Conventional and Advanced Non-destructive Test Techniques for Evaluation of Welds

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1. INTRODUCTION

Non-destructive Testing (NDT) is an integral and the most important constituent of the Quality Assurance (QA) programme of any industry. The objectives of the QA programmes are safety, reliability and economy. Non-destructive evaluation (NDE) places due emphasis on characterisation of material including quantitative determination of the size, shape and location of a defect or anomaly thus enabling evaluation of structural integrity of a component. NDT along with material properties and operating conditions is vital for successful prediction of damage and residual life. In India, NDT techniques are being applied for the evaluation of components used in atomic energy, space, defence, transport, energy and other industries.

NDT methods are required to obtain necessary information for evaluating welds which are to be placed in service. The primary advantage of the NDT methods is that the product can be examined without destroying its usefulness. Non-destructive evaluation can be conveniently applied for ensuring that the weldments are fit for the purpose.

Quality characteristics of welds such as cracks, inclusions, porosities, lack of penetration, lack of fusion, lack of bond, undercut, alloy identification, alloy composition, etc. can be evaluated by NDT methods. Present range of NDT techniques and evolved capabilities of NDT techniques promise evaluation of weld joints for the most stringent service conditions. However, proper choice of materials, welding processes, etc. is a necessity to ensure building the quality in the product. Choice of a technique or complementary techniques should be carefully selected to ensure structural integrity during designed life of welded structures on cost effective basis.

2. COMPARISON OF NON-DESTRUCTIVE AND DESTRUCTIVE TESTING

The chief value of non-destructive testing is that it allows the manufacturer to inspect a part that actually will be sold. Also, a customer can inspect the same part before it is used. By its very nature, destructive testing makes a part unsuable and therefore of no commercial value. Destructive tests have been used for routine inspection with the assumption that results derived from such tests are typical of the population from which the test samples were taken. However, this assumption is not always valid.

Various advantages of NDT over DT are :

1) Can be done directly on production items without regard to part, cost or quantity available, and no scrap losses are incurred except for bad parts.
2) Can be done on 100% of production or representative samples.
3) Can be performed on parts in service
4) Different tests can be applied to the same item simultaneously or sequentially
5) Little or no specimen preparation is required.

3. FITNESS FOR PURPOSE APPROACH (FFP) [1]

If a fitness for purpose approach is intended, it must be appreciated that certain prior conditions must be met before NDT can be usefully applied.

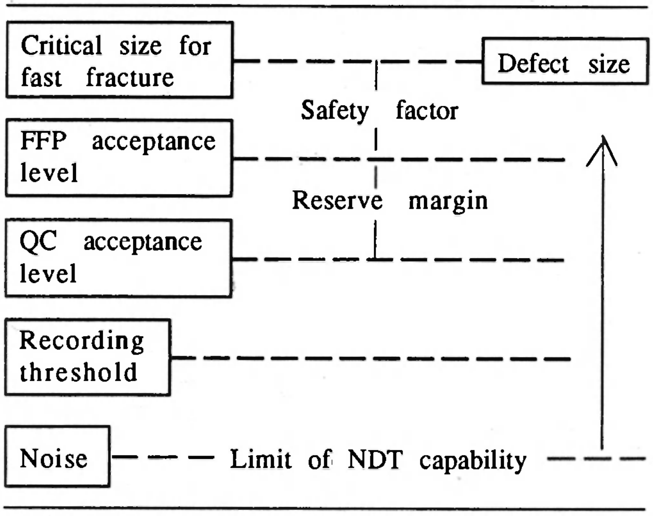
a) The design, access and surface preparation should take into account the requirements of the various NDT methods for the detectability and evaluation of defects of structural concern. In particular, it must be recognised that root profile and weld cap condition significantly affect the capabilities of all NDT methods for the important inner and outer regions of the weld.
b) There is a need to design and plan the fabrication and to set sufficiently high quality levels with future inservice inspections in mind.

General relations between quality control, fitness for purpose, and NDT

3.1 Scheme for Discussion Based on Defect Size

Table 1 below sets out a scheme for discussing the relations between quality control of weld defects, fitness - for - purpose and NDT. It shows a scale (vertical) of increasing defect size, divided into ranges.

Table 1 : Defect size ranges covering Quality Control (QC), FFP and NDT capability



Points arising from this diagram are:

a) The weldment must be designed to tolerate defects which are larger than the limits of NDT capability. A high level of background inclusions and other sources of spurious signals will hamper the inservice inspection for structurally significant defects.
b) Defects which are larger than the quality control acceptance level should in general be repaired.
c) Fracture mechanics specialists should not put arbitrary large safety factors on the critical defect sizes as this can result in acceptance criteria which unnecessarily approach the limits of NDT capability.

The diagram can also be used to explain the historical development of workmanship and NDT techniques. The QC levels have been arrived at over many years by the accumulation of experience and empirical results. They are related to the welding practices to the type of component and the state of development of the NDT techniques in use. Development of NDT techniques for quality assurance (QA) thus ensuring performance (In-service) for newer materials or different weld geometrics would improve if such approach is adapted.

3.2 Choice of NDT Techniques for Fitness for Purpose [1]

Structural integrity assessments recognise the various mechanisms by which a structure may fail. For many highly stressed components, failure can be in an elastic manner involving fast fracture. For this important case, fracture mechanics shows the prime importance of detecting and measuring planar defects. Therefore, the capability to detect planar defects is the first criterion according to which the relative merits of the various NDT techniques can be judged. Moreover, fracture mechanics shows the importance of the through wall size and the through wall position of a defect; length is by comparison usually much less important. A surface breaking defect is about twice as significant as the equivalent embedded defect.

Following from this, the NDT techniques which are most valuable for use in conjunction with a FFP approach are:

a) ones sensitive to planar defects, whatever their orientation and position,
b) ones sensitive to surface breaking defects,
c) ones capable of discriminating planar from non-planar (eg. volume or threadlike) defects.

In view of this, the most effective NDT techniques are for many applications:

For steel and other ferromagnetic materials.	Magnetic particle inspection of the near surface and ultrasonic inspection of the far surface and the volume of weld and HAZ.
For other materials.	Dye penetrant inspection and ultrasonics.

Radiography is somewhat less effective at detecting planar defects. Its value lies largely in its ability to detect volume defects such as slag inclusions and porosity. These are strong indicators of weld quality and also may indirectly indicate the presence of more serious deficiencies. However, for small (= 10mm) wall thicknesses and for complex weld shapes, radiography is the preferred method even for cases where a FFP approach is to be pursued.

Welding industry relies heavily on conventional non-destructive test techniques to ensure quality of welds for meeting code requirements. Table 2 gives the summary of applicability and capabilities of conventional NDT methods in relation to demonstrating fitness for purpose of welds. We briefly describe the capabilities of conventional techniques in subsequent sections of this paper.

4. CONVENTIONAL NDT TECHNIQUES

4.1 Visual Inspection (VI)

Visual inspection has wide application for inspection of wrought and cast materials. However for welds,

Table 2. Summary of applicability and capabilities of common NDT methods in relation to demonstrating fitness for purpose of welds

METHOD	APPLICABLE WELD GEOMETRY		DETECTION CAPABILITY			LENGTH MEASURE-MENT	MEASURE-MENT OF SMALL LIGAMENT	THROUGH-WALL SIZE MEASURE MENT	CHARAC-TERISA-TION
	Linear	non-linear	surface defects	internal volume defects	internal planar defects				
Liquid penetrant	Y**	Y**	Y**	N	N	Y**	N	N	Y**
Magnetic particle (MPI)	Y**	Y**	Y**	N	N	Y**	N	N	Y**
eddy currents	Y*	Y?	Y*	N?	N?	Y?	Y?	Y?	Y?
A.C. potential drop	Y**	Y**	Y	N?	N?	Y?	Y?	Y**	N
radiography	Y**	N?	Y**	Y**	Y?	Y**	N	N?	Y**
ultrasonics	Y**	Y**	Y*	Y**	Y**	Y*	Y*	Y**	Y?

KEY:
Y Yes, is applicable, has reasonable capability
N No, not applicable, no capability
Y? Capability dubious, but inspection may be possible with special techniques (see text for explanation)
N? Not normally practicable
* Good
* Very good

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this all the more important as at various stages of welding, visual inspection gives useful information. For many non-critical welds, integrity is verified principally by visual inspection. Even when other non-destructive methods are used, visual inspection still constitutes an important part of practical quality control. Visual inspection can and should be done before, during and after welding. Visual inspection is useful for assessing the following :

a) dimensional accuracy of weldments
b) conformity of welds to size and contour requirements
c) acceptability of weld appearance with regard to surface roughness, weld spatter, undercuts and overlaps.
d) cracks

Although visual inspection is a very valuable method, it is unreliable for detecting subsurface flaws. Therefore, judgment of weld quality must be based on information of bulk material in addition to that afforded by surface indications. Capabilities of VI can be enhanced considerably by using simple gadgets and instruments for viewing, dimension measurements etc.

4.2 Liquid Penetrant Inspection (LPI)

This is a method which can be employed for detection of open to surface discontinuities in any industrial product in all kinds of weldments. In this method, a liquid penetrant is applied to the surface of the product for a certain predetermined time during which the penetrant seeps through the surface opening defect by capillary action. After which the excess penetrant is removed from the surface. The surface is then dried and a developer is applied to it. The penetrant which remains in the discontinuity is absorbed by the developer to indicate the presence as well as the location, size and nature of the discontinuity. Care should be taken that, chemical contents in

Table 3 : Typical capability for defect detection in a weld by manual ultrasonics (All dimensions in millimetres)

Defect Type	Joint thickness	Defect close to a surface		Defect fully embedded
		Scanning srf.	Back srf.**	
Isolated pores or inclusions	10 - 25	3 diam #	2 diam	2 diam
	25 - 75	4 diam #	3 diam	3 diam
	75 - 125	4 x 6 #	3 x 4	3 x 4
Linear inclusions (slag lines)	10 - 25	1 x 6 #	0.5 x 4	1 x 4
	25 - 75	2 x 8 #	1 x 6	1.5 x 5
	75 - 125	3 x 10 #	2 x 7	2 x 6
Linear cracks & lack of fusion	10 - 25	1 x 6 #	0.5 x 4	2 x 4
	25 - 75	2 x 8 #	1 x 6	3 x 6
	75 - 125	3 x 10 #	1.5 x 7	4 x 8
Porosity cluster Cluster of small cracks	10 - 25	5 x 5 #	3 x 3	4 x 4
	25 - 75	6 x 6 #	4 x 4	5 x 5
	75 - 125	8 x 8 #	5 x 5	6 x 6

Note : # means that detection is at the "full skip" position, i.e. where the beam is reflected off the back surface and up the underside of the scanning surface. Defect immediately under the probe cannot usually be detected if they do not extend more than 3 mm down

** means that the back surface is parallel to the scanning surface so that the corner effect can operate.

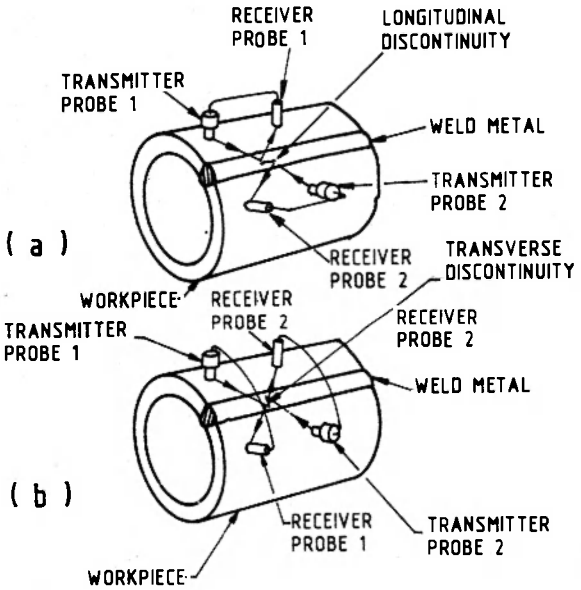


Fig. 1. *Diagram of arrangements of probes in ultrasonic inspection of submerged arc welded pipe for detection of*

(a) Longitudinally oriented and

(b) Transversely oriented discontinuities

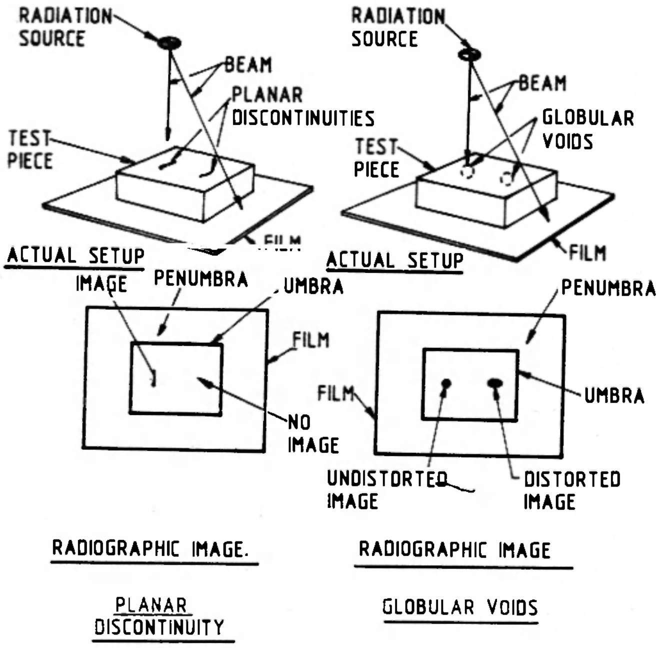


Fig. 2. *Radiography inspection*

the liquid penetrant should not affect the material. The fluorescent dye penetrants have high sensitivity and are particularly useful for detecting defects having small width (0.005 mm). The increased sensitivity is due to the absence of any visible background either white or coloured layer, covering the area under inspection, which would otherwise absorb a part of incident light.

4.3 Magnetic Particle Testing

For detection of surface, sub-surface defects in welded components, liquid penetrant testing or magnetic particle examinations are being very widely used. In the case of ferromagnetic materials, magnetic particle technique has been preferred since this will also detect subsurface flaws which are not open to surface. Because of this advantage over liquid penetrant, it has become customary to specify magnetic particle testing for all ferromagnetic materials.

This method is based on the principle that when a ferromagnetic material under test is magnetised, discontinuities which lie in a direction generally transverse to the field will cause a leakage field around the discontinuity.

When finely divided ferromagnetic powder is sprinkled over the surface, some of those particles will be gathered and held by the leakage field. This magnetically held collection of particles, form an outline of the discontinuity and indicates its location, shape and extent. To get the highest sensitivity, fluorescent magnetic particles suspended in oil using full wave DC continuous technique is also employed.

The test method, therefore, consists of magnetisation of the component, applying magnetic powder, examination of powder patterns and demagnetisation of the component.

4.4 Leak Testing (LT)

Leak testing is the determination of the rate at which a liquid or gas will penetrate from inside a "tight" component or assembly to the outside, or vice versa, as a result of a pressure differential between the two regions. This technique is a very reliable and fast technique for some enclosed welded components like pressure vessels, pipelines and vacuum devices.

Direct sensing in gas systems at pressure is done by acoustic method, bubble testing or flow detection. Specific gas detector like sulphur hexafluoride, halogen and helium detector are also used in leak detection. The major factors that determine the choice of the leak testing method are : the physical characteristics of the system, the trace fluid, the size of the anticipated leak and the reason for conducting the test, i.e. whether to locate or detect the leak or measure the leak rate.

4.5 Ultrasonic Testing (UT)

Ultrasonic Testing is a NDT method that uses sound waves having frequencies in the mega cycle range. UT can detect discontinuities oriented both in the plane of and normal to the surface of welded components. Table 3 gives typical capabilities for defect detection in carbon steel weldments by manual ultrasonic method. In case of stainless steel welded pipes, discontinuities in the plane of the wall can be detected by using a compression wave probe scanning at normal incidence. For discontinuities normal to the wall, the beam is converted to a shearwave which is propagated around or along the tube. Fig. 1 shows the arrangement of Transmitter-Receiver probes for detection of longitudinally and transversely oriented defects in welds.

Generally only one transducer is used for both transmission and reception to scan the entire volume of the weld components. The direction of scanning is changed suitably to detect defects oriented in different directions. This volumetric method can be used to test materials of thickness from a few mm to a few meters. Unfavourable geometries and coarse anisotropic grain structures are the difficulties for successful exploitation of this technique.

4.6 Radiographic Testing (RT)

Radiography is a non-destructive inspection method that uses a beam of penetrating radiation such as x-rays and gama rays. When the beam passes through a component, some of the radiation energy is absorbed and the intensity of the beam is reduced. Variations in beam intensity are recorded in film, and are seen as difference in shading that are typical of the types and sizes of any flaws present. Fig.2 shows Radiography set up for planar and globular type of defects. Fig. 3 shows the general Radiography set up for testing welded pipes. Fig. 4 shows the double wall single image technique set up. Radiography is used for detection of internal flaws as well as those that are open to the surface.

Surface flaws that are detectable by radiography include undercuts, longitudinal grooves, concavity at the weld root, incomplete filling of grooves, excessive reinforcements, overlaps and electrode spatter. Internal flaws detectable by radiography include gas

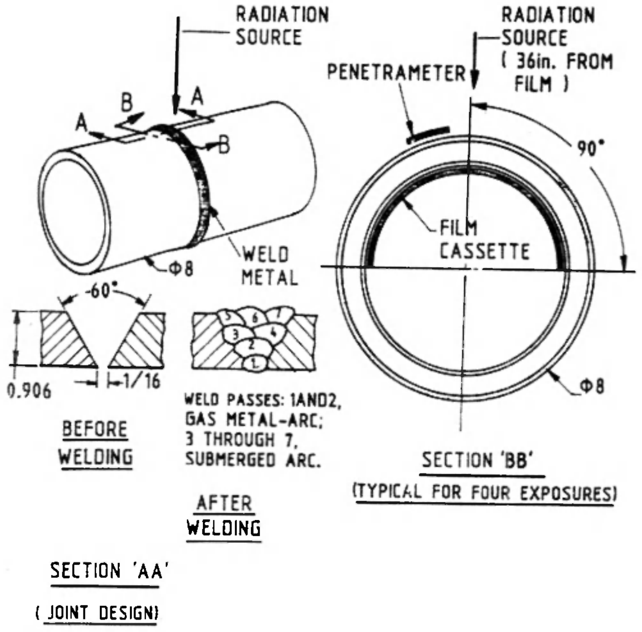


Fig. 3. *Radiography examination set-up*

porosity, slag inclusion, crack, incomplete penetration, incomplete fusion and tungsten inclusions.

As material thickness increases, conventional radiography becomes less sensitive as an inspection method. Radiographic examination has a serious limitation that it does not reveal flaws whose linear dimension lies at an angle more than few degrees from the beam axis.

4.7 Eddy Current Testing (ECT)

ECT is a NDT technique based on induction of electrical currents in the material being inspected and observing the interaction between those currents and the material. ECT is used extensively to identify or differentiate between a wide variety of physical, structural and metallurgical conditions in welded stainless steel tubes.

The test coil is the main link between the test instrument and test object and serves two main functions - the first to establish a varying electromagnetic field which includes eddy currents within the test object and the second is to feed the response due to the electromagnetic field to a signal analysis system.

Welded tubes upto 75 mm diameter are tested for discontinuities using an external encircling coil. When the diameter of the tube exceeds 75mm, it is generally no longer practical to inspect with an external encircling coil for reasons of flaw resolution. A satisfactory technique is the use of multiple probes with sensitivity similar to the encircling coil inspection. Solenoid type coil is applied to tubular part and pancake type coil to a flat surface (Fig.5).

5. RECENT ADVANCES IN NDT TECHNIQUES

5.1 Visual Examination

The advances in optics has had far reaching consequences in the field of visual examination which is still one of the important tools of NDT. The advent of fibrescopes with rotating heads has increased the versatility of visual examination. It is possible to have remote scanning of inaccessible areas, concavity/ convexity profiles of welds in tubes etc., even under very low levels of illumination. While only subjective methods of evaluation were available earlier wherein the inspector makes an immediate decision based solely on what he sees, it is now possible to have a "Hard Copy" or visual record, by means of a photograph, videotape or movie film. This has distinct advantages as the hard copy can be compared to a set of "normal" or "abnormal" standards. In addition, comparisons can be made with other records of prior inspections to determine whether with other records of prior inspections to determine whether there has been crack growth or other progressive changes.

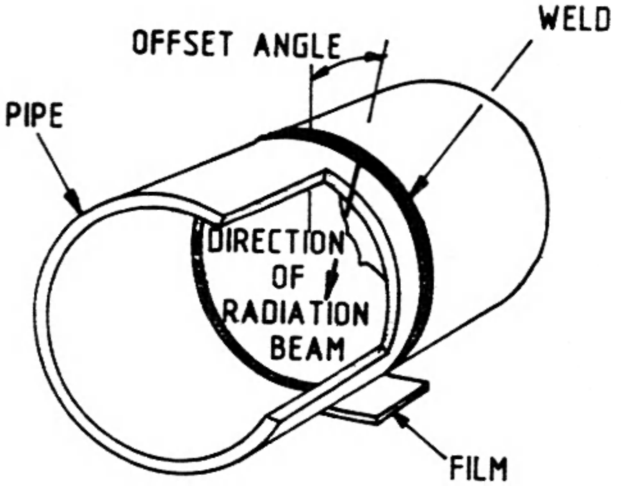


Fig. 4. *Schematic representation of the double - Wall, Single-image inspection technique applied to a circumferential butt weld in a large-diameter pipe, showing relation of radiation beam, weld and film*

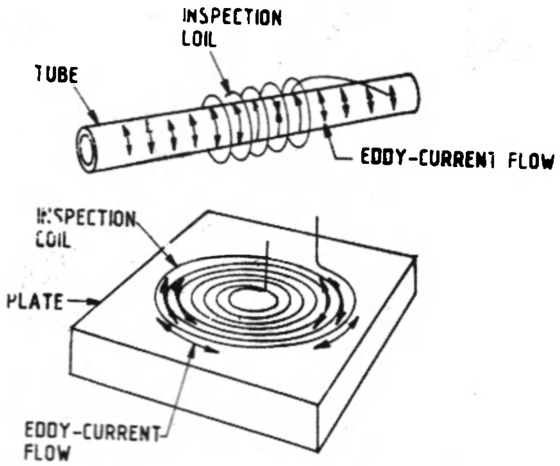


Fig. 5. *Two common types of inspection coils and the patterns of eddy-current flow generated by the exciting current in the coils. Solenoid-type coil is applied to cylindrical or tubular parts; pancake-type coil, to a flat surface*

Further, many can study these to obtain expert opinion which reduces the errors due to eyesight fatigue. The use of image processing techniques on these images has also greatly enhanced the quality of the images obtained.

5.2 Radiography

The advances in electronics and instrumentation has revolutionised the filed of radiography, the oldest and most reliable technique for weld inspection. We have today 450 kv industrial x-ray units, portable equipments (70-300 kV, 5mA) and ultra small light weight (15.5 kg) portable x-ray equipment (output 200 kV, 3 mA) for the purpose of piping inspections in confined space and maintenance inspections [2]. Recent advances in x-ray tube technology have resulted in focal spots which are an order of magnitude smaller than those which were available only a few years ago, giving rye to a whole new classification of microfocus radiography techniques. It is thus possible to detect minute defect in thin metal plate welds of steel, aluminium alloy or titanium which was earlier not possible either by conventional radiography or x-ray television fluoroscopy. The most impressive feature of the microfocus x-ray source is its ability to produce extremely sharp radiographs at exceedingly short film to focus distances. An outstanding example of this capability is the bore side radiography of tube to tubeheet welds in 2.25 Cr - 1 Mo tubes of steam generators having an internal diameter of less tubes of steam generators having an internal diameter of less than 12 mm (fig. 6). Using rod anodes with true radial panoramic emission, full circumferential radiographs can be obtained at around 80 kV in less than one minute on a Agfa D2 film with a sensitivity better than 1% [3]. This sensitivity is an order of magnitude greater than that can be obtained with the radioisotope technique. Modular microfocus units are now available upto 300 kV in which manual and automatic focal spot control is possible.

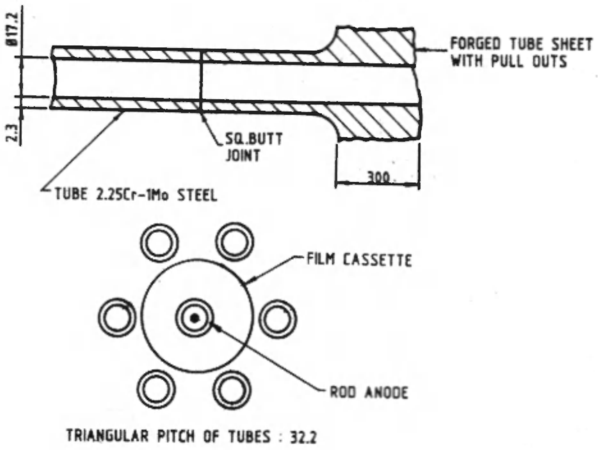


Fig. 6. *Sketch showing joint detail and tube layout configuration in steam generator assembly*

The advent of x-ray image intensifiers is replacing the conventional fluoroscopy system in real time radiography. Improved resolution of around 6 lines/mm for magnification mode, decreased distortion and greater brightness gain of over 10,000 are the hallmarks of these Csl (Na) intensifiers. The latest state of art is however the integration of microfocus units with real time imaging systems and computers which results in a fully automated system with automatic defect recognition capability. Such systems are being used for the inspection of welds, composites and routine industrial applications resulting in increased productivity, reduction of errors normally arising out of human fatigue and savings in manpower. This is a step short of the development of expert systems using artificial intelligence for radiography.

In field of high energy radiography, radiation sources as synchrotons and betatrons are freely available. Transportable linacs [4] upto 9 MeV are available which give a radiation output of 3000 rad/min at 1m capable of penetrating more than 200 mm of steel. The addition of real time facility further enhances the capability of these systems.

Gamma radiography has seen the development of modern gamma cameras permitting safe and reliable remote operations. Apart from the normally used gamma ray sources like caesium 137 or cobalt 60, a number of other sources as europium, ytterbium, etc., are finding increasing application. Ytterbium sources

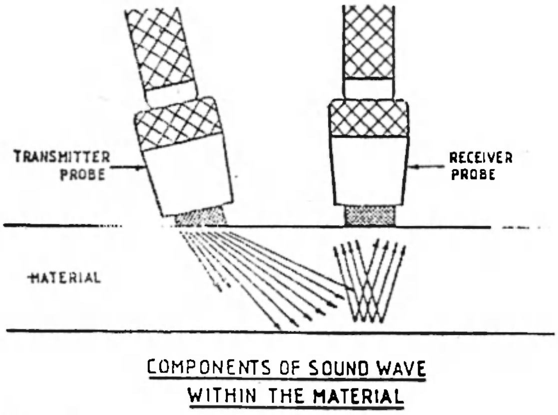


Fig. 7. *Dry couplant technique*

with a source size of 650 microns are now available which can be used for examination of welded pipes with an ID of 10 mm.

5.3 Ultrasonics

In the field of ultrasonics, the advent of dryscan techniques has widened the horizons of application (figs. 7,8). It is now possible to inspect reliably nonmetallic materials as composites, weldments in complex geometries where conventional ultrasonics did not give satisfactory results. Miniaturized pipe scanners are now available for the inspection of pipe welds in complicated pressure piping systems with a minimum of accessibility (fig. 9). The hardware and software capabilities of P-scan (projection scanning) systems have developed to such an extent that we have today a reliable, precise, high resolution and minimal operator dependent non-destructive inspection system [5]. This system is now being extensively used for weld inspection in nuclear, oil and other industries. Synthetic aperture focused probes with 32, 64 and 128 elements have now been developed. Figs. 10 & 11 show the data acquisition methods for Synthetic Aperture Focusing Technique. The basic advantage of these probes is that a highly focused beam can be obtained. Thus if a particular point is to be examined for defects, it can be done reliably. Further the beam can also be angled and frequency

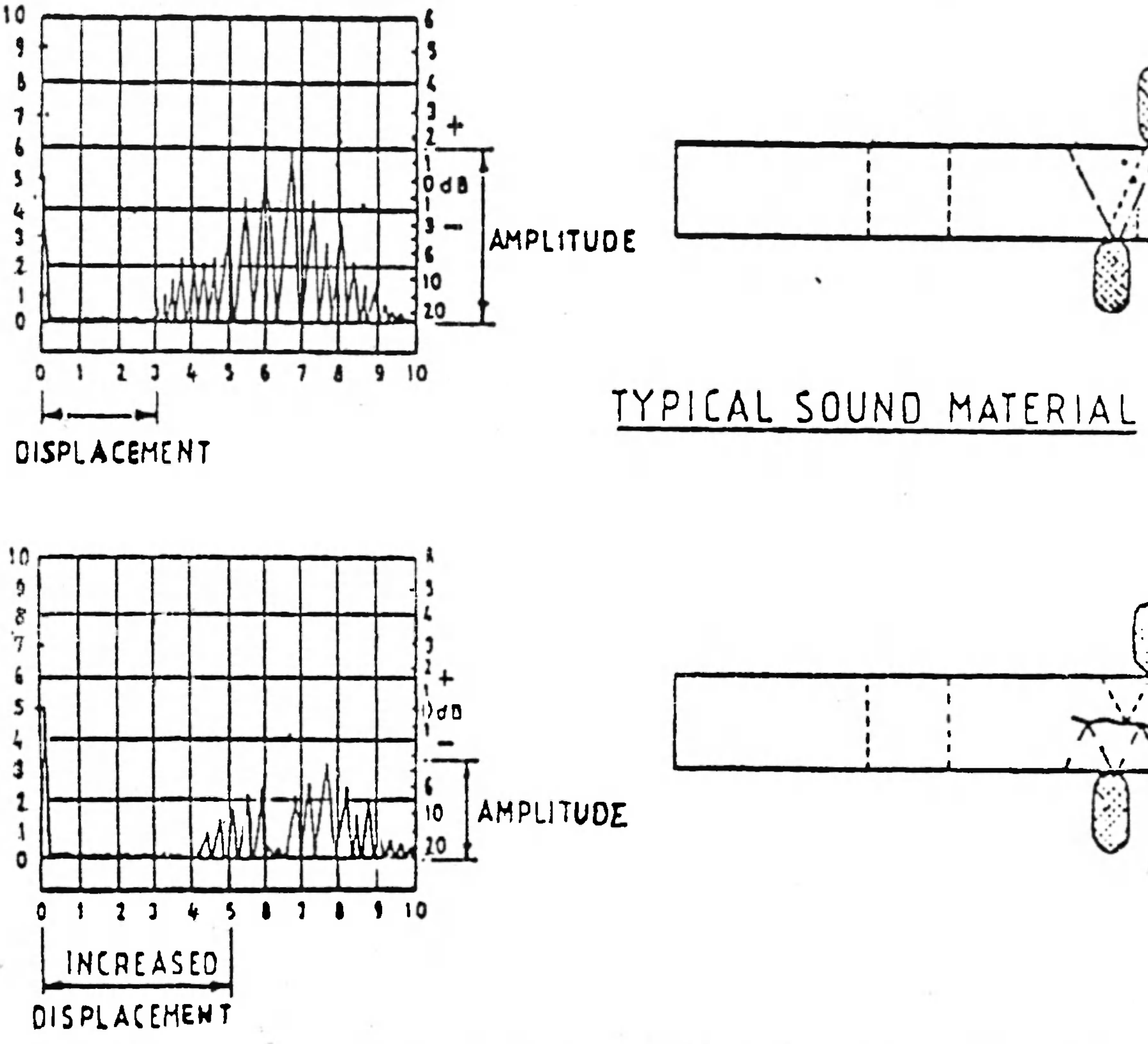
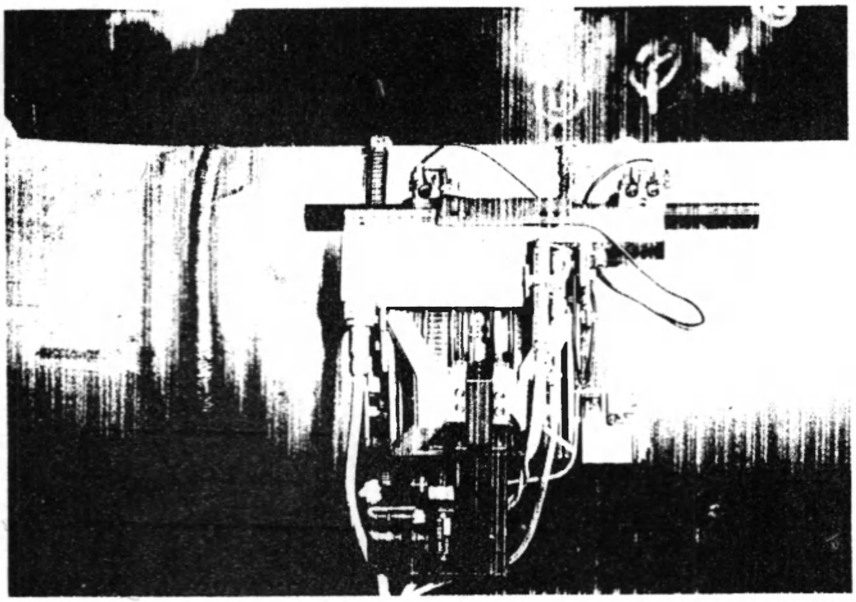


Fig. 8. *Part energy transmission around edge of delamination small percentage of signal*

P-scan Ultrasonic Weld Inspection and Corrosion Mapping



Features

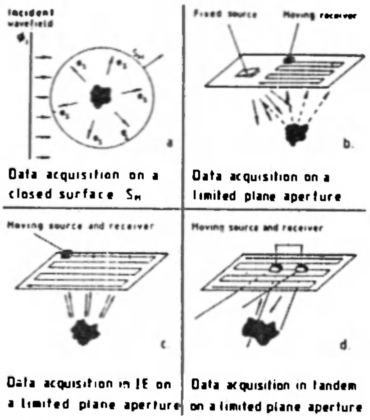
- ▼ Ideal for scanning in high radiation areas
- ▼ Easy to set up. Very little set-up time required
- ▼ Compact. Less than 3 inches high
- ▼ Flexible. Different configurations and different modules
- ▼ Extensively used for Inter-Granular Stress Corrosion Cracking inspection (IGSCC)

Fig. 9. *Automatic scanning of circumferential welds. The scanner is guided by a flexible snaplock track pre-mounted around the pipe. The probe module, with dual ultrasonic probes, is mounted on the front of the scanner.*

can be varied within the elements of the probe which leads to very high sensitivity limits.

5.4 Acoustic Emission Testing (AET)

Acoustic emission is emerging as an important NDT tool for on-line monitoring of critical components in various industries, because of its inherent capability for crack identification and location in real time when it forms and or starts propagating. Acoustic emission is a phenomenon of transit elastic stress wave generation due to a rapid release of strain energy caused by a structural alteration in a solid material. Since acoustic emission behaviour is strongly dependent on microstructural parameters like carbide precipitation and carburisation in austenitic stainless steel, effect of microstructural changes in austenitic stainless steel on acoustic emission behaviour should be critically evaluated. Carbide precipitates influence acoustic emission by way of (a) influencing dislocation movement, and (b) through grain boundary



Data acquisition on a closed surface S_H

Data acquisition on a limited plane aperture

Data acquisition in IE on a limited plane aperture

Data acquisition in tandem on a limited plane aperture

Fig. 10. *Data acquisition methods within a synthetic aperture*

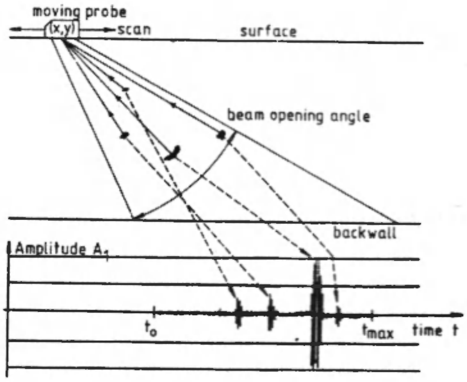


Fig.11. *Data acquisition for saft*

cracks. The acoustic peak amplitudes are high whenever cracking takes place. Two types of acoustic emissions are observed normally depending on the nature of the energy release process. These are (1) continuous emission and (2) burst emission.

Some of the ways in which AE signals are processed to evaluate the results are :

(1) Counting ringdown counts, ringdown count rate, events and event rate
(2) Energy analysis
(3) Amplitude analysis and
(4) Frequency analysis

AET can be adopted for simultaneous detection of defects as the welding progresses in real time. The defect so found, can be immediately rectified thus avoiding the finishing of defective weld.

The main problem in AE monitoring of welding process is eliminating of signals due to slag cracking, shoe rubbing in electroslag welding processes and electromagnetic interference from the arc. But these noises can be eliminated by proper signal conditioning and processing techniques.

5.5 Infrared Thermography

Infrared thermography has made rapid strides in the last few years. The development of semiconductor detectors with thermoelectric cooling has overcome the limitations of maneuverability in case of liquid nitrogen cooled detectors. While the normal methods for creating a temperature differential through a material include passive heating (using dry-ice, liquid nitrogen, etc.) and techniques which are a combination of the two, advanced techniques as vibrothermography and pulsed laser heating having also been tried successfully. Computer aided image enhancement of the thermographic image data enables the detection of defects not normally identified by conventional thermographic data [6]. Thermography has proved to be a valuable tool in the investigation of weld pools.

The latest development in this field is pulsed video thermography - a method pioneered by the National NDT Centre at Harwell, UK. There is a widespread interest in the method because of its speed, lack of surface contact, ease of recording and subsequent data access in pictorial form and ease of interpretation. The combination of high performance video-compatible thermal imagers and powerful xenon lamps have revealed sub-surface defects and variations in structure in far more details than in normally achieved with conventional thermographic methods [7].

5.6 Holographic and Speckle Interferometry

The use of advanced NDE techniques as laser holographic interferometry (HI) and speckle interferometry (SI) has increased the scope of NDE considerably. HI and SI, have been demonstrated as useful methods for inspecting nuclear pressure vessels and piping. The fabrication/welding process alters the mechanical properties of the material, which leads to local variation in tensile strength. Thus under pressure non-uniform deformations are manifested. The techniques of HI and SI are well suited to measure this deformation resulting in interpretation of differences in residual stresses or mechanical properties.

Holographic interferometry has been used to measure residual stress in a High Energy Rate Formed (HERF) stainless steel pressure vessel introduced during pressure testing at Sandia Laboratories, Livermore [8]. An accept-reject criteria was developed based on HI technique. Good quality vessels are charecterised by small and reasonably uniform deformation fields. On the other hand, poor quality vessels exhibit large local yielding and much greater overall residual strains.

Gregory [9] has reported the use of SI on the study of flaw behaviour in a reactor pressure vessel (3 m long, 1.75 m dia. with 8 cm thick walls) at United Kingdom Atomic Energy Authority, Risley, UK. The vessel was positioned with the crack of know dimensions on the top. The crack was sealed on the inside surface with a large membrane. The vessel was loaded by applying hydraulic pressures from 0 to 13 MPa. Double Exposed Laser Specklegram technique was used. The camera was placed on the vessel itself, to eliminate

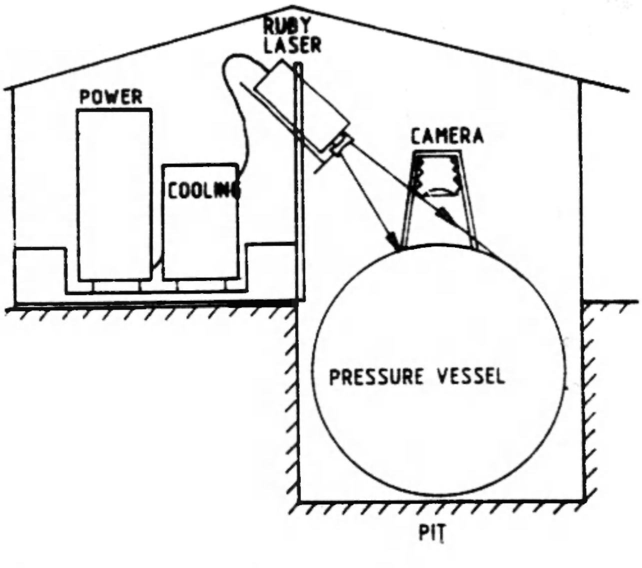


Fig. 12. *Laser specklegram technique*

the effects due to expansion of the vessel (fig. 12). Thinning of walls around the crack under pressurisation was studied. Depression and effected surface area were determined for various pressures.

Nuclear Industry needs detailed charecterisation of the mechanical behaviour of the material before and after irradiation. Non-contact methods play an important role in studying radioactive materials specially in inaccessible areas.

Holography and Speckle correlation has been used [10] for studying fatigue damage in materials under cyclic loads. On the basis of a correlation function, it has been established that rapid drop in correlation indicates impending failure of the material. One significant advantage here is that correlation studies can be used to access fatigue damage at any time during the lifetime of a structure.

Free surface properties of a material change as a function of plastic deformation of the material. The surface roughness of the material increases with increasing plastic deformation. Since the scattered laser speckle is characteristic of the surface roughness, real time measurement of deformation is possible using laser speckle. Yamaguchi has used laser scattering to measure high temperature strain in tensile specimens using correlation methods [11]. Azushima et. al. monitored plastic zone around a fatigue crack using scattered laser speckle [12]. Though many of the methods mentioned above have not been used for weldments, the physics of techniques allow their utilisation for characterisation of weldments.

5.7 Other NDE Techniques

In the field of eddy current testing, axisymmetric numerical analysis techniques using finite element and finite difference methods have thrown new light in understanding the physics of electromagnetic field/defect interaction and in simulating those test situations which are difficult and/or expensive to replicate in the laboratory. Since with the assumption of axisymmetry, actual defects like transverse and longitudinal cracks cannot be modeled, the necessity for the development of 3D models has been realised. Efforts are in USA, UK and Canada for the development of such models. Inservice inspection procedures are now well established and 3D eddy current systems have been developed for the examination of steam generator tubings. The basic advantage of this system compared to conventional units is that it utilises a three coil bridge circuit which makes it sensitive to all types of defects that occur at the highly stressed expansion transition zones in heat exchangers.

AE apart from being utilised for monitoring the formation of defect free weldments has proven complementary to the conventional tests in pressure vessels and is being increasingly employed for in-service inspections too. Some of the techniques which are now in their primes but are bound to have quite a good potential include acoustic-ultrasonics and acoustic microscopy. The former involves the inputting of ultrasonic energy at one location of the object and detecting at another location in the object. By capturing digitally the detected wave form, analysis provides considerable sensitivity to the nature of the material condition through which the ultrasonic wave traveled. This is especially true for characterisation of inhomogenous materials such as composites where damages are extremely complex in nature. The systems analysis approach is adapted in these cases. The purpose here is to compare the frequency responses and material properties via ultrasonic techniques at known conditions and at various stages on the way to failure. These results are combined with theory and knowledge of the failure mechanisms in order to devise a sensitive and reliable technique for investigating the material condition.

The acoustic microscopy technique uses the digitised amplitude of the spatially and temporally resolved acoustic signals for processing and displaying the image. This technique has made significant progress over the last two decades and has established itself as a powerful tool for materials characterisation. The system has found usefulness in flaw detection in thin, flat or smoothly curved surfaces such as plates or skins. With the use of phased array and a solid coupling system, acoustic microscopy could be a fast and cheap method for inspecting parts both during pre-service and in-service.

The technological innovations has led to the development of robots which are being widely used in operations characterised by a high degree of hazard or discomfort to human operators, such as radioactive materials and wastes. Even though in many cases these early robots did not necessarily perform the task more economically or at a higher quality than their human counterparts, the elimination of unpleasant tasks for workers was enough of a justification to use robots. Today robots are also used in applications where they offer clear economic or quality advantages over human workers as in manufacturing processes characterised by a high degree of order, simplicity, repetition and moderate production volumes. In the coming years, the advances in microprocessors and instrumentation would lead to robots with vision sensing, tactile sensing, voice actuation, artificial intelligence and improved control capabilities thus enhancing the value of robots for quality assurance and in-service inspection applications.

6. CONCLUSION

NDT techniques cover a wide spectrum of capabilities and sensitivity limits. The choice of a technique or a combination of complementary techniques requires careful analysis and maturity. Multidisciplinary efforts are essential for exploitation of tremendous benefits offered by NDT in ensuring cost effective fitness for purpose of components and plants in energy sector. Increasing use of appropriate NDT would lead to better availability of power plants and help in extending life of the plants.

It is noteworthy that the role of NDT is being recognised in our country more and more. Still it is a matter of concern that many a time the importance of NDT is appreciated only when major disasters or failures take place. It is not appreciated that these failures and disasters may be considered only as "headlines" in a large report. Economically more important are the lack of proper use of NDT in the industry leading to poor quality of welds sometimes resulting in multiple of failures, not reported any where. If properly implemented, NDT has the capability to contribute in an important manner to achieve the plan objectives in many sectors of the economy such as power, steel, materials technology, space, defence, petrochemical, railways and others. On the other hand, major investments in key sectors without assigning a proper place and role of NDT and without assuring quality in terms of fitness for purpose can do significant damage to the national economy and prestige. Today we have the relevant expertise in most of the advanced NDT techniques being used abroad and of relevance to our industries. The need of the hour is pooling our expertise together and applying the resources in a well streamlined manner for the effective utilisation of NDT science and technology.

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