Online Diagnostics of Steam Pipes and Thick-Walled Boiler Components - A Comparison of Methods Based on Operational Experience

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1. Challenges in the field of condition monitoring

The operation and the monitoring of highly stressed pipes and thick-walled boiler components are facing new challenges. Owing to the European Union, the legislation on the production and the operation of the components of pressure equipment is subject to sometimes significant changes Europe-wide. In Germany, the condition monitoring of affected equipment is regulated by the Pressure Equipment Directive that has been introduced into German law as the Pressure Equipment Act (14. GPSGV). [1] The work safety directives are the minimum requirement for the field of the operation. In Germany, these are implemented according to the Ordinance on Industrial Safety and Health (BetrSichV) and amended by changes in the technical set of rules. The field of condition monitoring is to be newly considered in order to make full use of the extended scope of action provided for by the Ordinance on Industrial Safety and Health and the TRBS (Technical Rules for Operational Safety) as a power plant operator. [1]

What does that mean in concrete terms? Paragraph 15, Section 5 of the Ordinance on Industrial Safety and Health stipulates maximum intervals for certain plant components, which can be extended in coordination with the responsible authority and the approved inspection body (ZÜS), which can now be freely chosen (cf. Ordinance on Industrial Safety and Health § 15, Section 17). VGB Guideline 506 describes an “action plan in the form of several modules for designing the inspections. Based on the modules selected by the operator, an effective design of the inspection of components […] including an extension of the inspection interval (cf. VGB-R 104 O) [is] possible.” [1] In the area of the steam generator, it is conceivable to extend the inspection intervals for internal inspections required by law from three to five years. In the case of new plants, the extension of the inspection intervals can, where appropriate, already be applied for along with the licensing (see VGB Guideline R 104 O) – provided that the operational safety can be adequately guaranteed. [1,2]

In addition, sites are facing the challenge to adequately counteract the drain of know-how caused by increasingly frequent task switching and to preserve operational experience and incidents for an operating time of more than 200,000 hours.

The following aspect mainly bothers operators of new plants. Due to high live steam parameters, new materials are used in modern steam generators, the strength characteristics of which are partially available in extrapolated form only. Thus it is easily conceivable that later corrections to the material values necessitate an up- or downgrading of the fatigue result of the components.

For conventional power plants, it becomes increasingly necessary to be able to react more flexibly to load changes in the national grid. For existing plants, this may require more frequent start-ups and shutdowns than had originally been taken as a basis in the course of the design. The additional alternating stress of the components has to be recorded and evaluated.

In total, the changed underlying circumstances for the condition monitoring require new methods and instruments. In the following, the use of online systems shall be explained on the basis of present operating experience.

2. Online systems as a central element of condition monitoring

On the basis of VGB Guideline 506, condition monitoring can be subdivided into the following parts:

Design
Definition and chronology of the intended operation and consideration of unavoidable additional stresses

Documented quality
All relevant documentation from the production and operation of the components (complete design documentation, material certificates, dimension records, non-destructive testing records, calibration records, technical modifications, etc.)

Diagnosis during operation
Determining the static and non-steady-state stress (e.g. by dead weight, creep damage and alternating stress, additional forces)

Diagnosis in the course of a shutdown
External and internal inspections

Condition assessment
Assessing the condition of the component in order to be able to subsequently determine required inspection and maintenance measures having regard to the aforementioned sources

In Chapter 5.6 (Issue 2009), VGB-R 506 describes two procedures that exceed the approach practiced in the past and represent a significant improvement over time-based maintenance cycles in terms of the condition-oriented maintenance strategy regarding economic efficiency and operational safety. The online system SR::SPM (SPM = steam pipe monitoring) of the company Evonik Energy Services GmbH follows Procedure 2 of the guideline (see Chapter 3).

By means of a central data acquisition, data archiving, and continuous calculations, online systems fully meet the requirements to the *diagnosis during operation*. Operating conditions can be assessed directly and chronological events of the condition can be traced historically. In addition, such systems are suited for the managing and linking of relevant documents, like e.g. as-built dimension records, calibration records, and material certificates. Technical modifications can be considered directly in the system and included in the further monitoring. In short: The *documented quality* is ensured.

3. Procedure for monitoring pipe stress

Due to high operating temperatures, expansions occur in the area of the highly stressed pipes that can be measured and have an impact on the stress of the pipe. As a general rule, the higher the stress, the shorter is the service life. For a quantitative determination of the residual service life, stresses have to be determined from the movements and the measured support reactions, respectively.

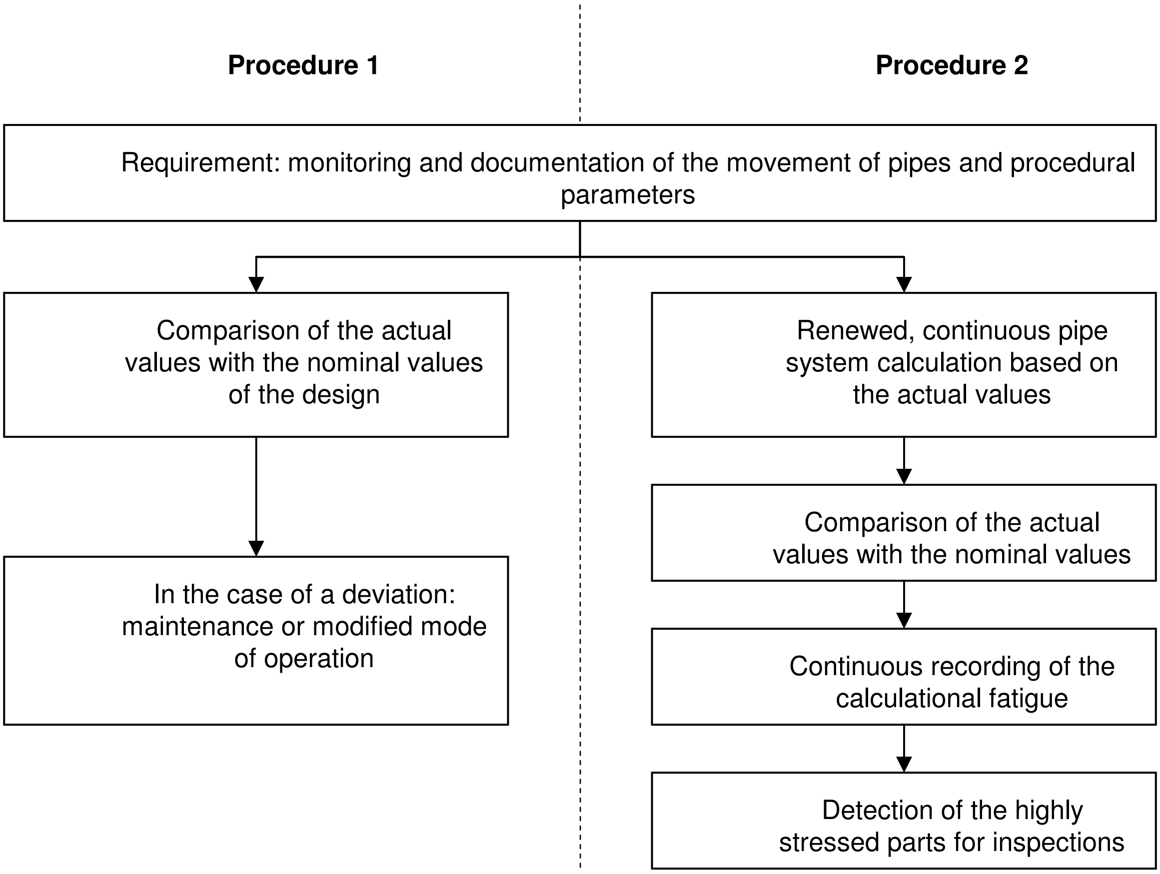
In Chapter 5.6, VGB Guideline R 506 describes two suitable procedures for the condition monitoring of pipes that exceed the requirements of the set of regulations and, based on a modeling of the pipe, determine the stress variables. Both procedures require a continuous metrological recording of forces and displacements at selected hangers and supports of the pipe.

Procedure 1
The functional interrelationship between movements/support reactions to stresses or strains is derived from similarity relationships. These relationships are determined during the planning stage of the pipe. When the measured actual values correlate with the nominal values of the design, the regular operation can be derived.

However, a reliable statement about the actual calculational degree of fatigue can only be made if the intended operation is adhered to. If a behavior deviating from this exists (e.g. jamming, fouling of constant hangers) which had not been considered during the planning phase, the occurring stresses have to be determined by means of complex offline recalculations.

Procedure 2

The functional interrelationship between movements/forces to stresses is not derived from similarity relationships, but determined by continuous pipe system calculations. In certain time intervals (e.g. five minutes), the monitored quantities (pressure, temperature, forces and displacements) enter into the simulation as boundary condition of the calculation. "This approach, expanded compared to Procedure 1, allows to collect pipe conditions that were not plannable or had not been expected prior to commissioning ." [1]



4. Pipe monitoring SR::SPM

The system SR::SPM follows Procedure 2 described above and is used for the continuous monitoring and calculation of highly stressed pipes (e.g. live steam and hot reheat). The stress of the pipe is recorded, besides the parameters of pressure and temperature, additionally by means of force and displacement measurements installed along the pipe in horizontal and vertical direction. The measured values enter as boundary condition into a complete pipe system calculation by means of the pipe statics program ROHR2. The ROHR2 model represents the complete course of the piping system and has been integrated into SR::SPM and qualified for the online calculation (e.g. every five to 15 minutes) (Fig. 2). The nominal stress of the pipe is determined considering pressure and temperature and is compared to the actual load based on the measured forces and displacements. Effective additional loads are thus determined with their effects (stress from external load and restrained thermal expansion). By means of the continuous complete pipe system calculations, also such modes of operation are considered that could not be predicted prior to commissioning – e.g. caused by the jamming of a constant hanger.

The additionally effective moments enter into the primary and secondary stress assessment and thus into the fatigue calculation together with the actual geometry of the pipe bends (wall thicknesses, diameter, ovality). The calculation of the creep damage is largely oriented towards the specifications of DIN EN 12952-4, additionally considering the external moments and as-built geometries.

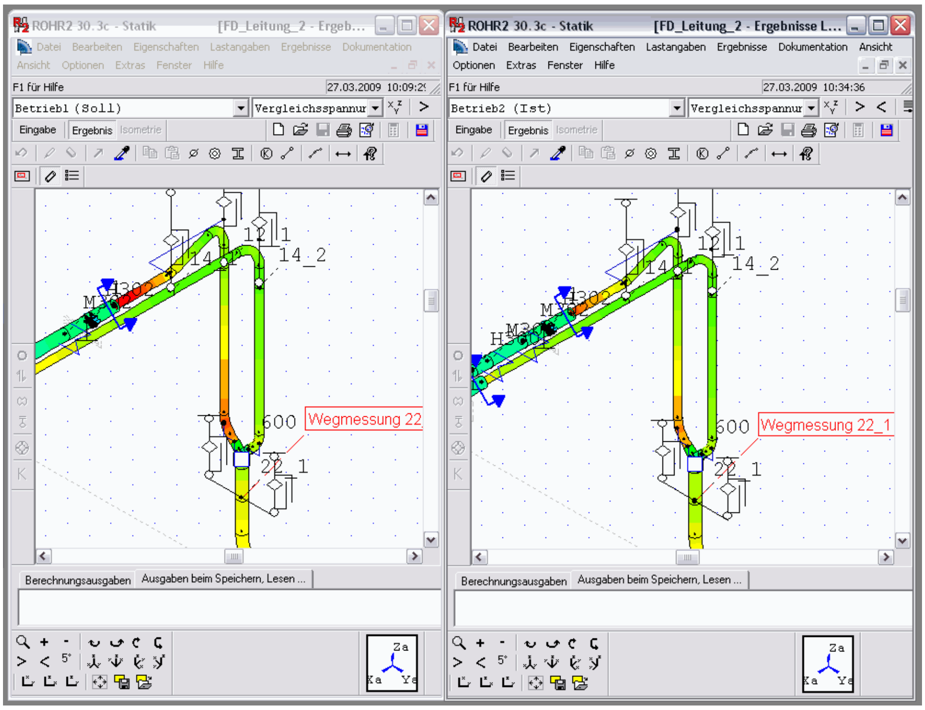


Fig. 1: Comparison of the section results calculated online for the expected (left) and the actual (right) behavior of the pipe

In addition, the following plant-specific process images and diagrams are available:

- Overall status overview and status diagrams for the monitoring and assessment of the intended operation
- Status overview of the force and displacement measurements (Fig. 3) as well as the monitored pipe bends
- Presentation of results (fatigue, stresses and moments of the pipe bends)
- Monitoring of all constant and spring hangers (Fig. 5)
- Excel fatigue overview (individual results, number of monitored hours, classification of the pressures, temperatures and moments for recalculation according to TRD 508 and DIN EN 12952-4, respectively)
- Result diagrams of all pipe bends, as well as force and displacement measurements for any time periods and compression levels (e.g. five-minutes, hourly, daily, or weekly values)

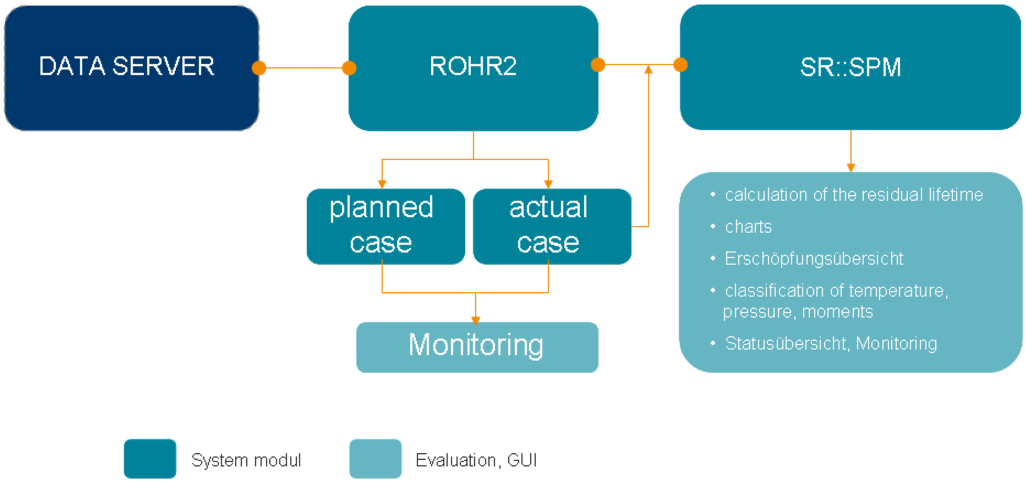


Fig. 2: Schematic representation of the system SR::SPM

5. Monitoring of the intended operation

Avoiding unplanned stresses is vital for the operational safety – however, it presupposes that critical incidents can be detected, assessed and remedied immediately. In the area of the piping system, unplanned conditions may occur e.g. due to jamming or fouling of constant hangers. As the following example shows, also the one-sided failure of a fixed point is conceivable. For the monitoring, a subdivision into the stress of the pipe bends and the behavior of the hangers and fixed points equipped with displacement and force sensors, respectively, makes sense.

The stress equations DIN EN 13480, no. S1, S4 and S5 can serve as a criterion for the regular operational demands of pipe bends. If all three equations are fulfilled, the condition of the pipe bends will be ranked and displayed as regular in the system.

For the intended behavior of the forces and displacements, a tolerance range is defined for each measured value. If this range is left, the user will be notified accordingly. Fig. 3 shows such a situation as it occurred in one of the monitored plants on June 1, 2008. The nominal-actual comparison of the measured support reactions and displacements along the live steam and cold reheat pipe, respectively, is represented here (displacement measurement 21.2 and 22.2). The nominal value calculated by ROHR2 states how the pipe in the respective section will expand according to expectations and with which force it will be stressed, respectively – each time considering the current operating pressures and operating temperatures.

The results (actual) of the two dual force measurements 30.1 (fixed point in the full-load leg below the cross valve) and 30.5 deviate from the tolerated range at the critical point in time – measurement 30.5 by 68 kN. The unplanned actual values are highlighted in red in the process image. On request, the plant personnel can be informed by a message.

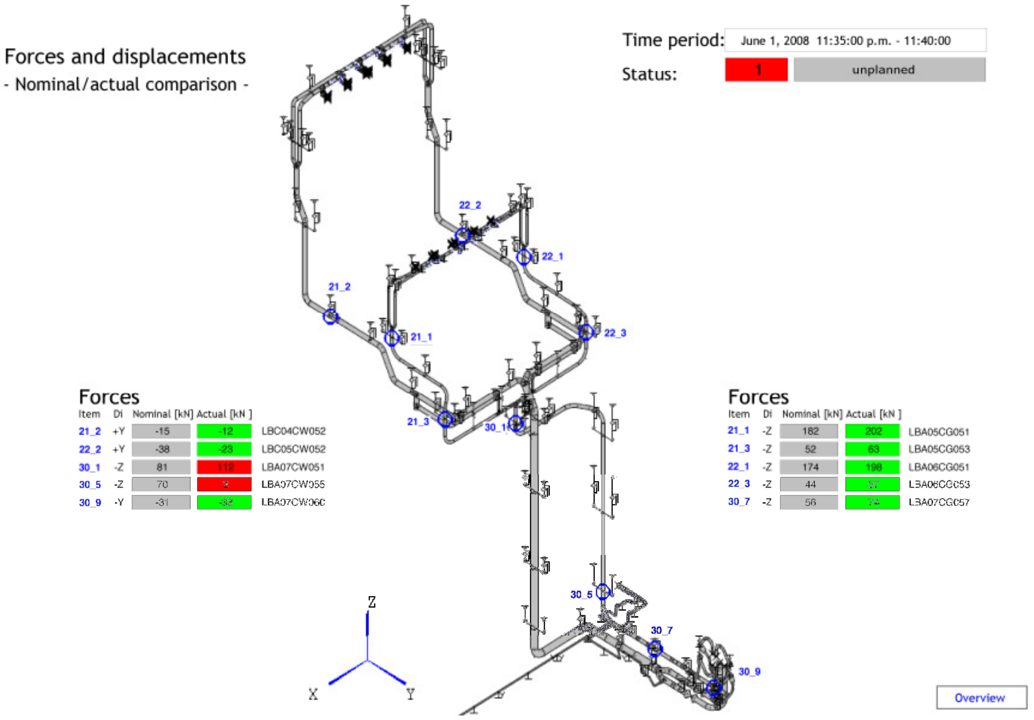


Fig. 3: Process image for monitoring the support reactions (forces) and displacements

The fixed point 30.5 consists of two holding devices that clutch the pipe offset by 180 degrees and at the other end are mounted on the steel construction. Both struts are equipped with a force measurement resulting in total in the overall force of the holding device. Fig. 4 shows the stored diagram of the force measurement during the critical time period (x-axis). The corresponding superheated steam temperature and the nominal and actual results of the force measurements are entered on the y-axis. At 11:25 p.m., the actual values suddenly decrease. The cause is the one-sided failure of the fixed point (A). Before the failure, the total of both measurements correlated with the determined nominal value.

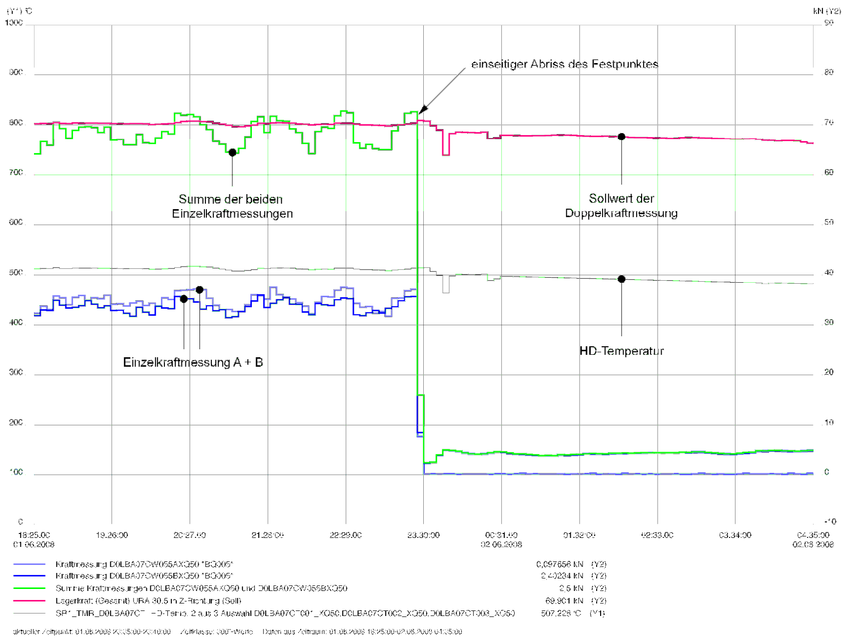


Fig 4: Diagram of the dual force measurement 30.5

The nominal-actual comparison of all hangers (Fig. 5) shows the influence of the incident on the adjacent supports (30.2 to 30.9). In Fig. 5, the actual displacement in Z-direction measured at five hangers is represented by dark bars. The displacement of all other hangers is calculated. By means of the stored pipe model, the measurements can be reduced, as some force and displacement measurements at central positions suffice as boundary condition to determine the movement and stress of the sections located in between. Thus for the fixed point 30.5 (nominal displacement = 5mm), an actual displacement of -129 mm is calculated. By means of the overviews, the incident could be detected on site. Based on the detailed available sectional strains (stresses, forces, moments, torsion, displacement), adjacent pipe segments were analyzed and assessed. Here it became apparent that due to the favourable support concept and the optimal route of the piping in this section presumably no stresses decreasing the service life occurred.

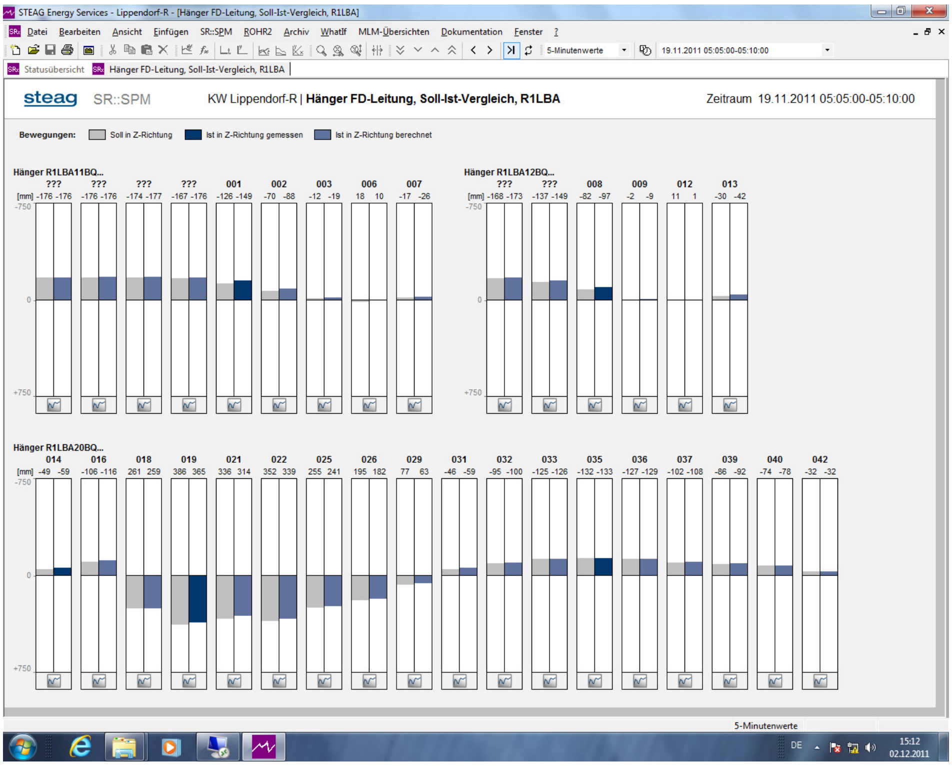


Fig. 5: Nominal-actual comparison of the hanger displacement

Summary

In future, online systems will make a large contribution to operation management and maintenance management. The more precisely the plant condition is recorded and assessed based on the modules named in Chapter 2, the more precisely can the inspection methods, scopes, and intervals for the recurrent inspections be planned. [1] In the case of new plants or when changing components, the monitoring and thus the recording of critical modes of operation is recommended from the beginning in order to be able to argue for individual inspection intervals (extension or reduction) and to plan and reduce the maintenance effort. In the case of existing plants, a recalculation of the operating time elapsed so far is possible – provided that the required operating data are available.

The continuous monitoring of the pipe condition reports unplanned stresses. A reduction of the service life and dangers due to unexpected stress can consequently be prevented. By means of the continuous pipe system calculation with SR::SPM, operating conditions not considered during the design enter into the condition assessment.
When using modern materials, the continuous data acquisition and the calculation of creep damage, alternating fatigue, and creep strain form the basis for a later recalculation – e.g. when the strength characteristics stored so far are updated.

6. Literatur

[1] VGB Guideline 506, Condition Monitoring and Inspection of Components of Steam Boiler Installations and Water or Steam Bearing High-Pressure Pipes, VGB PowerTech e.V., April 2008 [quotes translated from German issue]

[2] VGB Richtlinie 104 O, Leitfaden zur Umsetzung der Betriebssicherheitsverordnung in Kraftwerken, Onlinerichtlinie, VGB PowerTech e.V.

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[4] TRBS 1201
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[5] Directive 97/23/EC of the European Parliament and of the Council on the Approximation of the Laws of the Member States Concerning Pressure Equipment

[6] DIN EN 12952-4:2000
Betriebsbegleitende Berechnung der Lebensdauererwartung

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