BEST PRACTICE FOR THE PROCUREMENT AND CONDUCT OF NON-DESTRUCTIVE TESTING

Part 1: Manual Ultrasonic Inspection

GAS AND PROCESS SAFETY
TECHNOLOGY DIVISION

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The recommendations contained in this document were aimed specifically to improve the inspection of conventional pressurised equipment. However, the drafting committee considers that these measures can also apply to any application of manual ultrasonic inspection including fairground or railway components, offshore equipment, and conventional plant in nuclear installations.

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1. INTRODUCTION

It is widely recognised that NDT can be less effective than anticipated by those applying it or by those using the results to determine component integrity. This has been confirmed in a number of trials and most recently, for manual ultrasonic in-service inspection[1], by the PANI project [Ref. 1]. Consequently, the Health and Safety Executive (HSE) has judged it appropriate to issue the recommendations of the PANI committee, which identify when problems can arise in the application of NDT and what solutions might be adopted.

The measures contained in this document are recommended by the HSE for the conduct of manual ultrasonic inspection. They are intended to promote the adoption of good practice and apply to in-service inspection of existing plant or to repairs. The measures could also be applicable to the inspections carried out during the manufacture of new or replacement plant. They apply both to inspections carried out by the NDT department of the company owning or manufacturing the plant and to those carried out by external NDT organisations under contract. In the latter case, they are intended to assist in the procurement process by highlighting the issues that need attention.

This document has been drawn up by a committee of experts assembled by the HSE for this purpose. Their names and affiliations are given in Appendix 1, from which it will be apparent that they represent a very wide range of those parts of UK industry using the relevant NDT methods. In addition, they have considerable expertise in and responsibility for the application of NDT to industrial plant. The recommendations contained in this document are based on two main sources. The first is the recently completed PANI exercise mentioned above. This was an HSE-funded project involving the application of manual ultrasonic methods used for in-service inspection to test-pieces, containing defects, representing a range of typical industrial plant items. The inspections were carried out as they would be in practice and the results have great significance in assessing the performance to be expected of current methods as well as in identifying areas and means for improvement. These measures represent an immediate application of the results of the PANI project pending a more protracted investigation of the issues raised. The second basis for the recommendations is the collective experience and expertise of the committee mentioned earlier. Many of the members were also members of the PANI Management Committee.

Section 2 contains a review of the current way in which most manual ultrasonic inspections are designed and carried out and the way in which the quality of the inspection is assured. The inspection methods examined in the PANI project were developed using this approach. Section 3 continues with an analysis of potential problems together with a list of the measures which can be adopted in response. In doing this, it is recognised that the extent to which it is reasonable to include additional features in the inspection, and incur additional costs as a result, depends on the role of the inspection in assuring plant safety, the economics of the inspection activity and the consequences of the inspection failing to achieve its objectives. Accordingly, Section 4 contains recommendations on how the effectiveness required of the inspection can be assessed and on how this then affects the adoption of the additional inspection measures identified in Section 3.

[1] The term “inspection” is commonly used to mean both NDT and inspection in its wider sense. Throughout this document, it is used to mean NDT.

2. CURRENT PRACTICE

Many manual ultrasonic inspections are designed on the basis of a national or international standard such as BS EN 1714 [Ref. 2]. The procedure for the inspection is written to simply reflect the requirements of the standard in terms of the beam angles, scanning patterns, sensitivities, probe types and so on. Often no account is taken in this approach of the detail of the defects which the inspection is intended to detect and size.

Operators may be trained and qualified according to the requirements of a qualification scheme based on international standards such as BS EN 473 [Ref. 3] or ISO 9712 [Ref. 4]. These typically require operators to pass a written examination and to demonstrate their practical skill on test pieces containing defects. Of necessity, the test pieces cover a limited range of geometries and contain a limited range of defect types. This means that the test pieces on which an operator qualified may not be directly relevant to a particular inspection. In addition, many qualification schemes concentrate on defect detection and length measurement. There is less emphasis on the measurement of defect through-wall size and so an operator's ability to carry out such measurements is not fully assessed.

The authority to approve a procedure for a specific inspection based on the more general requirements of a code or standard requires skills and qualifications additional to those required of the operators who apply the inspection in the field. Such qualifications are denoted as Ultrasonic Testing (UT) Level 3 and involve demonstrating a greater understanding of the particular inspection method than expected of the Level 1 or 2 operators who normally carry out the inspection. As an example to illustrate this point, complete definitions, for one particular qualification scheme, of the areas in which operators at Levels 1, 2 and 3 have demonstrated competence and the tasks they are qualified to perform are given in Appendix 2. These are taken from the documentation of the UK PCN scheme [Ref.5] which complies with the requirements of BS EN 473.

The approach outlined above can be effective in certain circumstances and represents a cost effective way of defining and implementing requirements for manual ultrasonic inspection. However, there are circumstances in which it can lead to the adoption of unsatisfactory inspection procedures or to the use of operators whose training and qualifications are inappropriate to the particular inspection. It is crucial that such circumstances are recognised and appropriate additional requirements are specified. The PANI programme illustrated the potential shortcomings of the uncritical adoption of the approach described above and highlighted the situations where additional measures are needed. These are discussed below.

3. THE NEED FOR ADDITIONAL REQUIREMENTS

In this Section, the issues highlighted by the PANI project are discussed along with others identified by the committee of experts described in the Introduction. In each case, the problems discussed are followed by a number of recommendations to address the particular difficulty. It is not intended that all these be adopted in every case. Instead it will be necessary for those responsible for the inspection to determine which recommendations are appropriate. Advice on making a selection is included in Section 4 of these guidelines.

3.1 Defect Type

The ultrasonic response of a defect and hence its detectability depends upon the defect characteristics. Shape, orientation, position, roughness, branching, length and through-wall size all affect the amplitude of the signal generated by a particular probe. If the inspection is not optimised for the detection of the defects of concern then the effectiveness of the inspection could be poor. In particular, inspection standards are often related to the detection of manufacturing defects. If such standards are applied to in-service inspections where the defect types could be very different, the procedure may be intrinsically unsuited to the problem. A further point about in-service inspection is that it is frequently necessary to measure through-wall size and/or ligament accurately for fitness-for-purpose considerations. Such requirements impose additional requirements beyond those often included in manufacturing inspections.

There are occasions when there is no information on the defect types that may arise and hence on their possible characteristics but it is still necessary to carry out an inspection. In such a situation, as wide a range of probe angles as practicable should be applied at the sensitivity required by standards, such as that in Reference 2, to detect defects over a range of orientations. Without a defect description, there can only be limited confidence in how effective the inspection has been in verifying the absence of defects.

Recommendations

- Those requiring the inspection should provide a clear description of the defects which the inspection must detect and size to those designing the inspection. Such a description should include as much information as possible on the possible ranges of the defect characteristics identified above.
- In addition to describing the defects to be detected, the particular defect characteristics which must be measured should also be specified by the inspection purchaser.
- Design of the inspection should be based on defect descriptions as above.
- Inspection procedures should be designed or approved by a UT Level 3 inspector.
- When no defect description is available, a wide range of beam angles should be used to detect defects over as wide a range of orientations as possible. It should be accepted that, in such a situation, it is difficult to be confident that an inspection will detect all potentially significant defects.

3.2 Component Geometry

The PANI programme and previous trials have shown that operators inspecting a simple geometry such as a flat plate butt weld can perform well but in general their performance deteriorates as the geometry becomes more complex and the demands of the inspection increase. The geometry can restrict the surfaces available for scanning probes, restrict the coverage of the weld by different probes, and generate echoes which interfere with the detection of defect responses. The latter includes echoes from the back-wall, from weld roots and caps and from any unfused lands within the welds. The thickness of the component is another aspect to be considered. For thin components with sections less than 8 mm or for very thick components, special probes may be required.

Recommendations

- The specific geometry of the component should be borne in mind when designing the inspection procedure.
- A qualified UT Level 3 inspector should be used to design or approve the inspection procedure.
- The operators who carry out the inspection should be given specific training and practice with feedback on representative test pieces containing defects.

3.3 Component Material

BS EN 1714 specifies methods for metallic materials which exhibit low ultrasonic attenuation and is primarily intended for use on full penetration welded joints where both the weld and parent material are ferritic steels. Other materials which are attenuative or have properties which scatter or distort the ultrasonic beam, such as austenitic steels and Inconel, will require adoption of more specialised ultrasonic techniques. Materials which scatter the ultrasonic beam can make the operator's job more difficult in detecting defect responses from the higher background noise.

Recommendations

- Inspection procedures for attenuative materials should be designed or approved by UT Level 3 inspectors with specific knowledge of this type of inspection. The procedure should be developed using representative test pieces.
- Inspectors should be given specific training and the opportunity to practice in advance of an inspection on representative test pieces containing defects.
- Qualification schemes (in-house or external) for this type of inspection should be established in the absence of suitable national certification arrangements.

3.4 Surface Finish & Coatings

Ultrasonic testing relies on sound being transmitted from the probe into the component and back again. Anything that affects this transmission is likely to reduce the effectiveness of the inspection by reducing the signal received at the probe from any defect and also by increasing the background noise. Rough surfaces have these effects. Paint and coatings can reduce the transmitted signal both by attenuation and by interference from multiple reflections in the layer. If the layer is not bonded to the material to be tested then the transmitted signal is drastically reduced. Undulating surfaces affect the efficiency of the coupling of the probe as well as tilting the beam, which leads to the incorrect positioning of any defects, and sizing errors. All the above make the operator's job more difficult which in turn increases the chances of error.

Recommendations

- Ideally, paint and coatings should be removed prior to inspection unless they can be shown not to be detrimental to the inspection.
- If coating removal is not carried out, inspection procedures for coated or painted surfaces should include a check for bonding and attenuation.

- The operator should satisfy himself (or herself) that, as a minimum, the surface finish of the component meets the requirements of the appropriate inspection standard and is satisfactory for ultrasonic inspection.

3.5 Access

The ultrasonic operator performs a complex task: scanning the probe precisely over the surface of the component whilst monitoring the flaw detector screen for the appearance of defect responses amongst the other echoes generated by the probe and the component. An operator's qualifications are obtained by inspecting portable test pieces on a bench, which represents an ideal situation. Access problems on site can lead to difficulties in maintaining a desired scan pattern whilst monitoring the flaw detector screen. Unstable platforms will have a detrimental effect on the scan pattern. Poor access can cause discomfort to the operator, leading to lapses in concentration. Detection failures and errors in measurements are likely to increase.

<u>Recommendations</u>

- Operators should be provided with a stable platform from which to conduct the inspection with good access to the inspection surface.
- All impediments to access should be removed wherever practicable.
- Consideration should be given to the use of mechanical assistance and semi-automated inspection methods whenever access to the inspection surface is intrinsically difficult. These would involve the operator scanning by hand but encoders attached to the probe would measure its position and establish that full coverage had been obtained. Data recording would allow signals to be interpreted later in more amenable circumstances rather than at the time of scanning.
- Operators should report any factors which have prevented the inspection from being carried out as intended.

3.6 Operator Performance

Like any complex task, ultrasonic inspection is prone to human error. Trials have shown these errors to arise from: poor technique producing scanning errors and errors in interpretation of the echoes on the flaw detector; random measurement errors for example in the measurement of range and probe position; lapses in vigilance; isolated inexplicable errors or blunders. All these sources of error are affected by the motivation of the operator, the difficulty of the inspection and external factors such as time pressure or uncomfortable environments. In addition, the inspection may impose technical demands which are beyond those for which the operator has been trained or qualified.

<u>Recommendations</u>

- Operators should be given appropriate training and qualification.
- Operators should be given practice on realistic test pieces prior to the inspection.
- The need for job-specific qualifications additional to the ones available through central certification schemes should be considered by the inspection purchaser.
- Inspections should be subject to supervision and audit, particularly when they are carried out on a large scale.

- Independent repetition of the inspection should be considered.
- Good access conditions should be provided.
- The use of semi-automated inspections should be considered.
- A reasonable time should be allocated for the inspection and should include regular breaks for the operators.
- The environment in which the inspection is carried out should be as benign as possible with regard to ambient temperature, dust, shelter from the elements, requirements for restrictive protective clothing and so on.

3.7 Organisation and Procurement of NDT

It is crucial, if NDT is to be effective, that the requirements are defined as discussed in 3.1 above. The procedure must then be written taking these requirements into account along with the other geometry and material requirements discussed above. UT Level 3 inspectors have a potential role in ensuring that this activity is carried out correctly. It is important that the contractual arrangements define the relative responsibilities of purchaser and supplier.

It is also important that organisations contracted to undertake NDT exercise adequate control over how it is implemented. NDT companies should have a quality control system in place relating to the whole of their activities against which they have been audited. Accreditation schemes for NDT companies are currently being introduced and, as these become established, it will become appropriate for purchasers to consider requiring such accreditation of their suppliers.

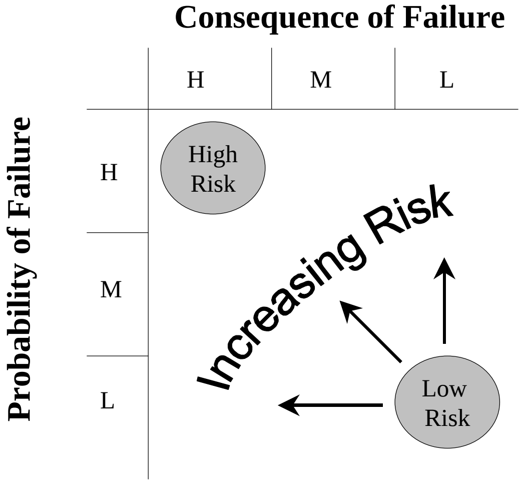
When a very high level of assurance is needed that the inspection is capable of meeting the defined objectives, qualification of the whole inspection as defined and described in Appendix 3 should be considered. Inspection qualification should also be considered whenever novel inspection methods which are not the subject of existing standards are used.

Recommendations

- The contractual responsibilities of purchaser and supplier should be made clear when inspection contracts are placed.
- NDT companies should have a quality system for controlling the implementation of the NDT or should be accredited against a suitable standard. It should be recognised that operators must work within the context of a company which can support their activities and not as individuals. Consequently when employed directly by the purchaser, operators should work within the purchaser’s quality system.
- Qualification of the entire inspection – procedure, equipment and operators should be considered when very high assurance is required that the inspection is matched to its objectives or when the inspection is a novel one. This process should be developed and overseen by NDT engineers with specific knowledge and experience.

4. INSPECTION IMPROVEMENTS AND COMPONENT RISK

The previous section describes the circumstances under which an approach to inspection based simply on the use of standards and national certification schemes may be inadequate. In each case, a list of possible remedial measures is also given. It is necessary for those who commission or purchase inspections to determine which of the measures is appropriate to their particular inspection and whether to adopt it. A major factor in determining which additional measures should be used is the role of the inspection and the effectiveness required of it in reducing the risk of component failure. The risk of component failure is determined by a combination of both the consequence and the probability of failure. The consequence relates to the safety or economic effects of the failure. If the consequence and probability parameters are denoted as high (H), medium (M) or low (L), their combined effects can be indicated on a 3x3 matrix as follows:



Inspection can only reduce risk by reducing the probability of failure, which , for example, could be related to the likelihood of defects being present in the component that could lead to failure.

Inspection effectiveness may be assigned a value of 1 (low), 2 (medium) or 3 (high) according to the reduction of probability of failure that it produces in a particular case. To reduce the probability of a component failure from high to low would require a high level of inspection effectiveness, whereas to reduce the probability from medium to low would require a medium level inspection effectiveness.

For example, for a component whose failure consequence is high, inspection should have the potential to reduce the probability of failure to a low level. Therefore, if the probability of failure is high, the inspection effectiveness must be high i.e. 3. However, in practice the precise contribution of NDT must be assessed prior to assigning the effectiveness level.

Conversely, for a component whose failure consequence is low and whose failure probability is medium or low, inspection has limited ability to reduce risk further and will generally be carried out as part of a routine in-service maintenance programme. In this case the requirements for measures additional to those normally involved in the approach (described in Section 2) will be small i.e. only a (1) low inspection effectiveness is required.

Using the above definitions of inspection effectiveness, Table 1 indicates which of the additional measures identified in Section 3 it is appropriate to consider. In each case it is assumed that there is technical merit in using the additional measure because it would be of benefit to the inspection. What is indicated in the table is whether the additional confidence that would result from adoption of the measure is justified by the effectiveness required of the inspection itself. Inspections where effectiveness 2 or 3 is required have been combined but it would be expected in general that more additional measures would be justified for level 3 than level 2.

Additional Measure	Reference in Text	Required Inspection Effectiveness 1	Required Inspection Effectiveness 2 and 3
Use of Defect Description	3.1	No	Yes
Specification of defect parameters to be measured	3.1	Yes	Yes
Geometry-specific Procedure	3.2	No	Yes
Geometry-specific Training	3.2, 3.6	No	Yes
Design of Inspection for Difficult Material	3.3	No	Yes
Material-specific Training and Qualification	3.3, 3.6	No	Yes
Coating Removal or Coating Bond Check	3.4	Yes	Yes
Surface Finish	3.4	Yes	Yes
Stable Inspection Platform	3.5	Yes	Yes
Removal of Access Impediments	3.5	Yes	Yes
Semi-Automated Inspection	3.5, 3.6	No	Yes
Oversight of Inspection	3.6	No	Yes
Independent Repetition	3.6	No	Yes
Use of Job-Specific Operator Qualification	3.6	No	Yes
Good Time Allowance	3.6	Yes	Yes
Good Environment	3.6	Yes	Yes
Inspection Qualification	3.7	No	Yes
Use of Quality System	3.7	Yes	Yes
Clear Contractual Responsibilities	3.7	Yes	Yes

Table 1 - Additional Measures to be Considered in Relation to Required Inspection Effectiveness

Note: Inspections where effectiveness 2 or 3 is required have been combined but it would be expected in general that more additional measures would be justified for level 3 than level 2.

REFERENCES

1. McGrath B.A., Programme for the Assessment of NDT in Industry, HSE Report on CD-ROM, Dec 1999.

2. BS EN 1714: 1998, 'Non-destructive examination of welded joints - Ultrasonic examination of welded joints.

3. BS EN 473 General principles for qualification and certification of NDT personnel

4. BS 96/707113 DC Non-destructive testing. Qualification and certification of personnel (ISO/CD 9712), Draft for public comment, Current May. 10, 1996

5. PCN/GEN/2000, General Requirements for Qualification and Certification of Personnel Engaged in Non-Destructive Testing, BINDT, Applicable 1.2.2001

APPENDIX 1 MEMBERS OF THE 'PANI' BEST PRACTICE DRAFTING COMMITTEE

Dr M J Whittle	Independent NDT Consultant (Chairman)
Mr H Bainbridge	Principal Specialist Inspector, HSE
Mr P Heyes	Head of Engineering Control, Health & Safety Laboratory
Mr R W Gregory	Engineering Associate, Esso Engineering (Europe)
Mr A Gorvett	Principal Consultant, BP Amoco Exploration
Mr R F Lyon	Corporate Engineer, Inspection management (NDT), National Power PLC (Innogy)
Dr L Morgan	Senior Principal Engineer, BG plc
Mr C Sinclair	Senior Engineer, Zurich Certification Limited, representing SAFeD (Safety Assessment Federation Ltd)
Mr S Hewerdine	NDT & Technical Welding Manager, OIS Ltd
Mr P Mudge	Operations Director, Plant Integrity Limited, TWI
Dr B Shepherd	Department Head - NDT Development & Services, Mitsui Babcock Ltd
Dr G Georgiou	Chairman of Technical Committee, British Institute of NDT
Dr B McGrath	Technical Consultant, Inspection Validation Centre, AEA Technology (Secretary)

APPENDIX 2 LEVELS OF PCN CERTIFICATION AVAILABLE

1. Level 1

Level 1 personnel are qualified to carry out NDT operations according to written instructions under the supervision of Level 2 or Level 3 personnel. PCN Level 1 certificated personnel have demonstrated the competence to:

- Set up equipment;
- Carry out the test;
- Record and classify the results in terms of written criteria;

- Report the results.

Level 1 personnel have not demonstrated competence in the choice of test method or technique to be used, nor for the assessment, characterisation or interpretation of test results.

2. Level 2

Level 2 personnel have demonstrated competence to perform and supervise non-destructive testing according to established or recognised procedures. Within the scope of the competence defined on the certificate, level 2 personnel may be authorised to:

- Select the NDT technique for the test method to be used;
- ISO 9712 does not include the above as a level 2 competence; the PCN Scheme therefore defaults to compliance with EN 473.
- Define the limitations of application of the testing method;
- Translate NDT standards and specifications into NDT instructions;
- Set up and verify equipment settings;
- Perform and supervise tests;
- Interpret and evaluate results according to applicable standards, codes or specifications;
- Prepare written NDT instructions;
- Carry out and to supervise all level 1 duties;
- Provide guidance for personnel at or below level 2, and
- Organise and report the results of non-destructive tests.

3. Level 3

3.1 Level 3 personnel are qualified to direct any NDT operation for which they are certificated and:

- Assume full responsibility for a test facility or examination centre and staff;
- Establish and validate NDT instructions and procedures;
- Interpret codes, standards, specifications and procedures;
- Designate the particular test methods, techniques and procedures to be used;
- Within the scope and limitations of any certification held, carry out all level 1 and level 2 duties, and
- Supervise trainees and level 1 and 2 personnel.

3.2 Level 3 personnel have demonstrated:

- A competence to interpret and evaluate test results in terms of existing codes, standards and specifications;
- Possession of the required level of knowledge in applicable materials, fabrication and product technology sufficient to enable the selection of NDT methods and techniques, and to assist in the establishment of test criteria where none are otherwise available;
- A general familiarity with other NDT methods;
- The ability to guide personnel below Level 3.

3.3 Level 3 certificated personnel may be authorised to carry out, manage and supervise PCN qualification examinations on behalf of the British Institute of NDT.

Where Level 3 duties regularly require the individual to apply routine NDT by a method or methods, the British Institute of NDT strongly recommends that this person should hold and maintain Level 2 certification in those methods.

APPENDIX 3 INSPECTION QUALIFICATION

A number of systems have been adopted for qualification of inspections but the one developed in Europe and most widely used in Europe is that produced by the European Network for Inspection Qualification (ENIQ). In addition, a draft European standard for qualification is currently being developed. This is based on the ENIQ Methodology (Reference A1) and so the latter is the most appropriate reference available at the time of writing.

Inspection qualification is defined by ENIQ as “The systematic assessment, by all those methods that are needed to provide reliable confirmation, of an NDT system to ensure it is capable of achieving the required performance under real inspection conditions”. An NDT system is the combination of inspection procedure, equipment and personnel.

Qualification involves a combination of:

- Practical trials of the inspection conducted on simplified or representative test pieces resembling the component to be inspected.
- Technical justification which involves assembling all the evidence available on the effectiveness of the inspection including previous experience of its application, laboratory studies, mathematical modelling, physical reasoning etc..

The relationship between the practical trials and the technical justification depends on the particular inspection. However, they are almost always complementary parts of the overall qualification process.

As can be judged from the above, qualification can be a complex and costly process, particularly when numbers of test pieces are needed. Its use, therefore, tends to be reserved for situations where high levels of inspection effectiveness must be demonstrated or where there is little previous experience of an inspection, e.g. when novel inspection methods are planned.

References

A1. “European Methodology for Qualification (Second Issue)”, ENIQ Report No 2, EUR 17299 EN, EC Luxembourg, 1997

This report contains notes on good practice which are not compulsory but which you may find helpful in considering what you need to do.