

Image quality indicators in industrial radiography

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1. Introduction

In radiography-on-film, one usually has a wide choice in the parameters of the radiographic technique. For example, one has a choice of source-to-specimen distance, choice of film type, choice of film density, choice of X-ray kilovoltage, X-rays or gamma-rays etc. The resulting radiograph therefore can vary between high quality and poor quality; quality in this case meaning the ability to detect small critical flaws such as cracks.

Many standards have been written, both national and international, giving advice or instructions on the choice of technique details, in order to ensure good quality radiographs and the usual method of measuring image quality is to include some standard detail in the image which will give a measurable indication of image quality. Such devices are known as "Image Quality Indicators (IQIs)" or sometimes as "penetrameters". IQIs must obviously be small and relatively cheap to manufacture if they are to be used on every radiograph and should obviously be as sensitive as possible to changes in the radiographic technique.

The quality of a radiographic image can be assessed in terms of three factors:

1. Image sharpness. Usually, in radiography, the inverse of sharpness - unsharpness or blurring - is used.

2. Image contrast. The density change on a film for a given thickness change in the specimen. If a small image detail shows only faintly, this is a low contrast image; if the detail is easily seen, this is a higher contrast image.

3. Image Noise. For radiography-on-film, this is effectively graininess. In radioscopy, there are additional features affecting image noise.

A good design of IQI should be able to show changes in all these three factors.



Fig. 1 Wire type IQI



Fig. 2 Step/Hole type IQI



Fig. 3 Plaque type IQI



Fig. 4 Duplex type IQI

2. IQI Design

There are four broad patterns of IQI in use today - the wire type, the step/hole type, the hole-in-plaque type and the duplex wire type. The first three of these are widely specified in many Standards for film radiography. The fourth type, the duplex wire type IQI, is not yet used for routine film radiography, largely because of its high production cost. It consists of a series of pairs of wires of high density material (tungsten and platinum) where each pair of wires of diameter (d) is spaced at a distance (d) apart. As one looks along the images of these wire pairs, one reaches a pair where the individual wire images are merged and one can no longer see two separate wires. The diameter (d) of this pair is a measure of the total effective unsharpness of the radiographic image. This duplex wire IQI measures only unsharpness and is easy to use. At present, its principal use is to measure the total unsharpness of radiosopic (real-time radioscopy) screen images where there are many causes of unsharpness acting simultaneously, and in laboratory experiments. The details of construction are described in IE-NDT Ltd's catalogue and in EN-462, part 5:1996.

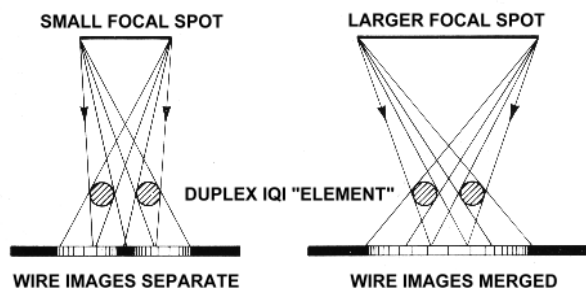


Fig. 5 Effects of increasing geometric unsharpness on an "element" in a duplex type IQI

Probably the most widely used IQI in radiography-on-film is the wire type. Various patterns of wire type IQIs are described in German, Scandinavian, British, Japanese, Chinese, American CEN and ISO Standards. These consist of a series of straight wires of the same or similar material to the specimen, the wires being of different diameters taken from the series 0.10, 0.125, 0.16, 0.20, 0.25, 0.32, 0.40, 0.50, 0.63, 0.80, 1.00,... The wires may

be 10, 20, 30, 50mm according to the various Standards and are held parallel to one another in a low density plastic mount, with appropriate identification symbols.

A typical wire IQI will contain six or seven wires taken from the above series and is therefore relatively cheap to make in any material in which standard wires are manufactured. EN 462 part 1:1994 shows typical construction details of one design.

The wire IQI is placed on the specimen and, on its image on the film, the diameter of the thinnest discernible wire is taken as a measure of IQI (wire) sensitivity. In many Standards, the IQI (wire) sensitivity is specified as a percentage value:

$$S (\text{wire IQI}) = \frac{\text{diameter of thinnest discernible wire}}{\text{penetrated thickness of specimen}} \times 100\%$$

But, the use of such percentage values has led to considerable confusion, particularly in pipe-weld radiography, and newer Standards specify acceptable IQI values in terms of an actual wire diameter (such as in the GOST Russian Standard) or wire number (such as in EN 462-1) which must be discernible on the image. ASTM E 747-94 gives a formula and charts for converting IQI percentage sensitivity into 1T and 2T levels.

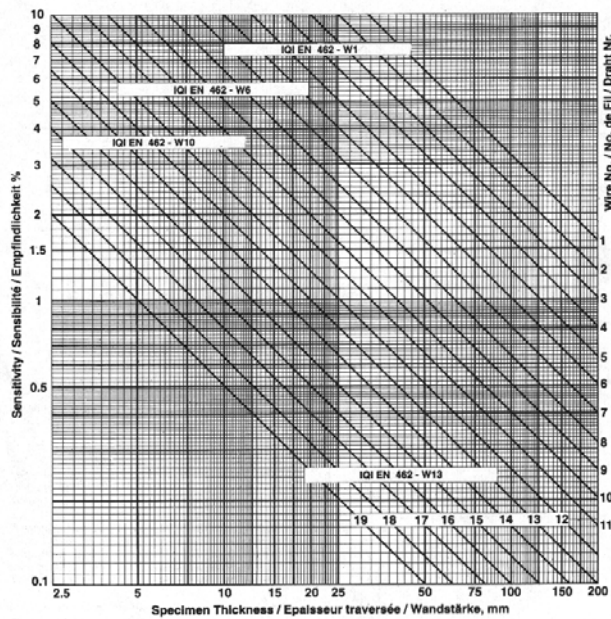


Fig. 6 IQI sensitivity chart (usable with wires in EN 462-1, DIN 54 109 and BS 3971 series)

Tables of acceptable wire diameters for different specimen thickness are given in Standards such as EN 462-3, EN 462-4 and EN 1435:1997. It is important to note that the wire or step/hole IQI sensitivity, whether specified as a percentage or absolute value, is not consistent with specimen thickness.

In some earlier Standards, the IQI sensitivity values are advisory rather than mandatory.

One of the greatest problems in using a wire IQI is the term “just discernible” or “visible” as applied to the images of the wires. As one looks along a series of wire images, the larger diameter wires are easily seen, then they become discontinuous, and finally invisible. There is a stage when one can “see” parts of a wire length but not its whole length; one knows therefore that this wire is present. EN 462-3 states “the image of a wire is accepted (as visible) if a continuous length of at least 10mm is clearly visible in a region of uniform optical density”. On a weld which is not uniform in thickness, this criterion is not always easy to apply and different radiologists (even experienced film readers) can set themselves different standards of discernibility and so produce different IQI sensitivity values from the same radiograph.



Fig. 7
All wires visible



Fig. 8
Some wires “just visible”

Some Standards specify that the wire IQIs are laid across a weld, some alongside the weld on a uniform thickness, some on a thickness-compensating shim alongside the weld. Some Standards specify the IQI in the centre of the weld length under examination; some require IQIs to be near the edge (end) of the film.

A second widely-used IQI is the step/hole type in which a step wedge of the same or similar material to the specimen has one or two drill-holes in each step, the hole diameter being the

same as the step thickness: the holes must not be chamfered. This type of IQI is shown in detail in EN 462-2:1994, AFNOR NFA 04 304 and BS 3971:1985. Typically, there are six steps, with two holes in the steps thinner than 0.8mm. The step thicknesses and hole diameters are from the same series given for wire diameters. IQI step/hole sensitivity is based on the smallest discernible hole diameter, not the step visibility: if there are two holes in the step, both must be discernible.

This IQI is therefore more expensive to manufacture than the wire type in that small holes down to 0.125mm have to be accurately drilled, but several European countries have preferred it to the wire IQI. There is less of a problem in assessing “just visible” than with the wire type. It can be fabricated in materials in which wires are not practical.

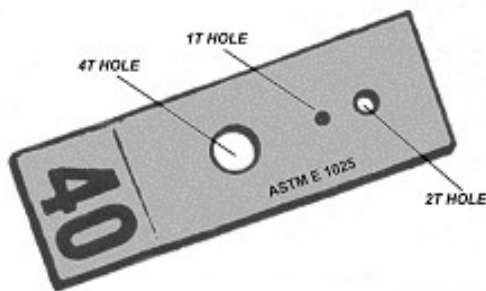


Fig. 9 IQI or “Penetrameter” to ASTM E 1025

In general, a different pattern of IQI is specified in the USA and these are still sometimes called “penetrameters”. There are several variations of the same basic design, the best known being ASTM and MIL types. These consist of uniform thickness plaques, thickness T, containing three drilled holes of diameter 1T, 2T, 4T, together with lead identification letters or numbers. The plaque is made of the same material as the specimen and the IQI sensitivity is measured by the discernibility of the drilled holes. The smallest hole used is 0.01” (0.25mm) for the 1T hole, and 0.02” (0.50mm) for the 2T hole, although these are still described as 1T, 2T etc.

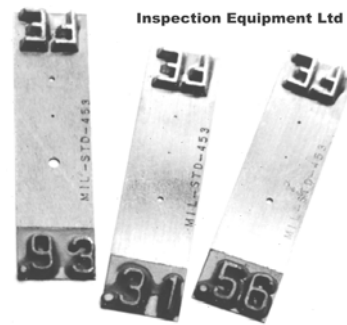


Fig. 10 IQIs (Penetrameters) to ASTM E 1742-95 (Formerly MIL-STD-453)

ASTM E 1742-95 is the latest version of what used to be known as MIL-STD-453 but the penetrameter design is unchanged. Some US companies, such as Pratt & Whitney, have their own variants of the 1T, 2T, 4T plaque pattern of IQI.

Normally a plaque in which T is 2% of the specimen thickness is used (ASTM E 1025-95) but, in some applications, a 1% plaque may be specified. If the 2T hole in a 2% plaque is discernible, this is quoted as 2-2T ASTM sensitivity level. At one time it was common practice to specify a 2-2T level of sensitivity, commonly called 2%, for most radiographic applications but today there is a realisation that a much wider range is possible, from 1-1T to 4-2T. It is important to realise that an American 2% sensitivity is not the same as 2% IQI sensitivity as it would be specified in Europe.

The American plaque type IQI has the same advantage as the step/hole type, in that judgement is based on the discernibility of the image of a small hole rather than a wire. But, on thin specimens, there can be confusion that the 1T and 2T holes may not be truly 1T and 2T in diameter.

2.1 Placement of IQIs

Standard practice is to place the IQI on the side of the specimen facing the radiation source, on the grounds that this is the region of the image where geometric unsharpness and therefore image blurring, will be the largest. Most tables of IQI values assume that the IQI is in this position.

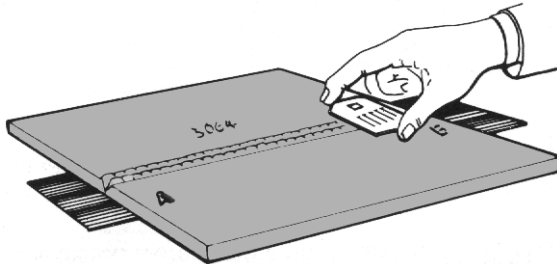


Fig 11 Normal placement of an IQI

In the case of double-wall/single-image pipe weld radiography, where there is no access to the inside of the pipe, the only practical place for the IQI is on the film side of the weld, that is, effectively on the film cassette. If the IQI is used in this position, a lead identification letter (F or FS) should be placed on the IQI. In this position, the IQI image is completely insensitive to geometric unsharpness factors such as source-to-film distance or source diameter and is an indication of contrast only. Normally, the IQI readings are 1 - 2 wires or holes better than with the IQI on the source side of the same specimen. Some Standards ask for a trial exposure on a sample piece of pipe, with IQIs on both source and film sides of the weld, for comparison. Some experts regard the IQI reading from the film side position as misleading and of little practical value, but tables of IQI sensitivities for the IQI on the film side are included in EN 1453:1997 and EN 462-3:1997.

3 Flaw Sensitivity

IQI sensitivity values are not flaw sensitivity values. Experiments and theory have shown that both the wire and step/hole pattern of IQI respond only slightly to sharpness factors, in comparison to crack images. Both patterns of IQI largely measure image contrast only. The image unsharpness must change considerably before it is indicated by any change in wire or hole IQI sensitivity. This inadequacy has led

to several attempts to design a more sensitive IQI, such as using narrow slots or notches on the IQI (the Russian GOST standard is an example), but the only useful advance to date is the more expensive duplex wire IQI.

For radioscopy, with an image on a screen, some authorities ask for a wire IQI sensitivity and a measure of unsharpness from a duplex wire IQI, but this dual criterion has not yet been specified for film radiography.

4 Quality

Given that IQI sensitivity is the only, if imperfect, guide available to determine whether an individual radiograph is capable of revealing the defects which fracture mechanics and other experts consider significant, obviously the IQI itself should be as near perfect as possible. For wire type IQIs, this means ensuring that only wires of the specified material and specified diameter are placed in the specified positions within each IQI. For step/hole and plaque type IQIs, the material, thickness and hole diameters are critical. For duplex IQIs, the positioning of the wires within each pair is even more critical. Whatever the type, it is important that any encapsulation does not obscure the image of the wires or holes and that the radio-opaque identification is not so dense as to cause distracting glare when the radiograph is viewed. IQIs are supplied to the user in a ready-to-use, encapsulated form, so there is little practical possibility for the user to check them against the Standard. Instead, the user has to rely on the manufacturer's own quality assurance and quality control procedures. As there is no specific scheme to audit and register manufacturers of IQIs, it is prudent to check that the manufacturer has a Quality System which is registered against the requirements of ISO 9001.

5 Conclusions

None of the existing designs of IQIs is sufficiently sensitive to image sharpness parameters, except the duplex wire type, which is costly. For metals where wire can be drawn, the wire type IQI is relatively cheap to manufacture and very fine wires, suitable for use on thin specimens, are available. For non-metals, the step/hole type is the most convenient in that it can be fabricated in any material, although it cannot easily be made for use on very thin specimens.

Some experience and skill is needed in “reading” the images of the wire type IQI and, for this reason, some authorities prefer the step/hole or plaque types.

The ideal design, sensitive to all technique parameters and cheap to manufacture, has still to be discovered. As such perfection is unlikely to be achieved in the foreseeable future, we must make best use of the time honoured, if imperfect, tools we have available by ensuring that Standards issuing authorities, practitioners of NDT and manufacturers of IQIs understand their importance and limitations.

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