

NON-DESTRUCTIVE EXAMINATION – CHOICE OF METHODS

1. INTRODUCTION

Non-destructive examination is used to search for defects, such as cracks or inclusions, in material or components, without affecting the fitness for use of that material or component. It is important that the requirements for non-destructive examinations be taken into consideration at the design stage in order that the components and assemblies can be examined economically and effectively both in service and during manufacture, see Table 5.1. Non-destructive examination covers a wide range of methods and processes. This Data Item is restricted to those methods that are in common use, and excludes laboratory methods and methods under development. It provides guidance on the choice of suitable non-destructive examination procedure(s) for a specific application by describing the mechanics of the various procedures available, their typical applications, advantages and limitations in use. In addition the approximate minimum defect sizes that could be expected to be found by each method are stated. Table 5.2 provides a list of the methods described, together with the key features of each.

The nomenclature used in documents dealing with non-destructive examination includes “non-destructive testing”, NDT and “non-destructive inspection”, NDI. To some these terms are synonymous, but others make subtle distinctions, such as only using ‘test’ when a physical measurement is made. For this Data Item the term non-destructive examination (NDE) has been chosen. Also, the terms ‘indication’, ‘defect’ or ‘flaw’ are sometimes used to describe the findings of a non-destructive examination. The term ‘defect’ is generally used in this Data Item. However, it does not imply that the component is necessarily defective and therefore unsuitable for its intended usage.

Attention is drawn to the fact that the minimum detectable defect sizes stated in this Data Item are approximate values only. Minimum detectable defect sizes are quoted in approximately equivalent millimeter and inch sizes; both are rounded values.

Sections 2 and 3 deal with general features of NDE, Section 2 discussing its applications and Section 3 treating features that are common to all the available methods. Tables 5.3 to 5.11 describe each method, commencing with the simplest and progressing through increasing technical and/or equipment complication. The final two Tables 5.12 and 5.13 deal with methods of less general application. Much more detailed information about most of the methods can be found in Reference 21, although some of the detectable defect sizes quoted there are for ideal conditions. Reference 24 also provides details of the more common NDE methods. Reference 9 deals with the application of a wide range of NDE methods in the nuclear industry. The Standards quoted as references in this Data Item are only a typical sample of those available.

2. APPLICATIONS AND THE EFFECT OF THE PROBABILISTIC NATURE OF NDE

2.1 Probabilistic Nature of NDE

Maximum acceptable defect sizes are usually determined from design considerations*, see Sections 2.2 and 2.3. An NDE method is then chosen that has sufficient resolution to identify such a defect with acceptable high probability. However, many factors influence the ability of each of the various NDE methods to detect defects. Thus, a defect of about the maximum acceptable size has only a certain finite probability of being found. The possibility of non-detection of a defect above the agreed maximum size must therefore be recognised and the resulting consequences taken into account in design and when specifying examination

* In some industries codes or standards specify, or indicate, initial or maximum acceptable defect sizes. Such values are usually product specific and cannot be used for other industries.

procedures and inspection intervals. The choice of an NDE method is further complicated since, with all the available methods, it is difficult to size defects accurately and hence to assess their importance. The probabilistic nature of NDE therefore leads to the selection of an acceptable defect size which gives a balance between the probabilities of rejecting satisfactory components and of accepting unsatisfactory ones, see References 3, 12, 14 to 16 and 18.

The philosophy of NDE can vary according to whether the defect is present during manufacture or occurs in service. Because of this, examination during manufacture and examination during service are dealt with separately in the following two sections. Table 5.1 summarises the important features that need consideration during design.

2.2 Examination During Manufacture

Raw material, manufactured parts and components can all be examined non-destructively as a quality control check at appropriate stages during manufacture. The defects expected in initial quality checks include cracks due to inclusions, shrinkage or handling, voids, porosity, weld-related defects, laps (folds in the material surface) and inadequate bonding. At each stage the particular method employed depends upon the defects being sought. The defect acceptance level is usually the level achievable by good practice at that stage of manufacture. The extent to which this is met is a check on workmanship standards and must be consistent with the fitness for purpose of the finished component. Once a method of examination and a defect acceptance level have been chosen, each examination becomes a 'go'/no go' procedure in which a part that shows no defects above the acceptance level is passed for the next stage of manufacture. As noted in Section 2.1 the acceptance level in critical regions of the part is decided by fitness for purpose, using a knowledge of the working stress levels and a fracture mechanics prediction. Reference 3 illustrates this for welded structures.

2.3 Examination During Service

In-service examination is used to search for defects resulting from use, or occasionally from transport and conditions of storage. Typically, the defects expected are cracks that may have originated from regions of high stress or from inclusions or cracks that were undetected or accepted during manufacture. Other defects include composite delamination (Reference 26), corrosion (surface, interlaminar or stress), wear, disbonding and accidental damage such as may be caused by tool drops, electrical discharge damage, vehicle collisions, lightning strikes or earthquakes.

Pre-existing defects may grow with service use; therefore NDE must be carried out periodically. Alternatively the in-service loading may initiate fatigue cracks. For suspected fatigue cracks a defect may be assumed to be a crack-like feature, of the size indicated by NDE, and the calculation method described in Data Item No. 80036* may be used to estimate the growth of the crack to a critical size (see also Reference 8). From this calculation a safe interval to the next examination can be predicted. Prior to finding a crack, the inspection interval is usually determined by assuming an initial defect size that is the largest that the chosen NDE procedure is likely to miss†. However, the initial inspection period (sometimes called the inspection threshold) might be set by assuming an initial defect exists of a size specified in the design requirements. This size might be less than the minimum defect size detectable by the chosen NDE method in which case it will influence the inspection philosophy. For composite materials, defect growth data based on laboratory tests on representative structural elements are required. For corrosion and accidental damage, the examination interval has to be based on experience with similar structures in a similar environment.

* Data Item No. 80036, "Introduction to the use of linear elastic fracture mechanics in estimating fatigue crack growth rates and residual strength of components."

† If a history of the type of component or structure and examination method exists this may be used to generate a curve of probability of detection versus size of defect. This curve may be used to assist with the determination of the initial inspection period.

For examination of a particular component the NDE methods used during manufacture and in service should, ideally, be identical. If this is not possible and different methods are employed, the detection incompatibility can only be resolved by reference to the different probabilities of detection of each of the methods and the consequences of non-detection of an in-service defect. Detection capabilities of different operators using the same NDE method can vary and this should also be taken into account.

It is clear from the preceding paragraph that records of all examinations should be retained. The potential of a method to provide a 'hard' record of the findings may influence selection of the method of examination.

3. COMMON FEATURES OF THE METHODS

The development of each examination specification requires experience with the process to ensure that full coverage of the required area or volume is obtained (References 7 and 19). For other than simple visual examinations it is essential that operators of NDE methods are formally trained in the use and limitations of the equipment. Some industries require operators to be approved.

The human element is an important factor in all examinations. Boredom, tiredness and distraction can all degrade the outcome of an examination as can environmental factors such as the quality of lighting, difficulty of access and the need for protective clothing. In order to provide consistent and complete examinations a number of automated or semi-automated procedures have been, or are being, developed. Certain of these degrade the defect threshold in the interests of examination time, whilst others achieve a greater reliability in detection than can be achieved by a human operative.

3.1 Detection Capability and Defect Sizing

If, for safety reasons, the detection capability is critical, it is important that examinations be repeated by several trained operators. These results may be analysed to provide a probability of detection (see References 19 and 20).

The detection capability can be influenced by residual stresses. For example, in unloaded components or structures, residual compressive stresses can close a fatigue crack thereby reducing its detectability. In some cases stress jacking, see Table 5.13, may be used to open any fatigue cracks.

Not all methods are capable of determining the most critical dimension of a defect. For example, most methods that detect only surface cracks give no information on crack depth which may be the critical dimension. Throughout, there remains an unavoidably wide variation in the accuracy of defect sizing by any one method.

3.2 Detection Thresholds

A fundamental fact of NDE is that no method can detect every defect. Each method has a threshold, or minimum detection level, below which defects cannot reliably be found. The threshold relates to the perceived defect, since the orientation of irregular or crack-like defects with respect to the viewing direction considerably alters the detection capability. In addition, the threshold is influenced by component size, geometry, surface finish, working conditions, *etc.* plus other factors more specific to each particular method. The method may, for example, also have blind spots where the characteristics of the system prevent the detection of certain types of defect. The limitations are often minimised by adopting more than one procedure, for example, by using one method to find surface defects and a second to find internal defects. For some components, national standards exist that define the methods and procedures to be used. Where thresholds are critical, it is important to establish them experimentally, see Section 3.3. Figure 1 gives a broad indication of the threshold values of the methods described in this Item.

3.3 Calibration

A particular NDE procedure can be calibrated by examining a component or sample of structure into which a simulated defect has been introduced, usually at a potentially critical feature, for example at a bolt hole or at a fillet weld or other area of high stress concentration. Simulated defects can be produced by fatigue cycling to induce fatigue cracks, by spark machining slots, by drilling small blind holes or by introducing deliberate disbands. When a fatigue crack is used only the surface length is known at the time of examination and the actual depth cannot be determined without breaking the crack open and destroying the specimen. Manufactured simulated defects are useful in that the defect size and location are known. Where a defect is found during service it is sometimes possible and useful to remove the defective component from service and to use it to calibrate the NDE procedure to be used when examining for similar defects.

Some industries employ standard specimens for use in calibrating NDE equipment. These often consist of blocks containing drilled holes or saw cuts. Although the relationship between the features of the specimens and real defects can be calibrated this is not an exact procedure.

4. REFERENCES

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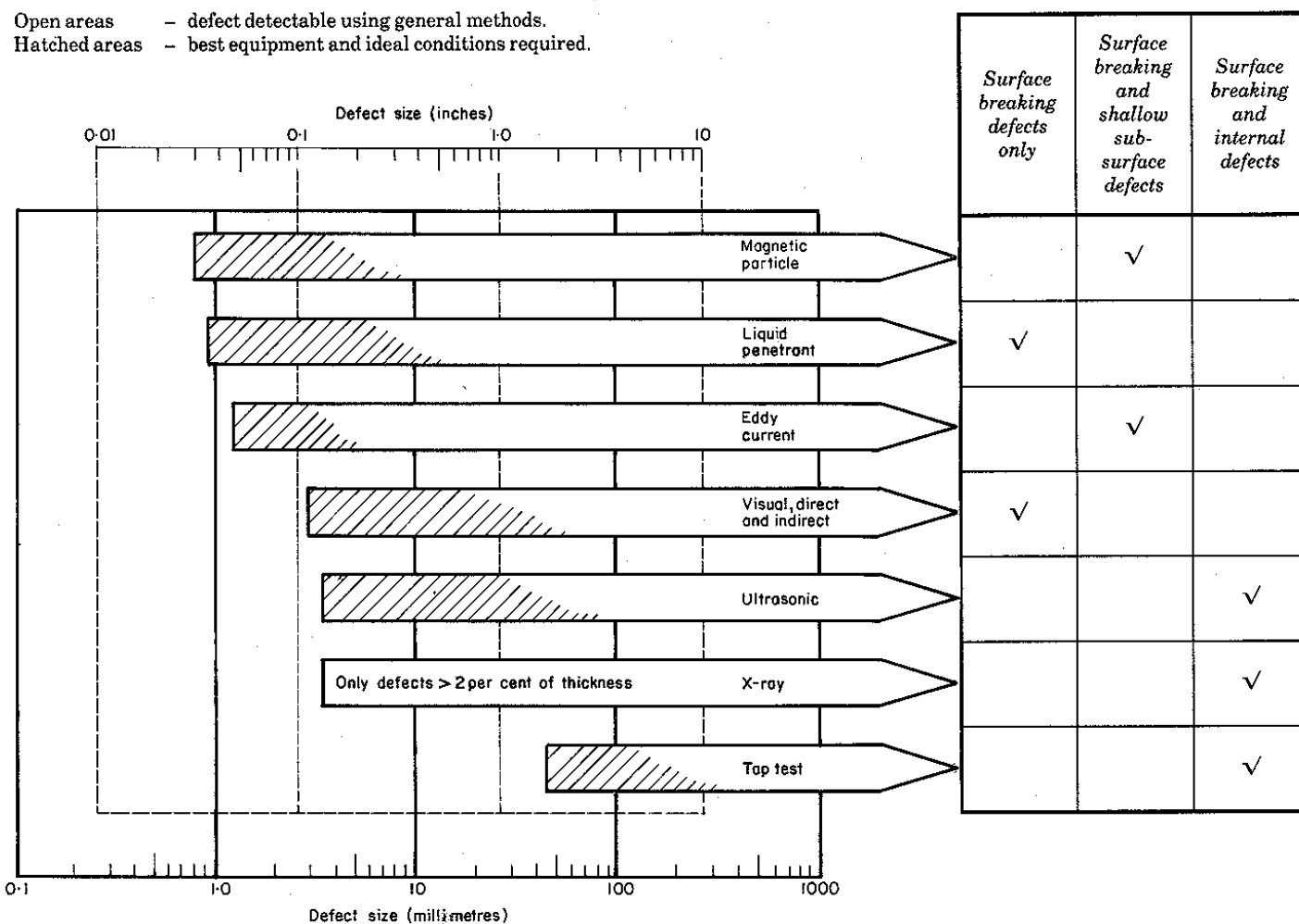


FIGURE 1 GUIDE TO DETECTION CAPABILITIES OF NDE METHODS
See Tables 5.3 to 5.13 for further details

5. TABLES

TABLE 5.1

FACTORS TO BE TAKEN INTO CONSIDERATION AT THE DESIGN STAGE

NDE during manufacture	NDE during service
Object: To find unacceptable defects in raw material or in finished components, for example inclusions in castings or weld faults. Major Considerations: Identification of poor materials and workmanship (for example poor weld control). Examination conducted under factory conditions allows use of a variety of methods. On mass produced items or large uniform items, such as sheet or tube, automation is economic and effective. Examination can be carried out on the final product only, or at one or more intermediate stages also. The choice is an economic balance between the costs of intermediate examinations and the costs of wasted processing. On raw material it is usually necessary to detect both internal and external defects. Acceptable defect sizes may be set by fracture mechanics analysis or may be a generally accepted value that is product specific. A method that provides a record of the results of NDE of finished components may be necessary. (This may need to accord with the method chosen for in-service examination.)	Object: To find unacceptable defects resulting from service conditions, for example fatigue cracks, wear, corrosion. Major Considerations: Defects, in particular cracks, must be detectable well before they become critical. Fracture mechanics analysis can be used to draw up a schedule for examination intervals. The schedule should be reviewed following in-service findings. The majority of defects occurring during service are surface-breaking defects. However, in structures and machines these may be at mating surfaces that are hidden. Examination of all critical surfaces must therefore be practical and provision made for easy access (or disassembly where necessary). A method of examination that provides a record of results may be required, particularly for fatigue cracks. Some methods of NDE cannot be used for reasons of contamination, for example, on food or chemical plant. Many methods of NDE require magnetisation, coating with dyes or removal of paint. These may not be possible without disassembly and may therefore be expensive. Further, all coatings removed must be reinstated.
All methods found suitable should be examined to select the lowest inspection costs compatible with requirements. Having selected an NDE method the possibility of missing a defect must be assessed and the consequences proved acceptable, if possible, by suitable trials and statistical analysis.	

TABLE 5.2 KEY FEATURES OF THE NDE METHODS

<i>Method</i>	<i>Defect type</i>	<i>Equipment cost¹</i>	<i>Operating cost²</i>	<i>Highlights</i>
Visual - direct and indirect	Surface	Negligible	Low	Quick for large areas or batches of parts. Large defects only.
Borescope	Surface	Low	Low	Gives visual access to internal features. Rigid probe.
Fiberscope	Surface	Low/Medium	Low	Flexible form of borescope. Resolution not as good.
Video-imagescope	Surface	Medium/High	Medium	Fiberscope with electronic viewing system. Resolution good.
Liquid penetrant	Surface	Low/Medium	Low	Easy to use. Will find relatively small defects.
Magnetic particle	Surface and sub-surface	Low/Medium	Low	Easy to use. Ferromagnetic material only, will find small defects.
Eddy current	Surface and sub-surface	Medium	Medium	Local features, bolt holes. Can find small defects. Bulk material with special equipment. Readily automated.
Magnetic field	Surface and sub-surface	High	Medium	Used on installed ferromagnetic pipes.
Ultrasonic	Internal and surface	Medium	Medium/High	Best on thick parts or composite laminates. Couplant required. Can be automated.
Microwave	Internal and surface	Medium	Medium	Used on non-metallics in place of ultrasonics. No couplant required.
Radiography (X- and gamma)	Internal and surface	High	High	Thick, thin parts, composites and coarse grain. Poor on cracks.
Radiography (neutron)	Internal and surface	High	High	Metals are transparent, corrosion, seals, etc. are detectable.
Computed tomography	Internal and surface	Very high	High	Equipment not portable. Can find defects in complex hollow parts.
Tap test	Internal and surface	Low	Low	Simple, large defects only in bonds or welds.
Proof pressure	Through thickness	Low	Medium	Leakage or failure shows defects in pressure vessels.

TABLE 5.2 KEY FEATURES OF THE NDE METHODS

<i>Method</i>	<i>Defect type</i>	<i>Equipment cost¹</i>	<i>Operating cost²</i>	<i>Highlights</i>
Structural proof test	All	Very high	Very high	No failure plus fracture mechanics gives next test timing.
Acoustic emission	All	Very high	High	Needs load applying. Can warn of possible failure in homogeneous structures. Cannot size defect.
Acoustic or vibration monitoring	All	High	Medium	Warns of failures in rotating machinery. Can locate defect.
Stress jacking	—	Low	Medium	Assists NDE, removes compression.

Note 1: Equipment cost is very much a function of the degree of complication within a given system, for example video image enhancement or automated tracking are very expensive.

Note 2: Operating costs are affected by consumables, setting up time and interpretation of the results.