

Space product assurance

This document is distributed to the ECSS community for Public Review.

(Duration: 8 weeks).

Start Public Review: 16 January 2018

**End of Parallel Assessment: 16 March 2018**

**DISCLAIMER** (for drafts)

This document is an ECSS Draft Standard. It is subject to change without any notice and may not be referred to as an ECSS Standard until published as such.

**ECSS Secretariat**

**ESA-ESTEC**

**Requirements &and Standards Division**

**Noordwijk, The Netherlands**

Non-destructive inspection

**Foreword**

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-Q-ST-70-15C Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

**Disclaimer**

ECSS does not provide any warranty whatsoever, whether expressed, implied, or statutory, including, but not limited to, any warranty of merchantability or fitness for a particular purpose or any warranty that the contents of the item are error-free. In no respect shall ECSS incur any liability for any damages, including, but not limited to, direct, indirect, special, or consequential damages arising out of, resulting from, or in any way connected to the use of this Standard, whether or not based upon warranty, business agreement, tort, or otherwise; whether or not injury was sustained by persons or property or otherwise; and whether or not loss was sustained from, or arose out of, the results of, the item, or any services that may be provided by ECSS.

Published by: ESA Requirements and Standards Division

 ESTEC, P.O. Box 299,

 2200 AG Noordwijk

 The Netherlands

Copyright: 2018 © by the European Space Agency for the members of ECSS

Change log

|  |  |
| --- | --- |
| ECSS-Q-ST-70-15C \_WG modif\_13\_Dec'17 | Delivery of updated DFR from WG |
| ECSS-Q-ST-70-15C DIR14 January 2018 | Parallel Assessment13 December 2017 – 31 January 2018Approved by TAAR for Public Review 9 Jan 2018 |
| Current step |  |
| ECSS-Q-ST-70-15C DIR116 January 2018 | Public Review16 January – 16 March 2018 |
| Next Steps |  |
|  | DRR implementation |
|  | DRR Feedback |
|  | TA Vote for publication |

Table of contents

[Change log 3](#_Toc503863230)

[Introduction 10](#_Toc503863231)

[1 Scope 11](#_Toc503863232)

[2 Normative references 12](#_Toc503863233)

[3 Terms, definitions and abbreviated terms 16](#_Toc503863234)

[3.1 Terms from other standards 16](#_Toc503863235)

[3.2 Terms specific to the present standard 16](#_Toc503863236)

[3.3 Abbreviated terms and symbols 18](#_Toc503863237)

[3.4 Nomenclature 19](#_Toc503863238)

[3.4.1 Formal verbs 19](#_Toc503863239)

[3.4.2 Conventions 20](#_Toc503863240)

[4 Principles 21](#_Toc503863241)

[4.1 General 21](#_Toc503863242)

[5 Generic requirements 23](#_Toc503863243)

[5.1 General 23](#_Toc503863244)

[5.2 Discontinuities and cracks 24](#_Toc503863245)

[5.3 NDI drawing callouts 24](#_Toc503863246)

[5.4 NDI process and configuration control 24](#_Toc503863247)

[5.5 NDI procedure capability demonstration 25](#_Toc503863248)

[5.6 Organizational guidelines and documentation requirement 25](#_Toc503863249)

[5.7 NDI personnel qualification and certification 26](#_Toc503863250)

[6 NDI methods 27](#_Toc503863251)

[6.1 Visual inspection 27](#_Toc503863252)

[6.1.1 Overview 27](#_Toc503863253)

[6.1.1.1 General process for visual inspection 27](#_Toc503863254)

[6.1.1.2 Visual inspection process variations 27](#_Toc503863255)

[6.1.2 General visual inspection requirements 27](#_Toc503863256)

[6.1.3 Visual inspection equipment 28](#_Toc503863257)

[6.1.3.1 Overview 28](#_Toc503863258)

[6.1.3.2 Requirements for visual inspection equipment 28](#_Toc503863259)

[6.1.4 Visual inspection application 28](#_Toc503863260)

[6.1.5 Visual inspection documentation 29](#_Toc503863261)

[6.1.6 Visual inspection process control 29](#_Toc503863262)

[6.1.7 Visual inspection process limitations and peculiarities 29](#_Toc503863263)

[6.2 Leak testing 30](#_Toc503863264)

[6.2.1 Overview 30](#_Toc503863265)

[6.2.1.1 General process for leak testing 30](#_Toc503863266)

[6.2.1.2 Leak testing process variations 30](#_Toc503863267)

[6.2.2 General leak test requirements 31](#_Toc503863268)

[6.2.3 Process application 31](#_Toc503863269)

[6.2.3.1 Leak test procedure 31](#_Toc503863270)

[6.2.3.2 Leak test documentation 32](#_Toc503863271)

[6.3 Proof testing 32](#_Toc503863272)

[6.3.1 Overview 32](#_Toc503863273)

[6.3.2 Proof testing requirements 32](#_Toc503863274)

[6.4 Penetrant inspection 32](#_Toc503863275)

[6.4.1 Overview 32](#_Toc503863276)

[6.4.1.1 General process for penetrant inspection 32](#_Toc503863277)

[6.4.1.2 Penetrant inspection process variations 33](#_Toc503863278)

[6.4.2 General penetrant inspection requirements 33](#_Toc503863279)

[6.4.3 Penetrant inspection equipment 34](#_Toc503863280)

[6.4.3.1 Overview 34](#_Toc503863281)

[6.4.3.2 Requirements for penetrant inspection equipment 34](#_Toc503863282)

[6.4.4 Pentrant inspection process application 34](#_Toc503863283)

[6.4.5 Penetrant inspection documentation 36](#_Toc503863284)

[6.4.6 Penetrant inspection process control 36](#_Toc503863285)

[6.4.7 Penetrant inspection process limitations and peculiarities 36](#_Toc503863286)

[6.4.7.1 Overview 36](#_Toc503863287)

[6.4.7.2 Etching requirements 37](#_Toc503863288)

[6.4.8 Standard penetrant NDI 37](#_Toc503863289)

[6.4.8.1 Overview 37](#_Toc503863290)

[6.4.8.2 Standard NDI requirements 37](#_Toc503863291)

[6.5 Eddy-current inspection 38](#_Toc503863292)

[6.5.1 Overview 38](#_Toc503863293)

[6.5.1.1 General process for eddy-current inspection 38](#_Toc503863294)

[6.5.1.2 Eddy-current process limitations and peculiarities 39](#_Toc503863295)

[6.5.2 Eddy-current inspection general requirements 39](#_Toc503863296)

[6.5.3 Eddy current inspection process variations 39](#_Toc503863297)

[6.5.4 Eddy current equipment 40](#_Toc503863298)

[6.5.4.1 General 40](#_Toc503863299)

[6.5.4.2 Instruments for the eddy-current inspection 40](#_Toc503863300)

[6.5.4.3 Probes for the eddy-current inspection 40](#_Toc503863301)

[6.5.4.4 Test-setup for the eddy current inspection 40](#_Toc503863302)

[6.5.5 Eddy-current inspection process application 40](#_Toc503863303)

[6.5.6 Eddy current inspection documentation 41](#_Toc503863304)

[6.5.7 Eddy current inspection process control 41](#_Toc503863305)

[6.5.7.1 Overview 41](#_Toc503863306)

[6.5.7.2 Reference material blocks for the eddy-current inspection 41](#_Toc503863307)

[6.5.8 Standard eddy-current NDI 42](#_Toc503863308)

[6.5.8.1 Overview 42](#_Toc503863309)

[6.5.8.2 Standard eddy current inspection requirements 42](#_Toc503863310)

[6.6 Magnetic particle inspection 43](#_Toc503863311)

[6.6.1 Overview 43](#_Toc503863312)

[6.6.1.1 General magnetic particle inspection process 43](#_Toc503863313)

[6.6.1.2 Magnetic particle inspection process variations 43](#_Toc503863314)

[6.6.2 General magnetic particle inspection requirements 44](#_Toc503863315)

[6.6.3 Magnetic particle inspection equipment 44](#_Toc503863316)

[6.6.3.1 General 44](#_Toc503863317)

[6.6.3.2 Dry particles 44](#_Toc503863318)

[6.6.3.3 Wet particles 44](#_Toc503863319)

[6.6.3.4 Fluorescent particles 45](#_Toc503863320)

[6.6.4 Magnetic particle inspection process application 45](#_Toc503863321)

[6.6.5 MPI documentation 46](#_Toc503863322)

[6.6.6 MPI process control 46](#_Toc503863323)

[6.6.7 MPI process limitations and peculiarities 46](#_Toc503863324)

[6.6.8 Standard magnetic particle NDI 47](#_Toc503863325)

[6.6.8.1 Overview 47](#_Toc503863326)

[6.6.8.2 Standard magnetic particle NDI requirements 47](#_Toc503863327)

[6.7 X-ray radiographic inspection 47](#_Toc503863328)

[6.7.1 Overview 47](#_Toc503863329)

[6.7.1.1 General process 47](#_Toc503863330)

[6.7.1.2 X-ray radiographic inspection process variations 47](#_Toc503863331)

[6.7.2 General X-ray radiographic inspection requirements 48](#_Toc503863332)

[6.7.3 X-ray radiographic equipment 48](#_Toc503863333)

[6.7.4 X-ray radiographic inspection process application 48](#_Toc503863334)

[6.7.5 X-ray radiographic inspection documentation 49](#_Toc503863335)

[6.7.6 X-ray radiographic inspection process control 49](#_Toc503863336)

[6.7.7 Standard X-ray radiographic NDI 49](#_Toc503863337)

[6.7.7.1 Overview 49](#_Toc503863338)

[6.7.7.2 X-ray radiographic inspection requirements 50](#_Toc503863339)

[6.8 Ultrasonic inspection 50](#_Toc503863340)

[6.8.1 Overview 50](#_Toc503863341)

[6.8.1.1 General process for ultrasonic inspection 50](#_Toc503863342)

[6.8.1.2 Ultrasonic inspection process variations 50](#_Toc503863343)

[6.8.2 General 53](#_Toc503863344)

[6.8.3 Ultrasonic inspection equipment 53](#_Toc503863345)

[6.8.3.1 General requirements 53](#_Toc503863346)

[6.8.3.2 Couplants 53](#_Toc503863347)

[6.8.3.3 Search units 53](#_Toc503863348)

[6.8.4 Ultrasonic inspection process application 53](#_Toc503863349)

[6.8.4.1 General 53](#_Toc503863350)

[6.8.4.2 Scanning 54](#_Toc503863351)

[6.8.4.3 Scanning index 54](#_Toc503863352)

[6.8.4.4 Qualification 54](#_Toc503863353)

[6.8.4.5 Ultrasonic test documentation 55](#_Toc503863354)

[6.8.5 Ultrasonic inspection process control 55](#_Toc503863355)

[6.8.5.1 Ultrasonice inspection calibration sensitivity and limitations 55](#_Toc503863356)

[6.8.5.2 Ultrasonic inspection thickness gauge 55](#_Toc503863357)

[6.8.5.3 Digital thickness gauge 56](#_Toc503863358)

[6.8.5.4 Reference standard blocks 56](#_Toc503863359)

[6.8.6 Ultrasonice inspection process limitations and peculiarities 56](#_Toc503863360)

[6.8.6.1 Overview 56](#_Toc503863361)

[6.8.6.2 Requirements 57](#_Toc503863362)

[6.8.7 Standard ultrasonic NDI 57](#_Toc503863363)

[6.8.7.1 Overview 57](#_Toc503863364)

[6.8.7.2 Standard ultrasonic inspection requirements 57](#_Toc503863365)

[7 Welds inspection 58](#_Toc503863366)

[8 Inspection of products 59](#_Toc503863367)

[8.1 Overview 59](#_Toc503863368)

[8.2 General 59](#_Toc503863369)

[8.3 Wrought products 60](#_Toc503863370)

[8.3.1 Overview 60](#_Toc503863371)

[8.3.2 Raw material inspection 60](#_Toc503863372)

[8.3.3 Common wrought defects 61](#_Toc503863373)

[8.4 Forgings 61](#_Toc503863374)

[8.4.1 Overview 61](#_Toc503863375)

[8.4.2 Raw material inspection 61](#_Toc503863376)

[8.4.3 Common forging defects 62](#_Toc503863377)

[8.5 Castings 62](#_Toc503863378)

[8.5.1 Overview 62](#_Toc503863379)

[8.5.2 Raw material inspection 62](#_Toc503863380)

[8.5.2.1 General 62](#_Toc503863381)

[8.5.2.2 Penetrant testing of castings 62](#_Toc503863382)

[8.5.3 Ultrasonic inspection of castings 63](#_Toc503863383)

[8.5.3.1 General 63](#_Toc503863384)

[8.5.3.2 X-ray radiographic inspection of castings 63](#_Toc503863385)

[8.5.3.3 X-Ray computed tomographic (CT) of castings 63](#_Toc503863386)

[8.5.3.4 Common casting defects 63](#_Toc503863387)

[9 Inspection of PFCI 65](#_Toc503863388)

[9.1 General 65](#_Toc503863389)

[9.1.1 Overview 65](#_Toc503863390)

[9.1.2 General requirements 66](#_Toc503863391)

[9.1.3 Capability demonstration 67](#_Toc503863392)

[9.1.4 Inspection of raw material 67](#_Toc503863393)

[9.1.5 Inspection of safe life finished items 68](#_Toc503863394)

[9.2 Non-destructive inspection of metallic materials 68](#_Toc503863395)

[9.2.1 General requirements 68](#_Toc503863396)

[9.2.2 NDI categories versus initial crack size 69](#_Toc503863397)

[9.2.2.1 Standard NDI 69](#_Toc503863398)

[9.2.2.2 Special NDI 74](#_Toc503863399)

[9.2.2.3 Crack screening proof test 76](#_Toc503863400)

[9.2.3 Inspection procedure requirements for Standard NDI 76](#_Toc503863401)

[9.2.3.1 Overview 76](#_Toc503863402)

[9.2.3.2 Requirements 76](#_Toc503863403)

[9.3 NDI for composites, bonded and sandwich parts 76](#_Toc503863404)

[9.3.1 Overview 76](#_Toc503863405)

[9.3.2 Inspection requirements 77](#_Toc503863406)

[9.3.2.1 General requirements 77](#_Toc503863407)

[Annex A (normative) NDI plan - DRD 78](#_Toc503863408)

[A.1 DRD identification 78](#_Toc503863409)

[A.2 Expected response 78](#_Toc503863410)

[Annex B (normative) NDI report - DRD 80](#_Toc503863411)

[B.1 DRD identification 80](#_Toc503863412)

[B.2 Expected response 80](#_Toc503863413)

[Annex C (normative) NDI procedure - DRD 84](#_Toc503863414)

[C.1 DRD identification 84](#_Toc503863415)

[C.2 Expected response 84](#_Toc503863416)

[Annex D (informative) Catalogue of potential defects 85](#_Toc503863417)

[Annex E (informative) POD evaluation example, software and documentation 87](#_Toc503863418)

[E.1 Theory 87](#_Toc503863419)

[E.2 POD demonstration 88](#_Toc503863420)

[Annex F (informative) Complementary material information 91](#_Toc503863421)

[F.1 Overview 91](#_Toc503863422)

[F.2 Forgings and rolled products 91](#_Toc503863423)

[F.3 Castings 93](#_Toc503863424)

[F.4 Composite products 93](#_Toc503863425)

[F.5 Ceramics 95](#_Toc503863426)

[Bibliography 96](#_Toc503863427)

**Figures**

[Figure 4‑1: Flow chart showing steps to be taken for a part and choice of NDI method and technique. 22](#_Toc503863428)

[Figure 6‑1: A-Scan, typical displays of ultrasonic signals 51](#_Toc503863429)

[Figure 6‑2:B-Scan, typical displays of ultrasonic signals 51](#_Toc503863430)

[Figure 6‑3:C-Scan, typical displays of ultrasonic signals 52](#_Toc503863431)

[Figure 6‑4: S-Scan, typical displays of ultrasonic signals 52](#_Toc503863432)

[Figure 9‑1: Initial crack geometries for parts without holes 72](#_Toc503863433)

[Figure 9‑2: Initial crack geometries for parts with holes 73](#_Toc503863434)

[Figure 9‑3: Initial crack geometries for cylindrical parts 73](#_Toc503863435)

**Tables**

[Table 6‑1: Examples of acceptance limits leak test rates 31](#_Toc503863436)

[Table 8‑1: Thickness differences between sheet and plate 60](#_Toc503863437)

[Table 9‑1: Initial crack size summary, Standard NDI 70](#_Toc503863438)

Introduction

Non-destructive Inspection (NDI) covers a wide range of processes used in quality control. The generic term NDI covers several sub processes such as Dye Penetrant Inspection, Radiography, Ultrasonic and Eddy Current. The processes are applied at the discretion of the design authority depending on the criticality of the part or component and inherent risk of the manufacturing process to create detrimental flaws. It is expected that every component used in spaceflight is subjected to some level of NDI in accordance with the present standard, which complements the ECSS-Q-ST-70-39C “Welding of metallic materials for flight hardware”.

The lack of NDI control throughout the supply chain has been evident in all space projects across the Europe. As no standard was in place at that time this has resulted in inconsistency in the rationale and application for NDI selection. NDI is generally applied for quality control to ensure that components are free of defects and discontinuities. For some components the NDI methods used form the basis of the fracture and fatigue verification and thus the assurance of design margins. The level of NDI is expected to be decided based on the manufacturing processes applied and the criticality of the part or component and the impact if that part fails in service.

# Scope

This standard specifies NDI requirements for flight parts, components and structures used for space missions. It covers the NDI methods and stipulates the certification levels for personnel. The qualification of such processes are also specified for non-standard NDI techniques or where complex components are concerned. This standard also identifies the best practice across the large range of international and national standards.

Visual inspection included in this standard is not intended to include incoming inspection of, for example, raw materials, damage during transport, storage and handling and parts procurement verification.

The minimum requirements for NDI documentation are specified in the DRDs of the Annexes.

This standard does not cover the acceptance criteria of components, structures and parts submitted to this examination; it is expected that these criteria are identified on specific program application documentation.

This Standard does not apply to EEE components.

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

# Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

|  |  |
| --- | --- |
| ECSS-S-ST-00-01 | ECSS system – Glossary of terms |
| ECSS-M-ST-40 | Space management - Configuration and information management |
| ECSS-Q-ST-10 | Space product assurance - Product assurance management |
| ECSS-Q-ST-10-09 | Space product assurance – Nonconformance control system |
| ECSS-Q-ST-20 | Space product assurance – Quality assurance |
| ECSS-Q-ST-70-39 | Space product assurance -Welding of metallic materials for flight hardware |
| ECSS-E-ST-32 | Space engineering – Structural general requirements |
| ECSS-E-ST-32-01 | Space engineering – Fracture control |
| EN 4179:2017 | Aerospace series – Qualification and approval of personnel for non-destructive testing |
| EN 12668-1:2010 | Non-destructive testing. Characterization and verification of ultrasonic examination equipment. Instruments |
| EN 13068-3:2001 | Non-destructive testing - Radioscopic testing - Part 3: general principles or radioscopic testing of metallic materials by x- and gamma rays |
| EN 1779:1999 | Non-destructive testing - Leak testing - Criteria for method and technique selection |
| EN ISO 3452-1:2013 | Non-destructive testing — Penetrant testing — Part 1: General principles |
| EN ISO 3452-2:2013 | Non-destructive testing -- Penetrant testing -- Part 2: Testing of penetrant materials |
| EN ISO 3452-3:2013 | Non-destructive testing — Penetrant testing — Part 3: Reference test blocks |
| EN ISO 5579:2013 | Non-destructive testing -- Radiographic testing of metallic materials using film and X- or gamma rays -- Basic rules |
| EN ISO 9712:2012 | Non-destructive testing -- Qualification and certification of NDT personnel |
| EN ISO 9934-1:2016 | Non-destructive testing -- Magnetic particle testing -- Part 1: General principles |
| EN ISO 9934-2:2015 | Non-destructive testing -- Magnetic particle testing -- Part 2: Detection media |
| EN ISO 9934-3:2014 | Non-destructive testing -- Magnetic particle testing -- Part 3: Equipment |
| EN ISO 15548-1:2013 | Non-destructive testing — Equipment for eddy current examination — Part 1: Instrument characteristics and verification |
| EN ISO 15548-2:2013 | Non-destructive testing — Equipment for eddy current examination — Part 2: Probe characteristics and verification |
| EN ISO 15548-3:2008 | Non-destructive testing — Equipment for eddy current examination — Part 3: System characteristics and verification |
| EN ISO 15549:2008 | Non-destructive testing — Eddy current testing — General principles |
| EN ISO 15708-2:2017 | Non-destructive testing – Radiation methods for computed tomography-Part2: Principles, equipment and samples |
| EN ISO 16810:2012 | Non-destructive testing — Ultrasonic testing — General principles |
| EN ISO 17635:2016 | Non-destructive testing of welds — General rules for metallic materials |
| EN ISO 17636-1:2013 | Non-destructive testing of welds — Radiographic testing — Part 1: X- and gamma-ray techniques with film |
| EN ISO 17636-2:2013 | Non-destructive testing of welds — Radiographic testing — Part 2: X- and gamma-ray techniques with digital detectors |
| EN ISO 17640:2017 | Non-destructive testing of welds – Ultrasonic testing – Techniques, testing levels and assessment |
| EN 13018:2016 | Non-destructive testing - Visual testing - General principles |
| AMS-STD-2154:2005 | Process for Ultrasonic Inspection of Wrought Metals |
| ASTM E 127:2015 | Standard Practice for Fabrication and Control of Aluminium Alloy Ultrasonic Standard Reference Blocks |
| ASTM E 137:2016 | Standard practice for evaluation of mass spectrometers for quantitative analysis from a batch inlet |
| ASTM E 164:2013 | Standard Practice for Contact Ultrasonic Testing of Weldments |
| ASTM E 426:2016 | Standard Practice for Electromagnetic (Eddy Current) Examination of Seamless and Welded Tubular Products, Titanium, Austenitic Stainless Steel and Similar Alloys |
| ASTM E 428-08(2013) | Standard Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing |
| ASTM B 594:2013 | Standard Practice for Ultrasonic Inspection of Aluminium-Alloy Wrought Products  |
| ASTM E 1254:2008 | Standard guide for storage of radiographs and unexposed industrial radiographic films |
| ASTM E 1417/1417M-11:2016 | Standard Practice for Liquid Penetrant Testing |
| ASTM E 1441:2011 | Standard Guide for Computed Tomography (CT) Imaging |
| ASTM E 1444/E1444M-:2011 | Standard Practice for Magnetic Particle Testing |
| ASTM E 1734:2016 | Standard Practice for Radioscopic Examination of Castings |
| ASTM E1742/E1742M:2012- | Standard Practice for Radiographic Examination |
| ASTM E1814 - :2014 | Standard Practice for Computed Tomographic (CT) Examination of Castings |
| ASTM E 2375:2013  | Standard Practice for Ultrasonic Testing of Wrought Products |
| ASTM E 2445:2014 | Standard Practice for Performance Evaluation and Long-Term Stability of Computed Radiography Systems |
| ASTM E 2698:2010 | Standard Practice for Radiological Examination Using Digital Detector Arrays |
| IR99: 1999 | Ionizing Radiation Regulations 1999  |
| NAS 410:2014 | NAS Certification and Qualification of Non Destructive Test Personnel |
| SAE-ARP-4402:2013 | Eddy Current Inspection of Open Fastener Holes in Aluminium Aircraft Structure |
| SAE-AS-4787:2013 | Eddy Current Inspection of Circular Holes in Nonferrous Metallic Aircraft Engine Hardware |
| SAE-AMS-2154C:2017 | Inspection, ultrasonic, wrought metals, process for |
| SAE-AMS-2644:2006 | Inspection material penetrant |
| QPL-AMS-2644:2016 | Inspection material, penetrant |

# Terms, definitions and abbreviated terms

## Terms from other standards

1. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.
2. For the purposed of this Standards, the term and definition from ECSS-E-ST-32-01 apply:
	1. safe life potential fracture critical item
3. This definition is equivalent to the definition of "damage tolerant fracture critical items" in NASA standards like NASA-STD-5019.

## Terms specific to the present standard

1. black light (UVA light)

near ultraviolet radiation used for exciting fluorescence

1. NDI method

discipline that applying a physical principle in non-destructive testing and non-destructive inspection

[EN 4179:2017]

1. NDI instruction

written description of the precise steps to be followed in testing to an established standard, code, specification or NDI procedure.

[EN 4179:2017]

1. This standard specifies in all cases an NDI procedure.
2. NDI technique

specific way of utilizing an NDI method

1. For example, ultrasonic immersion technique.

[EN 4179:2017]

1. NDI procedure

written description of all essential parameters and precautions to be applied when non-destructively testing products in accordance with standard(s), code(s) or specification(s)

1. An NDI procedure can involve the application of more than one NDI method or technique.

[EN 4179:2017]

1. responsible Level III

person Level III designated by the employer with the responsibility and authority and act on behalf of the employer for qualification and certification of NDI personnel

[adapted from EN 4179:2011-02]

1. special fracture control NDI

NDI methods applied in the context of fracture control implementation on safe life items that are capable of detecting cracks or crack‐like flaws smaller than those assumed detectable by standard fracture control NDI or do not conform to the requirements for standard fracture control NDI.

[adapted from “Special NDI” definition of ECSS-E-ST-32-01]

1. Special NDI methods are not limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle.
2. standard fracture control NDI

NDI methods of metallic materials for which the required statistically based flaw detection capability has been established.

[adapted from “Special NDI” definition of ECSS-E-ST-32-01]

1. Standard NDI methods addressed by this document are limited to fluorescent penetrant, radiography, ultrasonic, eddy current, and magnetic particle.
2. personnel qualification

skills, training, knowledge, examinations, experience and visual capability required for personnel to properly perform to a particular level

[EN 4179:2009]

1. personnel certification

written statement by an employer that an individual has met the applicable requirements

[EN 4179:2009]

1. In some standards employer is called certifying agency or body.
2. product family

combination of the following penetrant testing materials: penetrant, excess penetrant remover and developer.

[adapted from EN ISO 3452 Part 2:2013]

* 1. 1 Excess penetrant remover does not include method A from EN ISO 3452 Part 2:2013.
	2. 2 During testing in compliance with EN ISO 3452 Part 2:2013 penetrant and excess remover are from the same manufacturer.
1. procedure verification

process of certifying the efficacy of an inspection process through a demonstration, on a representative structure, in a representative environment, and by representative inspection personnel.

[adapted from MIL-HDBK-6870B]

* 1. 1 Equipment, reference standards and written procedures are examples of inspection process include
	2. 2 The term "qualification" from the ECSS-Q-ST-70-15 is synonymous with the term "verification" used in ECSS documentation.

## Abbreviated terms and symbols

For the purpose of this Standard, the abbreviated terms and symbols from ECSS-S-ST-00-01 and the following apply:

|  |  |
| --- | --- |
| Abbreviation | Meaning |
| AMS | Aerospace Material Specification |
| ASTM | American Society for Testing and Materials |
| CR | computed radiography |
| CT | computed tomography |
| DDA | digital detector array |
| DRD | document requirements definition |
| DR | digital radiography |
| ET | eddy current testing |
| EEE | electrical, electronic and electromechanical  |
| EN | European Norm |
| FMECA | failure modes, effects and criticality analysis |
| FSW | friction stir welding |
| MMC | metal matrix composites |
| MPI | magnetic particle inspection |
| MPCB | materials and processes control board  |
| MT | magnetic particle testing |
| NASNCR | National Aerospace Specificationnonconformance report |
| NDI | non-destructive inspection |
| NDT | non-destructive testing |
| NRB | nonconformance review board |
| PFCI | potential fracture control critical |
| POD | probability of detection |
| PSM  | penetrant system monitoring |
| PT | dye penetrant testing |
| RFD | request for deviation |
| RT | radiography testing |
| QQI | quantitative quality indicator |
| QMS | quality management system |
| TIG | tungsten inert gas welding |
| TWI | The Welding Institute |
| UT | ultrasonic inspection testing |
| UTG | ultrasonic thickness gauge |
| UV | ultraviolet |
| VDT | visual damage threshold |

## Nomenclature

### Formal verbs

The following nomenclature applies throughout this document:

1. The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.
2. The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.
3. It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.
4. The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.
5. The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.
6. In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.
7. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

### Conventions

The term "qualification" from the ECSS-Q-ST-70-15 is synonymous with the term "verification" used in ECSS documentation. This is not applicable to the qualification of personnel.

# Principles

## General

The NDI of materials is carried out in such a way that product integrity and surface texture remain unchanged. The NDI inspection of parts is particularly important for products or components where failure or malfunction can have serious implications.

These include loss of mission hardware and for flight hardware.

This standard specifies the necessary requirements to perform NDI for materials for space applications.

This is presented in the following Figure 4‑1 which shows the steps taken and the choice of NDI method and technique.

1. Additional complementary material information can be found in Annex F.



Figure 4‑1: Flow chart showing steps to be taken for a part and choice of NDI method and technique.

Examples for potential defects are presented in Annex D.

ECSS-E-ST-32-01 requires many parts subjected to fracture control are subjected to NDI and proof testing to screen for internal and external cracks. This is addressed further in clause 9.

# Generic requirements

## General

The supplier shall establish and maintain documented NDI procedures for each part to be inspected.

The supplier shall submit NDI procedure for customer approval.

The design definition authority shall specify NDI acceptance criteria.

1. It is assumed that accept and reject criteria reflect the possible need to ensure that cracks smaller than the targeted crack size are reported as “detected cracks” in line with ECSS-E-ST-32-01 clause 10.7 (for example > 50 % of the targeted crack size).

NDI procedure shall include NDI plan in conformance with DRD from Annex A for the chosen NDI method, report and number of samples tested.

All NDI procedures shall be verified to assure repeatable defect sensitivity needed for classification of the part.

The NDI plan shall be prepared prior to carrying out any NDI.

The NDI plan shall be prepared by Level II and approved by Level III who is certified in the corresponding method in compliance with requirements from clause 5.7.

The identified part areas shall be inspected.

NDI shall be performed by certified NDI inspectors in accordance with requirements from clause 5.7 and requirements from clause 5.1.2 of ECSS-Q-ST-20.

All written instructions shall be prepared by NDI Level II inspector as a minimum and approved by Level III responsible.

The instructions specified in requirement 5.1j shall be uniquely identified.

Application of new versions or issues of the instruction specified in the requirement 5.1j shall be submitted for customer approval.

All parts subject to an NDI examination shall be recorded in the logbook.

All NDI plans shall be subject to agreement between customer and supplier during MPCB in consultation with Level III responsible.

Supplier shall raise NCRs about any flaws detected during NDI inspection not meeting the customer specifications.

For any deviations from the customer requirements an RFD shall be raised in conformance with ECSS-M-ST-40.

## Discontinuities and cracks

Any unknown or critical discontinuities shall be recorded.

For the discontinuities specified in the requirement 5.2a the Level III responsible for the specific method shall assess the need to raise an NCR in conformance with the DRD in Annex A from ECSS-Q-ST-10-09.

The processing of the NCR shall be in compliance with requirements from ECSS-Q-ST-10-09.

1. This can lead to new inspection or to re-inspection of parts after identification of discontinuities to be performed by using the same NDI plan and procedure, and to the need of customer agreement.

All detected cracks or crack-like flaws, regardless of size, shall be cause for rejection, unless approved by NRB and customer.

## NDI drawing callouts

NDI inspection specifications for all parts to be inspected shall be identified or referred to in all drawings.

The drawings shall identify or refer to each inspection requirement by zone when different zones require different NDI inspection requirements and acceptance criteria.

The drawings shall be updated when NDI inspection requirements are updated.

## NDI process and configuration control

A written NDI procedure, in conformance with DRD from Annex C, shall be developed for each part to be inspected, and approved by the responsible Level III of the appropriate NDI method.

Configuration control shall be performed in compliance with ECSS-M-ST-40 for the following:

Personnel qualification and certification

NDI specification

NDI standards

NDI part-specific procedures

1. It is important that the meaning of NDI procedure, instruction, and specification is clarified between customer and supplier.

All certification records, NDI reports, and associated paperwork shall be in accordance with requirements from ECSS-M-ST-40 clause 5.3.7 and ECSS-Q-ST-10 clause 5.2.6.

## NDI procedure capability demonstration

Supplier shall demonstrate NDI capability in accordance with clause 9.1.3.

Capability demonstration test specimens not covered by clause 9.1.3 shall be agreed between customer and supplier.

The test specimens shall be representative of the material, defect types and part geometry to be inspected.

* 1. 1 NDI procedures can be verified on parts or on test pieces simulating the actual part and which provide the essential features of the part with regard to the important application variables which can affect defect sensitivity and confidence level. These aspects can differ significantly between different NDI methods.
	2. 2 Examples are similarity based on wetting behaviour for penetrant inspection and microstructure features for eddy current and ultrasonic inspection.

POD demonstration by “hit and miss” method needs not be performed for:

Guided manual inspection

Local manual inspection of small area or volume with reference to the applied procedure and equipment, if coverage of the complete area or volume can be guaranteed.

For detected defects the accuracy of the sizing method shall be demonstrated.

1. The concept of POD does not apply to already detected defects.

## Organizational guidelines and documentation requirement

The NDI organization shall be specified in the suppliers QMS.

1. Examples for the definition of this organization are provided in EN 4179:2017 and NAS 410:2014. Further guidelines are presented in NASA-STD-5009:2008 Appendix A.

## NDI personnel qualification and certification

For penetrant, magnetic, eddy current, ultrasonic, radiographic, thermographic and shearographic testing, personnel for non-destructive inspections, shall be certified, in accordance with EN 4179:2017 or NAS 410:2014.

For NDI methods not explicitly covered by EN 4179:2017 or NAS 410:2014, personnel certification shall be specified and recorded in the written practice and referenced in NDI plan, in accordance with requirements of clause 6.4 of EN 4179:2017 or NAS 410:2014.

1. Clause 6.4 of EN 4179:2017 is called “Emerging NDI methods”.

Other standards may be accepted on a case by case basis, if agreed between the customer and supplier.

1. Examples of commonly applied standards are: EN ISO 9712:2012 that covers leak testing and visual inspection not covered by EN 4179:2017 and NAS 410:2014.

# NDI methods

## Visual inspection

### Overview

#### General process for visual inspection

Visual inspection contains the detection and appraisal of surface attributes by use of the human eye. In difference to any other NDI method that provide indications to be interpreted visual inspection provides quality indications like material flaws, dimensional deviations and surface quality levels that can be inspected directly.

To judge about the level of quality deviation it is necessary to use auxiliary equipment like magnifiers, microscopes, mirrors, endoscopes or borescopes.

The registration threshold is specified by the individual inspection procedure and depends from kind of test object, application and criticality rating.

#### Visual inspection process variations

The visual inspection can be performed as direct or indirect inspection:

1. All methods that do not interrupt the glance of the human eye to the inspection surface are direct visual inspection methods. For example: visual inspection by use of a magnifier or a microscope.
2. All methods that interrupt the glance of the human eye to the inspection surface are indirect visual inspection methods. For example: visual inspection by use of a camera endoscope.

### General visual inspection requirements

Visual inspection shall be performed in accordance with EN 13018:2016 and EN ISO 17637:2016.

Additional viewing conditions shall be agreed with the customer, with the exception of welds.

Visual inspection of welds shall be performed in accordance with EN ISO 17637:2016.

The inspection object shall be accessible in that way, that the surface can be inspected within a distance of 600 mm and with a viewing angle > 30°.

Inspection personal shall be qualified in accordance with the company written practice or EN ISO 9712:2012.

A written instruction shall be prepared and approved by the responsible Level III.

1. During visual inspection special attention is given to optimization of colour, temperature of illumination source, strength against the capability of surface reflection of the test object.

### Visual inspection equipment

#### Overview

Typical pieces of equipment in use for the visual inspection are:

* Magnifiers
* Microscopes
* Endoscopes
* Lenses
* Mirrors
* Vernier callipers
* Scales
* Gauges
* Photometer
* Illuminations sources
* Comparison catalogues.

#### Requirements for visual inspection equipment

Electrical equipment shall be serviced and calibrated at least once a year.

All electrical and mechanical measurement instruments shall be calibrated at least once a year.

All devices shall be listed and controlled in the user's measurement instruments calibration list.

### Visual inspection application

Visual inspection sequence as a minimum shall include the following:

An overview of the part to be inspected:

Check that the available documentation includes inspection specification, drawings.

Check of the test designation

Check of inspection conditions,

Check of inspection sensitivity,

Check of surface indications against specification,

Appraisal of found indications against the acceptance criteria,

Classification of indications.

The acceptance criteria of visual inspection shall be agreed between customer and supplier.

### Visual inspection documentation

The visual inspection documentation shall be in compliance with NDI report from the DRD from Annex B.

### Visual inspection process control

The visual inspection methods shall be subjected to a trial inspection by use of test body.

The test body of requirement 6.1.6a shall be representative of the inspection object with respect to reflection behaviour, surface texture, accessibility and contrast conditions.

The test body may be replaced by an original test object or an approved reference system.

1. Special test cards are in use to demonstrate the performance of endoscopes and borescopes.

### Visual inspection process limitations and peculiarities

In the case of critical applications the visual inspection should be combined with additional NDI processes to verify inspections results.

* 1. 1 Misinterpretation can result from peculiarities as, for example, grain boundaries at the surface which can be misinterpreted as cracks.
	2. 2 Examples of additional NDI process are dye penetrant, eddy current or magnetic particle testing.

The magnification of the visual inspection should be chosen based on the size and characteristic of the object.

For small and smooth welds a magnification larger than five times shall be used.

## Leak testing

### Overview

#### General process for leak testing

Leak testing applies mainly to pressurized structures to justify that pressure loss over time does not lead to a critical hazard especially for components containing hazardous fluids or gases.

Furthermore leak testing can be used to localize a leak or measuring the leak rate or both.

Typical leak tested components are:

1. Pressure vessels and tanks including:
	1. Sealing
	2. Welds
2. Valves and regulators
3. Tubing
4. Diaphragms

The major characteristics of leak testing are:

1. Tracer gas and concentration
2. Differential pressure
3. Temperature
4. Leak rate

#### Leak testing process variations

Leak testing can be performed globally (integral) or locally.

The most efficient method of leak testing is global testing performed in a vacuum chamber. This however applies only to parts with limited size.

Welds of large propellant tanks are mainly leak tested locally with a sniffer. Usually, gaseous helium is mixed to nitrogen or air during proof testing and leak testing is then performed under reduced inner pressure.

Global leak rate then applies to the complete component, whereas local leak rates apply to the location under inspection.

Examples of acceptance limits leak test rates are provided in Table 6‑1.

Table 6‑1: Examples of acceptance limits leak test rates

|  |  |  |
| --- | --- | --- |
| Component | Leak test | GHe leak rate acceptance limit |
| Composite overwrapped pressure vessel (COPV) | Vacuum chamber (global) | 1 × 10-6 scc/s |
| Propellant tank | Vacuum chamber (global) | 1 × 10-6 scc/s |
| Large aluminium propellant tank welds (20 % GHe) | Sniffer (local) | 1 × 10-3 to 1 × 10-5 scc/s |
| Gas control panels | Vacuum jacket (global)  | 1 × 10-7 scc/s |
| 1 scc/s ≙ 1,013 mbar × l/s ≙ 0,1 Pa × m³/s |

### General leak test requirements

Leak test shall be performed according to EN 1779:1999.

A written instruction for the leak test shall be prepared and approved by the responsible Level III.

Inspection personal shall be qualified in accordance with the company written practice or EN ISO 9712:2012.

### Process application

#### Leak test procedure

A leak test procedure shall be established and include:

Description of components to be tested

Description and reference of all customer requirements

General references

Internal instructions

Type of leak rate testing

Required leak rates

Applicable and justified tools and devices

Definition of test parameters

Calibration and check procedures,

Measurement of ambient gas concentration

Test procedure

Documentation

Control of inspection, measuring and test equipment

1. The acceptance leak rate is specified for each component taking into consideration functional and safety aspects, which can differ significantly from one part to the other. This is part of the failure mode effects and criticality analysis (FMECA).

#### Leak test documentation

The leak test documentation shall be in compliance with NDI report from the DRD from Annex B.

## Proof testing

### Overview

Proof testing is in most cases applied as workmanship verification test without a clear and reliable relationship with defects and flaws to be detected. In some cases proof tests are designed to screen for flaws of certain types and exceeding a specified sizes. There can be significant risk of causing damage during proof testing that can degrade the residual strength after proof testing below what is acceptable, without causing failure during proof testing. It can require significant effort to ensure that no such unacceptable damage occurs.

### Proof testing requirements

Application of proof testing for flaw screening shall be only performed with approval of the customer.

Proof testing for flaw screening shall be in accordance with clauses 8.7 or 10.4.2.3 from ECSS-E-ST-32-01.

1. NASA/CR-1999-209427 and NASA/CR-1999-209426 give guidelines for Proof Test Analysis.

## Penetrant inspection

### Overview

#### General process for penetrant inspection

Penetrant inspection is also known as liquid penetrant inspection method to locate surface breaking defects in non-porous materials, ferrous and non-ferrous metals including non-magnetic stainless steels and ceramics by covering the part with a penetrant liquid which is drawn into the discontinuity by capillary action.

Penetrant techniques can be used on materials independent of their physical properties provided the surface is normally non-absorbent and compatible with the penetrant process.

The efficiency of the process depends upon the ability to carry out each separate operation correctly. The inability to accomplish any single operation correctly can affect the validity of the inspection. The effectiveness of the penetrant inspection strongly depends on the technical competence of the personnel.

#### Penetrant inspection process variations

There are several process variations defined in the applicable specifications. The product family used for penetrant testing is given a designation comprising the type, the method, the form and the sensitivity level.

The combination of the different variations depends on the type of application and the specific requirements.

1. Type: Fluorescent or non- fluorescent (colour contrast) penetrant.
2. Method: Different excess penetrant removers; water washable, lipophilic, solvent removable, hydrophilic, water and solvent removable.
3. Form: Different developers: dry powder, water-soluble, water suspendable, solvent based for type I, solvent based for types II and III and special application
4. Sensitivity level: Different sensitivity levels: 0.5, 1, 2, 3, 4
5. Type of application of penetrant: spraying, brushing, flooding, dipping or immersion
6. Type of application of developer (dry powder): dust storm, electrostatic, spraying, flock gun, fluidized bed or storm cabinet.
7. Type of application of developer (water-suspendable and water - soluble); immersion, spraying
8. Type of application of developer (solvent- based); spraying

### General penetrant inspection requirements

Products of a qualified product family shall not be mixed with products of another product family.

1. As specified in EN ISO 3452 Part 2:2013 only approved product families are used.

Penetrant inspection shall be performed in accordance with EN ISO 3452 Part 1:2013, Part 2:2013, Part 3:2013 or ASTM E 1417:2016.

Specific differences between EN ISO 3452 Part 1:2013, Part 2:2013, Part 3:2013 and ASTM E 1417:2016 shall be discussed and agreed case by case

For penetrant inspection, materials listed and qualified in QPL-AMS-2644:2016 shall be used.

Inspection personnel shall be qualified in accordance with the company written practice and EN 4179:2017.

A written instruction shall be prepared and approved by the responsible Level III.

For parts that are shot peened, dry vapour blasted, machine polished or burnished in the inspection area the qualification programme shall demonstrate that defects are not closed by the surface processes.

### Penetrant inspection equipment

#### Overview

In general there are two types of equipment for penetrant testing:

1. Equipment suitable for carrying out in situ penetrant testing techniques:
	1. Portable spray equipment
	2. Cloth
	3. Brushes
	4. Personnel protective equipment
	5. White light source
	6. UVA source (different UV source technologies can be used to achieve sufficient luminance for penetrant inspection)
	7. Reference test block
2. Equipment for fixed installations (in addition to the above mentioned equipment):
	1. Tanks
	2. Pipework
	3. Ducting
	4. Ventilation
	5. Equipment for drying
	6. Cabinets.

#### Requirements for penetrant inspection equipment

Electrical equipment shall be serviced and calibrated at least once a year.

All electrical and mechanical measurement instruments shall be calibrated at least once a year.

All devices shall be listed and controlled in the user's measurement instruments calibration list.

### Penetrant inspection process application

Penetrant inspection sequence shall include the following:

An overview of the part to be inspected:

Check the availability of required documentation

Check the test designation

Check the inspection conditions,

Check the product family behaviour by use of reference block.

Preparation and pre-cleaning of inspection object:

Prior to penetrant testing clean the test surface to remove any dirt, paint, oil, grease or any loose scales which can lead to false or irrelevant indications.

Apply cleaning methods, including solvents, vapour degreasing or alkaline cleaning steps.

Etch machined or mechanically disturbed metallic surfaces prior to standard penetrant inspection to remove smeared or masking material on safe life PFCI parts.

Application of penetrant:

Ensure that the surface is wetted by penetrant during the penetration time.

Apply the penetrant between 5 min and a time to be agreed.

Excess penetrant removal:

Ensure that the inspection surface is not over washed.

For use of fluorescent penetrant check the inspection surface for penetrant residues under a UVA source.

For use of fluorescent penetrant check that the minimum UVA radiation is less than 1 W/m² and the visible light not more than 100 lx.

For use of non- fluorescent penetrant check the inspection surface for penetrant residues under a white light illuminance of not less than 350 lx.

Ensure that the drying after excess penetrant removal do not heat up the inspection surface above 50 °C.

Application of developer

Apply the developer in that way, that a thin uniform layer is placed on the inspection surface and that the surface shines through the developer layer.

Inspection of surface:

Carry out the examination of the parts immediately after the application of the developer.

Carry out the final inspection when the development time has elapsed.

Use equipment for visual examination

Compliance with acceptance criteria:

While performing penetrant inspection, check the compliance of found indications with acceptance criteria agreed between customer and supplier.

Post cleaning:

After final inspection of the parts, clean all parts to eliminate remnant of penetrant which can affect the service specification of the actual part.

* 1. 1 For requirement 6.4.4a.3 check of availability of required documentation include inspection specification, drawings
	2. 2 For requirement 6.4.4a.4(c) for further details see 6.4.7.2
	3. 3 For requirement 6.4.4a.5(b) the penetration time depends on the inspected material and penetrant system. The maximum time is typically 60 mins.
	4. 4 For requirement 6.4.4a.8(c) equipment for visual examination can include: magnification instruments and contrast spectacles.

### Penetrant inspection documentation

The penetrant inspection documentation shall be in compliance with NDI report from the DRD from Annex B.

### Penetrant inspection process control

To maintain the integrity of the penetrant inspection process, the penetrant system shall be controlled according to the standards specified in the requirement 6.4.2a.

1. The system performance of the product family used for penetrant inspection is checked by use of a reference block (control panel 2 or PSM-5).

A record of the process and control test result for each penetrant method shall be stored.

Deviations from the process control shall be noted and reported to the responsible NDI/PT Level III responsible and quality manager.

### Penetrant inspection process limitations and peculiarities

#### Overview

Although the process distinguishes between non-linear and linear indications, it is not possible to make a conclusion about the real flaw type. Therefore it is recommended to combine the penetrant inspection with a visual inspection.

#### Etching requirements

Etching process shall be applied to remove smeared or masking material prior to standard penetrant inspection on safe life PFCI parts with machined or mechanically disturbed metallic surfaces

Minimum metal thickness removal shall be demonstrated.

The etching process shall be developed and controlled to prevent damage to the parts undergoing test.

1. Excessive etching can seriously increase the risk of pitting, intergranular attack, surface roughness, cladding removal and dimensional degradation

Etching shall not be applied on close tolerance holes, close tolerances and faying surfaces where the functionality of the part or assembly degrade.

1. Etching is not always needed for intermediate examination when the surface is not retained in final configuration of the part, depending on the purpose of the intermediate inspection

Etching may be omitted depending on the material and process if it is demonstrated that defects are not smeared over.

### Standard penetrant NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

#### Standard NDI requirements

Penetrant NDI standard flaw sizes shall be applied to fluorescent dye penetrants of minimum Level III sensitivity as specified in ASTM E 1417:2016, SAE-AMS-2644:2006, SAE-AMS-2647:2009, EN ISO 3452-2:2013 or customer approved supplier internal specifications.

For metals other than titanium, inspected with fluorescent penetrant to Level II sensitivity as specified in requirement 6.4.8.2a, the standard crack sizes of Table 9‑1, specified for titanium alloys shall be applied.

All machined, or mechanically disturbed surfaces, to be penetrant inspected, shall be etched to ensure removal of masking material prior to penetrant application for all processes and materials, where masking can appear.

1. The final penetrant inspection can be performed prior to metal finishing operations such as buffing or sanding that do not by themselves produce flaws.

An etching procedure shall be developed by the supplier.

The etching procedure shall specify the minimum amount of material to be removed to ensure that smeared metal does not mask cracks.

The etching process shall not affect engineering drawing tolerances for part dimensions and finishes.

1. When very close tolerances are required, critical surfaces can be machined near final dimensions, etched and inspected, and finish machined.

For welds, the standard crack sizes of Table 9‑1, specified for titanium alloys, shall be used in all cases, unless the weld surface is smoothened after welding to a level agreed with the customer.

1. Limited verification of the crack detection capability of the actual weld inspection can be appropriate. Etching can be necessary after weld surface treatment.

Interface surface finish shall be Ra=3,2 μm or lower.

## Eddy-current inspection

### Overview

#### General process for eddy-current inspection

The eddy-current method is based on the principle of electromagnetic induction. An alternating current, typically with a frequency in the range of 1 kHz – 6MHz, is passed through an excitation coil generating an external primary magnetic field. This changing magnetic field in close proximity of a conductive part induce in this last electrical currents (eddy current). The induced electrical currents flow in a circular path inducing a secondary field in opposition to the primary field. The reaction can be measured as a change of the impedance of the coil that is shown, in its simplest form, by the needle deflection of a meter.

The alternating current frequency, supplied to the coil, is modified for detecting surface and sub-surface discontinuities. High frequency concentres the eddy current below the surface by detecting surface discontinuities, while reducing the frequency it can be possible to detect sub-surface discontinuities. Most eddy current equipment have an impedance plane display on which the variations of the probe impedance are shown by the movement of a dot; the analysis, in terms of phase and amplitude, of the dot movement is used for defect characterization.

The method is very good at detecting fine surface cracks and defects like cracks, coatings, for example, paint need not be removed provided they are reasonably uniform in thickness and are taken into account during calibration. Testing ferromagnetic materials is not always reliable due to the ferrous effects within the material and changes in surface coatings such as cadmium can give spurious indications. Eddy current inspection can only be applied to conductive metals.

The inspection of magnetic or ferromagnetic materials can use specific eddy current techniques.

#### Eddy-current process limitations and peculiarities

Reported limitations of the eddy-current method are:

1. Only conductive materials can be inspected
2. The penetration depth of the eddy current is limited

The peculiarities of the eddy current method are:

1. Detection of surface and sub-surface defects;
2. Physical contact with the part inspected is not required
3. Automatization and high throughput speeds are applicable
4. Additional measures can be carried out simultaneously (conductivity, heat treatment, thickness of coating).

### Eddy-current inspection general requirements

Except the cases specified in the requirements 6.5.2b and 6.5.2c, eddy current inspections shall be performed in accordance with EN ISO 15549:2008 or a standard approved by the customer.

Fastener holes shall be inspected in accordance with SAE-ARP-4402:2013 or SAE-AS-4787:2013.

Tubular products shall be inspected in accordance with ASTM E 426:2016.

1. Standardised terminology for eddy current testing is given in EN ISO 12718:2012.

For automated inspection or inspection with signal recording and analysis a reduction of this ratio, as approved by the customer, may be applied.

The interface surface finish shall be Ra = 3,2 μm (125 μin) or lower.

1. Eddy current test does not require a coupling medium.

### Eddy current inspection process variations

Array probe may be used to perform the eddy-current inspection for large surfaces.

1. Examples of large surface are flat surface, weld surface and product with specific shape

### Eddy current equipment

#### General

Eddy-current equipment, instrument, probe and test set-up shall be verified in accordance with the EN ISO 15548-1:2013, EN ISO 15548-2:2013 and EN ISO 15548-3:2008.

#### Instruments for the eddy-current inspection

The instrument for the eddy-current inspection shall be equipped with complex plane and time-synchronous display.

The instrument for the eddy-current inspection shall be able to operate at least in the range between 100 kHz and 4 MHz.

Instrument for the eddy-current inspection shall be equipped with an audio and visual alarm system.

The selection of the eddy current instruments and their set-up for a particular inspection shall be under responsibility of the Level III method responsible as a minimum.

#### Probes for the eddy-current inspection

The probes for the eddy current inspection shall be marked with their operating frequency or frequency range.

1. The probes can have an absolute or differential coil arrangement and can be shielded or unshielded

The scan direction shall be indicated on the differential probes

#### Test-setup for the eddy current inspection

The eddy current techniques implemented shall be specified.

1. The test set-up is designed to examine a defined product or perform a defined measurement
	* + 1. A reference test set-up comprises
		+ Instrument
		+ Interconnecting elements
		+ Probe arrangement
		+ Mechanical arrangement
		+ Accessories
		+ Reference block

### Eddy-current inspection process application

A written instruction on how to perform the eddy-current inspection shall be prepared and include the following information:

Reason for examination

Part number and description of part to be examined;

Application documents;

Area to be examined;

Details of qualification and certification of personnel;

Equipment required;

Preparation of component;

Calibration procedure;

Examination procedure: sketches or photographs where appropriate to show the area of examination and scanning details;

Acceptance procedure;

Acceptance criteria;

Recording of results;

Reporting procedure;

The instruction .

### Eddy current inspection documentation

The Eddy current inspection documentation shall be in compliance with NDI report from the DRD from Annex B.

### Eddy current inspection process control

#### Overview

Utilization of reference material blocks, in accordance with EN ISO 15549:2008, is used to perform a correct eddy current inspection, calibration and set of the equipment. It is important to use and realize the reference material blocks in correct way as they can be used as acceptance standard.

#### Reference material blocks for the eddy-current inspection

The non-ferrous reference material blocks used to standardize the eddy current equipment for detection of surface and subsurface discontinuities shall be of an alloy having the same major base metal and the electrical conductivity, surface texture, configuration and discontinuity location of the part to be inspected.

Ferrous reference material blocks shall be of the same alloy and heat treatment or temper condition and surface texture, configuration and discontinuity location like the part to be inspected.

1. Discontinuities utilised in the reference material blocks can be either natural or artificial.

Artificial discontinuities shall be cut in the reference material blocks with suitable equipment that does not increase the surface roughness of the reference material blocks.

* 1. 1 Artificial cracks can be produced by electric discharge machining.
	2. 2 Reference material blocks can be fabricated from actual parts or from test blocks.

The reference material blocks shall be reheat treated if machining or drilling changes the conductivity and affects coil response.

The equipment setting and item inspection shall be performed with the same probe.

The reference material blocks shall be identified with the following information:

Drawing or specification number

Serial number

Alloy and heat treatment

Type and dimension of each defect

Applicable program

Applicability for eddy current equipment calibration.

The reference material blocks shall be certified and approved by the Company ET/Level II as the minimum.

### Standard eddy-current NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

Eddy current inspection can only be applied to non-magnetic, non-ferromagnetic, and conductive metals .

#### Standard eddy current inspection requirements

Eddy current inspections shall be in accordance with ASTM E 426:2016, SAE-ARP-4402:2013, SAE-AS-4787:2013, or customer approved internal supplier specifications.

The influence of coatings and lift-off variations on the reliability of an eddy-current Standard NDI process shall be evaluated and included in the procedure.

1. Lift-off variations can be experienced as well with thickness variations when inspecting through the thickness.

A minimum signal-to-noise ratio of 3:1 shall be achieved for the standard eddy-current NDI.

1. Considering credible worst case conditions (of lift-off, flaw opening)

For automated eddy-current inspection or inspection with signal recording and analysis a reduction of this ratio, as approved by the customer, may be applied.

For performing the standard eddy-current NDI, the interface surface finish shall be Ra = 3,2 μm or lower

## Magnetic particle inspection

### Overview

#### General magnetic particle inspection process

Magnetic particle inspection (MPI) is applied to detect surface and subsurface defects in ferromagnetic materials such as Stainless Steels S143, S144, S145, S80, Iron, Nickel alloys, Cobalt alloys. The process of MT is a magnetic field is put into the part. The part can be magnetized either by direct or indirect magnetization.

The process can be used on raw materials and at any stage during component manufacture. The final magnetic flaw detection of any part is applied after final heat treatment, plating and de-embrittlement stages but before painting stages unless stated otherwise on the job card or drawing.

#### Magnetic particle inspection process variations

The magnetic particle inspection can be selected within the following main options:

1. Instrumentation
	1. Direct current
	2. Half-wave rectified
	3. Pulsating DC
	4. Alternating current
2. Application of particles
	1. Dry
	2. Wet
	3. Fluorescent
	4. Non fluorescent
3. Method of magnetization
	1. Yoke
	2. Prod
	3. Wrapped coil
	4. Stationary coil
	5. Contact plates

### General magnetic particle inspection requirements

MPI shall be performed in accordance with ASTM E 1444:2011 or EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015.

On phosphated parts MPI shall be applied after final heat treatment, but before phosphating, de-embrittlement and painting stages.

### Magnetic particle inspection equipment

#### General

Equipment used for the MPI shall be in accordance with EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015.

The magnetic particles shall be fluorescent or non-fluorescent.

The detection media shall be traceable and in compliance with EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015 and ASTM E 1444/E 1444M:2016.

1. The detection media can be either in dry powder or liquid form.

#### Dry particles

The colour of the dry particles shall provide contrast with the surface of the part being examined.

1. Dry particles can be of either fluorescent or non-fluorescent type.

When dry particles are used, ensure the surface temperature of the part shall be in accordance with EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015 .

#### Wet particles

The colour of the wet particles shall have contrast with the surface being examined.

* 1. 1 Wet particles can be both in fluorescent and non-fluorescent concentrates.
	2. 2 The particles are suspended in a suitable liquid medium such as water or petroleum distillates.

Limitations of wet particle systems shall be applied in compliance with requirements from EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015.

The checking of wet particles concentration shall be performed in accordance with requirements from EN ISO 9934 Part 1:2016, Part 2:2015, Part 3:2015 .

#### Fluorescent particles

The testing of parts with use of fluorescent particle shall be performed in a dedicated darkroom.

1. This is performed under an ultraviolet light which is called “Black Light”.

### Magnetic particle inspection process application

The following steps for the magnetic particle preparation and inspection shall be performed:

Demagnetize the part prior to testing.

Ensure that the surface condition and finish is smooth, clean, dry, free of oil, scale, machining marks and any other contaminants which can cause interference with the efficiency of the magnetic field.

Apply masking and plugging of the parts as specified in the engineering drawing.

Ensure where electrical contact is made, the parts are cleaned to prevent electrical arcing.

For magnetization current application use:

Full wave, rectified current (1 or 3 phase),

Half wave direct current and AC- alternating current.

Ensure that yokes and permanent magnets are dead weight checked at 6 month intervals as specified in Table 1 of ASTM E 1444:2016.

Magnetize each part in a minimum of two directions at a right angles to each other, to ensure the detection of a discontinuity in any orientation.

Limit the electrical current to prevent overheating in any area of the part.

1. 1 For requirement 6.6.4a.5(a) full wave, rectified current has the deepest penetration
2. 2 For requirement 6.6.4a.6 full wave rectified current is used for sub-surface flaw detection only when using wet MPI of sub-surface discontinuities.
	1. 3 For requirement 6.6.4a.6 half wave direct current is also used for inspecting sub-surface discontinuities and it is due to the pulsating nature of the waveform.
	2. 4 For requirement 6.6.4a.6 AC-alternating current is only used for the detection of discontinuities near to the surface.
	3. 5 For requirement 6.6.4a.7 magnetic field direction- discontinuities are difficult to detect by MPI at angle of <45° to the direction of magnetization. Detection of a discontinuity in any orientation is also dependant on the geometry of the part. For further reference, refer to ASTM E 1444:2016.
	4. 5 For requirement 6.6.4a.8 direct Magnetization is applied by passing a current directly through the part to be inspected. Electrical contact is made by using head and tail stock, prods, clamps, magnetic leeches.

Unless agreed between customer and supplier prods shall not be used to examine aerospace parts, flight hardware and on finished surfaces.

### MPI documentation

The MPI documentation shall be in compliance with NDI report from the DRD from Annex B.

### MPI process control

The MPI process control shall include:

Measurement of magnetization

Function control with standardized reference samples according to MPI standards specified in the requirement 6.6.2a including characterization of appearance conditions

Special NDI qualification by the hit and miss method

### MPI process limitations and peculiarities

The magnetic particle inspection shall be applied only to ferromagnetic materials and open or closed surface or near surface defects.

1. Magnetization and carrier fluid can change material characteristics.

### Standard magnetic particle NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

#### Standard magnetic particle NDI requirements

Magnetic particle inspections shall be in accordance with ASTM-E-1444:2016, or customer-approved supplier internal specifications.

The magnetic particle inspection shall be the wet, fluorescent, continuous, or multimag method.

The interface surface finish shall be Ra = 3,2 μm or lower

A QQI shall be used to validate the local field intensities.

Hall probes may be applied provided that they are verified with a QQI.

Pie gages shall not be used for measuring field intensities.

## X-ray radiographic inspection

### Overview

#### General process

This clause establishes the quality specifications for X-ray radiographic examination on parts, components, structures, metallic or non-metallic, in order to detect internal discontinuity.

The process is based on an electromagnetic waves beam generation passing into the entire thickness of the examined item: the radiation residual, more or less reduced respect to the transmitted one, is used to show the internal structure or its internal discontinuities.

X-ray radiographic inspection is mainly intended to detect voids, cavities, pores and inclusions.

#### X-ray radiographic inspection process variations

The following additional RT techniques are available:

1. The standard film technique
2. Digital RT technique (DR). This is an advanced method of inspection, which is depended on digital detection systems. The image is displayed on the computer screen. The X-Ray radiation is converted into an electrical charge and then to a digital image through the detector sensor. The flat panel detector (DDA) produces high quality digital images when it is compared with other imaging devices. Flat panel detection uses:
	1. Indirect conversion utilizes a photographic diode matrix of amorphous silicon;
	2. Direct conversion uses a photographic conductor such as amorphous selenium or Cadmium telluride, giving sharpness and better resolution.
3. Computed Radiography (CR). This technique by application of photo stimulated luminescence (PSL) foil, is a DR technique utilizing storage phosphor foils as an intermediate storage media prior to the final digital image
4. Computed tomography (CT) is able to produce a complete 3-D volume model of the test object.

### General X-ray radiographic inspection requirements

X-ray radiographic inspections shall be in accordance with the following standards or customer-approved, supplier internal specifications.

For film techniques ASTM E 1742/E 1742M:2012, EN ISO 17636 Part 1:2013 or EN ISO 5579:2013.

For digital RT techniques EN ISO 17636 Part 2:2013 or ASTM E 2698:2010.

For computed Radiography EN ISO 17636 Part 2:2013 or ASTM E 2445:2014.

Computer tomography EN 13068-Part 3:2001

### X-ray radiographic equipment

Use of radioactive substances and electrical equipment emitting ionization radiation shall be in compliance with requirements from IR99:1999.

### X-ray radiographic inspection process application

Accessible surfaces of welds, under X-ray radiographic inspection, shall not contain irregularities which can cause interference with the interpretation of X-ray images.

The valleys between beads weld ripples or other surface irregularities shall be blended to a degree such that the resulting X-ray contrast due to surface condition cannot mask or confused with any other defect.

Each radiograph shall be traceable on the area being inspected and examined.

Each radiograph shall include the following identification:

Identification of the part;

Viewing number;

Number of times that repairs were carried out;

Date of examination;

NDI facility inspecting the part.

Each part that passed X-ray radiographic examination shall be labelled with a stamp.

1. Stamp can be in a form of laser marking, vibro- engraving, etching or ink stamping.

Radiographs and unexposed film shall be stored in conditions in compliance with requirements from ASTM E 1254:2008 and ensuring that the film is used within the expiry date.

### X-ray radiographic inspection documentation

The X-ray radiographic inspection documentation shall be in compliance with the NDI report from the DRD Annex B.

### X-ray radiographic inspection process control

Image quality indicators shall be used to evaluate quality of X-ray images in the X-ray control, consisting of a series of wires or a series of plate-containing holes having different diameters.

1. For the image quality indicators the diameter of the visible hole or the diameter of the visible wire gives a numeric value of the X-ray image quality and sensitivity.

The application of RT flaw detection shall be qualified in agreement with the customer as follows:

On pre-cracked specimens X-ray tests are performed in order to verify the sensitivity of the inspection with respect to a flaw located in specific parts;

Specimen definition and selection is agreed with the customer.

### Standard X-ray radiographic NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

#### X-ray radiographic inspection requirements

X-ray radiographic inspections shall be in accordance with ASTM E 1742:2012, or customer-approved supplier internal specifications.

Film density shall be 2,5 to 4,0.

The X-ray radiographic quality level shall be equal or better than 2-1T in conformance with clause 6.9 of ASTM E 1742:2012.

The radiation of the beam shall be within ±5° of the orientation of the plane of the crack to be detected.

1. X-ray exposures at different orientations can be needed to ensure that the complete volume of an item is sufficiently inspected for potentially critical cracks that can be in a wide range of orientations. When agreed with the customer, the orientation of the crack plane can be assumed along and perpendicular to the fusion plane or planes.

## Ultrasonic inspection

### Overview

#### General process for ultrasonic inspection

Ultrasonic inspection is applicable to a wide range of materials covering metallic, non-metallic and composite structures.

The inspection typically requires a coupling medium between the probe and the test object. A common practice is local coupling with water or non-water coupling media. Another practice is to inspect the parts in a water bath where the size, function and material of the inspected part allow complete immersion with water.

The most common ultrasonic inspection technique is the impulse-echo technique. The principle is to generate and introduce an ultrasonic impulse (mechanical waves) into a test object and evaluate the receiving signals, which are reflected at interfaces between different media. With knowledge of the specific velocity of sound the position of the reflector can be determined. The characteristic of the received signal is compared to a reference reflector and delivers information about a comparable shape and size of the reflector. The equipment primarily consists of a UT device, a transducer, couplant and reference or calibration blocks.

#### Ultrasonic inspection process variations

Main types of ultrasonic inspection are:

1. Straight beam
2. Angle beam
3. Phased array
4. Phased array with some modifications (for example, sampling phased array)

The ultrasonic testing inspection can be performed manual, semi-automated or automated mostly in immersion, squirter (through-transmission technique) or contact technique.

The straight beam ultrasonic inspection (same method used for wall-thickness measurement) is applied perpendicular to the inspection surface and is very effective in finding embedded (laminar) defects in various materials (for example, metals, composites).

Angle beam (refracted waves in the test object of typically 45°, 60° and 70°) is mainly used for weld inspection and is effective in finding defects not parallel to the inspection surface.

Phased Array is a state of the art technique which combines multiple single elements (“transducers”) in one probe. These elements can be pulsed separately and so form a sector scan (sweep through a range of refracted angles, for example 35° to 70°), linear scan (several “straight beam transducers” in line) or focus the mechanical wave front in depth.

|  |
| --- |
| A-Scan: |
| Used in manual single transducer angle/ straight beam and phased array. |
|  | The echoes are shown in amplitude (reflected signal strength) over time (sound path or depth) |

Figure 6‑1: A-Scan, typical displays of ultrasonic signals

|  |
| --- |
| B-Scan: |
| Used in automated single transducer angle/ straight beam and phased array. |
|  | The echoes are shown in depth over linear position. Cross sectional view and amplitude (colour chart) |

Figure 6‑2:B-Scan, typical displays of ultrasonic signals

|  |
| --- |
| C-Scan: |
| Used in automated single transducer angle/ straight beam and phased array. |
|  | 2D. Similar to a X-ray image. Top view. The echoes are shown in their x-y position and amplitude (colour chart). |

Figure 6‑3:C-Scan, typical displays of ultrasonic signals

|  |
| --- |
| S-Scan: |
| Used in phased array. |
|  | Sector Scan. The echoes are shown in depth over linear position. Cross sectional view and amplitude (colour chart) |

Figure 6‑4: S-Scan, typical displays of ultrasonic signals

Range of detectable defects (the ability to detect the listed defects is limited by their size):

1. Volumetric defects
2. Voids, cavities, pores
3. Inclusions (with Young’s modulus different to the surrounding material)
4. Cracks, delamination or any further material separation vertical to the ultrasonic beam

The major characteristics of the inspection probe (transducer) are:

1. Frequency
2. Active element diameter
3. Sound beam characteristic

The result of a conventional ultrasonic inspection (straight- or angle beam) shows reflected signals which are compared to artificial defects of reference blocks. These artificial defects are flat bottom holes (FBH), side drilled holes (SDH) or notches of calibration. It is important that this evaluation allows only a rough estimation of defect size and shape by comparison of the signal to the artificial defects for calibration.

More details of defect size and geometry (shape) can be evaluated by the use of adopted inspection technique regarding to the defect position for example phased array technique or a combination of standard inspection and local scanner techniques. In this case the inspection is applied pixel by pixel on a predefined surface grid, which allows the determination of the defect geometry over the pixel grid. This is called defect edge scanning comparable to -6dB method used in manual ultrasonic inspection.

Surface crack inspection of defects with orientation nearly perpendicular to the surface requires angle beam inspection, phased array or sampling phased array technique.

### General

The ultrasonic inspection shall be performed in compliance with requirements from AMS-STD-2154:2004, ASTM E 2375:2013 or EN ISO 17640:2017.

1. These documents cover raw material inspection.

### Ultrasonic inspection equipment

#### General requirements

The ultrasonic electronic test equipment shall produce test frequencies and energy levels to perform examination and readout of the result.

The test equipment shall be calibrated in accordance with ASTM E 137:2016 or EN 12668 Part 1:2010.

#### Couplants

Couplants shall not degrade or cause an adverse effect on the part being tested.

In case that water based couplants are used, it shall be ensured that couplants are free of rust inhibiting compounds.

#### Search units

Transducers for pulse echo and immersion testing techniques shall transmit and receive ultrasound on the part being tested.

For near surface defects a delay line probe shall be used.

Shape adapters which provides aid to the surface in contact of the part being inspected may be used.

1. Example of shape adapters are shoes.

### Ultrasonic inspection process application

#### General

The surface finish of the part to be UT inspected shall be free from scale, dirt, swarf, debris and corrosion.

The surface finish of a part shall be smooth and clean.

Ultrasonic inspection for weld materials thicker than 8 mm shall be performed in accordance with requirement 9.1.5a of the ECSS-Q-ST-70-39.

Ultrasonic inspection for weld materials thinner than 8 mm shall be performed in accordance with requirement 9.1.5b of the ECSS-Q-ST-70-39.

In the case the presence of randomly distributed defect orientations, automated complex phased array or sampling phased array shall be applied.

#### Scanning

All accessible surfaces of the part shall be UT inspected.

In case scanning is restricted to one side then scanning shall be performed by using a twin crystal probe for the near surface scans and a single probe for the remaining and the scanning speed not exceed 100mm/s.

1. That allows the detection of all discontinuities in the reference standard blocks used to set up the equipment.

For automated inspections the scan speed shall be stated in the inspection instruction and test report.

#### Scanning index

The scanning index shall be applied in accordance with NDI procedure specified in DRD in Annex C.

For large area of a part being inspected, a plastic straight edge shall be used in order to aid the scan map.

1. The scanning can be carried out as a continuous or spot to spot scan which is depended on the geometry of the part being inspected.

#### Qualification

The qualification of both Standard and Special NDI shall be performed as follows:

The 90 % probability and 95 % confidence level of an automated ultrasonic inspection is demonstrated by a signal to noise ratio of 3:1, 12dB or better.

In the case of a plane, two dimensional manual ultrasonic inspection, the required POD level are demonstrated by the hit and miss method.

1. POD (90 % probability and 95 % confidence level) evaluation example is given in the Annex E.

#### Ultrasonic test documentation

The ultrasonic test documentation shall be in compliance with NDI report from the DRD from Annex B.

### Ultrasonic inspection process control

#### Ultrasonice inspection calibration sensitivity and limitations

Straight beam examination shall be calibrated on flat bottom holes according to AMS-STD-2154:2005 or ASTM E 2375:2013.

In the case of surface or embedded crack like defects the NDI sensitivity shall be demonstrated and calibrated on suitable reference defects.

* 1. 1 Standard practice is to introduce spark eroded defects (notches).
	2. 2 Ultrasonic inspection is not using fatigue cracks for demonstration. Size of representative notches is agreed between customer and supplier. Material separation used for detection by ultrasonic inspection but flaw opening is negligible.

If flaw faces are closed by compression with contact between the faces ultrasonic inspection shall not be applied directly.

1. For example as “kissing bond” defect in friction stir welds.

#### Ultrasonic inspection thickness gauge

The velocity reference block used for the calibration of the instrument to perform the ultrasonic inspection should:

Be of from the same material of the test piece.

Be flat and smooth and as thick as the maximum thickness of the test piece.

1. The principle of operation of an ultrasonic thickness gauge is that the instrument measures the time of flight of an ultrasonic pulse through the test piece and multiplies this time by the velocity of sound in the material. Thickness measuring error is minimized by ensuring that the sound velocity to which the instrument is calibrated is the sound velocity of the material being tested. Actual sound velocities in materials often vary significantly from the values found in published tables.

#### Digital thickness gauge

The digital thickness gauge instrument shall be calibrated on a velocity reference block made from the same material as the test piece.

* 1. 1 Operators need to be aware that the sound velocity cannot be constant in the material being tested; heat treating, for example, can cause significant changes in sound velocity. This is important to consider when evaluating the accuracy of the thickness provided by this instrument.
	2. 2 In contrast to analogous UT thickness measurement, the application of digital instruments does not need Special NDI skills or knowledge.

#### Reference standard blocks

For metals the reference standard blocks shall be flat bottom type or contain side drilled holes and notches as specified in ASTM E 127:2015 or ASTM E 428-08:2013.

The reference standard blocks shall be representative in the terms of material specification and surface finish of the part being inspected.

The reference standard blocks shall be recorded and be permanently marked for identification.

When inspecting composite materials, the reference standard blocks shall be constructed from the same materials and lay up with artificial faults built-in, to stimulate a response equivalent to the fault under inspection.

If there is an acoustic difference between the reference standard blocks and the part being inspected, an attenuation correction shall be made to compensate the difference.

1. Attenuation correction is achieved by noting the difference between the signals received by using the same reference reflector, i.e. back wall reflection in the reference standard and the part. Back wall reflection is corrected by adding or removing attenuation.

When measuring diameter curvatures smaller than 25 mm, reference standard blocks shall be used with similar geometry to ensure UTG accuracy.

### Ultrasonice inspection process limitations and peculiarities

#### Overview

It is important to consider the following limitations of the ultrasonic inspection:

1. Compliance of required sensitivity in near surface region (dead zone)
2. Signal to noise ratio
3. Penetration depth (sound attenuation)

#### Requirements

The reference blocks with defects for demonstration and calibration shall be manufactured representative for the conditions of the inspection part including the specific influence factors of the ultrasonic inspection as follows:

Material

Microstructure

Surface conditions: roughness

Geometry

Wall thickness

Shape

1. Examples of shape include grooves, edges, borders, holes.

### Standard ultrasonic NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

#### Standard ultrasonic inspection requirements

Ultrasonic inspection shall be in conformance with SAE-AMS-STD-2154C:2017 Class A.

Ultrasonic inspections for wrought products shall be in accordance with ASTM E 2375:2013 Class A, SAE-AMS-STD-2154C:2017 Class A, or customer-approved supplier internal specifications.

Linear discontinuities of any length shall not be accepted.

Ultrasonic inspection shall be performed using longitudinal or shear waves, applied via unobstructed bare flat surfaces, at right-angles to all possible orientations of the cracks to be detected.

Interface surface finish shall be Ra=3,2 μm or lower.

Ultrasonic inspection for surface or embedded flaws in welds or in parent material surrounding the welds shall be in conformance with ASTM E 164:2013.

# Welds inspection

Inspection of welds shall be performed in compliance with requirements from clause 9 of ECSS-Q-ST-70-39.

The minimum amount of NDI to be performed for weld inspection shall be in accordance with Table 12-2 of ECSS-Q-ST-70-39.

# Inspection of products

## Overview

This clause covers differences, limitations and peculiarities appearing during inspection of:

* Raw material
* Final processing

The different kinds of materials and processing can have different influences on different inspection methods mentioned in clauses 6. and therefore are mentioned in this clause individually.

This clause contains requirements and recommendations only for performance of raw material inspection at the material supplier.

1. The final condition of a new product can vary significantly between different materials and geometries such that specially adopted and very different inspection methods is applied individually. This is specified and qualified individually and cannot be specified generally.

## General

For the examination of wrought metals, forged and rolled, parts, the customer shall specify in consultation with Level III:

Who is certified to inspect wrought products

The NDI method to be used

The class and acceptance criteria

The aerospace quality standards to be applied, and their applicability

The added and modified requirements to these standards.

* 1. The customer normally specifies in the purchase order or other contractual document, based on final piece part usage.

## Wrought products

### Overview

A wrought product is defined as a product that was subjected to mechanical working that include extruding, rolling, or other processes to get a rough and semi-finished shape configuration.

Two types of wrought product procurements typically applies:

1. Standard size, form and shape procured to international aerospace quality standards
2. Non-standard size, form and shape procured via dedicated procurement specification

Wrought products are generally classified into two categories:

* Sheet
* Plates

The difference in thickness between sheet and plate significantly affects ultrasonic inspection and the resulting dead zones. These are specified in the Table 8‑1 according to AMS standard definitions.

Table 8‑1: Thickness differences between sheet and plate

| Material | Sheet | Plate |
| --- | --- | --- |
| Aluminium | T < 6,35mm | T > 6,35mm |
| Steel and Titanium | T < 4,76mm | T > 4,76mm |

### Raw material inspection

For standard wrought product, the following NDI shall be applied:

Ultrasonic inspection

The NDI specified by the customer in accordance with requirement 8.2a.

* 1. These NDI are specified based on part typology: typically Ultrasonic inspection is applicable, but if necessary by a specific application or configuration, dedicated NDI can be specified by procurement or contractual documentation.

For non-standard parts volumetric defects shall be 100 % verified by Ultrasonic Inspection according to ASTM E 2375:2013 with acceptance criteria Class A.

Raw materials for all safe life, fail safe and low-risk fracture items shall be NDI inspected to ensure conformance with the general material quality specification and absence of unacceptable embedded flaws.

* 1. These tests are performed in a manner that does not affect the future usefulness of the object or material.

For safe life items requiring Special NDI, the raw material inspection shall be performed in conformance with ASTM E 2375:2013 Class A as a minimum.

1. Alternative equivalent inspection methods are subject to customer review.

In the case of thin material ultrasonic inspection may be performed in the intermediate conditions of the rolling process because of limitations of standard ultrasonic inspection to reduce dead zones in case of limiting thickness or omitted.

1. This is a compromise of the physical limitations of the method.

### Common wrought defects

The following defects depending on their size shall be the cause for rejection of wrought product:

Inclusions

Delamination

Doublings

Folds

## Forgings

### Overview

Forgings are classified as the following:

1. Die forgings
2. Drop forgings
3. Hand forgings
4. Rolled rings
5. Upset forgings

Forgings in general are non-standard products which are qualified individually.

### Raw material inspection

Forgings and rolled rings shall be subjected to:

Caustic etch followed by visual examination of the product surfaces for indications,

Ultrasonic inspection in accordance with ASTM B 594:2013,

In special cases, to fluorescent penetrant inspection in accordance with ASTM E 1417:2016 or magnetic particle according EN ISO 9934-Part 3:2015 and ASTM E 1444:2011.

### Common forging defects

The following defects shall be the cause for rejection of forging:

Bursts, caused by insufficient soaking time at high temperatures prior to forging

Clinks, internal stress cracks

Flakes, hydrogen cracks or hairline cracks

Thermal stress cracks

Grain structure variation

Acceptance criteria shall be agreed between customer and supplier.

* 1. Alternative equivalent inspection methods are subject to customer review

## Castings

### Overview

Casting is a manufacturing process used to form solid metal shapes out of molten metal. The molten metal is poured into a cavity or a mould. The solidified part is also known as a casting, which is ejected or broken out of the mould to complete the process.

### Raw material inspection

#### General

Castings in ferrous and non-ferrous composition shall be subject of NDI as part of the final production inspection to track inner or surface defects also called discontinuities, induced by the process that can alter its behaviour or its mechanical properties.

#### Penetrant testing of castings

PT shall be carried out for the detection of discontinuities that are open or connected to the surface of the device under examination.

* 1. This NDI is especially dedicated to track discontinuities like cracks, slag inclusions, cold shuts, open gas porosity, or shrink holes.

Testing specified in the requirement 8.5.2.2a shall be performed according to ASTM E 1417:2016 and EN ISO 3452 Part 1:2013, Part 2:2013, Part 3:2013.

### Ultrasonic inspection of castings

#### General

Castings shall be subjected to ultrasonic inspection in accordance with ASTM B 594:2013 or EN ISO 16810:2012,

#### X-ray radiographic inspection of castings

The radioscopic inspection shall be used for detecting volumetric discontinuities and density variations that are resulting of the presence of gas porosity, inclusions, misrun , or shrink hole.

Examination specified in the requirement 8.5.3.2a shall be performed according ASTM E1742:2012 and ASTM E1734:2016 .

#### X-Ray computed tomographic (CT) of castings

CT for NDI of castings shall be carried out for locating and characterizing discontinuities.

* 1. Example of such discontinuities are gas porosity, inclusions, misrun and shrink hole.

Examination specified in requirement 8.5.3.3a shall be performed in accordance with ASTM E 1814:14 or EN ISO 15708 Part 2:2017.

#### Common casting defects

The following defects shall be the cause for rejection of castings as follows:

Slag

Slag Inclusions

Slurry

Shrink hole

Gas porosity

Hot tears

Pouring metal defects

Sink

Acceptance criteria shall be agreed between customer and supplier.

1. Alternative equivalent inspection methods are subject to customer review.

# Inspection of PFCI

## General

### Overview

The application of NDI for fracture control can be performed with different objectives.

General NDI with major focus on quality control of parts is performed without demonstration of a minimum required sensitivity in terms of flaw sizes. The feasibility and validity of the inspection, in this case, is justified by the proper application of relevant NDI standards as specified in Clause 6.

In case when NDI applied for parts which are justified by damage tolerance (crack growth) approaches,. it is necessary to demonstrate the minimum required NDI limits in terms of flaw sizes.

Two different general NDI levels are defined based on current state of the art of NDI and available POD studies:

1. Standard NDI
2. Special NDI

The Standard NDI limits according to Table 9‑1 can be applied without formal POD demonstration under following conditions:

1. The method is properly applied and calibrated in accordance with the relevant standard(s) and meeting the requirements of clause 9.2.3.
2. The part of inspection shows a noise comparable to the smooth samples which have been used for the determination of these POD proven NDI limits. Violation of these conditions can appear, for example, in the case of rough or irregular surface conditions or in the case of material conditions with complex microstructure (coarse and or irregular grain).
3. This applies also for welds in the case both conditions above are met (noise, surface, microstructure).
4. The definition of noise can differ significantly between different NDI methods. For ET and UT inspection, noise can be quantified from the signal amplitude, whereas for PT inspection noise is the disturbance of the visual inspection caused by surface effects.

Even if formal capability demonstration is not required for Standard NDI, requirements 9.2.1a and 9.2.1b specify that customer and supplier need to agree on the limited verification applied, calibration method and accept or reject criteria in order to ensure that the inspection procedure is adequate to reliably detect the targeted standard crack size, as well as to ensure that cracks smaller than the targeted crack size are reported as “detected cracks” in line with ECSS-E-ST-32-01 clause 10.7 (for example >50 % of the targeted crack size). This allows to consider the standard crack sizes as improbable to exist in the hardware in the case that no detected crack or crack-like flaw is reported.

The detection capability relies significantly on the heritage in detecting cracks and crack-like flaws on NASA programs like Space Shuttle and ISS, reflected in for example NASA-STD-5009. The requirements intend to meet the requirements of NASA-STD-5009 for cracks and crack-like defects and therefore the requirements for Standard NDI are rather precise. Deviations from such requirements can be agreed between customer and supplier, especially in case of less critical applications, for example unmanned applications.

Capability demonstration for the inspection method and inspection personnel in accordance with clause 9.1.3 is necessary in the case of Special NDI applies:

1. Either for NDI limits smaller than specified for Standard NDI in accordance with Table 9‑1.
2. Procedures that do not conform to the ones are specified in clause 9.2.3.
3. This applies to methods and materials other that those specified in requirements from clause 9.2.3. Example: composite materials, ceramic materials, visual inspection procedures from cracks.
4. Or even in the case of Standard NDI limits if the conditions of the inspected parts strongly deviate from the backgrounds of these definitions which can be:
	1. Complex surface conditions (welds, roughness, shot peened)
	2. Complex geometry conditions (notches, transitions, wall thickness gradients).

### General requirements

The applied NDI procedures and the justification of their crack detection capability shall be approved by the customer.

1. This applies to all NDI procedures applied for implementation of fracture control, including Standard NDI procedures.

NDI procedure calibration on simulated or real crack-like flaws shall demonstrate detection of the minimum detectable crack size.

1. Calibration also ensures that accept and reject criteria (specified in requirement 5.1c) can be implemented with sufficient reliability and with acceptable risk of false indications.

Rolled threads shall not be etched.

1. This refers to both the inspection for cracks of safe life fasteners (where eddy current inspection is preferred in conformance with clause 6.5), and penetrant inspection of other fasteners which is sometimes performed as part of process control.

### Capability demonstration

NDI capability demonstration specimens shall be used for determining the detection capability for all Special NDI applications.

NDI capability demonstration specimens may be used to validate the capabilities of Standard NDI procedures.

Capability demonstration test specimens shall be agreed between customer and supplier.

Specimens shall be representative of the material to be inspected and the critical inspection area for the applicable hardware, and of the flaw size, type, location, and orientation.

1. The list of parameters can vary by NDI method.

All relevant linear and non-linear defects shall be measured and reported.

Any unintended defects shall be reported in the final NDI verification report.

### Inspection of raw material

For metallic items, the raw material inspection shall be performed in conformance with AMS-STD-2154C:2017, Class A.

Alternative equivalent inspection methods shall be subject to customer approval.

For safe life items requiring Special NDI, the raw material inspection shall be performed in conformance with SAE AMS-STD-2154C:2017, Class AA.

In the case of thin sheet material, Class AA specified in the requirement 9.1.4c, need not be applied.

For the case specified in requirement 9.1.4d only alternative procedures shall be agreed on case by case basis between customer and supplier.

* 1. 1 The standard inspection applied at raw material suppliers is Class A. Application of Class AA can either not be available at the supplier or lead to increased raw material cost. In some cases even a Class A inspection is not available at suppliers for thin sheet material.
	2. 2 For critical human spaceflight applications it can be mandatory.

### Inspection of safe life finished items

Metallic safe life items shall be inspected in conformance with clause 9.2.

Items to be inspected using penetrant, shall have their mechanically disturbed surfaces etched prior to inspection.

1. See also clause 6.4 for the case of standard penetrant NDI.

Where etching or inspection cannot be performed on the finished part, that etching and penetrant-inspection may be performed at the latest practical stage of finishing.

1. For example, before final machining of parts with precision tolerances, or at the assembly level before holes are drilled.

Etching may be omitted, in agreement with the customer, for materials and processes where it can be demonstrated that pre-existing defects cannot be smeared by the applied process.

Composite, bonded and sandwich safe life items shall be inspected and proof tested in conformance with clause 9.3.

## Non-destructive inspection of metallic materials

### General requirements

NDI levels shall be categorized as Standard NDI, Special NDI or Proof testing NDI.

The responsible for planning, definition and supervision of Special NDI activities shall have a qualification Level III in conformance with NAS 410:2014 or EN 4179:2017.

Personnel performing Special NDI shall be qualified and certified for each Special NDI method and be qualified to NAS 410:2014 Level II and EN 4179:2017.

The demonstration of 90 % probability of detection at a 95 % confidence level of the written procedure and inspector performing the Special NDI shall be performed on NDI capability demonstration specimens, except for cases specified in requirements 9.2.2.2f and 9.2.2.2g.

In case there is a failure to demonstrate capability specified in the requirement 9.2.1e, then improved inspector skills shall be demonstrated prior to a retest.

The following all conditions shall be met for personnel qualification, except for cases specified in requirements 9.2.2.2f and 9.2.2.2g:

Qualification for Special NDI are specific to the procedure and the inspector.

Special NDI inspection are not transferable to another procedure or inspector.

The period of Special NDI certification is 3 years, with skills demonstrated during the certification period.

### NDI categories versus initial crack size

#### Standard NDI

The initial crack sizes and geometries as specified in Table 9‑1 shall apply for Standard NDI of metallic materials.

1. Initial crack geometries are shown in Figure 9‑1, Figure 9‑2 and Figure 9‑3.

Table 9‑1: Initial crack size summary, Standard NDI

| NDI method | Crack location | Part thickness*t*[mm] | Crack configuration number (see NOTE 1) | Crack type | Crack depth*a*[mm] | Crack length*c*[mm] |
| --- | --- | --- | --- | --- | --- | --- |
| Eddy current NDI | Open surface | *t* ≤ 1,27*t* > 1,27 | 41, 3, 8 | Through surface | *t*0,511,27 | 1,272,541,27 |
| Edge or hole | *t* ≤  1,91*t* > 1,91 | 5, 92, 7 | Through corner | *t*1,91 | 2,541,91 |
| Cylinder | N/A | 10 | Surface | see Note 2 | 1,27 |
| Penetrant NDI Sensitivity Level ≥3 | Open surface | *t* ≤ 1,271,27 ≤ *t* ≤ 1,91*t >*1,91 | 441, 3, 8 | Through surface | *t**t*0,811,91 | 2,543,82 - *t*4,051,91 |
| Edge or hole | *t* ≤ 2,50*t* > 2,50 | 5, 92, 7 | Through corner | *t*2,54 | 3,813,81 |
| Cylinder | N/A | 10 | Surface | see Note 2 | 1,91 |
| Penetrant NDI of titanium alloys, welds and Sensitivity Level 2 for all other materials in unmanned applications | Open surface | *t* ≤ 3,0*t* > 3,0 | 41, 3, 8 | Through surface | *t*3,001,50 | 3,003,007,50 |
| Edge or hole | *t* ≤ 3,0*t* >3,0 | 5, 92, 7 | Through surface | *t*3,00 | 3,813,81 |
| Cylinder | N/A | 10 | Surface | see Note 2 | 3,00 |
| Magnetic Particle NDI | Open surface | *t* ≤ 1,91*t* > 1,91 | 41, 3, 8 | Through surface | *t*0,971,91 | 3,184,783,18 |
| Edge or hole | *t* ≤ 1,91*t* > 1,91 | 5, 92, 7 | Through corner | *t*1,91 | 6,356,35 |
| Cylinder | N/A | 10 | Surface | see Note 2 | 3,18 |
| X-ray radiographic NDI | Open surface | 0,63 ≤ *t* ≤ 2,72*t* > 2,72 | 1, 2, 3, 7, 8 | Surface | 0,7 × *t*0,7 × *t* | 1,910,7 × *t* |
| Ultrasonic NDI | Open surface | *t* ≤ 2,54 | 1, 2, 3, 7, 8 | Surface | 0,761,65 | 3,811,65 |
| NOTE 1 The crack configuration numbers refer to the crack configurations shown in Figure 9‑1, Figure 9‑2 and Figure 9‑3NOTE 2 For cylindrically shaped items (see **Figure 9‑3**) the crack depth a can be derived from the crack length c of this table for a/c = 1,0 with the following formula:  Exception: Fastener thread and fillets, to which the crack size for a/c=1,0 applies. |



Figure 9‑1: Initial crack geometries for parts without holes



Figure 9‑2: Initial crack geometries for parts with holes



(10)

Figure 9‑3: Initial crack geometries for cylindrical parts

For the Standard NDI level of inspection one or more of the following standard industrial NDI techniques applied to metallic materials shall be used in accordance with requirements from clause 9.2.3:

Fluorescent penetrant

X-ray

Ultrasonic

Eddy current

Magnetic particle.

Implementation of Standard NDI on metallic parts based on the crack sizes specified in Table 9‑1 may be performed without a formal demonstration of the crack detection capability specified in requirements of clause 9.2.2.2.

1. The crack size data in Table 9‑1 are based principally on NDI capability studies that were conducted on flat, fatigue cracked panels. When the component’s geometrical features, such as sharp radii, fillets, recesses, surface finish and cleanliness, material selection, reduced accessibility and other conditions can influence the detection capability of the applied Standard NDI method, the method is evaluated based on similarity with proven applications or demonstration testing on a small number of samples representative of the minimum detectable crack size. This is done to ensure that the detection capability of the applied Standard NDI inspection is not influenced.

Standard NDI shall provide crack detection to at least 95 % confidence and 90 % probability level.

* 1. 1 Table 9‑1 gives, for various NDI techniques and part geometries, the largest crack sizes that can remain undetected at these probability and confidence levels.
	2. 2 Dedicated capability demonstration is not needed for the method specified in clause 9.2.3.

X-ray radiographic NDI standard flaw sizes shall not apply to very tight flaws.

1. For example, tight flaws are: forging flaws, heat treatment induced flaws, welding induced cracks, fatigue cracks, flaws in compressive stress field.

For tight flaws specified in 9.2.2.1e, Special NDI requirements shall apply as specified in the requirement 9.2.2.2.

All deviations from Standard NDI requirements shall be approved by the customer.

#### Special NDI

A statistical demonstration of 90 % probability of detection with 95 % confidence shall be performed for the Special NDI method.

1. The demonstration is specific to the relevant procedure, part and individual inspector.

The demonstration specified in requirement 9.2.2.2a shall be carried out on specimens representative of the actual configuration to be inspected.

The flaw detection capability of the Special NDI inspection method shall be demonstrated by testing with flawed specimens.

The NDI capability demonstration tests shall be approved by the customer.

1. Examples of applied methods are Point Estimate Method the Probability of Detection Method

Special NDI capability demonstration plan shall be approved by the customer.

1. The preparation and control of demonstration specimens and how to administer demonstration tests normally meets the intent of MIL-HDBK-1823:1999.

When approved by the customer, for NDI processes which are fully automated, the statistical demonstration specified in requirement 9.2.2.2a may be replaced by verification by test of process parameters and their tolerances which can affect the sensitivity.

1. For example, automated eddy current scanning.

In the verification by test specified in requirement 9.2.2.2f, a minimum of five samples shall be used, which cover the full range of parameters of the cracks to be detected by the automated process, in combination with the structural details to be inspected.

1. Depending on, for example, the complexity of the item to be inspected, variability in response to structural variations and flaw and the criticality of the defects to be found, the number of samples to be used can be significantly higher than 5. Example human space flight.

Special NDI inspection procedures shall be approved by the customer.

Special NDI demonstration specimen selection shall be justified and approved based on the similarity between the hardware to be inspected and the demonstration specimen.

1. In the case of penetrant inspection Special NDI capability can be demonstrated with fatigue-cracked specimens, whereas spark eroded notches can be applicable for UT, ET and MT inspection.

The justification specified in requirement 9.2.2.2i shall be documented in the NDI summary report.

In special cases, flaws or crack types other than fatigue cracks that are more representative of the application may be used for the demonstration with the approval of the customer.

1. The most accepted method of demonstrating Special NDI capability is with fatigue-cracked specimens.

The underlying assumptions of the point estimate method shall be demonstrated or verified by documented evidence before the point estimate method can be implemented.

1. The point estimate method approach assumes that the capability of flaw detection increases with the size of flaws in the neighbourhood of the test flaw size. Since only a small number of flaws are required by this method, the minimum detectable flaw size is not always a determinant.

#### Crack screening proof test

Crack screening proof testing shall be performed in accordance with requirements from clause 10.4.2.3 of ECSS-E-ST-32-01.

### Inspection procedure requirements for Standard NDI

#### Overview

Standard inspection methods, for which the initial crack sizes of Table 9‑1 apply are to a large extent based on the heritage obtained in the frame of fracture control implementation for manned spaceflight. Tailoring can be acceptable for unmanned applications.

#### Requirements

Standard penetrant NDI shall be performed in accordance with requirements from clause 6.4.8.

Standard eddy current NDI shall be performed in accordance with requirements from clause 6.5.8.

Standard magnetic particle NDI shall be performed in accordance with requirements from clause 6.6.8.

Standard X-ray radiographic NDI shall be performed in accordance with requirements from clause 6.7.7.

Standard ultrasonic NDI shall be performed in accordance with requirements from clause 6.8.7.

## NDI for composites, bonded and sandwich parts

### Overview

NDI inspection of composites is very complex and is rarely standardized. Therefore it is always classified as Special NDI if applied to fracture critical items.

### Inspection requirements

#### General requirements

The NDI methodology and rationale shall be provided in the fracture control plan, in conformance with DRD from Annex F of ECSS‐E‐ST‐32, and approved by the customer in compliance with requirement 5.2.b of ECSS-E-ST-32-01.

Analogy to heritage of metallic material inspection may be used.

* + - 1. **Close visual inspection**

The maximum distance to perform the inspection shall be 0,3 m.

An inspection procedure shall be written, which specifies:

Access requirements

Distance between eyes and inspected area

Optimum lighting

Cleaning

The location of the successive inspected area

The minimum inspection time needed to inspect each area.

1. A formal statistical capability demonstration of the detectability of the VDT by means of close visual inspection is not needed, but the procedure is agreed between customer and supplier.

When an indication is found, optical magnification, lenses, and other NDI methods shall be applied to classify as detected defect in conformance with requirements from clause 10.7 of ECSS-E-ST-32-01.

* + - 1. **NDI methods other than close visual inspection**

The capability of an NDI method the reliably detectable defect size shall be demonstrated by test on specimens with induced defects.

Specimens with induced defects shall be used in the inspection procedure as standard for calibration.

The capability of the inspection method shall be investigated on at least five specimens in order to analyse all defect parameters.

* 1. 1 Defect parameters to be investigated include defect type, position, size, shape and orientation.
	2. 2 Depending on, for example, the complexity of the item to be inspected and the criticality of the defects to be found the number of samples to be used can be significantly higher than five. Example human space flight.
1. (normative)
NDI plan - DRD
	1. DRD identification
		1. Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-15, requirement 5.1d.

* + 1. Purpose and objective

The purpose of the NDI plan is to have a detailed plan of the NDI method chosen for a part to be inspected.

* 1. Expected response
		1. Scope and content

An NDI plan shall be developed which addresses the following as a minimum:

Applicable specifications and standards;

Calibration artefact traceability;

Inspector training, qualification, and certification;

NDI responsibility;

Method selection, qualification, application, and process control;

Description of procedure to demonstrate robust process parameters, working operation field;

Acceptance criteria;

Application of requirements during manufacturing, maintenance, and operations;

NDI applied to safe life PFCI;

NDI applied to structural parts;

Standard NDI selection, application, and control;

Special NDI selection, application, and configuration control.

* + 1. Special remarks

None.

1. (normative)
NDI report - DRD
	1. DRD identification
		1. Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-15, requirements 6.1.5a, 6.2.3.2a., 6.4.5a, 6.5.6a, 6.6.5a, 6.7.5a and 6.8.4.5a.

* + 1. Purpose and objective

The purpose of the NDI report is to record all necessary details that are needed for traceability of inspection conditions and results.

The layout for NDI report can be prepared as per the example shown in EN ISO 3452 Part 1:2013 Annex C.

* 1. Expected response
		1. Scope and content

General

The NDI report shall be developed and include, but not limited to, the following:

Reference to a test procedure or a plan

Environment

Date and place of inspection

Facility

Temperature

Humidity

Illumination

Description of the object

Part ID number

Object classification

Dimensions

Material

Quantity

Batch number

Surface condition

Manufacturing stage process details

Designation of test object

 Conditions of inspection

 Inspection of equipment used

Manufacturer and model number of all instruments to be used for NDI inspection

Calibration status

Consumables

Critical zones inspection

Classification and justification of Standard NDI or Special NDI inspections.

Registration level

Acceptance criteria.

Indications above registration level

Indications above acceptance level

Appraisal of indications against acceptance criteria

Any detected cracks or crack-like flaws regardless of their size or disposition

Non-acceptance of inspection object

flaw descriptions,

locations,

sizes

non-conformances and problems encountered

any detected cracks or crack-like flaws regardless of their size or disposition

Personnel of inspectors and approvals

name and qualifications level of inspector

signature

Evaluation of special conditions that affect Standard NDI.

Applied software and its version

Data storage

Anomalies

Responsible Level III shall approve the following

Relevant NDI procedure

Release of a part with indication

Presence of peculiarities identified by inspectors shall be recorded in non-conformance reports if confirmed to be nonconforming by Level III.

Additional requirements for different inspection types

Visual test

The visual test report shall contain information in accordance with documentation requirements from EN ISO 17637:2013 and EN ISO 17635:2016.

Leak test

The leak test report shall include:

Leak testing method

Leak testing devices

Leak test medium and gas concentration

Test pressure and test time

Leak detection threshold

Ambient gas concentration

Determined leak rate

Sketch of the test set-up and leakage plan

Evaluation

Dye penetrant test

The dye penetrant test report shall contain information in accordance with documentation requirements from EN ISO 3452 Part 1:2013, Part 2:2013, Part 3:2013 or ASTM E 1417:2016.

Eddy current test

The eddy current test report shall contain details of the test carried out and include the following information:

Technique identification

Results of test, including sketches, instrument settings

Test set used

Magnetic particle test

The magnetic particle test report shall contain information in accordance with documentation requirements from ASTM E 1444:2011 and EN ISO 9934 Part 1:2016.

X-ray radiographic inspection test

The X-ray radiographic test report shall contain information in accordance with documentation requirements from ASTM E 1742:2012 or EN ISO 17636:2013 Part 1 and Part 2.

Ultrasonic inspection test

The ultrasonic inspection report shall include the following:

Inspection method:

frequency

sensitivity level

Inspection equipment:

device

probes

software

Sensitivity calibration (reference)

Defect characteristics:

defect amplitude, size

location (position, depth)

type

geometry

peculiarities

Sketch for non-standard defects and peculiarities

Scanning speed and index in case of automatic inspection

* + 1. Special remarks

In the case of application of proprietary processes and methods restriction of documentation shall be clarified between supplier and customer prior to program.

The documents supporting the NDI Report shall be kept as agreed between customer and supplier.

In the case of NDI qualification test reports the following additional information is required:

Certification of inspectors

Demonstration of required POD

1. (normative)
NDI procedure - DRD
	1. DRD identification
		1. Requirement identification and source document

This DRD is called from ECSS-Q-ST-70-15, requirement 5.4a.

* + 1. Purpose and objective

The purpose of the NDI procedure is to ensure the proper application of all inspection are detailed with relevance to inspectors as specified in the NDI plan and qualified in subsequent test programs.

* 1. Expected response
		1. Scope and content

The NDI Procedure shall include, date, issue and revision number.

The NDI Procedure shall include the following information:

NDI methods and techniques

NDI Level and certification of personnel

Equipment and calibration of equipment

Detailed description of parameters

Process control and acceptance criteria

* + 1. Special remarks

Any change of NDI procedure shall be be submitted to the customer for approval.

1. The NDI procedure in most cases is supplier proprietary and is not released to the customer.
2. (informative)
Catalogue of potential defects

NDI planning and selection of appropriate methods and sensitivity always includes the assumption of existing defects in the material or structure. These existing defects can differ significantly within different materials as for example cast (inclusions, pores) or composite (delamination, porosity), but also for different processes such as welding-TIG, or FSW.

A catalogue of potential defects can be established by the material or processes responsible person to give the basis for the NDI planning and implementation that include:

1. Designation of each defect type to be used in the documentation
2. Clear and unique description of each potential defect
3. Schematic figures supporting the description
4. Its expected size and orientation
5. Any potential peculiarity

In the case of new material and/or processes a preliminary catalogue can be established at the beginning of the program based on

1. Preliminary results
2. Open literature
3. Engineering judgement
4. Similar materials or processes

This catalogue can be updated based on experience gained with time to allow best possible calibration or adoption of the selected NDI method and potential reduction of inspection or inspection steps in the case that sufficient reliability can be demonstrated

Weld defects and imperfections can be designated according to the definitions given in the following standards in order to allow unique understanding:

1. EN ISO 6520-1: 2007: Welding and allied processes - Classification of geometric imperfections in metallic materials - Part 1: Fusion welding
2. ISO 17659: 2002: Welding - Multilingual terms for welded joints with illustrations
3. CEN ISO/TS 17845: 2004: Welding and allied processes - Designation system for imperfections

Weld imperfection acceptance limits can be as specified in the following standards:

1. AIA NAS 1514-1972: Radiographic Standard for Classification of Fusion Weld Discontinuities (Rev. 2) R(2011)
2. DIN 29595:2007-04: Welding in aerospace - Fusion welded metallic components – Requirements
3. MSFC-SPEC-3679 (October 2011): MSFC Technical Standard, Process Specification, Welding Aerospace Hardware
4. EN ISO 25239-5:2011: Friction stir welding - Aluminium - Part 5: Quality and inspection requirements
5. AWS D 17.3: 2010. Specification for Friction Stir Welding of Aluminium Alloys for Aerospace Applications
6. AWS D 17.1 2001 (19 Jan) Specification for Fusion welding for aerospace applications
7. AWS C 7.4:2008 (13 March) Process Specification and Operator Qualification for Laser Beam welding
8. AMS 2680 (issue C April 2006) electron Beam welding for fatigue critical application
9. AMS 2681 (issue B 2006 April) Welding electron beam
10. (informative)
POD evaluation example, software and documentation
	1. Theory

The crack size is defined by the three dimensions length *c*, depth *a* and width *w*. The first two dimensions are important for damage tolerance assessment of spacecraft structures, whereas the width is an important parameter for penetrant inspection. This is the reason why special reference samples with flaws of minimized width are manufactured for the POD demonstration.

By general experience, it is well known that a certain value of measurement can be achieved only with an uncertainty, which often increases with the decrease of the value until it is impossible even to detect the flaw. The probability of detecting and making the correct measurement is specified by the probability of detection (POD). In a conservative approach, the POD is a step function of the variable like length *c* (Figure E-1). Below a critical value *cc*, the POD is zero and above the value 1,0.

In a modern approach, the function is smeared out showing also some POD below and a POD smaller than 1,0 above the value *cc* with an asymptotic approach to 1,0. The function of POD can be established for a defined problem by tests. Because the tests are always performed with a limited number of tests the result contains uncertainties and for conservative estimation limit curves which grant a certain confidence can be statistically calculated. The crack length c0 which can be detected with the pre-defined probability and confidence can be determined from this curve.

: Example for the probability of detection

* 1. POD demonstration

The POD demonstration can be performed in two ways [Metals Handbook Vol.17]

* method of hit and miss

In this method only the hits are counted for each inspection site.

* method of <c> data

In this method the value <c> of the inspection variable c is measured for each inspection site during test. This test method is more flexible, uses less test specimens but the evaluation is much more complex and difficult.

In general, the test performance is complicated by combining several attributes like length, depth, and inspectors as well as multiple inspections with reproduced settings and different probes of the same type of the equipment. If necessary all are subjected to a factorial test plan if precise analysis is necessary to determine the different influences.

Only the hit and miss method is considered as the <c> data method is too complex.

* + 1. Sample size for Method "Hit/Miss"

Two approaches can be chosen:

* The full POD curve can be evaluated or
* A so-called “one point procedure” delivers a tested POD valid for the maximum crack size 2c of the test samples

Full POD Curve:

For this method, most of the samples are in the supposed interval between a (P=0,10) and a (P=0,90). Cracks outside this interval do not provide much information because they belong to the almost certain miss respectively detection range. Because this interval is not certainly known and specimens are often applied for multiple use, flaw sizes should be uniformly distributed between the minimum and maximum of the sizes of potential interest. A minimum of 60 flaws should be distributed in this range. The number of unflawed inspection sites should be at least twice of that of flawed sites.

One-Point Procedure:

If all cracks are detected, the number of flaws to be inspected is at least 29 (for 90/95 see below).

* + 1. Test evaluation for method "Hit/Miss" (90 % probability with 95 % confidence)
			1. Full POD curve

The POD curve can be determined applying the methods in W.D. Rummel ”Recommended Practice for a Demonstration of Non-Destructive Evaluation (NDE) Reliability on Aircraft Production Part” with available software. However, depending on the distribution of the flaw sizes, the software sometimes does not converge. In this case no results can be evaluated.

* + - 1. One-point procedure

The POD can be calculated from the test results by the formula of the binomial distribution:

$$POD=1-\frac{1}{1+\frac{(n-f)}{\left(f+1\right) F\_{1-α} (2\left(f+1\right), 2\left(n-f\right))}} $$

In the chosen test procedure no failure is expected and the equation simplifies to:

$$POD=1-\frac{1}{1+\frac{n}{F\_{95}\left(2,2n\right)}}$$

By solving the equation for n, the lowest number of defects to be inspected can be estimated (F95 (2, 2n) depends only weakly on n ):

$$n≈F\_{95}\left(2,2n\right)\frac{POD}{1-POD}≈29$$

|  |  |
| --- | --- |
| c | actual length of defect |
| <c> | measured length of defect |
| C | confidence |
| P | probability |
| POD | probability of detection  |
| F1-α (x, y) | figure of F – distribution (from F distribution type) with degree of freedom 2(*f*+1), 2(*n-f)* |
| n | number of tests |
| f | number of failures |
| s | standard deviation |
| (1-α) | confidence |

In order to demonstrate inspection capability of 90 % probability and 95 % confidence the following results are achieved during inspection:

1. 29 successes in 29 trials
2. 45 successes in 46 trials
3. 59 successes in 61 trials

For each trial a separate sample with appropriate defect is required.

Example 1: POD (90/95) is demonstrated if 29 samples are successfully inspected.

Example 2: If one sample of 29 is missed during inspection, additional 17 samples are inspected successfully to achieve the require number of 45 successes.

* + 1. POD software and documentation

Recommendations and instructions for POD evaluation can be found in the following web sites:

<http://www.statisticalengineering.com/mh1823/index.html>

<http://www.r-project.org/>

http://www.cnde.iastate.edu/mapod/index.htm

<http://www.jsm.or.jp/ejam/Vol.4No.3/AA/AA45/AA45.pdf>
Considerations for Statistical Analysis of Nondestructive Evaluation Data: Hit/Miss Analysis Jeremy KNOPP1,\*, Ramana GRANDHI2,†, Li ZENG3, and John ALDRIN49

<http://www.dtic.mil/dtic/tr/fulltext/u2/a393073.pdf>
(AFRL-ML-WP-TR-2001-4010 Probability of detection (POD) analysis for the advanced retirement for cause (RFC)/engine structural integrity program (ENSIP) non-destructive evaluation (NDE) system development, volume 1 – POD analysis, Alan P. Berens

1. (informative)
Complementary material information
	1. Overview

This clause contains information specific to different materials which supports selection and application of inspection methods.

Defects that are summarized in this clause can appear mostly in non-optimized processes. For optimized and mature processes it can be possible to eliminate defect types from the list of probable defects to be addressed by the applied NDI when agreed between customer and supplier.

* 1. Forgings and rolled products

In the forging process, metal is shaped by pressing, pounding, or squeezing under very high pressure, to form parts called forgings. Forging processes include cold forging or heading, impression or closed die, open die, and seamless rolled ring. Forged parts usually require further processing to achieve a finished part.

The product, as received by purchaser, can be uniform in quality and condition, sound, and free from foreign materials and from imperfections detrimental to usage of the product.

Two types of forging product procurements typically applies :

* Standard size, form and shape procured to international aerospace quality standards
* Non-standard size, form and shape procured via dedicated procurement specification

Common defects in forging are:

* Bursts – forging defect which occurs due to insufficient soaking time at high temperature prior to forging.
* Clinks – internal stress cracks. Cracks (internal) – these are arrowhead in appearance shaped fractures caused by impurities in the material or an incorrect die angle. These are also known as chevron cracking or cupping.
* Excessive Flash – this is caused by using a too large blank billet size in closed die forgings.
* Flakes (hydrogen cracks or hairline cracks) – Small pockets of hydrogen gas builds up within the structure in forgings. The trapped hydrogen gas pressure causes rupturing along the grain boundaries.
* Lack of fill – caused by too small billet size in closed die forgings.
* Mechanical tool marks – surface marks caused by damaged or worn our equipment (damaged roll)
* Mismatch – this occurs in closed die forgings when two halves of the die fail to engage properly.
* Underfill – this is caused by when an undersized blank is placed in the die, resulting the forging to be incomplete.

Rolling can be performed by either on hot or cold metal. The material is passed between cast or forged steel rolls which compresses the metal before moving it forward.

Common defects in rolling are:

* Banding- caused by segregation in the original cast billet, bloom or slab
* Cracks – (cold rolling) caused when the rate of deformation is too great or when attempting to reduce a section too greatly in one operation. Cracks can be either on the surface of a part or sub-surface.
* Folds- this occurs when the corner of the material folds over and rolled but it is not welded into the material.
* Inclusions – (Non Metallic) – resulting from oxides, nitrides, silicates which are commonly found in the molten metal.
* Laminations- slag, sand, oxides or porosity from the original cast billet, bloom or slab.
* Laps- found when oversize or faulty rolls and dies are used where there is an overfill on the forming process and the material folds over. The material is flattened but it is not fused together onto the surface of the material on subsequent passes.
* Rokes – a discontinuity found on the exterior of bar sections which consist of fissures which become elongated in the direction of the rolling process. Rokes originate from blow holes which are formed below the surface of the ingot that have broken during the rolling process.
* Seams – these are shallow groves or striations that are formed by elongation during rolling of oxidized surface, sub-surface blow holes or the result of splashes of molten metal. Seams can also occur during a poor rippled surface.
* Slugs – this is a piece of foreign material from a splash of molten metal within the ingot which occur during the teeming. The slug does not fuse which is removed by blasting or pickling process.
* Stringers and Reeds –found in rolled sections such as I beams, angles or channels.
	1. Castings

Typical surface and inner defects are as follows:

1. Slag

It is a film that forms on top of molten metal as a result of impurities. Slag is composed of non-metal elements.

1. Slag Inclusions

They are imperfections of the surface of metal caused by slag (impurities in the molten mix).

1. Slurry

It is a product resulting from the casting operation including : watery mixture such as the gypsum mixture for plaster moulding, moulding medium used for investment casting, core dips, and mould washes.

1. Shrink hole

It is a cavity that forms in a metal part when there was not enough source metal fed into the mould during the casting process.

1. Gas porosity

It is the formation of bubbles within the casting after it has cooled. This occurs because most liquid materials can hold a large amount of dissolved gas, but the solid form of the same material cannot, so the gas forms bubbles within the material as it cools. Gas porosity may present itself on the surface of the casting as porosity or the pore may be trapped inside the metal.

1. Hot tears

This is a very rough defect usually occurs during changes in sections.

1. Pouring metal defects

They include misruns, cold shuts, and inclusions. A misrun occurs when the liquid metal does not completely fill the mould cavity, leaving an unfilled portion. Cold shuts occur when two fronts of liquid metal do not fuse properly in the mould cavity, leaving a weak spot.

1. Sink

This is a dished area on the surface of a casting caused by shrinkages.

* 1. Composite products

A composite material is made from two or more constituting materials, having different physical or chemical properties. Ultrasonic inspection is the most appropriate method for inspection of sub-surface defects.

Typical composite materials are as follows:

1. Composite building materials, such as cements, concrete
2. Reinforced plastics, such as fibre-reinforced polymer, carbon fibre reinforced plastics, resin systems, solid laminate and cored structures
3. Metal composites
4. Solid laminates
5. Sandwich structures
6. Metal matrix composites
	* 1. Metal Matrix Composites (MMC)

MMC are highly resistant at elevated temperatures with high ductility and remain tough comparison with polymer based matrix composites.

* + 1. Sandwich structures

A sandwich structure composite is fabricated by attaching two thin-stiffened skins to a light weight but with a thicker core.

Although the core material is low in strength but due to high thickness giving the sandwich structure a high bending stiffness with overall low density.

During the manufacturing processes, there are many defects which can be introduced into the material. Commonly found defects are follows:

1. Incorrect fibre volume fraction
2. Bonding defects
3. Fibre and ply misalignment
4. Incomplete cured matrix caused by incorrect curing
5. Wavy fibres
6. Ply cracking
7. Delaminations
8. Fibre defects
9. Ingress of moisture
10. Fracture or buckling of fibres
11. Failure of interface between the fibres and matrix.
	* 1. Common flaws found in composite material
12. Common flaws found in composite material are as follows:
	1. Inclusions
	2. Unbonds and Disbonds
	3. Delaminations
	4. Voids
	5. Porosity
	6. Volume fraction – Dry fibres – Resin rich areas
	7. Fibre breakage
	8. Matrix cracking
	9. Other flaw types
	10. Ceramics

The term Ceramics covers a wide range of materials, such as oxides, carbides, nitrides, refractory materials, glasses, brick, concrete and clay.

Ceramics are usually very hard and brittle materials but have excellent electrical and thermal insulating properties as well as good resistance to chemical attack.

The properties of ceramics are determined by the composition and the microstructure produced as a result of its fabrication. Ceramics do not behave in the same manner as metallic materials, i.e. it is not possible to change the microstructure by working or further heat treatment. The majority of ceramics start as powders or a mixture of powders which are shaped in order to be subjected to the required temperature in consolidation.

Ceramics are grouped in the following categories:

1. Domestic ceramics: these are porcelain, earthenware, stoneware and cement.
2. Natural ceramics: stones are classed as natural ceramic material.
3. Engineering ceramics: these are oxides, nitrides, silicon carbides, borides, and silicates. These are widely used in furnace components, combustion tubes, tool tips and grinding tools.
4. Glasses: these include various types of glass and glass ceramics. Ceramics are crystalline but amorphous states are possible.
5. Electronic ceramic materials: these are ferrites, ferroelectrics and semiconductors.

For ceramics inspection Dye penetrant inspection is the most appropriate method of NDI with the exception of visual inspection. For surface breaking discontinuities, PT is the most appropriate method of NDI.

Bibliography

|  |  |
| --- | --- |
| ECSS-S-ST-00 | ECSS system – Description, implementation and general requirements |
| Metals Handbook Vol. 17 | chapter „Application of NDE Reliability to System“ ASM International, l9th edition (1989) |
| W. D. Rummel | Recommended Practice for a Demonstration of Non-Destructive Evaluation (NDE) Reliability on Aircraft Production Parts Materials Evaluation 40 (Aug. 92) p. 922 |
| MIL-HDBK-1823:1999 | NDTI – Nondestructive testing and inspection |
| MIL-HDBK-6870B:2012 | Inspection program requirements nondestructive for aircraft and missile materials and parts (14-feb-2012) |
| NASA-STD-5009:2008 | Nondestructive evaluation requirements for fracture critical metallic components |
| NASA/CR-1999-209427 | Guidelines for Proof test analysis |
| NASA/CR-1999-209426 | A comparison of single-cycle versus multiple-cycle proof testing strategies |
| AMS-2632-A:2013 | Inspection, Ultrasonic of thin Materials 0.50 Inch (12.7mm) and Under Cross-Sectional Thickness |
| ASTM E 114:2015 | Standard Practice for Ultrasonic Pulse-echo Straight Beam Examination by Contact Method  |
| ASTM E 213:2014 | Standard Practice for Ultrasonic Examination of Metal Pipes and Tubing |
| ASTM E 214:2005 | Standard Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves  |
| ASTM E 587:2015 | Standard Practice for Ultrasonic Angle Beam Examination by Contact Method |
| ASTM E 1065:2014 | Standard Guide for Evaluating Characteristics of Ultrasonic Search Units |
| ASTM E 1570:2011 | Standard Practice for Computed Tomographic (CT) Examination |
| ASTM E 2192:2013 | Standard Guide for Planer Flaw Height Sizing by Ultrasonic  |
| ASTM E 2580:2012 | Standard Practice for Ultrasonic Testing of Flat Panel Composites and Sandwich Core Materials Used in Aerospace Applications |
| SAE-AMS-647C:2009 | Fluorescent Penetrant Inspection, Aircraft and Engine Component Maintenance |
| SAE-ARP-5605 | Solid Composite Laminate NDI Reference Standards |
| SAE-ARP-5606 | Composite Honeycomb NDI Reference Standards |
| ISO/FDIS 18563-1:2014-11 | Non-destructive testing - Characterization and verification of ultrasonic phased array equipment - Part 1: Instruments |
| EN ISO 18563-3:2014-04 | Non-destructive testing - Characterization and verification of ultrasonic phased array systems - Part 3: Combined system (ISO/DIS 18563-3:2014) |
| ISO 9606-1:2017 | Qualification testing of welders - Fusion welding - Part1: Steel |
| ISO 12718:2008 | Non-destructive testing — Eddy current testing — Vocabulary |
| ISQ-NDI-GDL-001, August 2008 | Special NDI Demonstration Guidelines |