The revised standard VGB-S-506 for condition monitoring and inspection of pressurized components

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Fit for Future – Advances in Materials, Manufacturing and Assessment

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Standard VGB-S-506
Outline

- Background/Initiative
- Content of the standard
- What is new?
- Condition monitoring modules & Condition assessment
- Which methods are described?
- The RBI application example
- Summary/Conclusion

Source: EnBW AG
A technical working group of members from the technical association VGB PowerTech e.V. describes in a document traditional and innovative methods for condition monitoring and inspection with emphasis on components from steam boiler plant, pressure vessels installations and steam pipelines, with due respect of possible hazards caused by steam and pressure.

This document aims to provide guidance for implementing a method to improve the inspection planning process with respect to the actual (national) regulations and technical rules.
Standard VGB-S-506

Content

- **Introduction**
  Scope of application and objective of the guideline

- **Condition monitoring modules**
  Explanation of modules for condition monitoring and expert tools for condition assessment

- **Test and inspections**
  Inspection period and scope
  Instructions for inspection in the context of assessment/technical safety assessment

- **Appendix**
  Information to expert tools and application examples

Condition monitoring includes the following aspects:

- **Design and calculation**
- **Documented Quality**
- **Condition monitoring/diagnostics during operation**
- **Condition monitoring/diagnostics during shutdown**

- **Condition assessment with measures e.g. concerning the inspection concept**

Decisive for extension of inspection period!
With respect to the last edition the following essential changes were made:

➤ Adjustments to the current rules and standards

➤ Supplementations:
  - Information which requirements to be set in contracts regarding documented quality
  - Selection of highly loaded components
  - Implementation of further alternative methods for condition assessment
    (Periodic lifetime monitoring based on technical rules/code, the fast fatigue evaluation method and the fracture-mechanics based method of damage tolerance analysis)
  - New chapter to test and inspections prior to restart upon changes on pressure equipment subject to supervision
  - Templates for documentation of a test and inspection concept to be submitted by the employer

➤ Revisions:
  - Chapter probabilistic methods and Appendix with RBI application example to DIN EN 16991:2018
  - Periodic inspections of pressure vessel installations and their components subject to supervision
Depending on pressure, temperature and mode of operation, power plant components are subject to life consumption. The damage concept in this guideline comprises e.g. the following aspects:

- Microstructural changes which are associated to a reduction of the material parameters used for the design, including a reduction of toughness;
- The formation of creep pores, micro-cracks and cracks which change the local stress conditions and thus lead to deviations from the stress condition assumed in the design;
- Material fatigue (microplastic processes and changes in the microstructure of the material) due to cyclic mechanical and/or thermal loadings, cyclic external influences;
- Reactions of the material with the environment (corrosion, oxidation, erosion) which lead to a local weakening (wall thickness reduction, crack formation) or to deviations from the design parameters (temperature, gradients).

If not specified different: Service life consumption refers to a linear accumulation of creep and fatigue damage!
Condition monitoring process

- shall be selected according to the existing or the expected damage mechanisms or hazards
- shall be adequately assessed with respect to the covered extent of plant monitoring and monitoring time

Examples suitable for condition assessment and, according to the technical situation, may be carried out individually or in combination:

- Statistical methods
- Probabilistic methods
  - RBIF [DIN EN 16991:2018] with strategies RCM & RBI
  - Expert methods
- Periodic lifetime monitoring based on technical rules (code based)
- Fast Fatigue Evaluation (FFE)
- Detailed inelastic analysis
- Fracture-mechanics based method of damage tolerance analysis

Results and conclusions concerning extent, content and period of tests and inspections shall be documented in a comprehensible manner during operation.
Standard VGB-S-506
Knowledge about condition

Condition monitoring modules for boiler, pressure vessels and piping

- **Design and calculation**
- **Documented quality**
- **Condition monitoring / diagnostics during operation**
- **Condition monitoring / diagnostics during shutdown**
- **Condition assessment (Expert methods)**

**Code based:**
- DIN EN 12952-4 [TRD 301/508]
- VGB-R 509 L
- äP, iP, DP
- DIN EN 12953
- VGB-R 171
  - Manufacturing: VGB-S 013
  - VGB-R 507 L
  - VGB-R 508 L
  - VGB-R 510 L
  - VGB-S 110
- DIN EN 13445
- DIN EN 13480
- AD2000
- (TRB, TRD, TRR, etc.)
- VGB Standards and Guidelines, e.g.
  - VGB-S-013

**Advanced**
- Forces
- Dislocations
- Strains
- Unbalanced temperatures
- 2-Phase-flow
- ...

**Operation:**
- NDT
- Maintenance
- Damages
- äP, iP, DP

**Visual tests**
- NDT
- VGB-R 509 L
- äP, iP, DP
- DIN EN 12952
- (BetrSichV §15, TRBS)
- Functional tests
- TRBS 1201

- Statistical methods
- Probabilistic methods
  - RBIF
  - Expert methods
- Periodic lifetime monitoring based on technical rules
- Fast Fatigue Evaluation (FFE)
- Detailed inelastic analysis
- Fracture-mechanics based method of damage tolerance analysis
Design is fundamental basis for condition monitoring.

Dimensioning is set forth in respective regulations e.g. harmonized standards (DIN EN 12952, DIN EN 12953, DIN EN 13445 or DIN EN 13480) or according to AD 2000, (TRB, TRD, TRR) and –if contracted- with consideration of VGB Standards and Guidelines or company specific requirements.

Mixing and mingling of regulation has to be avoided \(\Rightarrow\) consistent philosophy.

The system analysis forms a model of the real system, and its quality depends on the details and quality of its entries. The following factors are important for its quality:

- Definition and time for intended operation
- Consideration of additional stress which cannot be avoided

During the subsequent operation, the design as intended should be compared at relevant places to the actual geometrical and process values and to the existing forces e.g. at supports as well as displacements of the pressurized pipes.

A significant component of the design is the hazard analysis. The additional submission of the hazard analysis is should be agreed under private law.
Standard VGB-S-506
Condition monitoring modules – Documented quality

- Distinguish between fabrication (manufacturing) and operation, basic make-up is given in VGB Guideline 171
In addition the following documentation for pressurized pipes (outside boiler) of steam generators is to be provided under private law e. g.:

- Design documents
- Complete strength and elasticity calculations with corresponding drawing
- Material certifications for all semi-finished products used, complete with all reports on non-destructive testing (NDT)
- Reports on annealing and heat treatments
- List of type and position of weld seams
- Working instructions and welding certificates for the completed weld seams
- Material certifications for the filler materials
- Reports on settings of constant and spring hangers
- .....
Periodic inspections and operation

In general the following documentation on periodic inspections is necessary for condition monitoring:

- NDT reports with findings
- NDT reports with results which are used for comparison for subsequent tests (e.g. replica, radiographic testing)
- Reports on external, internal and strength tests (pressure tests)
- Reports on position and operation checks of pipe hangers in hot-cold-hot condition with commentaries on possible maintenance adjustment works of the examined system

Continuous records of the operating states by means of temperature and pressure records which are the basis for the calculation of the life-time consumption.

Overhaul

Overhauls have to be carried out according to the requirement of the condition of the installation, of which a comprehensible documentation must be drawn up. The documentation a pressure of equipment must also contain e.g. the material certification and manufacturing records of parts of the pressurized casing.
The following loads and associated damage mechanisms should be described:

<table>
<thead>
<tr>
<th>Loading/damage mechanism</th>
<th>Possible parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Static loading/creep damage</td>
<td>Pressure, temperature, actual dimensions, material parameters</td>
</tr>
<tr>
<td>2 Unsteady loading/fatigue due to cyclic loading</td>
<td>Wall temperature difference, pressure and temperature transients, actual dimensions, material parameters, number of load cycles (cold, warm or hot start-ups)</td>
</tr>
<tr>
<td>3 Additional loadings deriving from the mode of operation</td>
<td>Medium temperatures, surface wall temperatures, flow rates and temperatures of spray-attemperation water</td>
</tr>
<tr>
<td>(e.g. temperature asymmetries, 2-phase flow, spray attemperation, inadequate drainage)</td>
<td></td>
</tr>
<tr>
<td>4 Other additional loads (e.g. change of position, restrained thermal expansion)</td>
<td>Forces on fixed points, movements of hangers and springs, movements of the boiler plant</td>
</tr>
<tr>
<td>5 Medium/oxidation, erosion, corrosion</td>
<td>Feedwater, fuels</td>
</tr>
</tbody>
</table>
Periodic inspections on the example of piping systems

- Visual inspections and Non-destructive materials testing are described e.g. in VGB Guideline 509 L
  - for piping components with operation under creep condition and with design of hot yield strength
  - for special component tests such as metallography or replication
    - VGB-S-517 “Guidelines for rating the microstructural composition and creep rupture damage of creep-resistant steel for high pressure pipelines and boiler components and their weld connections”
  - for tests on special components like hot steam injection cooler, fold pipe bend, compensators, not constantly flowed lines etc.
  - with references to modern monitoring systems on pipelines (measurement of forces and displacements for system evaluation)

Functional tests

- According to TRBS 1201 (technical standards for plant safety) functional tests are demanded for safety systems, process control and equipment.
The following 178 components of the main steam line were specifically be assessed:

- 80HAH80 super heater 4 outlet header
- 80LBA01 BR010 (16 welds, 8 bends, 8 straight pipes, orifice)
- 80LBA02 BR010 (16 welds, 8 bends, 6 straight pipes, orifice)
- 80LBA03 BR010 (6 welds, 4 fittings, 3 straight pipes)
- 80LBA04 BR010 (15 welds, 6 bends, 7 straight pipes, main steam gate valve)
- 80LBA05 BR010 (14 welds, 7 bends, 5 straight pipes, main steam gate valve)
- 80LBA11 BR010 (6 welds, 7 bends)
- 80LBA12 BR010 (8 welds, 8 bends)
- 80LBA13 BR010 (7 welds, 7 bends, 1 straight pipe)
RBI Input data:

› Knowledge gained from component manufacturing (documented quality)
› Component geometry (as built) and material data /certificate
› Design and operating data (start-ups, temperature, pressure,...)
› Inspection reports (NDT, e.g. Replication) – performed to satisfy requirements of applicable rules/directives
› Maintenance and repair documents
› Determination of the consumption from creep damage and fatigue loads (TRD 301/508 , today DIN EN 12952-4), damage accumulation

The extensive data base was set up with involvement of the accepted body (ZÜS).
Risk of selected components was determined by iteration at various levels of detail by the RBI team:

Level 1 – simplified screening analysis:

- Start condition for risk ranking:
  GFF: conservative assumption by RBI team
  GCC: derived from literature (statistics, e.g. VGB TW 104)
- Modified by factors of influence which will be determined by the RBI team assessment catalogues
- GFF: 4 factors concerning damage statistics, design, operating conditions, and inspections
- GCC: 3 factors concerning safety/health, environment and economic efficiency (highest risk level is used)

Level 2:

- Procedure corresponds to Level 1
  GFF: 25 factors
  GCC 9 factors
- Assessment by the RBI team will be performed in a clearly more detailed manner

GFF=Generic Failure Frequency
GCC=Generic Consequence Class
For the purpose of visualization the results from Level 2 assessment were transmitted into the geometric overview.

The measures in the RBIM plan will be updated in correspondence with the RBI results of the components.

The main results are in compliance with following principles:

› Statutory regulations; Ordinance on occupational safety and health (BetrSichV), TRBS 2141

› ISO 31000:2009

› DIN EN ISO 12100:2010

› CEN CWA 15740 (RIMAP)

› DIN EN 16991:2018

… and compatible with current relevant practice of the operator

… and with the position of ZÜS

e.g. life steam system
80LBA01 BR010
RBI is defined as risk assessment and management process to plan, implement and evaluate inspections in a structured and documented way (=> Risk=PoF x CoF). One of the main goals of RBI/RBM has been to make inspection and maintenance programs more cost-efficient while, at the same time, safety, health, and environmental performance is maintained or improved.

**Risk Map**

Reduce frequency of failure or the degradation of the functioning of an item

*Inspection strategy & Optimization of repair time and spare part stock (Preventive/Predictive Maintenance)*

Reduce Maintenance & Inspection

*Run-to-failure strategy (Reactive/Corrective Maintenance)*

Reduce number of weak points

*Optimization/Improvement strategy (Advanced monitoring & diagnose, extensive inspection, remnant life assessment, replace/repair,...)*

Reduce consequence of failure

*Repair-/Replacement strategy (Total Productive Maintenance, Condition Based Maintenance)*

**Risk Map**

- **A**: negligible
- **B**: low
- **C**: medium
- **D**: high
- **E**: very high

**Consequence of failure**

- **1**: negligible
- **2**: low
- **3**: medium
- **4**: high

**Probability of failure**

- **1**: negligible
- **2**: low
- **3**: medium
- **4**: high
- **5**: very high
Standard VGB-S-506
Conclusion

- The revised VGB-Standard taken into account the current landscape of directives, technical regulations/rules and standards
- New examples/methods suitable for condition assessment have been included
- Consistent application leads to higher availability of the considered systems
- Fundamental avoidance of monetary significant events (damage, failure)

Benefits regarding RBI as one of the proposed methods for condition assessment and inspection concept

- Transparency, traceability in decision-making
- Optimized test program, targeted component investigations, unnecessary inspections can be avoided
  -> Risk development of the components for multi-year planning of maintenance expenses, etc
- Consistent application leads to higher availability of the considered systems
- Fundamental avoidance of monetary significant events (damage, failure)
The persons involved in the establishment of this revised VGB Standard:
TG “Condition monitoring and inspection“
- Dr. Mario Arnold (STEAG Energy Services GmbH)
- Dr. Jörg Bareiß, Patrick Buhl (EnBW AG)
- Olaf Baumann, Jens Ganswind (VGB PowerTech e.V.)
- Christoph Bolte (STEAG GmbH)
- Tino Fischbeck (RWE Technology International GmbH)
- Jens Hälbig, Dr. Martin Widera (RWE Power AG)
- Thomas Hansen (BASF SE)
- Dr. Klaus Metzger (GKM AG)
- Renato Rachel (LEAG)
- Heinz-Peter Schmitz (Translation of this Standard into English)

The persons give special contributions to the methods of condition assessment:
- S. Bergholz, Framatome GmbH
- Prof. A. Jovanovic, Steinbeis Advanced Risk Technologies
- A. Schulz, TÜV Nord Systems GmbH & Co. KG
- J. Wasseveld, TÜV Rheinland Werkstoffprüfung

for their remarks and comments on the draft of the revised VGB Standard
Thank you for your attention!
5. VGB WORKSHOP

„ZUSTANDSÜBERWACHUNG UND PRÜFUNG VON PRÜFFLICHTIGEN DRUCKANLAGEN“


Programmänderungen vorbehalten


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<th>Zeit</th>
<th>Vortragende</th>
<th>Themen</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:00</td>
<td>G. Baumann</td>
<td>Begrüßung</td>
</tr>
<tr>
<td>10:10</td>
<td>V1</td>
<td>Einführung (Anforderungen der BetSichV, TRBS 1201-2, Gliederung VGB-506)</td>
</tr>
<tr>
<td>10:30</td>
<td>V2</td>
<td>Inbetriebnahmeprüfung an Druckanlagen (VGB-506, Bauausgabe)</td>
</tr>
<tr>
<td>10:50</td>
<td>V3</td>
<td>Wiederauflösende Prüfungen an Druckanlagen (VGB-506, Anlagenprüfung)</td>
</tr>
<tr>
<td>11:20</td>
<td>V4</td>
<td>Einfluss der Betriebsumwelt auf Zeitstandbeanspruchung und Ermüdung</td>
</tr>
<tr>
<td>11:40</td>
<td>V5</td>
<td>Zustandsüberwachung Einführung, Voraussetzungen z.B. Dokumentation, Bausteine der Zustandsüberwachung (Überblick), Einbindung ZSD</td>
</tr>
<tr>
<td>12:00</td>
<td>V6</td>
<td>Verlängerte Prüfzeiten (Voraussetzungen, Erfahrungen)</td>
</tr>
<tr>
<td>12:30</td>
<td>V7</td>
<td>Mittagspause</td>
</tr>
<tr>
<td>13:30</td>
<td>V8</td>
<td>Risikobasierte Inspektion nach EN 16991 (RIBA)</td>
</tr>
<tr>
<td>14:00</td>
<td>V9</td>
<td>Druckbeaufschlagte Schadensbehebungsanleitungen (THERI-Methodik)</td>
</tr>
</tbody>
</table>

Lebensdauerberechnungsverfahren „fast fatiguelle Evaluation“ (FAME-Methode)
S. Bergholz, Framatome GmbH, Erlangen
Kaffeepause
Wirtschaftlich optimierte Kombination von Offline- und Online-Lebensdauerüberwachung an druckbeanspruchten Hochtemperaturkomponenten
J. Wassel, TÜV Rheinland Werkstoffprüfung GmbH, Köln
Engineering Informationen zur Zustandsüberwachung aus elastische FE-Analysen
D. A. Klen, MPA Stuttgart
Abschlussdiskussion
Ende der Veranstaltung