FATIGUE DESIGN RULES

Theoretical, Engineering and Experimental Validation Program

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1. Introduction

1.1. European Regulation (PED) and consequences

The essential safety requirements, to Design and Manufacture a European Pressure Equipment, laid down in this Directive [1] are **mandatory**. The obligations following from those essential safety requirements apply only if the corresponding hazard exists for the pressure equipment in question when it is used under conditions which are "reasonably foreseeable" by the manufacturer.

The manufacturer is under an obligation to analyze the hazards and risks in order to identify those which apply to his equipment on account of pressure; he shall then design and construct it taking account of his risk analysis

Pressure Equipment shall be designed for adequate strength associated to pressure loads **and for loadings appropriate to its intended use and other reasonably foreseeable operating conditions**. In particular, different degradation mechanisms shall be taken into account, as: fatigue, ratcheting, creep, creep-fatigue, corrosions, erosion…

Pressure equipment and assemblies below or equal to the limits set out in points (a), (b) and (c) of paragraph 1 and in paragraph 2 respectively shall be designed and manufactured in accordance with the sound engineering practice of a Member State in order to ensure safe use. Pressure equipment and assemblies shall be accompanied by **adequate instructions for use**. (Art. 4.3 of [1])

From PED [1] Annex 1: ESSENTIAL SAFETY REQUIREMENTS

1. *General*
   - *1.1. Pressure equipment shall be designed, manufactured and checked, and if applicable equipped and installed, in such a way as to ensure its safety when put into service in accordance with the manufacturer's instructions, or in reasonably foreseeable conditions.*
   - *1.2. In choosing the most appropriate solutions, the manufacturer shall apply the principles set out below in the following order:*
     - eliminate or reduce hazards as far as is reasonably practicable;
     - apply appropriate protection measures against hazards which cannot be eliminated;
     - where appropriate, inform users of residual hazards and indicate whether it is necessary to take appropriate special measures to reduce the risks at the time of installation and/or use

Consequently:

- some margins have to be justified in front of the **basic pressure equipment failure modes**, as: plastic collapse, plastic instability, local failure without crack, buckling, creep… at the Design Level
- **potential degradation** that can affect the pressure boundary has to be considered at the design stage: no thinning, no loss of material properties (material strength and toughness), no cracks, associated to do different degradation mechanisms, as fatigue, plastic shakedown, corrosions or thermal ageing….
- in some cases of user specification, the **"flaw tolerance"** of the pressure equipment has to be evaluated at design level to assure safe operation life of the equipment
- in operation, **a dedicated surveillance program** has to be developed by the Operator with In-Service Inspection, location, performance and frequency, associated to acceptance criteria; this operation activity is not covered directly by PED, generally through national regulation, nevertheless a part of these degradation analyses can be used in the Design hazards and risk analysis to develop the Instruction Notice.

1.2. Needs of standards or Harmonized European Rules

- assure "easy to use" Standards, sufficiently explained, justified, at the state of the art technical level
- assure European "competitiveness" with similar international standard to assure relevance of the Standard to assure safe and competitive PE operation
- anticipate "specific or future needs" of European Pressure Equipment industry on the future "Clean Energy" market and other innovative Pressure Equipment application.
- 2 specific topics have to be covered:

- Fitness For Service (FFS) with analyses rules of major PE degradations
- Risk Based Inspection (RBI) with proposed surveillance program associated to consequences of degradation (as operation time shutdown or loss of operation…) associated to reliability target.

2. Major Objectives of EPERC TG1

- help all the users of EN Design and Construction Standards on Pressure Equipment: EN 15492-15493 for Boilers, EN 13445 for Vessels and EN 13480 for Piping System to design pressure equipment and **perform Hazard and Risk Analyses** and develop the required **Instruction Notice**
- review format and content of existing international codes & standards for:
  - nuclear: ASME III- Division 1- NB- NC; ASME III- Division 1 NH or Division 5; RCC-M; RCC-MRx; JSME; PNAEG; KTA; KEPIC; CSA?; R5?
  - non-nuclear: ASME I; ASME VIII – Div 1- 2- 3; ASME B31-1 and B31-3; other B31; PD 5500; ADM 2000; API Standards; EN 12952 – EN 13445 – EN 13480
  - ISO design Standards
- collect all the references that support and justify all the proposal available inside the standards
- identified gaps and needs to remain competitive at the State Of the Art Level and to cover new needs associated to innovation use of Pressure Equipment (pressure, temperature, environment…),
- analyze all the uncertainties (methods, criteria and material properties) associated to Failure Modes and Degradation Mechanism considered
- propose improvement or new rules in a dedicated EPERC set of Reports to support a European Standard with R&D validation program and new rules proposal
- a dedicated topic has to be associated to PE reliability evaluation and probability of leak or failure
- propose a set of typical Benchmarks to assure applicability of the new standardized rules
- develop a dedicated Road Map for regular reviews of Project and Tasks advancement
- develop a set of practical examples on typical cases for the more complex rules
- Reports and knowledge dissemination closely connected, including participation to Workshop and Conferences, training courses or Master Class proposals…

3. Potential EU Research Support

A dedicated Report has been proposed by CEN-CENELEC:

- "How to Link Standardization with EU research projects" [2] can be found on www.cencenelec.eu/research .
- "Horizon 2020" December 2019 [3] on https://ec.europa.eu/programmes/horizon2020/en/background-material
- "Strategic Plan" December 2019 [4] on https://ec.europa.eu/info/files/strategic-planning-process-and-strategic-plan_en
- "Different CEN cooperation working products": ES, TS, TR, GU, CWA [5] https://www.cen.eu/work/products/cwa/pages/default.aspx

4. EPERC TG1 - Detailed Proposed Working Program

4.1. Project Introduction

The major objective is to consider how the Pressure Equipment and major accessories are design to fatigue by simple engineering codified rules, to help in margins understanding associated to major uncertainties on Methods, Data, Parameters and Material properties used in each analysis. Identification of essential variables for each Work Package will be covered.

4.2. Potential Topics

4.2.1. List of Codes considered for comparison (last published edition if possible)

4.2.1.1. Nuclear Codes

4.2.1.2. Non-nuclear Codes and ISO Standards

4.2.2. Review of major comparison topics

4.2.2.1. General Analysis method and Objectives

- Objectives of the Fatigue rules:
  - protection against small crack initiation / through wall crack
  - base metal / weld/ heat affected zone
  - different temperatures
  - different environments
  - different surface finished
- no creep condition
- Creep-Fatigue interaction (this report or another one with TG6 "Creep"???)
- no cracked equipment

4.2.3. Material Properties: base metal / welds

4.2.3.1. Thermo-mechanical properties: base metal / weld/ heat affected zone

4.2.3.2. Cyclic stress-strain curves

4.2.3.3. Fatigue curves: standards used, mean/design curves, different temperatures, air / other environments…

4.2.4. Strain/ Strength Evaluation

4.2.4.1. Equivalent stress: Tresca/ Von Mises/ Rankine

4.2.4.2. Cycle combination

4.2.4.3. Turning principal stress along a transient

4.2.4.4. Plasticity consideration (K_e, K_n, K_υ …)

4.2.5. Specific Cases

4.2.5.1. Fatigue Strength Reduction Factor for local discontinuity

4.2.5.2. Welds

4.2.5.3. Bolts

4.2.5.4. Crack like defects

4.2.6. Piping Fatigue Analysis

4.2.7. Support Fatigue Analysis

4.3. Codes Considered in the comparison

4.3.1. Nuclear Codes

4.3.1.1. ASME III- Division 1- NB- NC

4.3.1.2. ASME III- Division 1 NH or Division 5

4.3.1.3. RCC-M

4.3.1.4. RCC-MRx

4.3.1.5. JSME

4.3.1.6. PNAEG

- Task 3.2 : Strain or stress parameter
- Task 3.3 : Cycle combination
- Task 3.4 : Dynamic loads: seismic, safety valve discharged, fluctuations…
- Task 3.5 : Turning principal stress along a thermal transient
- Task 3.6 : Plasticity consideration (K_e, K_n, K_υ …)

5.4. Work Package 4: Particular cases

- Task 4.1 : Fatigue Strength Reduction Factor for local discontinuity
- Task 4.2 : Welds
- Task 4.3 : Bolts
- Task 4.4 : Crack like defects

5.5. Work Package 5: Piping Fatigue Analysis

- Task 5.1 : General rules and scope
- Task 5.2 : Fatigue Rules
- Task 5.3 : Stress indices

5.6. Work Package 6: Pumps and Valves

5.7. Work Package 7: Support Fatigue Analysis

5.8. Work Package 8: Benchmarks

- To be defined by TG 1 members, CEN TG and industry

5.9. Work Package 9: Recommended Practices and Code Cases

- Task 9.1 : for vessels
- Task 9.2 : for piping
- Task 9.3 : for other components

5.10. Work Package 10: Practical Examples

- To be defined by TG 1 members, CEN TG and industry

5.11. Work Package 11: Final Reports and Conclusion

Topics to be covered through contribution of different Work Packages:

1. Introduction and Definition
2. Existing Codes & Standards Synthesis
3. Gaps and Needs
4. Experimental Program: definition, performance, pre- and post-test analyses
5. Benchmarking
6. Code Case Proposal
7. Recommended Practices
8. Practical Examples
9. Knowledge Transfer
10. Program Synthesis and Conclusion

5.12. Work Package 12: Management, Synthesis and Conclusion of the Project

- Chairman and list of members
- Detailed "Roadmap" of R&D program and each tasks
- Periodic updated Planning and Roadmap review
- Report: review by Project members and selected International Key Actors of the domain

- All the documents of each Work Package will be released to: all the sponsors and EPERC TG1 members

6. EC proposal for TS, TR, Guides or CWA

6.1. Proposal preparation

These detailed description of the Work Package have to be filled up with TG7 members (or potential members) to prepare a CEN Committee proposal for a ES (European Standards), TS (Technical Specification), TR (Technical Reports), Gu (Guides) or CWA (CEN Workshop Agreement) (https://www.cen.eu/work/products/guides/Pages/default.aspx)

6.2. Detailed Work Package Developments

To be defined with TG1 members at the first TG1 meeting

6.2.1. Work Package 1: General Analysis method and Objectives

6.2.2. Work Package 2: Material Properties: base metal / welds

6.2.3. Work Package 3: Strain/ Strength Evaluation

6.2.4.

6.2.5. Work Package 4: Particular cases

6.2.6. Work Package 5: Piping Fatigue Analysis

6.2.7. Work Package 6: Pumps and Valves

6.2.8. Work Package 7: Support Fatigue Analysis

6.2.9. Work Package 8: Benchmarks

6.2.10. Work Package 9: Recommended Practices and Code Cases

6.2.11. Work Package 10: Practical Examples

6.2.12. Work Package 11: Final Reports and Conclusion

6.2.13. Work Package 12: Management, Synthesis and Conclusion of the Project

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(1) A **knowledge base** (**KB**) is a technology used to store complex structured and unstructured information used by a computer system. The initial use of the term was in connection with expert systems which were the first knowledge-based systems.
The term "knowledge-base" was coined to distinguish this form of knowledge store from the more common and widely used term database. At the time (the 1970's) virtually all large Management Information Systems stored their data in some type of hierarchical or relational database. At this point in the history of Information Technology, the distinction between a database and a knowledge base was clear and unambiguous.

https://en.wikipedia.org/wiki/Knowledge_base

6.3. Deliverables, planning and meetings

To be defined later with TG1 Chairman and Work Package Leaders…

A first SKYPE/TEAMS/WEBEX meeting with volunteers will take place before end of June 2020

6.4. Meetings and Preliminary Budget

6.4.1. TG1 Project Meetings

- To be defined later with TG1 Chairman and Work Package Leaders…
- Max of web-meetings: SKYPE or ZOOM video conference
  - At WP level
  - At TG1 Project level with TG1 Chairman and WP Leaders
  - 1 EPERC workshop per year

6.4.2. TG1 Budget

To be defined later with TG1 Chairman and Work Package Leaders…

7. References

1. DIRECTIVE 2014/68/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 May 2014 on the harmonization of the laws of the Member States relating to the "making available on the market of pressure equipment"
2. "How to Link Standardization with EU research projects" can be found on www.cencenelec.eu/research and https://www.cen.eu/work/products/cwa/pages/default.aspx
3. "Horizon 2020" December 2019 on https://ec.europa.eu/programmes/horizon2020/en/background-material
4. "Strategic Plan" December 2019 on https://ec.europa.eu/info/files/strategic-planning-process-and-strategic-plan_en
5. "Different CEN cooperation working products": ES, TS, TR, Gu, CWA https://www.cen.eu/work/products/cwa/pages/default.aspx