VINYL CHLORIDE

INDUSTRIES

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January 24, 1983

Mr. Bruce J. Brocka
Personnel & Safety Manager
CertainTeed Corporation
P. O. Box 253
Sulphur, LA 70663

Dear Bruce:

At the Louisiana Loss Prevention Meeting of last week, you asked what was the standard inspection interval for vessels which store vinyl chloride. I mentioned that we do inspect the external surfaces of our vinyl chloride storate tank on an annual basis. Our internal inspections of storage tanks have not been on a scheduled routine basis as we do for say liquid chlorine storage (once every 3 years).

In the vinyl chloride processing unit, we annually inspect our vessels both internally and externally. Per your request, I tried to find some published guidelines on recommended internal inspection frequencies. PPG's Ben Reynolds indicated you had probably already received B. F. Goodrich recommendations (after their 700 ton leak in Australia) on inspections. As I understand it, BFG recommends an internal on storage tanks once each 3 years.

The only published source of information with actual internal inspections listed is an excellent British text entitled "Loss Prevention in the Process Industries" by Dr. Frank Lees. In chapter 19, it states that Imperial Chemical Industries would inspect such a vessel as a vinyl chloride storage tank either once each 6 years or more probably once each 12 years.

I've attached the appropriate pages from Dr. Lees book which cover both vessel inspection frequency and testing methods. Please call me if I can further help.

Sincerely,

Roy

Roy E. Sanders
Supt. of Loss Prevention
& Industrial Engineering

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met the requirements. The condition of the metal surface should be inspected for defects which may give rise to crack growth. A check should be made on assemblies which may be subject to wear and on stress raisers such as sharp angles, changes of section and attachments such as nozzles or lugs. The presence of dissimilar metals and stray electric currents which may give rise to corrosion should be considered. The suitability of joints, gaskets and seals should be checked; so should that of the lagging and protective finishes. The adequacies of the vents and drains on the vessel should be confirmed and the means of access reviewed.

Other aspects of inspection, such as tests during commissioning and pressure and leak testing, are considered in Sections 19.1 and 19.5, respectively.

19.2.6 Inspection register and records

It is essential to keep a register of the equipment to be inspected and records of the results of the inspections. The precise contents of the register depend on the item concerned but in general should include

(1) identification number, order number and drawing number;
(2) specification, design parameters, process fluids;
(3) inspection/test reports during manufacture;
(4) inspection category, interval, method;
(5) special features relevant to deterioration, failures;
(6) materials/parts list;
(7) date of entry into service.

Such a register is equally appropriate to pressure vessels, protective devices, rotating machinery or instrumentation.

The specific information requirements given in the ICI *Pressure Vessel Inspection Code* for the registration of pressure vessels are described in Section 19.3.

For a pressure vessel there should be full information on inspections/tests during its manufacture, including reports on tests on the material of construction, radiographs or other records of tests on welds, and reports on pressure and leak tests.

Reports of the regular inspections/tests on the equipment should be prepared and filed in the register. These reports should generally cover the results of the main inspection/test and of any additional monitoring and tests, any deterioration or failure detected and repairs carried out, and any modifications or changes of duty.

Again the requirements given in the ICI *Pressure Vessel Inspection Code* for pressure vessel reports are described in Section 19.3.

19.3 PRESSURE VESSEL INSPECTION

The inspection of pressure vessels and their protective devices is crucial to the maintenance of the integrity of the pressure system and is the main activity of the inspection authority.

An account of pressure vessel inspection is given in *Inspection of Chemical Plant* by Pilborough (1971). In the U.K. relevant codes are the *Registration and Periodic Inspection of Pressure Vessels Code* by ICI (ICI/RoSPA 1975 IS/107) and the *Pressure Vessel Inspection Code* by the IP (1976), and in the U.S.A. the *Guide to the Inspection of Refinery Equipment* by the API (1962–).

The description of pressure vessel inspection given below is based primarily on the ICI *Pressure Vessel Inspection Code.*

19.3.1 Definition

It is necessary first to define the equipment which is to be brought within the scope of the pressure vessel inspection system. The ICI *Pressure Vessel Inspection Code* gives the following definition of pressure vessels falling within the code:

> 'A pressure vessel is a closed vessel of any capacity consisting of one or more independent chambers, any or each of which is or may be subjected to internal pressure greater or less than atmospheric.
>
> This definition includes
>
> (a) Vessels not normally subject to internal pressure but in which internal pressure would occur in the event of a failure of any part, maloperation, isolation or other circumstances, for example, the failure of an internal steam coil in a vessel not adequately vented to prevent a pressure rise.
>
> (b) Vessels in which vacuum can develop, for example, steam receivers, steam condensers and other vessels containing condensable gases and vapours.'

For other equipment the code states

> 'Consideration should also be given to the registration and routine inspection of other items which although not normally classified as pressure vessels, may give rise to hazardous situations, e.g. fired equipment, large diameter piping, expansion bellows, and pressurized equipment subjected to erosive or corrosive conditions. Where cross-country pipelines are employed special arrangements will be necessary for their routine examination.'

The code defines a protective device as

> 'Any automatic device which protects equipment from over-pressure, over-temperature, over-filling, corrosion, explosion or other hazardous conditions; including atmospheric vents, lutes, flame traps, deadweight flaps, some non-return ~~valves,~~ relief valves, fusible plugs, bursting discs and instrumental trip systems, many of which incorporate an advance alarm indication.'

The code also lists equipment which, subject to approval, may be excluded from the requirements of the code itself, although it may still require some degree of inspection. Some important items in this list are vessels subject to static head only or to applied pressures not exceeding ± 0.07 bar (± 1 lbf/in^2) and not subject to corrosive risks; parts of prime movers and of machines driven by them; protective devices whose failure does not result in a hazard.

The IP *Pressure Vessel Inspection Code* defines a pressure vessel as either

'(i) A closed vessel of not less than 0.1 m^3 capacity consisting of one or more independent chambers any or each of which may be subject to an internal pressure greater than 70 mbar gauge or less than 930 mbar absolute or

'(ii) A closed vessel wherein $P \times V > 1$ where P is the internal pressure in bars and V is the enclosed volume in cubic metres.'

'Excluded are vessels subject to pressure generated solely by static head and storage tanks designed and constructed to Standards and codes such as BS 2654, BS 2594 and API RP 620.'

19.3.2 Registration

Before any equipment or device covered by the system is brought into service it should be registered.

It should be a requirement for such registration that the equipment has full documentation. The ICI *Pressure Vessel Inspection Code* states

'For equipment the file shall include its identification number, the order number, the drawing reference, specifications, materials lists, inspection reports during manufacture, test certificates relating to the material and tests on the completed equipment. It shall also contain details of the design conditions, the process fluids, of the expected operating conditions, and the date of entering service. In addition the file shall include a note of any special kinds of deterioration—e.g. stress corrosion—to which the equipment may be subject.'

The register should give the equipment classification and inspection categories. It should specify the initial and subsequent inspection intervals, the type of inspection to be done and, where appropriate, the inspection acceptance standards.

To this initial information should be added other relevant information generated during the life of the equipment. This includes reports of periodic inspections and tests, reports of failures, failure examinations and repairs; records of corrosion and other condition monitoring; details of modifications or changes of duty.

The registration of protective devices should be along similar lines, but it is necessary with some devices to include in addition specifications for special test procedures and records of such tests.

The IP *Pressure Vessel Inspection Code* gives broadly similar requirements.

19.3.3 Classification

It is convenient to classify pressure vessels according to whether or not they are covered by statutory requirements for inspection.

The ICI *Pressure Vessel Inspection Code* gives the following classification of pressure vessels:

Class A Pressure vessels for which periodic inspection is a statutory requirement or is required by regulation (e.g. local authority regulations).

Class B Pressure vessels not in Class A and certain other equipment.

The schedules of Class A and Class B pressure vessels and of protective devices listed in the code are given in *Tables 19.7–19.9*, respectively.

The IP *Pressure Vessel Inspection Code* also classifies equipment as Class A and Class B according to whether or not there is a statutory inspection requirement, so that the classification given in this code is similar to that of the ICI *Code*.

19.3.4 Inspection categories

On the basis of the classification of equipment it is possible to specify inspection categories which define the interval between inspections.

For Class A pressure vessels the inspection intervals are specified by the statutory or other requirements. The ICI *Pressure Vessel Inspection Code* states: 'It is almost impossible to obtain any relaxation from the responsible authorities.'

The inspection intervals for Class A vessels are given in *Table 19.7*.

For Class B pressure vessels there is more flexibility. The ICI *Code* defines three inspection grades, Grades Z, Y and X, according to the inspection interval. Grade Z having the shortest interval.

A vessel which it is recognized may deteriorate in service and for which there is little information on which to predict behaviour is classified as Grade Z. If experience shows that deterioration is slow, the vessel may be reclassified as Grade Y. The Grade Z inspection intervals given in *Table 19.8* are 2–6 years.

Grade Y applies to a vessel which is not expected to deteriorate significantly but on which there is insufficient information to justify assigning it to Grade X. Again it may be reclassified as Grade X, if experience shows that deterioration is insignificant. On the other hand, if unexpected deterioration is found, then it may be necessary to reclassify the vessel as Grade Z. *Table 19.8* gives Grade Y inspection intervals as 4–6 years.

Where there is a group of similar vessels of Grade

Table 19.7 Inspection categories for Class A pressure vessels (Imperial Chemical Industries Ltd—ICI RoSPA 1975 IS 107)

Item	*Vessel*	*Initial period*	*Subsequent periods*	*Inspection required*
1	Steam boilers or other vessels that are defined within the meaning of the Factories Act as steam boilers including waste heat boilers; also economizers and steam superheaters			
	Large installations, less than 21 years since first commissioned	14 months	26 months	Examination
	Small steam boilers and large boilers after 21 years since first commissioned	14 months	14 months	Examination
2	Steam receivers	26 months		Examination
3	Air receivers	26 months		Clean and examination and/or test
	Air receivers (solid drawn)	4 years		
4	Gasholders (water sealed) greater than 5000 ft^3 (140 m^3) capacity	2 years external 20 years internal	2 years external 10 years internal	Examination
5	Containers for the transport of compressed and liquefied gases	[a]		
6	Vessels for the underground storage of petrol, benzole, etc.	Will vary according to by-laws[b]		Examination and test
7	Transport containers for goods other than compressed or liquefied gases	[a]		

(a) Original table refers to text of code
(b) Reference should be made to local authorities.

Table 19.8 Inspection categories for Class B pressure vessels (Imperial Chemical Industries Ltd—ICI/RoSPA 1975 IS/107)

Item	*Vessel*	*Initial period* (y)	*Maximum period* (y) Z	Y	X
1	Steam containers, i.e. vessels which exhaust through a permanent outlet to the atmosphere or into a space where the pressure does not exceed atmospheric pressure or approximately that pressure	6	6	6	12
2	Compressed or liquefied gas containers (not used for transport)	6	6	6	12
3	Process vessels (including fired heaters and vacuum vessels)	2	2	4	12
4	Gasholders (water sealed) less than 140 m^3 (5000 ft^3) capacity. Waterless of any capacity	2 (external) 20 (internal)	2 (external) 10 (internal after first internal inspection)		
5	Static storage tanks with 'under the roof' or over the liquid pressure:				
	(a) less than 0.07 bar (1 lbf/in^2 g)	6	6	6	12
	(b) greater than 0.07 bar (1 lbf/in^2 g)	2	2	4	12
6	Transport containers for dangerous goods other than compressed or liquefied gases	[a]			
7	Intercoolers, aftercoolers, condensers, damping and other similar vessels associated with prime movers and machines driven by them (inspection grading to be assessed as for process vessels)	2	2	4	12
8	Selected pipework in known erosive/corrosive service or high hazard. Includes selected expansion bellows and other critical fittings	2	2	4	12

(a) Original table refers to text of code.

Table 19.9 Inspection categories for protective devices (Imperial Chemical Industries Ltd—ICI RoSPA 1975 IS 107)

Item	Device	Routine examination	Maximum interval for thorough examination, overhaul and test
1	All types, when fitted to Class A vessels	(a)	(a)
2	Relief valves fitted to Class B vessels	Only in special cases	2 years
3	Bursting discs (on Class B vessels)	Check that they are in operable condition and have not ruptured, at intervals depending on process conditions	2 years or not greater than that for the vessel being protected, whichever period is shorter
4	Atmospheric vents or lutes	Visual examination at intervals depending on process conditions	2 years or not greater than that for the vessel being protected, whichever period is shorter
5	Instrumented trip systems	Check on operability, 1, 2 or 4 weekly or as required. The Competent Person will witness these tests at his discretion	2 years

(a). Original table refers to text of code.

Y, the code allows a system of sampling, so that not every vessel need be inspected during the Grade Y inspection interval.

Classification as Grade X is allowed if a vessel has been examined on successive occasions and has shown no deterioration over a period of 6 years or if the vessel is new and is essentially similar in duty and construction to an existing Grade X vessel. The Grade X inspection interval is 12 years, as shown in *Table 19.8*. The code does not permit an inspection interval longer than 12 years.

Inspection intervals for protective devices on Class A vessels are subject to statutory requirements as shown in *Table 19.9*. There are many other protective devices and it is not appropriate to give inspection intervals for all these, although the table gives guidance on a few principal devices. In addition, the code states the two general principles that a protective device should be examined at an interval not exceeding that used for the equipment which it protects and that the inspection interval between examination/test for a protective device should not exceed 2 years.

In the IP *Pressure Vessel Inspection Code* the inspection intervals for Class A equipment are similar to those in the ICI *Code*. For Class B equipment the inspection categories are somewhat different. Inspection Grades I, II and III are defined in a rather similar way to Grades Z, Y and X in the ICI *Code*, but there is also a Grade 0 into which, with some exceptions, all equipment is put until it has received its first inspection.

The inspection intervals for Class B non-statutory equipment given in the IP *Code* are shown in *Table 19.10*. These inspection periods apply to the U.K. only.

Equipment in Grade III is subject to review at the periods given, in order to check that the conditions which led to that classification are still applicable.

19.3.5 Inspection procedures

Inspection should be carried out by a competent person within the inspection interval specified for the equipment.

The ICI *Pressure Vessel Inspection Code* describes the objectives of inspection as follows:

Table 19.10 Inspection grades for Class B pressure vessels (Institute of Petroleum—IP 1976 Pressure Vessel Inspection Code)

Equipment	Inspection period (months)				Review
	Grade 0	Grade I	Grade II	Grade III	
Process pressure vessels and process vacuum vessels	24	36	72	108	72
Pressure storage vessels	60	60	90	120	90
Heat exchangers	24	36	72	108	72
Protective safety devices	24	36	60	—	—

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'The objective of vessel inspection is to detect any deterioration such as corrosion, cracking or distortion indicating possible weaknesses that may affect the continued safe operation of the vessel. Primarily inspection shall be visual, but it shall be supplemented by other techniques and measurement when necessary to determine the extent of any losses of thickness, pitting, cracking, etc. Resorting to a pressure test as the sole method of periodic inspection is an inferior alternative to examination and should be used only when examination is not practicable or the findings of the visual examination are inconclusive.'

The inspection should also include examination of the protective devices.

There are various preparatory measures which need to be taken before an inspection is carried out. The inspector should brief himself on the history of the vessel and, where applicable, on that of other similar vessels.

The vessel is normally taken out of service, isolated, emptied and cleaned. The surfaces of the vessel are then exposed and prepared for inspection. This may involve such measures as removal of lagging from the outside of the vessel or cleaning of internal surfaces. These activities should be covered by appropriate procedures and permit-to-work systems as described in Chapter 21. The inspection is then carried out. On the examination of vessels the ICI *Code* states

'The purpose of examination is to record fully the state of the vessel at the time of inspection. This implies that a record should be made of any unusual or notable features whether or not they are considered significant to the operation of the vessel at that time; thus any change in condition between subsequent inspections can be reliably traced and rates of deterioration assessed.

'Particular attention should be paid both to any features of the vessel that are known to have given rise to problems in previous service or in other vessels, and to regions which may be particularly at risk from either process or design considerations.'

All fittings on the vessel which affect its safe operation should also be examined/tested.

The ICI *Code* also places on the inspector a responsibility to satisfy himself that the protective devices are examined/tested according to the specified intervals and procedures.

In a few instances it is not practicable to enter a vessel or to carry out a hydraulic pressure test on it. Entry into a vessel may be difficult, for example, due to toxic, flammable or corrosive substances. For such vessels the code requires that a written case be made stating the reasons for dispensing with internal examination and the alternative means to be employed.

The code requires pressure testing after any modification or repair which may affect the strength of the vessel and allows it at discretion as an alternative method of inspection where visual or other methods of examination are inadequate.

If it is found that the vessel has deteriorated or has a defect, it may be necessary to modify or repair it. The repair is normally carried out according to the code by which the vessel was originally designed.

In other cases it may be necessary to downrate the vessel so that it can be operated only at a lower pressure. If this is done, all necessary changes should be made to the protective devices and to the documentation for the vessel, for the protective devices and for plant operation.

19.3.6 Defects and failures

Some of the features which may be revealed by an inspection are

(1) internal corrosion;
(2) surface defects;
(3) weld defects;
(4) wear defects;
(5) deposits and debris;
(6) high stress situations;
(7) inadequate drainage;
(8) external corrosion.

Some of the types of internal corrosion which occur in process plant were described in Chapter 12. Corrosion may reduce not only the thickness of the metal but also its strength. Methods of detection include visual examination, thickness measurement including ultrasonics, and corrosion monitoring. Changes to the base material such as graphitization or hydrogen embrittlement may be detected by metallurgical examination.

Surface defects such as cracks or pitting arising from such causes as corrosion, erosion or crack growth may be detected by visual examination or by methods such as magnetic particle or dye penetrant techniques.

The avoidance of surface defects is particularly important where there is a risk of fatigue failure, since a rough surface can greatly reduce the fatigue strength of a steel.

These methods of crack detection may also be used to find weld defects. The latter include weld deterioration, which may arise due to the roughness of the weld, or weld decay, which is intergranular corrosion and occurs in austenitic stainless steels.

Cracks may be particularly serious as they can grow and lead to failure. It is often possible to remove a crack from a weld by chipping it out and depositing fresh weld metal. Small cracks may sometimes be stopped by drilling small holes at the extremity, which reduces the stress concentrations.

Wear on moving parts is normally found by visual examination and may result in failure if not rectified.

The build-up of deposits of materials and/or debris can create a hazard if equipment such as pipes and valves, or devices such as vents, pressure relief valves or instruments become blocked. Such deposits are revealed by visual examination.

There are certain undesirable features which as far as practicable are eliminated in the original design of the equipment but which may be reintroduced by plant modifications. High stress situations may have been created at vessel connections or at lugs. There may be elements which are under high stress due to the limitation of thermal expansion or contraction. Similarly, modifications may have been made which impede complete drainage. Visual examination may detect these facts.

External corrosion of the plant is detected by visual examination. It can be severe and can lead to serious loss of metal thickness.

19.3.7 On-line monitoring

Some of the non-destructive testing and condition monitoring techniques described in Sections 19.4 and 19.6 are applicable to the on-line monitoring of pressure vessels.

The ICI *Pressure Vessel Inspection Code* allows that where by reason of process conditions a vessel has been given an inspection interval less than the maximum for its grade, on-line monitoring methods may permit the interval to be increased to the maximum value.

19.4 NON-DESTRUCTIVE TESTING

Non-destructive testing techniques are used to detect defects in equipment such as pressure vessels and pipework during both its construction and its operational life.

Equipment is tested by non-destructive methods during fabrication. Pressure vessel codes such as BS 5500 lay down detailed non-destructive testing requirements. These are minimum requirements. For some pressure equipment it may be necessary to carry out more extensive testing. This is particularly the case where equipment has been fabricated on site.

It may be necessary to carry out further non-destructive testing of some equipments during construction and commissioning.

The condition of the equipment during the operation of the plant is checked by non-destructive testing, particularly, but not exclusively, during plant shutdown.

Once the plant is operational, it becomes difficult to obtain access for visual examination of some parts of the equipment, e.g. internal surface of a refrigerated storage tank, so that non-destructive testing techniques which can be used externally become very attractive.

Accounts of non-destructive testing are given in *Non-Destructive Testing* by Hinsley (1959), in *Techniques of Non-Destructive Testing* by Hogarth and Blitz (1960) and in *Principles and Practice of Non-Destructive Testing* by Lamble (1962) and by Pilborough (1971).

Some non-destructive testing and monitoring methods are

Visual inspection	Dye penetrant methods
boroscopes	Stress wave emission monitoring
Radiography	Holography
X-rays	Electrical measurements
γ-rays	resistivity
Ultrasonics	capacitance
Magnetic methods	
magnetic particles	
magnetic prints	
eddy currents	

These methods are now described in more detail.

19.4.1 Visual examination

Visual examination is the original and most widely used method of inspection and is non-destructive. It is effective in detecting surface defects ranging from cracks to corroded areas, and defective assemblies.

The range of visual examination can be extended by the use of aids such as periscopes or boroscopes. Boroscopes are available with lens or fibre optics. They are used to examine the condition of internal components such as the blades of turbines and compressors.

BS 5500 requires only visual examination for Category 3 pressure vessels.

19.4.2 Radiography

An important non-destructive testing method is X-ray radiography. This is used during fabrication to detect internal defects principally in welds but also in parent material.

Radiographic examination is covered by BS 2600: 1962 *General recommendations for the radiographic examination of fusion welded butt joints in steel* and in various other British Standards, some of which are given in Appendix 4.

BS 5500 requires non-destructive testing by radiography and/or ultrasonics for Category 1 and 2 pressure vessels. Details are given below.

The X-rays used are produced by an X-ray machine which is relatively immobile and expensive. X-rays are recorded on a photographic plate.

In X-ray radiography it is important that there be a high quality image. Standards generally call for a technique which is capable of recording deviations from the normal of not more than 2% of the maximum thickness of the item under test and specify the use of image quality indicators, or penetrameters. Image indicators are dealt with in BS 3971.

The interpretation of X-ray radiographs is a skilled matter and contains a considerable subjective element. The first step is to identify the type of defect and the second to quantify it, if quantification is appropriate. Below are listed some of the principal defects in welds. Terminology and symbols for weld defects are given in BS 499 and BS 2597.

Planar defects
- cracks
- lack of fusion (side, root, interrun)
- lack of root penetration

Cavities
- porosity (isolated, localized, linear)
- wormholes (isolated, aligned)
- crater pipes
- surface cavities

Slag inclusions

Other solid inclusions
- tungsten
- copper

Once a defect is identified, it is necessary to decide whether it is sufficiently serious to require rejection. This has again tended to be a subjective matter and has therefore caused considerable difficulty. In consequence, much work has been done to develop acceptance standards. BS 5500 contains a list of defects similar to that given above, together with the corresponding acceptance levels.

X-ray radiography is used to detect internal defects in parent metal such as pressure vessel walls and pipework and in castings as well as in welds.

γ-rays are also used for radiography. They are produced by a radioactive isotope source such as Cobalt 60. Equipment using γ-rays is portable and relatively cheap. It is used particularly for radiography of castings. The method is to arrange the castings in a circle with the γ-ray source in the centre and with photographic plates behind the castings.

Isotope sources have a relatively large area emitting radiation (usually about 2–6 mm diameter) and therefore tend not to give such good definition as X-rays.

If a permanent record is not required, X-rays may be used with a fluorescent screen instead of a radiographic plate. X-ray fluoroscopy is widely used for rapid inspection of components on conveyor belts to detect coarse defects and unwanted objects.

Another technique for rapid inspection is nucleonic gauging of thickness of materials passing a β-ray source.

19.4.3 Ultrasonics

Ultrasonics is another important non-destructive testing technique. This too is used during fabrication to detect internal defects in parent metal and in welds and to measure thickness.

Ultrasonic testing is dealt with in BS 3923:1968–*Methods for ultrasonic examination of welds.*

BS 5500 generally gives ultrasonics as an acceptable alternative to radiography for Categories 1 and 2 pressure vessels.

Ultrasonic waves are generated by a transmitter and detected by a receiver and are usually displayed on an oscilloscope or on a recorder.

Two basic techniques in ultrasonics are (1) transmission and (2) reflection.

In the transmission method the ultrasonic waves are generated by a transmitter on one side of the item under test and are detected by a receiver on the other. The method is shown in *Figure 19.1(a)*.

The reflection method generally uses pulsed waves which are generated by a transmitter and detected by a receiver on the same side of the item. One way in which the method may be applied is shown in *Figure 19.1(b)*, which is known as the A scan. Another application is the B scan, illustrated in *Figure 19.1(c)*. Both these methods give the depth of the defect. A third method is the C scan, shown in *Figure 19.1(d)*, which does not show the depth.

Ultrasonics is also used during operational inspections to detect weld defects and to measure thickness.

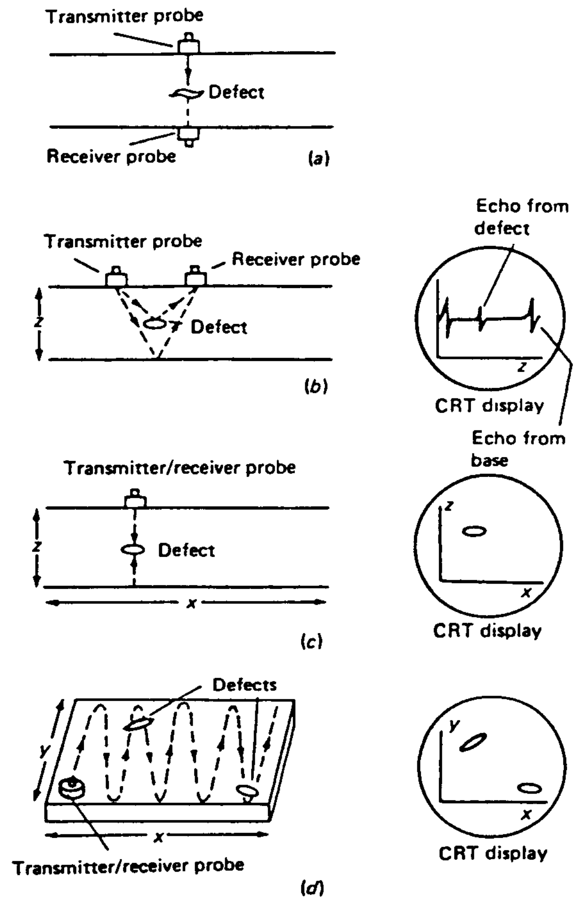

Figure 19.1 Some ultrasonic testing methods: (a) transmission method; (b) reflection method—A scan; (c) reflection method—B scan; (d) reflection method—C scan

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19.4.4 Magnetic particle methods

Magnetic particle methods are applicable to ferromagnetic materials and are used to detect surface and some subsurface defects.

BS 5500 gives magnetic particle methods as an acceptable method for the testing of welds for surface defects.

Magnetic particle testing is treated in BS 4397:1969 *Methods for magnetic particle testing of welds* and in several other British Standards, some of which are listed in Appendix 4.

There are various methods of magnetic particle testing, but the basic principle is to magnetize the item and coat it with a dry powder of iron or iron oxide particles, or, more usually, a wet powder or 'ink' of particles suspended in kerosene. The particles concentrate at places where there is no continuous magnetic path such as cracks. Defects may then be detected visually. As a further aid to visual detection, a fluorescent substance may be added to the particles and an ultraviolet lamp used. Defects show up best when they are at right angles to the lines of magnetic flux and it is usual to test the component on two different planes. It is often necessary to demagnetize the item, which is usually done by subjecting it to a magnetic field in the reverse direction to that of the initial one and then gradually reducing the field strength.

19.4.5 Eddy current methods

Magnetic particle methods are applicable only to ferromagnetic materials. An alternative which can be used for the detection of defects in ferromagnetic and other conducting materials is eddy current testing.

Eddy current testing is dealt with in BS 3889:1965 *Methods for non-destructive testing of pipes and tubes.*

In eddy current testing the item is subjected to an alternating magnetic field which induces eddy currents in it. These induced currents are measured and defects are detected from variations in the currents.

19.4.6 Dye penetrant methods

Dye penetrant methods are used to detect defects such as cracks.

BS 5500 gives dye penetrant methods as an acceptable method of testing of welds for surface defects and requires this method rather than magnetic particle testing for austenitic steels.

Dye penetrant methods are covered in BS 4416:1969 *Method for penetrant testing of welded or brazed joints in metals.*

The original dye penetrant method was to immerse the item in a heated mixture of paraffin and oil, dry it and clean it, and then dust it with chalk. On cooling the oil seeps out of any cracks in the article and stains the chalk.

More modern methods use variations on this such as special white developer and red dye.

19.4.7 Other methods

There is a growing number of other non-destructive testing methods such as stress wave emission analysis, holography and electrical resistance methods. In some cases these techniques are useful for inspection mainly during fabrication, but in others their application is to operational inspection. Some of the latter are considered in Section 19.6 on condition monitoring.

19.4.8 Acceptance standards

It is difficult to overemphasize the importance of acceptance standards. Unless the increasing number of techniques which are capable of detecting defects is matched by the development of standards which define levels of defect below which no action is necessary, there is an obvious danger of unnecessarily frequent rejection.

Much work has been done on this problem by bodies such as the Welding Institute and the American Welding Society, and there is an increasing amount of guidance available. As already mentioned, BS 5500 lists acceptance levels for certain defects.

19.4.9 Non-destructive testing of welds

The distinction between the different categories of pressure vessel is largely based on the extent of non-destructive testing of welds. For vessels in Category 1 BS 5500 requires for examination of internal flaws

> 'The full length of all full penetration butt welds including the welds of forged butt welded nozzles shall be examined by radiographic and/or ultrasonic methods. Unless otherwise agreed the full length of all other welds (e.g. nozzles and branches) in or on pressure parts shall be examined by ultrasonic and/or radiographic methods where the thickness of the thickest part to be welded exceeds that given in table 5.6.4.1.1.'

For examination of surface flaws the standard states

> 'The full length of all welds other than full penetration butt welds shall be examined by magnetic particle or penetrant methods. Full penetration butt welds shall be examined by these methods when agreed between the manufacturer, the purchaser and the Inspecting Authority.'

For vessels in Category 2 the standard requires

> 'At least 10% of the length of all full penetration butt welds shall be examined by radiographic and/or ultrasonic methods. Such examination shall include each intersection of longitudinal and circumferential seams. For each longitudinal and circumferential seam there shall be at least one radiograph or, where ultrasonic testing is specified, at least a 200 mm length shall be examined. At least 10% of the length

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of all other full penetration butt welds shall be examined by radiographic and/or ultrasonic methods.

'At least 10% of the length of all welds other than main longitudinal and circumferential seams shall be examined by magnetic particle or penetrant methods.

'In addition to the above when openings occur in, or within 12 mm of, welded seams, such seams shall be examined each side of the opening for a distance of not less than the diameter of the opening.'

The standard also specifies the further non-destructive testing required if defects are found.

For vessels in Category 3 the standard states

'Non-destructive testing for internal flaws is not required. However, insofar as magnetic particle or penetrant methods are aids to visual examination, which is required, they may be used subject to agreement between the manufacturer and the purchaser, or the Inspecting Authority.'

19.5 PRESSURE AND LEAK TESTING

Pressure testing and pressure leak testing are potentially hazardous operations and it is essential to observe the appropriate precautions in carrying them out.

The equipment to be tested should always be given as thorough a visual inspection as practicable before any test is done.

19.5.1 Pressure testing

Pressure testing is carried out to check that a pressure vessel can be safely operated at the design pressure.

As already described, the pressure testing of pressure vessels is in some instances a statutory requirement, while in others it may be required by an inspecting authority.

In such cases it is a general requirement that the pressure test must be carried out in the presence of the appropriate inspector.

Pressure testing is covered in BS 5500 and the ICI *Pressure Vessel Inspection Code*, and is discussed by Pilborough (1971). Safety precautions in pressure testing are given in these sources and in GS/4 *Safety in pressure testing* by the HSE (1977).

Types of test include (1) acceptance tests—(a) standard test, and (b) proof test; and (2) routine tests.

A standard test for acceptance is carried out on a pressure vessel where the required thickness of all pressure parts can be calculated. The object of the test is to confirm that the calculated design pressure is a safe working pressure.

If it is not possible to calculate the strength of a vessel satisfactorily, a proof test for acceptance may be conducted to establish a design pressure. In this case the purpose of the test is to determine whether the expected design pressure is a safe working pressure.

In addition to these tests, which are carried out just before or after installation, there are periodic routine tests which are carried out during the operational life of the vessel.

Methods of testing are (1) pressure tests—(a) hydraulic tests, (b) pneumatic tests, and (c) combined hydraulic/pneumatic tests; and (2) vacuum tests.

The preferred method of pressure testing is the hydraulic rather than the pneumatic method, because in the latter the energy available is large and any failure during the test is likely to be highly explosive. This point is discussed in Chapter 17.

Thus BS 5500 states that pneumatic testing should only be carried out 'Either on vessels of such design and construction that it is not practicable for them to be filled with liquid, or on vessels for use on processes that cannot tolerate trace liquids and where the removal of such liquids is impracticable'. and only in consultation with the Inspecting Authority.

Where hydraulic testing with water is not used, the reasons are generally that the vessel and the structure cannot withstand the weight of water, that the water may be difficult to remove completely or that it may freeze.

The standard test pressure for a hydraulic, pneumatic or hydraulic/pneumatic test given in BS 5500 is

$$p_t = 1.25 \frac{p f_a t}{f_t (t - c)} \tag{19.5.1}$$

where c is the corrosion allowance; f_a the nominal design stress at test temperature; f_t the nominal design stress under design temperature based on short term properties; p the design pressure; p_t the test pressure; and t the nominal thickness of section under consideration. Various qualifications to this test pressure are given in the standard.

The procedure for a standard hydraulic test is broadly as follows.

The test fluid should normally be water, but other liquids may be utilized instead if necessary. If another liquid is used, any appropriate precautions should be observed. The ICI *Code* states that the liquid should be well below its boiling point and, if flammable, should have a flash point above 45°C.

If water is used with austenitic stainless steel, it is essential to control the chloride and alkali content. The ICI *Code* specifies the use of demineralized or clean condensate with a chloride content less than 1 ppm.

The test is normally carried out at about ambient temperature. The hazard of brittle fracture should be considered and, if necessary, the test temperature should be chosen so that it exceeds the ductile/brittle transition temperature. Also a temperature in excess of 7°C is recommended in order to avoid the risk of freezing.

There are various precautions which should be