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Correlation Methods of Verification and Validation for Well Control Equipment Systems

Ballot: 7048

STANDARD 16N

FIRST EDITION, XXX 202X

Ballot Draft

Correlation Methods of Verification and Validation for Well Control Equipment Systems

1 Scope

This standard establishes acceptance criteria for the correlation of strain gages to the testing of API riser tools, equipment, and drill-thru equipment. It also discusses guidelines for measurement and analysis methods. Other equipment outside of the scope of this document are not prohibited from using this document.

2 Terms, Definitions, and Abbreviations

2.1 Terms and Definitions

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

2.1.1

current equipment manufacturer CEM

Design owner or remanufacturer of the traceable current assembled equipment, single equipment unit, or component part.

NOTE The original equipment manufacturer (OEM) can be the current equipment manufacturer (CEM).

2.1.2

High stress area

High stress areas are defined by the OEM / CEM and are typically regions in the primary load path that see significant stress change due to the applied load.

2.1.3

Low stress area

Low stress areas are defined by the OEM / CEM and are typically regions not in the primary load path that do not see significant stress change due to the applied load.

2.1.4

Local peak stress

Highest stress in the region or component under consideration.

NOTE The basic characteristic of a peak stress is that it causes no significant distortion and is principally objectionable as a possible initiation site for a fatigue crack. These stresses are highly localized and occur at geometric discontinuities.

2.1.5

Manufacturer

OEM or CEM of the product or part.

2.1.6

original equipment manufacturer OEM

Design owner or manufacturer of the traceable assembled equipment, single equipment unit, or component part.

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2.1.7

Preload

Compressive bearing load developed between connections at their interface.

2.1.8

Primary load path

Distribution of loading through components whose failure would result in assembly separation due to the applied loading.

NOTE Examples are components that carry all or a major part of the tension in the riser.

2.1.9

Stress amplification factor

SAF

Ratio of the incremental change of local peak stress (maximum cyclic principal stress) to the corresponding incremental change of the reference stress used for fatigue analysis.

2.1.10

Stress load ratio

SLR

Ratio of the incremental change of local peak stress (maximum cyclic principal stress) to the corresponding incremental change in the global load (tension/compression or bending) used for fatigue analysis.

2.2 Abbreviations and Symbols

For the purposes of this document, the following abbreviations and symbols apply.

DIC	Digital Image Correlation
OEM	original equipment manufacturer
CEM	current equipment manufacturer
SAF	stress amplification factor
SLR	stress load ratio

3 Correlation Requirements

3.1 General

Strain gages shall be used to correlate calculated and measured values. Annex A contains a discussion of strain gage application and methods. Other methods, including those discussed in Annex B, shall be validated and proven for general use prior to being approved for correlation according to this document. Analysis methods used for correlation are discussed in Annex C.

3.2 Strain Gages

It shall be acceptable to use strain or stress to correlate calculated and measured values placement of gages and the decision of which gages to correlate to API criteria shall be determined by the OEM / CEM.

Strain should be correlated for testing if thermal expansion / contraction are encountered during testing. Zeroing gages after thermal loads are applied can help to minimize the effects of this behavior. Stresses may be used for correlation for ambient temperature testing without this concern.

High stress areas shall be considered correlated if the measurement is within $\pm 20\%$ of the calculation value.

$$\frac{\text{abs}(\text{Measured} - \text{Calculation})}{\text{Calculation}} * 100 \leq 20$$

Low stress areas shall be considered correlated if the difference between calculation and measurement is within $\pm 2\%$ of the specified minimum yield strength of the component.

$$\frac{\text{abs}(\text{Measured} - \text{Calculation})}{\sigma_{ymin}} * 100 \leq 2$$

Note: If strain is used to correlate for low stress areas, yield stress value to be converted to yield strain based on modulus of elasticity for allowable value calculation

Note: Strain gage correlation is intended for correlation of overall assembly behavior to analytical predictions. It is not intended to have correlation calculations for every part in the assembly tested unless otherwise specified.

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INFORMATIVE ANNEX A

4 Measurement Methods – Strain Gages

The placement of strain gages can be summarized by two groups:

1. Correlation strain gages
 - a. High stress correlation strain gages
 - b. Low stress correlation strain gages
2. Behavior strain gages
 - a. Placed in high gradient areas, areas with limited accessibility and potential for failure during test, areas affected by friction

One challenge with strain gage sensors is the variability in sensor results. Two gages, when placed in mirror image locations, on a symmetric component loaded evenly can result in significant strain gage differences due to errors in strain gage application, measurement systems, or other failures.

It is recommended to place more gages than required on the component in order to have sufficient data to identify failed gages, and have enough sensors to be able to accurately correlate with calculations. It is permissible to discard strain gage values based on engineering judgement. Examples of conditions causing erroneous strain gage values are erroneous equipment due to wiring, adhesion, locations where high gradient / variability due to contact or friction.

Another area in which strain gages can diverge from calculated values is in test method load application; if loads are applied with unintended side loading, or if the component differs slightly from analysis models (tolerance, ovality, perpendicularity, etc.).

If gages are placed in challenging areas such as the locking segments of a wellhead connector which can be affected by high strain gradient and those affected by friction variability, correlation may not be feasible but sensors can assist in observing overall assembly behavior.

Strain gages should be placed in areas of low stress gradient (continuous stress), and areas that are accessible or able to have gage wiring accessible for the measurement system.

INFORMATIVE ANNEX B

5 Optional Supplemental Measurement Methods

5.1 Optical Strain Measurement

Annex A describes DIC, which is a form of optical strain measurement. DIC measures the strain field on surfaces of the object that are visible to the cameras. The results can be presented as heatmaps or contour plots that are directly comparable to FEA results.

DIC can also be used to measure displacements of objects, relative movement of objects, and gaps between objects. DIC spatial resolution is determined by the size and spacing of the dots, the resolution of the cameras, and the field of view of the cameras. These parameters can be adjusted as needed to match the requirements of a test. DIC, strain measurement, and displacement measurement can occur simultaneously.

This standard does not specify acceptance criteria for strain measurements made using DIC.

DIC can resolve the strain field throughout an area of interest. This information can supplement strain gage and displacement results with information about the strain and displacement at locations where no strain gages or displacement transducers have been installed.

To get the most benefit from DIC, the user of correlation data should prepare a specification that states the objectives and performance requirements of the DIC portion of a testing program so that the provider of the DIC data can design the DIC data acquisition setup to meet them.

Where anomalous strain gage data or displacements occur, DIC can be used to support a determination about the credibility of the strain gage or displacement data. DIC can be used to support a determination about the alignment of FEA boundary conditions with test conditions. If a credible DIC result contradicts strain gage results, the two results should be reconciled.

NOTE: Either method can resolve a high strain gradient better than the other in specific cases. For example, DIC that has been designed to resolve a strain field that is much (orders of magnitude) larger than a strain gage or has dot spacing that is larger than a strain gage might fail to resolve a peak strain that a strain gage could resolve. On the other hand, it is possible for DIC that has been designed to resolve strain in a relatively small area to resolve peaks in the strain field that are too localized for a strain gage to resolve.

5.2 Linear Voltage (LVDT)

LVDTs are used to observe overall assembly behavior with respect to loads. If used, LVDTs should be used in coordination with another measurement method that measures stresses / strains.

For the purpose of this document, there is no set acceptance criteria for LVDTs.

LVDTs can be used to measure assembly behavior of a complex system as a response to applied loading. LVDTs are regularly used in concert with another measurement method (strain gages etc.) in order to gain additional understanding of assembly behavior and increase confidence in calculated vs measured behavior.

An example of LVDT usage is to capture separation distance / liftoff behavior with respect to preload for a hydraulic connector. Strain gages may not be able to be placed in critical regions (locking profile, piston) to understand preload or stress state during applied loading, however using LVDTs to

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measure displacement of the hydraulic connector can provide an understanding of how accurate the calculated preload is to actual. This can then assist the OEM/CEM in refining friction modeling / preload behavior to improve calculated methods for correlation.

Another example of LVDT use is in observing separation distance near wellbore seals (BX / OEC gaskets), and establishing a serviceability criteria based on the separation distance.

5.3 Ultrasonic Measurement of Bolting

Ultrasonic measurement is used to measure bolt preload and bolt stress during loading by observing the change in length of a bolt. This method has benefits of using existing bolting without modification to the OD of the bolt for application of a strain gage, and avoids concerns of wiring access or potential strain gage damage.

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INFORMATIVE ANNEX C

6 Analysis Methods

Correlation testing has two primary objectives: to verify any assumptions made about preloading, separation behavior, friction coefficients, structural material response, and boundary conditions and to substantiate the analytical stress predictions.

Analysis models should be similar to models used for other API assessments (strength calculations, SAF / SLR calculations etc.) in order to confirm modeling practices accurately reflect actual component behavior.

Examples of changes to tested equipment include using pup joints instead of full length riser joints, using mandrels instead of wellheads, and changes to end connections (blind flanges etc.) to allow load application.

Additional discussion related to validation of FEA is provided in ASME V&V 10, *Guide for Verification and Validation in Computational Solid Mechanics*.

6.1 FEA

Changes to the model to properly simulate the tested equipment, loading application, boundary conditions, and test setup are appropriate. Overall model behavior (2d / 3d, contact vs tied connections, level of detail) should be the same as the FEA model used for other calculations.

Care should be taken to refine the mesh in regions of a strain gage or other measurement application in order to have more accurate local values at measured locations.

6.2 Arithmetic Calculations

When performing calculations for strain gage correlation, care should be taken to properly simulate the tested equipment and accurately model the loading, boundary conditions, and test setup.

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7 Bibliography

ASME V&V Guide for Verification and Validation in Computational Solid Mechanics

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