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Boilers and pressure vessels —

Part 1: Performance requirements

Chaudières et récipients sous pression —

Partie 1: Exigences de performance

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 16528-1 was prepared by Technical Committee ISO/TC 11, *Boilers and pressure vessels*.

This first edition of ISO 16528-1, together with the first edition of ISO 16528-2, cancels and replaces ISO/TS 16528:2002, which has been technically revised.

ISO 16528 consists of the following parts, under the general title *Boilers and pressure vessels*:

— *Part 1: Performance requirements*

— *Part 2: Procedures for fulfilling the requirements of ISO 16528-1*

Introduction

This part of ISO 16528 specifies performance requirements for boilers and pressure vessels, to ensure the integrity of the pressure boundary.

An important safety requirement is the suitable provision of technical requirements taking into account the various modes of failure that can occur in boilers and pressure vessels. Guidance is given on these modes together with the criteria for satisfying these.

There are significant differences among countries in regulating the supply and operation of boilers and pressure vessels. These differences include compliance with specific standard(s) limiting source or specification of materials, use of specific inspection bodies and discriminatory certification systems or import licenses. However, these standards have a proven history of supporting public safety and good commercial operating experience.

This part of ISO 16528, which is performance-based, enables these standards to co-exist, providing an approach that can accommodate technical innovations, existing regulatory frameworks and market needs. Compliance with the requirements of this part of ISO 16528 does not relieve parties from obligations under local, national or international laws or regulations.

ISO 16528-2 provides a procedure to identify existing prescriptive standards that fulfil the requirements of this part of ISO 16528.

Boilers and pressure vessels —

Part 1:
Performance requirements

1 Scope

This part of ISO 16528 defines the performance requirements for the construction of boilers and pressure vessels.

It is not the intent of this part of ISO 16528 to address operation, maintenance and in-service inspection of boilers and pressure vessels.

In relation to the geometry of the pressure-containing parts for pressure vessels, the scope of this part of ISO 16528 includes the following:

a) welding end connection for the first circumferential joint for welded connections;

b) first threaded joint for screwed connections;

c) face of the first flange for bolted, flanged connections;

d) first sealing surface for proprietary connections or fittings;

e) safety accessories, where necessary.

In relation to the geometry of pressure-containing parts for boilers, the scope of this part of ISO 16528 covers the following:

f) feedwater inlet (including the inlet valve) to steam outlet (including the outlet valve), including all inter-connecting tubing that can be exposed to a risk of overheating and cannot be isolated from the main system;

g) associated safety accessories;

h) connections to the boilers involved in services, such as draining, venting, desuperheating, etc.

This part of ISO 16528 does not apply for nuclear components, railway and marine boilers, gas cylinders or piping systems or mechanical equipment, e.g. turbine and machinery casings.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
boiler
assembly intended for generation of steam or hot water above atmospheric pressure

2.2
pressure vessel
housing designed and built to contain gases or liquids under pressure

2.3
certification
procedure by which a third party or manufacturer gives written assurance that a product, process or service conforms to specified requirements

NOTE Adapted from ISO/IEC 17000:2004.

2.4
conformity
fulfilment of specified requirements

2.5
construction
processes that include design, material specification, manufacture, inspection, examination, testing and conformity assessment of boilers and pressure vessels

2.6
contracting party
individual or organization procuring boilers and pressure vessels for a user or for resale

2.7
designer
organization or individual that performs design of boilers and pressure vessels in compliance with a standard

2.8
examination
activity carried out by qualified personnel using qualified procedures to assess that given products, processes or services are in conformance with specified acceptance criteria

2.9
inspection
activity to check that the results of required testing or examinations comply with specified requirements

2.10
manufacturer
individual or legal entity who is responsible for the construction of boilers and pressure vessels in accordance with

— specifications provided by the contracting party, and

— requirements of the standard applicable to boilers and pressure vessels under consideration

NOTE The manufacturer may entrust subcontractors with all or part of the operations or works (including design or assembly), after informing (if applicable) the third party inspection body. The manufacturer remains fully responsible for the operations or works subcontracted.

2.11
maximum allowable pressure
maximum pressure for which boilers and pressure vessels are designed

2.12
owner
individual or organization having legal title to boilers and pressure vessels

2.13
qualification
proof of suitability of an individual, process, procedure or service to fulfil specified requirements

2.14
regulation
rules promulgated by a government authority in accordance with legal statutes or directives

2.15
safety accessory
devices designed to protect boilers and pressure vessels against the allowable limits being exceeded

NOTE Such devices include

— devices for direct pressure limitation, such as safety valves, bursting disc safety devices, buckling rods, controlled safety pressure relief systems;

— limiting devices, which either activate the means for correction or provide for shutdown or lockout, such as pressure switches or temperature switches or fluid level switches;

— safety related measurement, control and regulation devices.

2.16
standard
code
document established and approved by a standard issuing body that provides for common and repeated use, mandatory requirements, guidelines or characteristics for activities or their results

NOTE The word “standard” used throughout this part of ISO 16528 shall be considered as the equivalent of “code” and vice versa.

2.17
testing
activity carried out to determine, by specific procedures, that one or more characteristic of a product, process or service meet(s) one or more specified requirements

2.18
third-party inspection body
organization that performs inspections on boilers and pressure vessels as provided for by standards and is independent of the manufacturer, contracting party, owner or user

2.19
user
organization or individual using or operating boilers and pressure vessels

3 Units of measurements

Measurements shall be in SI Units. Product standards that are available only in other units may be used.

4 Classification of boilers and pressure vessels

Due to the broad application of boilers and pressure vessels, this part of ISO 16528 does not provide a use-based application scheme. This part of ISO 16528 addresses a minimum set of failure modes and technical requirements that aid users of this part of ISO 16528 in determining appropriate applications.

5 Duties and responsibilities

5.1 General

It is essential that the duties, responsibilities and the interfaces between contracting parties, manufacturers and third-party inspection bodies are clearly established. The general duties and responsibilities are provided in 5.2 to 5.4.

5.2 Users and contracting parties

The user or the contracting party should establish the technical requirements for the boilers and pressure vessels, taking into consideration factors associated with all aspects of use. The following is a summary of the major design elements that shall be considered by the user in establishing these requirements:

a) construction standard;

b) installation site or application of boilers and pressure vessels built for stock;

c) vessel classification;

d) vessel configuration and controlling dimensions;

e) design conditions, e.g. loads and load cases and environmental requirements;

f) design life (fatigue, creep, corrosion);

g) materials of construction;

h) overpressure protection, e.g. safety accessories.

NOTE Where the manufacturer is the only party involved in the construction of boilers or pressure vessels (e.g. built for stock, turnkey units, etc.), the manufacturer also has the responsibilities of the user.

5.3 Manufacturers

The manufacturer is responsible for assuring that boilers and pressure vessels comply with the user's requirements and with a standard fulfilling the requirements of this part of ISO 16528. Information documenting compliance with a standard fulfilling the requirements of this part of ISO 16528 and the user's requirements specification should be available in the manufacturer's documentation, including as a minimum the following:

a) detailed and general assembly drawings;

b) design calculations and analysis that establish the construction details;

c) documentation of design by experiment or testing, when employed;

d) documentation of material, fabrication, examination and testing processes and results, e.g. forming, welding, heat treatment and radiography, etc.;

e) documented statement signed by the manufacturer and, where appropriate, verified by a third-party inspection body, that the boilers and pressure vessels comply with the applicable standard;

f) any necessary operating or maintenance instructions.

5.4 Third-party inspectors

It is the duty of inspectors to make all necessary inspections and verify that boilers and pressure vessels comply with all requirements of a standard fulfilling the requirements of this part of ISO 16528. The following is a summary of the major inspection categories:

a) confirming requirements for design, material, welding, heat treatment, examination and testing;

b) monitoring of the manufacturer's quality-control system when the manufacturer employs a quality system (see Clause 8);

c) verifying the maintenance of records.

The inspector may be either

— independent from the manufacturer's organization and reporting to a third-party organization,

— independent of production but within a manufacturer's approved quality-management system, or

— within an independent inspection division of the user.

6 Failure mode

6.1 General

The design shall consider the following failure modes and specifically address those listed in 6.2. This requirement does not mandate detailed analysis of the failure modes listed in 6.2 if the design parameters for the boilers and pressure vessels do not require such an analysis, e.g. it is not necessary to analyse creep rupture for boilers and pressure vessels operating at essentially ambient temperatures. In such cases, the designer shall document the reason for not addressing one or more of the failure modes listed in 6.2.

It is not the intent to describe in detail each potential failure mode. Annex A contains a brief description of some common failure modes for guidance.

6.2 Common failure modes

6.2.1 Classification

The possible ways in which boilers and pressure vessels can fail are classified into short-term, long-term and cyclic-type failures, or a combination of these.

6.2.2 Short term failure modes

Failure modes due to the application of non-cyclic loads that lead to immediate failure can be classified as follows:

— brittle fracture;

— ductile failures (crack formation, ductile tearing due to excessive local strains, gross plastic deformation and plastic instability (bursting);

— excessive deformations leading to leakage at joints or other loss of function;

— elastic or elastic-plastic instability (buckling).

6.2.3 Long-term failure modes

Failure modes due to the application of non-cyclic loads that lead to delayed failure can be classified as follows:

— creep rupture;

— creep: excessive deformations at mechanical joints or resulting in unacceptable transfer of load;

— creep instability;

— erosion, corrosion;

— environmentally assisted cracking, e.g. stress corrosion cracking, hydrogen induced cracking, etc.

6.2.4 Cyclic failure modes

Failure modes due to the application of cyclic loads that lead to delayed failure can be classified as follows:

— progressive plastic deformation;

— alternating plasticity;

— fatigue under elastic strains (medium and high cycle fatigue) or under elastic-plastic strains (low cycle fatigue);

— environmentally assisted fatigue, e.g. stress corrosion cracking or hydrogen induced cracking.

6.3 Failure modes to be addressed

As a minimum, the following failure modes shall be taken into account in establishing design criteria and methods for boilers and pressure vessels:

a) brittle fracture;

b) ductile failures (crack formation, ductile tearing due to excessive local strains, gross plastic deformation and plastic instability (bursting);

c) excessive deformations leading to leakage at joints or other loss of function;

d) elastic or elastic-plastic instability (buckling).

7 Technical requirements

7.1 General

The integrity of the pressure boundary of boilers and pressure vessels is based on the application of a combination of design techniques, material selection, manufacturing features and levels of inspection. The technical requirements for each are stated in 7.2 to 7.5.

7.2 Materials

7.2.1 General

Materials of pressure-bearing parts, materials for non-pressure bearing parts (e.g. supports and attachments) and welding consumables used for the manufacture of boilers and pressure vessels shall be suitable for intended application and to other foreseeable but unintended conditions.

7.2.2 Specification of materials

The material properties shall

a) be appropriate for all operating conditions that are reasonably foreseeable and for all test conditions and, in particular, they shall be sufficiently ductile and tough. Moreover, due care shall be exercised in selecting materials in order to prevent brittle fracture;

b) be sufficiently chemically resistant to the fluid contained in the boilers and pressure vessels;

c) not be adversely affected at operating conditions, e.g. by ageing;

d) be suitable for the intended fabrication procedures;

e) be selected to avoid significant undesirable effects when dissimilar materials are employed.

The manufacturer shall specify any additional material properties required to support the design basis, e.g. impact properties.

7.2.3 Material certification

The manufacturer shall take appropriate measures to ensure that materials used conform to the requirements of specifications permitted by the applicable standards. The manufacturer shall obtain material identification and certification as required by the applicable material specification.

7.3 Design

7.3.1 Loadings and other design considerations

Boilers and pressure vessels shall be designed for loadings appropriate to their intended use, including those induced by reasonably foreseeable operation conditions and external events (see Clause 5).

Boilers and pressure vessels shall be designed for internal and/or external pressure at coincident material temperature(s).

As appropriate, the following conditions shall also be considered:

— weight of the component under operating conditions and hydraulic-pressure test conditions;

— loads supported by or reacting on the component;

— wind loading;

— earthquake loading;

— temperature differences due to transient conditions or differences in coefficient of thermal expansion;

— fluctuations of pressure and temperature during normal operating and upset conditions;

— degradation mechanisms, e.g. corrosion, erosion, creep and fatigue;

— handling, transportation and installation loads, etc.;

— probability and magnitude of coincident loadings.

7.3.2 Design methods

Design methods shall address the integrity of boilers and pressure vessels by applying one or an appropriate combination of the following methods:

a) design by rule;

b) design by analysis;

c) design by experiment or testing.

These methods shall be based on a coherent system of design, including provisions for design input and recognition of modes of failure (see Clause B.5).

7.3.3 Design margins

Design margins on material properties and types of design (including appropriate fabrication details) for boilers and pressure vessels shall address foreseeable failure modes under specified loading conditions.

Material properties to be taken into account, where applicable, include

— yield strength;

— tensile strength;

— time-dependent strength, i.e. creep strength;

— fatigue data;

— modulus of elasticity;

— strain;

— impact strength;

— fracture toughness.

7.3.4 Design factors

In addition to the design margins specified in 7.3.3, appropriate design factors (such as weld efficiency based on extent and type of examination, shape or size of component, etc.) to address uncertainties for manufacturing, complex stress fields and material behaviour shall be provided.

7.3.5 Means for examination

Boilers and pressure vessels shall be constructed to provide access for internal inspection.

Other means of examining the condition of boilers and pressure vessels may be applied, as appropriate, when physical access is not possible.

7.3.6 Draining and venting

When necessary, adequate means for draining and venting shall be provided for boilers and pressure vessels.

7.3.7 Corrosion and erosion

Where necessary, adequate allowance or protection against corrosion, erosion or any other chemical attack shall be provided, taking account of intended and reasonably foreseeable use.

7.3.8 Overpressure protection

7.3.8.1 General requirements

Pressure-relief devices or systems for limiting overpressure shall be provided for boilers and pressure vessels. Protection systems shall be designed to prevent overpressure of boilers and pressure vessels beyond intended limit, considering operation, classification and probability of an upset.

However, unrelieved pressure beyond design conditions may occur, providing the pressure is consistent with design margins for anticipated failure mode(s). If overpressure protection is provided by system design, an analysis shall be conducted to confirm that all credible operating and upset conditions have been accounted for, including boilers and pressure vessels and instrumentation malfunctions.

7.3.8.2 Types of devices

Types of devices shall be appropriate for intended loadings and reasonably foreseeable use, content and process environments of boilers and pressure vessels.

7.3.8.3 System overpressure protection accessories

The design and construction of safety accessories, including pressure-limiting devices, temperature-limiting and monitoring devices, shall be suitable for their intended use.

7.4 Manufacture

7.4.1 Methods

Manufacturing methods and techniques shall be appropriate for all aspects of the fabrication process, considering degradation of materials from fabrication, heat treatment or forming, etc.

7.4.2 Identification of materials

Identification of materials used for boilers and pressure vessels shall be ensured through appropriate measures, like matching to mill certificates, positive material identification, etc.

7.4.3 Preparation of parts

Appropriate methods for preparation of parts (e.g. cutting and forming, etc.) shall be selected to assure that defects, such as cracks or detrimental changes in the mechanical and chemical characteristics, are avoided.

7.4.4 Welding

Appropriate welding processes shall be selected for materials to be used. Welded joints and adjacent zones shall be free of any surface or internal defects detrimental to production of adequate welds.

The mechanical properties of welded joints shall satisfy those specified for the materials to be welded, unless other relevant property values are specifically taken into account in the design calculations.

Suitably qualified welders using qualified welding procedures shall perform welding of pressure parts and non-pressure parts directly attached to pressure boundaries.

7.4.5 Welding-procedure qualification

Welding procedures used in production of boilers and pressure vessels shall be qualified by a competent third party or under an international or a national qualification scheme or in accordance with the manufacturer's quality programme. Qualification shall consider intended fabrication and operating conditions, such as materials, welding positions, etc., and shall include appropriate examination and tests.

7.4.6 Welder qualification

Welders engaged in production of boilers and pressure vessels shall be qualified by a competent third party or under an international or a national qualification scheme or in accordance with manufacturer's quality programme. Qualification shall consider intended fabrication conditions, such as materials, welding positions, etc., and shall include appropriate examination and tests.

7.4.7 Welder identification

Welders engaged in production of boilers and pressure vessels shall be identified.

7.4.8 Heat treatment

When there is a risk that the fabrication process can cause unacceptable changes in the properties of the material or weld, suitable heat treatment shall be applied at appropriate stage(s) of manufacture, such as cutting, forming and welding, etc.

7.4.9 Tolerances

Tolerances or ranges of welding grooves, weld reinforcement, dimensions and heat treatment shall be maintained at the appropriate stages of fabrication and on the finished boilers and pressure vessels.

7.5 Inspection, non-destructive testing and examination

7.5.1 General

Boilers and pressure vessels shall be examined for dimensional conformance and indications of imperfections by appropriate visual and non-destructive examinations.

7.5.2 Methods

Inspection and examination methods and any limitations shall consider material types, fabrication process, thickness, configuration, intended application, etc.

7.5.3 Procedures

Inspection and examination procedures shall be qualified by a recognized party or under a national qualification scheme or in accordance with the manufacturer's quality programme.

7.5.4 Personnel qualification

Inspection and examination personnel shall be qualified by a recognized party or under a national qualification scheme or in accordance with the manufacturer's quality programme.

7.5.5 Evaluation of indications and acceptance criteria

Criteria for evaluation of indications and acceptance criteria shall be consistent with material types and thicknesses, design factors and boilers and pressure vessels applications.

7.5.6 Disposition of unacceptable imperfections

Methods of dispositioning (sentencing) unacceptable imperfections in component shall be suitable for the intended design and application and shall not impair the boilers and pressure vessels. Methods may include repair, demonstrating fitness for purpose or rejection.

7.6 Final inspection and testing

7.6.1 Final inspection

Boilers and pressure vessels shall undergo a final inspection to assess visually and by review of the accompanying documents compliance with the requirements of the applicable standard. Tests carried out during manufacture may be taken into account. When practical, the final inspection shall be carried out internally and externally on every part of the boilers and pressure vessels; when access for a final inspection is not possible, appropriate inspections shall be made during the course of manufacture.

7.6.2 Final pressure test

Final assessment of boilers and pressure vessels shall include a test for pressure containment and, when necessary, beneficial pre-stressing. When possible, a hydrostatic test is recommended. When a hydrostatic pressure test is harmful or impractical, other tests of a recognized value may be employed. For tests other than the hydrostatic pressure test, additional measures, such as non-destructive tests or other methods of equivalent validity, shall be applied before those tests are carried out.

7.7 Marking/labelling

Required information shall be physically marked on boilers and pressure vessels in accordance with the applicable standard. As a minimum, the information shall include

— a unique identification number or type series identification,

— an indication of conformity,

— manufacturer’s identification,

— for pressure vessels the maximum allowable pressure(s) at coincident design temperature(s), and for boilers the maximum allowable pressure and design temperature at the boiler outlet.

When physical marking is not practical, alternative means are allowed such as records traceable to the boilers and pressure vessels or a suitable label attached to the boilers and pressure vessels.

8 Conformity assessment

Boilers and pressure vessels shall be constructed under a conformity assessment system agreed to by the parties concerned. A statement of conformity to the standard shall be supplied by the appropriate conformity assessment body or manufacturer.

Conformity assessment may be accomplished by one or a combination of the following systems:

a) **Manufacturer’s use of a quality management system:** Manufacturer’s use of a quality system commensurate with the type of boilers and pressure vessels being produced and the methods of design and manufacture;

b) **Third-party inspection:** Inspection performed by third-party inspection bodies;

c) **Inspection by users:** Inspection performed by users of boilers and pressure vessels;

d) **Certification of manufacturers:** Certification of manufacturers responsible for conformity. In this case, it is necessary to specify the certification programmes;

e) **Inspection by manufacturer:** Inspection performed by the manufacturer of the boilers and pressure vessels.

Annex A
(informative)

Description of some common failure modes and limit states

A.1 Failure modes

A.1.1 Brittle fracture

Prevention of this mode of failure under loadings of mainly static nature shall be the subject of specific requirements. Fracture toughness properties should be specified for the materials. Adequate heat treatment following forming and welding operations is important to prevent brittle fracture and this should be clearly defined by the standard. Similarly, where a vessel is operating at colder temperatures, the critical defect sizes permitted may be smaller than those at normal operating conditions.

Most standards specify a minimum temperature at which the hydrostatic test should be carried out.

A.1.2 Ductile failure

This failure mode should be taken into account for all loading conditions of boilers and pressure vessels. Ductile failure is due to unstable, gross plastic yielding resulting in unstable reduction of thickness or unstable crack growth.

Local plastic deformations that remain confined enough to exclude any risk of collapse are permitted by the design rules covering ductile failure, provided that the parent material and the welded areas have a sufficient plastic deformation capacity.

The concept of gross plastic deformation applies to the overall vessel pressure boundary. Under this condition, some sections or whole regions yield and no increase in load beyond this limit is possible. The mechanical characteristic relating to the resistance of the material against gross plastic deformation is the yield strength.

Plastic instability occurs under increasing loading, when after considerable yielding, the increase in strength of the material by work hardening can no longer compensate for the section reduction induced by the plastic deformation.

The mechanical characteristic relating to the resistance of the material against plastic instability is the tensile strength. The prevention of ductile failure is ensured by means of the same design rules, through the concept of nominal design stress that introduces a sufficient margin on yield strength as well as tensile strength, explicitly or implicitly.

NOTE When in the standard it is stated that a rule covers failure by gross plastic deformation, it implicitly means that it also covers failure by plastic instability.

A.1.3 Leakage at mechanical joints

Generally, the rules in a standard tend not to cover failure due to leakage at mechanical joints. However, there may be functional requirements, e.g. tightness, limitations with respect to deformation, gasket seating, etc., that are the subject of specific calculation rules or of particular construction provisions (i.e. tightness of bolted flange connections).

A.1.4 Buckling

This failure mode generally results from elastic or elastic-plastic instability under compressive stresses; certain specific rules of the standard, such as the design rules for shells under external pressure, torispherical vessel heads, etc., are based on it.

This failure mode shall be considered for all loading conditions for a vessel subject to compressive stresses. In order to prevent such a failure, checks should ensure that applied loadings do not exceed the loadings of the same nature that result in collapse, divided by a suitable design factor.

The method used shall take into account the possible geometric imperfections, within the limit of the values permitted by the standard.

A.1.5 Creep rupture

These modes of failure affect boilers and pressure vessels whose design temperature is high enough to lead to gradual material yielding under constant loading.

This mode of failure should be taken into account only under operating conditions, including temporary excursions that can be foreseen by the designer.

The nominal design stress is usually based on factor(s) applied to the creep rupture stress of the material. In some standards, a review may be required after 2/3 of the design life has been used.

A.1.6 Progressive plastic deformation (incremental collapse)

Failure by progressive plastic deformation can occur in boilers and pressure vessels subjected to combined loadings, some of which remaining fairly uniform, whereas others showing large cyclic variations.

It results in a cumulative increase in deformation under the action of these repeated variations. Where there is a risk of failure by instability, progressive plastic deformation increases this risk.

This failure mode shall be taken into account only for normal operating conditions. In practice, operating conditions leading to progressive plastic deformation are rare. The most commonly known case is thermal ratchetting, which can affect boilers and pressure vessels subjected to great periodic variations in temperature of the fluid contained, the pressure remaining constant or slightly variable.

The shakedown criterion (twice yield criterion) used in many standards covers the risk of failure by progressive plastic deformation. Fulfilling this criterion is usually sufficient but might not be necessary. A standard may give the manufacturer the possibility to justify the absence of failure by progressive plastic deformation using any other means.

Note When the shakedown criterion is not fulfilled, the most common result is alternating plasticity (low cycle fatigue) not progressive plastic deformation.

A.1.7 Fatigue cracking

Failure by fatigue cracking affects boilers and pressure vessels subject to variable loadings. This failure can occur for a fairly low number of cycles in regions where plastic deformation occurs at each cycle (alternating plasticity). It can also occur for a very large number of cycles in the elastic range, even when the stress range is small, e.g. in the case of vibrations, in stress concentration areas.

Fatigue cracking shall usually be taken into account only for normal operating conditions.

Special attention is necessary when fatigue loading occurs under creep conditions, as this can significantly reduce the permissible number of cycles.

A.1.8 Environmentally induced failure mechanisms

Wastage due to corrosion or erosion and failures due to environmentally induced cracking, etc., are often referred to in a standard but the method of addressing these is usually left to the designer.

A.2 Limit states

The limit state should be taken into account when considering any particular failure mode.

A limit state is defined as a structural condition when the design performance requirements are not met and is classified as either an ultimate or a serviceability limit state.

An ultimate limit state is a structural condition (of the component or vessel) associated with burst or collapse, or with other forms of structural failure that can endanger the safety of people, e.g. failure by gross plastic deformation, rupture caused by fatigue, collapse caused by instability of the vessel, or part of it, etc.

A serviceability limit state is a structural condition (of the component or vessel) beyond which the service criteria specified for the component are no longer met, e.g. deformation or deflection that adversely affects the use of boilers and pressure vessels, leakage that affects the efficient use of boilers and pressure vessels, but does not compromise safety or cause an unacceptable environmental hazard, etc.

Annex B
(informative)

Guidance on selection of standards

B.1 Purpose

The purpose of this annex is to describe the types of standards which are available and to give guidance on their selection. It is not the purpose of the annex to define how to select a particular standard, but to give an understanding of the issues to be considered when making a selection. It is also not the intent to recommend any specific standard for any particular application.

B.2 Background

Boilers and pressure-vessel standards result from the consensus distillation of experience, research and development. They have proven to be a successful means of ensuring optimal performance, safety, economy in trade and compliance with regulations.

One thing common to all standards is that they must address the various failure modes applicable to boilers and pressure vessels. This evaluation of failure modes can be carried out by different methods and some standards might not cover all potential failure modes.

Before specifying the use of a standard, there should be an awareness of the various failure modes that the standard being considered addresses.

B.3 Introduction

This annex contains information on the two main types of standards and the way in which they tend to address failure modes. The different design methods that may be applied are also described together with other aspects such as plant operation that it can be necessary to take into consideration.

In general, the responsibility for compliance of boilers or pressure vessels with a standard is with the manufacturer. However, the user or the contracting party is responsible for defining the service conditions and it is necessary that the potential failure modes be considered in the design. In addition, the user may also specify which standard should be used. The user, therefore, requires some basic knowledge of failure modes to understand how standards address these in order to ensure the operating conditions of the boilers and pressure vessels are adequately addressed.

The designer may mitigate against failure modes through a combination of design techniques, material selection, manufacturing features, levels of inspection and operation of boilers and pressure vessels.

B.4 Type of standards

Conceptually, there are two basic types of standards or system of standards; those that cover basic requirements and those that cover comprehensive requirements. In practice, most standards do not fit directly into one or other of these two types but the concept generally applies. In some cases, these two types can be combined in one standard, and, in other cases, a standard can lie somewhere between these two extremes.

A basic standard is applicable to boilers and pressure vessels planned for steady-state operational conditions (no rapid temperature changes, nominal load cycles, etc), where there is minimum design effort required, essentially based on mandatory equations for determining wall thicknesses, etc. In general, the failure modes are addressed by the use of limits that result in relatively low stresses when the loadings are applied and this also accommodates secondary effects, which are not considered in detail.

A comprehensive standard is applicable to both low-duty and severe-duty vessels. The allowable design stresses are relatively higher than those in a basic standard and a design assessment to address the applicable failure modes should be carried out by competent engineers. In this type of standard, there is usually detailed methodology directly addressing the failure modes that can result in the failure of boilers and pressure vessels.

In both cases, failure modes can be addressed through more than just design calculations, e.g. limitations on use of materials, welding techniques, heat treatment requirements, etc. Geometric features may also be specified to minimize the stress-concentration factors for cyclic loading or excessive local strains. The acceptable limits for non-destructive examination may also vary, depending on the failure modes being considered.

There is usually a level of involvement by a third-party inspection body, either inherent within the standard or specified by regulation, which may vary depending on the type and service of boilers and pressure vessels.

B.5 Design methods

The majority of standards cover failure modes through what is generally known as “design by rule” or “design by formulae” where prescriptive equations are applied to determine the shell thickness, compensation for nozzle openings, etc. These normally provide satisfactory designs for pressure loading of a typically non-cyclic nature. However, according to the criteria that are used when basic failure modes are assessed, a margin may exist permitting a certain number of operational fatigue cycles (e.g. 500 cycles based on experience) rather than have the standard directly address loads such as thermal cycling, rapid start-up and shutdown. Standards may provide different criteria according to the classification of load cases into normal operating conditions, occasional conditions and exceptional conditions.

Design by analysis may be used as an alternative or to supplement “design by rule” applications and it can be necessary to use it for cases not covered by the “design by rule” criteria e.g. significant fatigue, thermal transients, environmental loadings, etc. It may also be used in cases where the specified manufacturing tolerances are exceeded and require a more accurate evaluation of the stresses in a component.

There tends to be two methods by which design by analysis is applied.

a) The first is a design where specific failure modes are directly addressed and assessed against limit states, i.e. the structural condition beyond which the design performance requirements are not satisfied. This normally entails the investigation of a component’s safety under the influence of specified combinations of loading with respect to specified limit states. Such an approach was often used to develop the rules used in “design by rule,” particularly in those standards that are product-specific.

b) The second method, based on stress categories, involves the interpretation of stresses calculated on an elastic basis into primary, secondary and peak stresses at any point in a part of a vessel and then assess these against specified maximum allowable limits for each category and their combinations.

Primary stresses limits are used to protect against sustained loads leading to ductile failure and secondary stress limits are usually associated with loads that are self-limiting. Peak stresses are additional to primary and secondary stresses and are associated with stress concentration that requires a fatigue assessment.

Generally, a basic standard uses a “design by rule” methodology, whereas a comprehensive standard may include the “design by rule” methodology as well as one or both of the “design-by-analysis” approaches.

When “design by rule or analysis” methods do not fully address a unique configuration, experimental methods may be applied.

B.6 Selection of standards

In addition to taking into account probable failure modes, it can be necessary to consider other factors in the selection of a particular standard for any specific application.

These include aspects such as the following:

— manufacturer's familiarity with a specific standard;

— accreditation and competence of the manufacturer;

— level of involvement of the inspection body and any supplementary regulations required to enforce this;

— margins within a standard in terms of design and acceptance criteria;

— particularly arduous conditions that can necessitate the application of a comprehensive standard or additional precautions;

— risk management of critical equipment where assessments are made of hazards, feasible failure modes, likelihood of failure and consequences;

— failure analysis to help determine and identify probable failure causes, methods of avoiding repetition and possible improvements by innovation.

B.7 Product life cycle

The assessment and mitigation for failure modes might not be fully addressed in a standard, as these may be addressed by other means through the full life cycle of boilers and pressure vessels from design through to operation and maintenance. Although these are outside the scope of ISO 16528 (all parts) in that it does not address operation, maintenance and in-service inspection, they are included here for reference as they can influence the approach taken to addressing failure modes.

Aspects which should be taken into account include the following.

— Operation of boilers and pressure vessels under possible conditions where the specified design limits are exceeded, in which case the likelihood of failure by different modes can be seriously increased.

— Training of operators on the background of the various practices aimed at achieving safety of people and the plant and the protection of the environment through prevention of failures.

— In-service inspection to assess acceptability, avoidance or rectification of any degradation. Most countries have legislative requirements for inspection of boilers and pressure vessels though their life. The scope and frequency of this can mitigate the requirement for detailed analysis at the design stage. Conversely, the design analysis can indicate increased frequency of examination.

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