could not be changed here.
(3) El-Khoms to Tripoli main gas pipeline

(7) Penetrameters ASTM E142 for indicating the quality of the radiographic technique. Penetrameter is [2] made of the same material (or a radiographic similar material) as the specimen being radiographed, and ct consists of a small rectangular piece of metal containing three holes of diameter t, 2t, 4t where t is the thickness of the penetrameter (see Figure 2). The thickness t is related to the thickness of the metal layer of the pipe, and each penetrameter is identified by a lead number showing the thickness in thousandths of mm as shown in table:

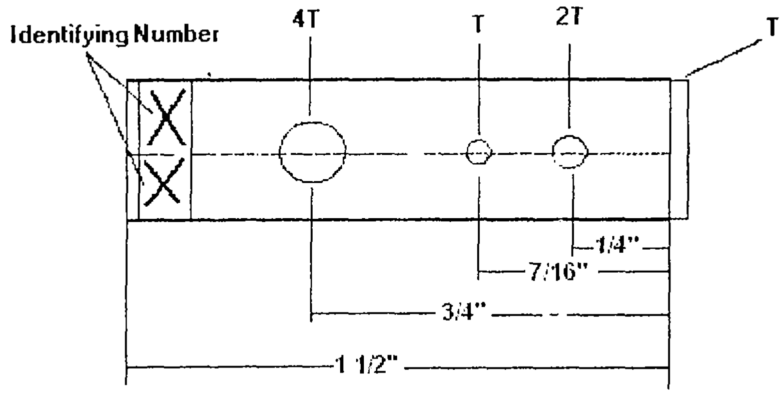


Fig. 2. Schematic diagram of penetrameter [1].

Table 3. Thickness of pipe versus thickness of penetrameter.

Pipe wall thickness (mm)	**Maximum penetrameter thickness (mm)**	**Identifying number**
0-6.35	0.127	5
> 6.35-9.52	0.190	7
> 9.52-12.70	0.254	10
> 12.70-15.88	0.317	12
> 15.88-19.05	0.381	15
> 19.05-22.22	0.444	17
> 22.22-25.40	0.508	20
> 25.40-31.75	0.635	25
> 31.75-38.10	0.762	30
> 38.10-50.80	0.889	35

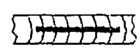
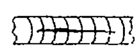
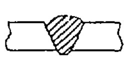
The ASTM penetrameter permits the specification of a number of levels of radiographic sensitivity, depending on the requirements of the job. For example, the specifications may call for a radiographic sensitivity level of 2-2T. The first symbol (2) indicates that the penetrameter should be 2% of the specimen thickness, the second (2T) indicates that the hole having a diameter twice the penetrameter thickness should be visible on the finished radiograph. However, critical components may require more rigid standards, and a level of 1-2T or 1-1T may be required. On the other hand, the radiography of less critical specimens may be satisfactory if a quality level of 2-4T or 4-4T is achieved. The more critical the radiographic examination (that is, the higher the level of radiographic sensitivity required) the lower the numerical designation for the quality level.

STANDARDS OF WELDS ACCEPTABILITY ACCORDING TO API STANDARD-1104

Exposed radiographic films are developed in specialized laboratories with manual and automatic processing equipment. Weld radiographs accepted for interpretation should show clearly penetrameter, identification markers, and measuring belt images. The optical density must be from 2 to 4 and the radiographic sensitivity level must be equal to 2-1T or 2-2T as per ASTM E142, if both conditions are not fulfilled in the film, then the weld joint must be re-shot again in order to obtain a radiograph that is accepted for interpretation. Later on it becomes possible to start the process of analysis of the radiographs where weld joints evaluation and rejection under the gamma-ray inspection results should be in strict compliance with API standard-1104.

Table 4 contains all the acceptable defects for the weld quality, if the defects appear in the weld joint with dimensions and shapes as those mentioned in the table, they are considered as acceptable ones, otherwise, defects of larger dimensions are not allowed.

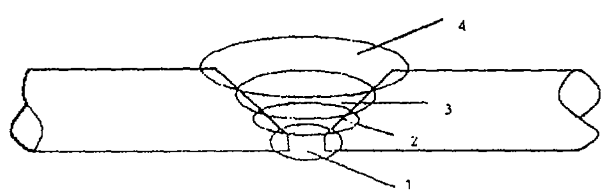
Table 4. Standards of Welds Acceptability.

Type of defects		Designation group	Schematic defect description		Acceptable sizes			Additional requirements
			On weld	On film	Isolated Defects		Total For 304.8 mm	
					Length mm	Width or diameter mm	Length Mm	
Inadequate penetration	Inadequate penetration of weld root	IP			25.4	N/A	25.4	N/A
	Inadequate penetration due to high-low	IPD			50.8	N/A	76.2	N/A
	Incomplete fusion at root or at top of joint between weld metal and base metal	IF			25.4	N/A	25.4	N/A
	Incomplete fusion due to cold lap	IFD			50.8	N/A	50.8	N/A

Continued Table 4.

	Internal concavity	IC			N/A	N/A	N/A	Not darker than base metal/all weld perimeter
Internal concavity Burn-through	Burn-through for pipe over 60 mm O.D.	BT			6.35	N/A	12.7	N/A
	Burn-through for pipe below 60 mm O.D.				6.35	N/A	N/A	Not more than one
Slag Inclusions	Elongated slag inclusions for pipe over 60 mm O.D.	ESI			50.8	1.59	50.8	N/A
	Elongated slag inclusions for pipe below 60 mm O.D.				3S	1.59	N/A	Parallel slag lines to considered as separate if the width of either of them exceeds 0.79 mm
	Isolated slag inclusions for pipe over 60 mm O.D.	ISI			N/A	3.17	12.7	The aggregate length of ESI and ISI indications exceeds of not less than 8% of the weld length
	Isolated slag inclusions for pipe below 60 mm O.D.				N/A	1/2S	2S	
Gas cavity	Spherical porosity	SP		4S	N/A	ϕ2-3	N/A	25% S ; max 3.17
				2S	N/A	ϕ1.6 -2	N/A	
				1S	N/A	ϕ0.6 -1	N/A	
	Cluster porosity in finish pass	CP			N/A	12.7	12.7	Max pore size 1.59 mm
	Hollow bead	HB		6.3 50 6.3	12.7	N/A	50.8	N/A
Cracks	Crater cracks	CC			3.96	N/A	N/A	Other not allowed
Under cuts	External under cuts Internal under cuts	EU IU			50.8	N/A	50.8	Depth – 0.4 mm Max
					Depth < 0.4 mm - acceptable regardless of length			

1.	Root pass-RP
2.	Hot pass -HP
3.	Filled pass-FP
4.	Cap pass - CP



RESULTS AND DISCUSSION

The polar radiographic method has been used for testing the weld quality for some specimens of weld joint in the regions, the kilometer 118 and the kilometer 123 for pipes of 86.36 cm in diameter (SNA 54T and SNA 75T, respectively) where the panoramic circular method becomes impossible (see, 2), and the kilometer 125 for pipes of diameter 20.32 cm in the station SLR7 (SAZ V461, SAZ V462, and SAZ V470)[1]. After developing the film, which belongs to each weld joint, measuring its optical density, and determining the level of its radiographic sensitivity (using the penetrameter), the process of analysis of each image was conducted according to quality specifications API-1104 (see Table 4). And since the process of welding includes some defects, and our purpose is to know these defects and classify them as acceptable defects and unacceptable ones according to quality specifications API-1104, one can divide the defects into two groups.

1. Acceptable Defects

These defects must have dimensions (or size) which are allowed by quality specifications API-1104, whether these defects were single, repeated, or mixed, in such a way that their total dimensions in a limited length (304.8 mm) do not exceed the upper limit accepted in the quality of welding, so these defects are considered as Acceptable, and are denoted by the symbol [OK].

2. Secondly- Unacceptable Defects.

These defects have dimensions (or size) which are larger than those allowed by quality specifications API-1104, whether these defects were single, repeated, or mixed, in such a way that their appearance as single defects or collective defects in one single welded joint are larger than the upper limit allowed by welding quality. Accordingly, these defects are classified as "Unacceptable", they must be repaired if they were contained in a narrow band in the circumference of the welded circle and denoted by the symbol [R]. Otherwise, if their spread was recurrent, then all the weld joint must be cut out and should be rewelded and retested again, in this case the defects are given the symbol [CO].

Table 5 shows the results obtained for weld joints in the kilometer 118 and the kilometer 123 regions, where three radiographic images were taken for each weld joint. Defects were not found in these weld joints, this means that the welding was of good quality.

Table 6 shows the results obtained for weld joints in the station SLR7 in the kilometer 125 region, where the three radiographic images were also taken for each weld joint. Again unacceptable defects were not found for the weld joints SAZ V461 and SAZ V462, while four spherical porosity defects were found in the weld joint SAZ V470, two of them were in the first image in the regions 0 mm and 3 mm in the first arc of the circumference of the welded circle, the others were in the third image in the regions 62 mm and 69 mm in the third arc of the circumference of the welded circle. These defects are spherical deformations that occur usually inside the two welded regions (the Hot Pass and the Root Pass). They appeared in the film as circles with diameter larger than 3 mm, these necessitate repairing those regions, re-welding and retesting them again. As a whole the number of defects is little, this is partly due to the good quality welding and partly due to the small circumference of the pipes that makes the probability of appearance of defects in the weld joint very small.

Table 5. Radiographic inspection report EKT 118 and EKT 123.

Steel grade : **X-60**		Inspection technique :**Polar**				Film Type **D4**	Source: γ-**ray**	Equipment : **Ir^{192}**
Location	Weld joint no.	Pipe		Film number	Sensitivity	Density	Description and location of defect	Final conclusion
		Dia. (cm)	W .T. (mm)					OK Acceptable R Repair RX Re-shoot CO Cut out
EKT118	SNA54T	86.36	11.91	1	2T	3.3		OK
				2	2T	3.1		OK
				3	2T	3.4		OK
EKT123	SNA75T	86.36	11.91	1	2T	3.4		OK
				2	2T	3.3		OK
				3	2T	3.3		OK

Table 6. Radiographic inspection report for SLR7 station in EKT 125.

Steel Grade : **GRB**		Inspection Technique :**Polar**				Film Type **D4**	Source: γ-**RAY**	Equipment : **Ir^{192}**
Location	Weld joint no.	Pipe		Film number	Sensitivity	Density	Description and location of defect	Final conclusion
		Dia. (cm)	W .T. (mm)					OK Acceptable R Repair RX Re-shoot CO Cut out
EKT125	SAZV461	20.32	8.18	1	2T	3.1		OK
				2	2T	2.9		OK
				3	2T	3.1		OK
EKT125	SAZV462	20.32	8.18	1	2T	3.1		OK
				2	2T	3.1		OK
				3	2T	3.1		OK
EKT125	SAZV470	20.32	8.18	1	2T	3.1	Spherical porosity 0, 3	R
				2	2T	3.0		OK
				3	2T	3.1	Spherical porosity 62, 69	R

REFERENCES

[1] Maximlyuk, Y. V., Radiographic Inspection of Weld Joints. Quality System Procedures Manual, Moscow, 2nd. ed., 1999, pp. 1-21.

[2] Quinn R. A., and Sigl C. C. (Eds.), Radiography in Modern Industry, (Eastman Kodak Company 4th. ed.), 1980, pp. 3-72

[3] Pherigo, G. L., Radiography Method. (The American Society for Nondestructive Testing), 1980, p. 57.

[4] Wogan, Q. J., Radix-D Densitometer. Directions for Use. 1980, pp. 1-4