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Guidance For The Evaluation Of The Structural Integrity Of Pressure Equipment

*Walther Stikvoort
Principal Consultant Static Pressure Equipment and Structural Integrity
Wagnerlaan 37, 9402 SH, Assen, The Netherlands (NL)
**Corresponding Author: Walther Stikvoort*

ABSTRACT: *This article provides the user of pressure equipment (i.e. pressure vessels and piping) with a framework to evaluate the structural integrity of pressure retaining equipment or components in which defects are present. Defects could jeopardize the structural integrity of pressure equipment and thus its safety. The choice has been made for a design referring to generally accepted 'Fitness for Service' (FFS) codes and guidelines that have proven their reliability. During the manufacturing and operating phase of pressure-retaining components defects can arise. This can cause collapse when used in pressure equipment or have serious consequences for the environment. Failure due to defects can also have great financial consequences with regard to (temporarily) interrupting production processes in industrial installations. Fortunately, not all defects lead to a failure of the component or object. Replacing or repairing such defects is not always economically and technically justifiable and can even lead to the introduction of more and critical defects. A Fitness For Service (FSS) procedure, based on fracture mechanics and plastic failure analysis, offers the possibility to evaluate these defects in a validated manner. Well-founded decisions with respect to the remaining life, repair, replacement or adjustment of the operational load can therefore be taken.*
KEYWORDS: *pressure equipment, failure, defects, collapse, Fitness For Service (FSS), fracture mechanics, plastic failure analysis, structural integrity.*

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I. INTRODUCTION

An FFS analysis is a multidisciplinary method whereby damaged constructions are assessed for integrity and safety. The reason for this is clear: often the design does not take into account specific failure mechanisms and their effect on the integrity of an installation. Moreover, the conditions during operation are often different than during the design of an installation. An FFS analysis determines whether a component or piece of equipment is still suitable for the conditions for which it was originally designed. Moreover an FFS assessment provides a quantitative measure of the structural integrity of a component containing flaws. Failure mechanisms such as corrosion, fatigue or creep cause a degeneration of the strength of a structure. A finger on the wrist is therefore necessary in this. Before starting an FFS analysis, the status of the installation must first be mapped. Different disciplines are involved for this. We therefore speak of a multidisciplinary approach.

II. METHODS

The outcome of an FFS analysis is a 'go / no go' decision about whether or not to continue running an installation. Another analysis can be a so-called residual life-span analysis. In that case, the goal is to determine an inspection interval and / or determine the necessary changes to the equipment or operating conditions. Within the FFS procedures various specific methodologies have been developed to be able to make a statement about the integrity of an installation.
All FFS analyses can be performed at different levels of complexity. These are the level 1, 2 and 3 analyses.

Level 1

A level 1 analysis involves checking whether the construction is in accordance with the construction /design code. Performing this analysis does not require complex analyses and can be performed relatively quickly. The safety margin in this approach is therefore relatively large.

Level 2

A level 2 analysis means that there is less safety margin in the calculation. The calculations are more complex. Moreover, more data is needed to carry out this analysis. Depending on the failure mechanism, it may be that a finite element analysis is necessary (level 3 tool) to get a good result.

Level 3

A level 3 analysis is very specific. There is almost always a finite element analysis needed to get a reliable result. The level of expertise is also higher and more information is needed to carry out the analysis.

III. APPROACHES

A distinction can be made between deterministic and probabilistic structural integrity analyses. The latter is less conservative. The deterministic approach assumes that the parameters are single-valued whilst the probabilistic approach directly determine failure probabilities and make use of the statistical variation of the input parameters and hence require estimates of the statistical distributions of the variable input parameters.

IV. DEFINITIONS

Fitness for Service (FFS) is defined as the suitability for safe operations during the planned lifespan.
In addition, the following descriptions apply:

- A fitness for Service Procedure (FFSP) is a quantitative evaluation of the structural integrity of pressure equipment (components) in which defects are present or otherwise showing deviations from the original requirements, with due observance of the working loads to be provided within the planned lifetime.
- Fitness for Service (FSS) is also referred to as Fitness for Purpose (FFP) while Engineering Critical Assessment (ECA) is synonymous with Fitness for Service procedure (FFSP).
- Structural integrity is the safe design, assessment and operation of components and structures under load. It integrates aspects of stress analysis, material behaviour and the mechanisms of failure into the engineering design process.

IV. AIM FFS PROCEDURE

An FFS procedure is intended to assess structural integrity of metallic welded or non-welded structures transmitting loads. Demonstrated should be that the probability of failure due to operating conditions within the planned operating period or lifespan, including all foreseen failure causes and degradation mechanisms taken into account, will be acceptably small according to an agreed FFS standard.
As mentioned before, Fitness-For-Service (FFS) assessments are quantitative engineering evaluations to demonstrate the structural integrity of an in-service component that may contain a flaw or damage.

V. SCOPE FFS PROCEDURES

FFS codes and guidelines are not limited solely to the assessment of hypothetical (postulated) or current cracks in constructions, but also focus on wall thickness reduction due to corrosion and erosion. Attention is also paid to creep and fatigue symptoms.

VI. FEATURES

An essential aspect of an FFS analysis is the recognition of the interconnection of three characteristic elements, namely stresses (component loads), fracture toughness (material resistance) and defect size (in-service damage). These elements are visualized in figure 1.

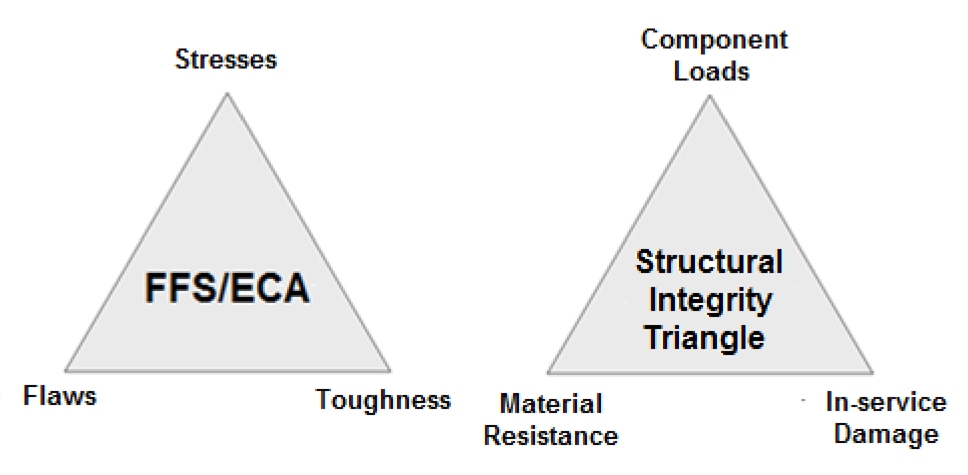

Figure 1: The so-called FFS and Structural Integrity triangles showing the parameters required for an ECA / FFS or structural integrity assessment

An FFS analysis combines the knowledge associated with strength related technical design aspects, fracture mechanics, metallurgy, corrosion and other degradation mechanisms, welding and other joining techniques, fabrication, inspection including destructive and non-destructive examination, installation and construction methods, operation and failure behaviour respectively failure consequences.

VII. PRACTICAL APPLICATIONS

The most common form of an FFS analysis concerns the assessment of defects in pressure equipment that exceed the applicable criteria according to the prevailing design code or standard.

An FFS analysis can be both applied and deployed during the manufacturing (installation) phase and during the operating phase. For a valid use of an FFS analysis for existing degraded equipment in the operating phase is subject to the condition that the degradation mechanism must be fully understood and that future further growth of defects must be predictable according to the agreed standard.

If abnormalities or unacceptable test results are found according to the requirements of the applicable code, then there is still the possibility to demonstrate the structural integrity with the aid of an appropriate and generally accepted FFS analysis.

VIII. GUIDELINES FOR FFS PROCEDURES

Commonly applied FFS codes or guidelines that can be applied to an FFS procedure include:

- BS 7910 [3]
- API 579-1 / ASME FFS-1 [4]
- FITNET (SINTAP) [1] [5] [7]

Prior to carrying out an FFS procedure, it is advisable to obtain agreement with the designated inspection or independent accredited authority on the approach and the starting points to be used and to establish this agreement in an agreed plan of action.

Comments

Consultation of [6] is recommended to assist with the execution of an FFS analysis. In addition, we would recommend the 'European Fitness For Service Procedure' developed by FITNET (FITness for service NETwork) in the execution of an FFS analysis [1] [7]. As a further guideline, the guideline 'Guidelines for Establishing Fitness for Purpose of Welded Constructions'[2] , drawn up under the auspices of NIL / PMP, is recommended.

Moreover it is strongly recommended to consult the workbook based on the European SINTAP/FITNET procedure entitled: "Fitness-for-Service Fracture Assessment of Structures Containing Cracks" which facilitate the use of fracture mechanics based failure assessment procedures for the evaluation and design of structures and components [8].

IX. DESTRUCTIVE AND NON-DESTRUCTIVE EXAMINATION ASPECTS

In general, FFS codes refer to standards that apply to destructive and non-destructive testing and research methods. The FFS expert (structural integrity specialist) must, in consultation with the materials and

NDE expert, establish the required material parameters and defect dimensions that are necessary as input for the FFS- procedure. It is important that they record a statement about the reliability of the assumed parameters and defect dimensions.

X. COMPETENCES

An FFS analysis must be carried out by an FFS expert with proven expertise in this specialist field. The FFS expert must be able to present an up-to-date overview of tracked courses, training and FFS analyzes carried out together with a concise analysis description and applied FFS codes. In the absence of proven expertise, the work must also be verified and approved by an authorized FFS expert. It must be realized that the records must be verifiable (auditable). Further requirements to be met by an FFS expert are described in the standards listed under "Guidelines for FFS procedures".

XI. SOFTWARE

Only validated software should be used for FFS analysis. Both input data and results must be verifiable. The results must be also presented in a format that can be tested against the applicable code or standard. The software to be used should preferably be accepted in advance by the authority in charge with the appraisal (i.e. Notified Body or independent accredited authority).
Examples of accepted software are:

- CrackWISE (BS 7910) and IntegriWISE (API 579-1 / ASME FFS-1); both developed by The Welding Institute (TWI)
- Becht FFS (API 579-1 / ASME FFS-1); developed by Becht Engineering Company

XII. CONCLUSIONS

Fracture mechanics principles, applied for the structural integrity assessment, provide an excellent tool to determine the defect tolerance of pressure equipment.
When evaluating the integrity of structures such as pipelines and pressure vessels, an ECA (i.e. a fitness-for-service procedure) enables the user to make informed and confident decisions on the most appropriate remedial measures to take.

An ECA is used to decide whether a given flaw is safe from brittle fracture, plastic collapse, fatigue crack growth or creep crack growth under specified loading conditions.
It can therefore be used:

- During design, to assist in the choice of welding procedure and/or inspection techniques.
- During fabrication, to assess:

a) the significance of known defects which are unacceptable to a given fabrication code; or
b) the maximum critical flaw size, minimum fracture toughness or maximum operating stresses.

- During operation, to assess flaws found in service and to make decisions as to whether they can safely remain, or whether down-rating, repair or replacement are necessary.

XIII. CLOSING REMARK

The safe use of FFS assessment must depend on having an adequate level of competency, training, information and support necessary to make technical judgements about potentially hazardous equipment.

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