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TREND PROGNOSIS AND ONLINE DIAGNOSTICS OF THICK WALLED BOILER COMPONENTS FOR A FLEXIBLE MODE OF OPERATION

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ABSTRACT

In a scenario of an increasing use of renewable energy, conventional power plants will be more and more forced to compensate for the volatility of the natural resources. Even huge coal-fired units which have been designed for baseload operation will face an increased number of start-up/shutdown cycles and the requirement for faster load changes.

For the power plant operator that means a challenge as well as a chance: a challenge because the plant experiences higher alternating stresses which may reduce the lifetime. A chance because usually there are incentives for contributions to the grid stability which may give him additional profits. Coping with the challenges and making the best of the chances will require a detailed and quantitative assessment of the lifetime consumption in various modes of operation.

In this paper, an online software solution is presented that provides this kind of information right at the fingertips of the plant engineers. The innovative approach integrates the most recent European standards concerning the calculation of lifetime consumption from load cycling with state-of-the-art methods of predictive analytics and cutting-edge FEM technologies: the recent standards supported by FEM calculations allow an estimation of lifetime consumption which is unchained from unnecessary allowances. The predictive analytics easily correlate plant operation and lifetime consumption and allow for a reliable prediction of fatigue. This in turn gives the necessary information to make the best of the chances of load flexibilization while mitigating the risks of increased lifetime consumption. If the expected fatigue in a given period is exceeded due to the current mode of operation one can react with a more moderate mode of operation– or the other way round, if the expected fatigue is not reached.

Examples from German coal-fired power plants which have been put under economic pressure by the ongoing “Energiewende” (energy turnaround) are presented to demonstrate this approach.

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, 2, 5] 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) [3] 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, 3, 4]

What does that mean in concrete terms? Paragraph 15, Section 5 of the Ordinance on Industrial Safety and Health [3] 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 [3]). VGB-Standard 506 [1] 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.

ONLINE SYSTEMS AS A CENTRAL ELEMENT OF CONDITION MONITORING

On the basis of VGB-Standard 506 [1], condition monitoring can be subdivided into the following parts:

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

2. **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.)

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

4. **Diagnosis in the course of a shutdown**
   External and internal inspections

5. **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 5.5 (Issue 2012), VGB-S 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 STEAG Energy Services GmbH follows Procedure 2 of the guideline [8].

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.

LIFETIME MONITORING OF THICK-WALLED BOILER COMPONENTS

Due to the rapid increase in the use of renewable energies, thermal power plants are required to handle flexible load scenarios. Hard coal- and lignite-fired power plants, initially designed for base load and medium load operation, are subject to steep temperature transients and high numbers of cycles to be able to economically react to the demands of the market. Particularly regarding thick-walled boiler components (e.g. drum, separator vessel, headers, moldings), the high cyclic loading by internal pressure and temperature leads to an increased alternating stress.

The stress is determined by means of online monitoring systems in order to allow for a realistic projection for optimizing the mode of operation. Thus the systems significantly contribute to ensuring a safe and economical plant operation.

LIFETIME MONITORING SYSTEM SR1

Components that are subject to high temperatures and pressures gradually lose their original stability over the years of operation. The lifetime consumption results from the creep damage of the material and from the alternating fatigue due to fluctuations in temperature and pressure.

Such components are designed according to the algorithms of TRD 300/301 [9] and DIN EN 12952 [6, 7], respectively. An operating time of 200,000 hours is taken as a basis for the dimensioning of the components – provided that pressure and temperature are constant. For example, the variation in stress is taken into account by specification of 500 cold start-ups with certain ramp-up gradients and 2,000 warm start-ups.

As the actual mode of operation deviates from the described design boundary conditions, a regular monitoring of the component stress is required according to TRD 508 [9] and DIN EN 12952-4. [6] This monitoring can be comfortably implemented using a continuously operating measured-data capture and calculation system.

SR1 is a program system for the continuous monitoring of the stress on thick-walled components of power plant boilers and turbines based on the procedure defined in the TRD code and DIN EN 12952. [6, 7, 9]

The SR1 report provides the following results for each monitored component:

- Total fatigue = f (creep, fatigue)
- Creep = f (pressure, temperature)
- Fatigue = f (pressure, temperature, differential temperature)
- Matrices for hours of operation and load changes

Optionally, SR1 can also be equipped with a feature to calculate reserves.

Calculation of Fatigue

The thick-walled parts in particular are subject to an alternating stress during the ramp-up and shutdown of the boiler system and during each load change, caused by changes in pressure and temperature differences in the component wall. The measured variables of pressure, temperature, and temperature difference have to be available for calculating the alternating stress. The temperature difference is to be established between the inner wall of the component and the middle of the wall.

SR1 can determine the temperature profile within the wall of the component from the time-related changes in the temperature of the medium. In SR1, this is done by taking account of the heat transfer relationships of the inner and outer walls of the component (Fig. 1). This reduces the need for technical measuring equipment. If the temperature profile inside the wall of the component has already been measured by technical means, SR1 can make use of this data.

Experience shows that such a determination by way of calculation is more reliable than the subtraction of two individual measured variables.

Mathematical-statistical methods are used to detect and assess load changes that decrease the service life. The alternating fatigue is the quotient of performed load changes to tolerable load changes.

The total lifetime consumption according to TRD 508 [9] and DIN EN 12952-4 [6] is the total of creep damage and alternating fatigue.

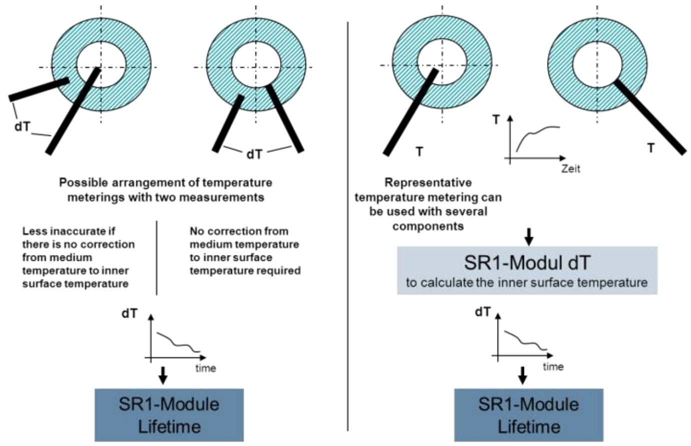

Figure 1: SR1 provides different methods to determine the temperature field within the wall of the component.

Measuring Points

Out of the available signals, the ones that most realistically represent the operating conditions of the components have to be chosen. Among those are e.g. the steam outlet temperatures of the corresponding components. In the case of long outlet headers, however, the temperature in the central region can be significantly higher than at the outlets or inlets, respectively. The temperature differences between the middle of the header and the outlets or inlets, respectively, are captured by additional recording of the metal temperatures or by means of an appropriate temperature allowance. Moreover, a couple of pressure measurements are needed that are simultaneously used for the automatic consideration of plant shutdowns.

It can be assumed that only such measuring signals are used that are installed for the purpose of operation monitoring anyway. So no additional measurements are required for a successful implementation of SR1.

Applications

- Plants with highly stressed, pressurized components such as tubes, collectors, and other hollow components that are typically found in steam generators in the industry. Because of the high process temperatures, these components are subject to time-related ageing and are usually the components with the shortest life expectancy.
- It is also possible and sensible to use SR1 in older plants in order to provide reliable data about past component fatigue so that a decision can be made whether to extend the operating time or not. This also applies when no continuous SR1 lifetime monitoring or

- IT-supported data storage has taken place before and when the operational data from the past is available only on paper strips.
- In addition, when online monitoring begins, it is possible to extrapolate backwards. When this is done, the currently registered fatigue gains are transferred to the history. After just roughly 5,000 hours of operation with online monitoring a reliable history can be generated.
- STEAG also offers the offline-calculation of consumed lifetime based on historical data as a service.

steag SR1 — Overview of Lifetime Consumption — 02.12.2012 23:00:00-00:00:00

KKS	Component	Operating hours		Lifetime Consumption		
		Operating	Failure	Creep damage	Low cycle fatigue	Total
HAH51BB011	Überhitzer 3 Sammler BB011 rechts	8301,0 h	9,8 h	1,698 %	0,021 %	1,718 %
HAH51BB011	Überhitzer 3 Sammler BB011 links	8301,0 h	9,8 h	1,517 %	0,008 %	1,525 %
HAH51BB021	Überhitzer 3 Sammler BB021 rechts	8301,0 h	9,8 h	1,491 %	0,021 %	1,512 %
HAH51BB021	Überhitzer 3 Sammler BB021 links	8301,0 h	9,8 h	1,703 %	0,023 %	1,726 %
HAH54-57 BR011 1	Bogen Vltg. Ü3-Ü4 vor Kühler 2	8301,0 h	9,8 h	1,536 %	0,002 %	1,538 %
HAH54AH001	Einspritzkühler 2 Strang 3	8301,0 h	9,8 h	1,950 %	0,003 %	1,953 %
HAH55AH001	Einspritzkühler 2 Strang 1	8301,0 h	9,8 h	2,130 %	0,020 %	2,150 %
HAH56AH001	Einspritzkühler 2 Strang 4	8301,0 h	9,8 h	2,015 %	0,020 %	2,035 %
HAH57AH001	Einspritzkühler 2 Strang 2	8301,0 h	9,8 h	1,782 %	0,011 %	1,793 %
HAH64-67 BR011 1	Bogen Vltg. Ü3-Ü4 nach Kühler 2	8301,0 h	9,8 h	1,576 %	0,001 %	1,577 %
HAH70BB011	Überhitzer 4 Verteiler BB011 rechts	8301,0 h	9,8 h	1,444 %	0,004 %	1,448 %
HAH70BB011	Überhitzer 4 Verteiler BB011 links	8301,0 h	9,8 h	1,644 %	0,011 %	1,654 %
HAH70BB012	Überhitzer 4 Verteiler BB012 rechts	8301,0 h	9,8 h	1,758 %	0,016 %	1,773 %
HAH70BB012	Überhitzer 4 Verteiler BB012 links	8301,0 h	9,8 h	1,566 %	0,007 %	1,573 %
HAH71BB011	Überhitzer 4 Sammler BB011 rechts	8301,0 h	6,8 h	3,627 %	0,119 %	3,746 %
HAH71BB011	Überhitzer 4 Sammler BB011 links	8301,0 h	6,8 h	3,644 %	0,266 %	3,911 %
HAH71BB012	Überhitzer 4 Sammler BB012 rechts	8301,0 h	7,0 h	3,507 %	0,159 %	3,667 %
HAH71BB012	Überhitzer 4 Sammler BB012 links	8301,0 h	7,0 h	3,525 %	0,233 %	3,758 %
HAJ10BB011	ZÜ1-Sammler BB011 rechts	8301,0 h	15,1 h	0,503 %	0,000 %	0,503 %
HAJ10BB011	ZÜ1-Sammler BB011 links	8301,0 h	34,4 h	0,610 %	0,000 %	0,610 %
HAJ10BB021	ZÜ1-Sammler BB021 rechts	8301,0 h	15,2 h	0,595 %	0,000 %	0,595 %
HAJ10BB021	ZÜ1-Sammler BB021 links	8301,0 h	34,2 h	0,552 %	0,000 %	0,552 %
HAJ11-14 BR011	Bogen Vltg.ZÜ1-ZÜ2 vor Kühler	8301,0 h	34,2 h	0,882 %	0,000 %	0,882 %
HAJ11AH001	Einspritzkühler Strang 3	8301,0 h	34,2 h	0,603 %	0,000 %	0,603 %
HAJ12AH001	Einspritzkühler Strang 2	8301,0 h	15,2 h	0,606 %	0,000 %	0,606 %

Figure 2: SR1 fatigue overview

OPTIMIZING THE PLANT OPERATION

Already today, a flexible plant operation is demanded of thermal power plants (more frequent start-ups, steeper transients) to be able to react to the highly fluctuating feed of renewables. In parts, the operation here significantly differs from the mode of operation assumed when designing the components. The following procedure is used to be able to assess the potential for a more flexible plant operation. In a first step, the current situation is evaluated. This includes:

1. Recording the previous mode of operation and determining the boundary conditions and limits.
2. Assessing the previous mode of operation regarding the material fatigue of the thick-walled components (calculation according to TRD 508 [9] and DIN EN 12952 [6, 7] respectively).

Based on the evaluation, a concept for improving the flexibilization and acceleration of the rates of start-ups and load changes is compiled. The admissible lifetime consumption is taken into account here.

3. Calculating the admissible rates of load changes for the thick-walled components.
4. Recommendation for the redefinition of the start-up times (cold, warm, and hot start-up) of the boiler plant.
5. Defining the critical load ranges and creating a matrix for the optimal use of the plants for the various load ranges.
6. Developing suggestions for the implementation of the higher rates of load changes on the DCS side.

PROJECTION OF THE LIFETIME CONSUMPTION

The objective of the projection of the lifetime consumption is to allow to assess the influence of future modes of operation and to optimize the plant operation.

Currently various approaches for the projection of the lifetime consumption are being developed and tested respectively. Initial approaches, considerations, and specific examples are presented below.

For the online projection, the mode of operation to be expected is described by load collectives for a realistic period of consideration (one to three years) in order to optimize the admissible gradients for various load ranges in this period of time. Here an optimization regarding certain, financially particularly attractive load ranges is conceivable. The boundary conditions of the projection can be adjusted to the expected requirements in intervals.

Yet another aspect is to be considered. Besides assessing the component stress, often DCS-related and procedural measures are required to increase the plant flexibility. In view of this fact, the load range-related optimization can be effected in a target-oriented way, and a fleet-wide application management can be developed.

In the case of a mode of operation with significantly higher stresses compared to the design calculation, additional inspection measures are to be considered in order to ensure a safe operation. The costs incurring in the context of the optimization (expenses, investment vs. returns) can be estimated during the pilot study.

A prerequisite for the continuous projection and optimization of the component stress is the use of online systems to precisely monitor the calculatory lifetime consumption and to be able to reliably use it as a basis for adjusting admissible gradients.

TREND ANALYSIS OF THE COMPONENT STRESS USING STATISTICAL METHODS

A continuous monitoring of the component stress using statistical methods is particularly helpful in this context. The increase of creep damage and alternating fatigue is monitored by means of the online system SR::SPC (Statistical Process Control) by STEAG Energy Services GmbH. When an admissible warning limit is transgressed, the user is immediately informed about the status.

In addition, the trend analysis can be used for an extrapolation of creep damage and alternating fatigue into the future. For this, the projection period and a fatigue admissible in this period are defined. Planned shutdowns of the plant (no increase in fatigue) can be taken into account. If the expected fatigue is transgressed during the projection period due to the current mode of operation, one can react with a more moderate mode of operation, or the additional consumption can be economically assessed and tolerated if applicable.

The trend analysis is explained in what follows, using the example of a superheater 4 header.

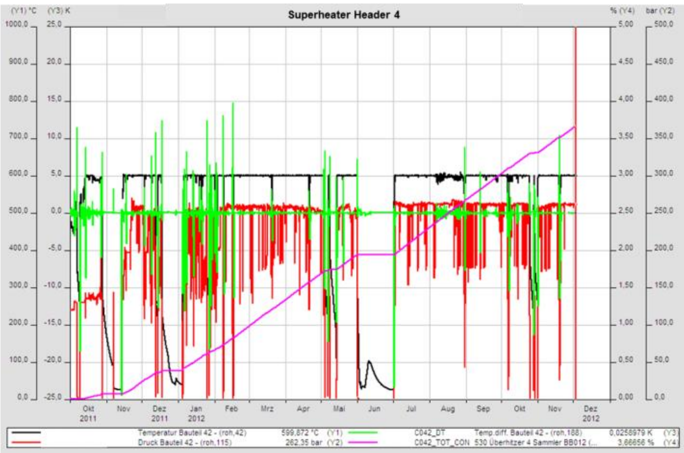

Figure 3: SR1 diagram, superheater 4 header

The SR1 component diagram (Fig. 3) shows the operating parameters (pressure and temperature) and the calculation results (temperature difference and total fatigue) for the entire history of the component. On the basis of the chronological sequence of the four parameters an assessment of the plant operation (critical or not) is not possible.

Creep damage

The SPC analysis of the gradient of the creep damage (Fig. 4) identifies two events where the increase was above the defined limit. The cause is a temperature transgression.

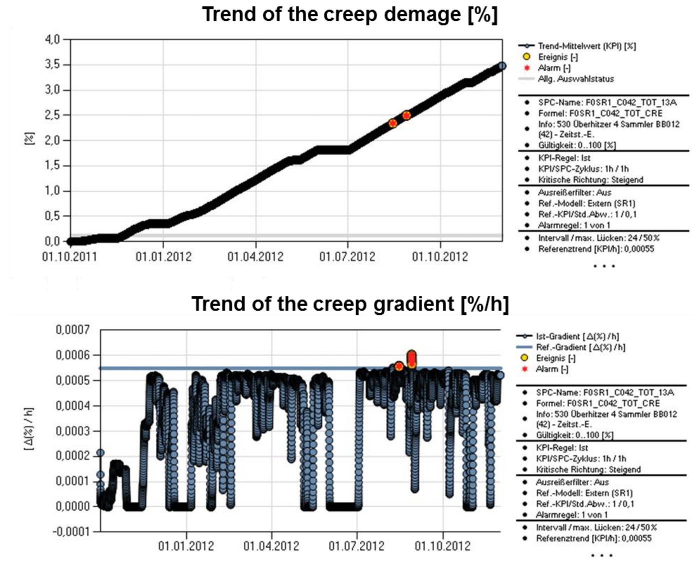

Figure 4: The continuous SPC trend analysis of the gradient of the creep damage

Alternating fatigue

The SPC trend analysis of the alternating fatigue also captures and reports the points in time when the component was calculatorily stressed the most (Fig. 5). Fig. 6 (SR1 diagram) exemplifies the operating condition responsible for the increase in alternating stress (high thermal stress due to temperature difference).

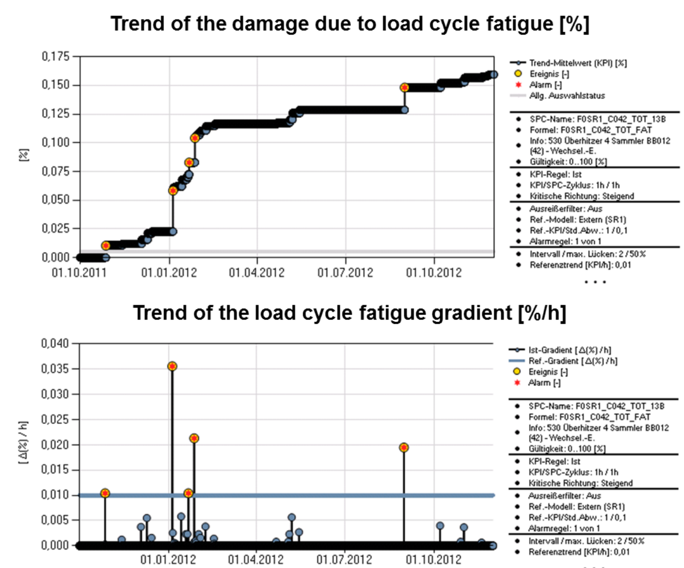

Figure 5: The continuous SPC trend analysis of the gradient of the creep damage

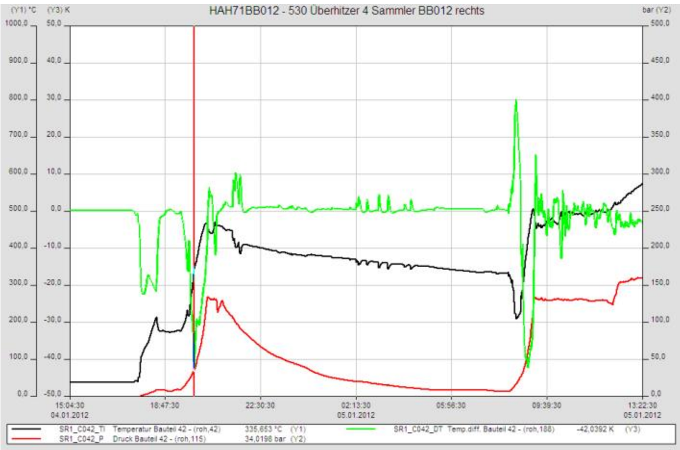

Figure 6: SR1 diagram, superheater 4 header

TREND PROJECTION

Examples of the operating scenarios "base load" and "energy turnaround" are shown below to contrast different modes of operation.

Both trend diagrams of the software SR::SPC (Fig. 7 and 8) show the extrapolation of the alternating fatigue over one year (projection period). The expected increase in fatigue in this time period amounts to 0.5 percent for both scenarios. In the scenario "energy turnaround", steep transient operating procedures and frequent load changes lead to a higher stress of the superheater 4 header. After six months already, 0.5 percent alternating fatigue would be reached with a comparable mode of operation. For 30 years, the alternating stress would double from 15 to 30 percent. According to damage accumulation [1], the fraction of the creep damage is to be added on top of this.

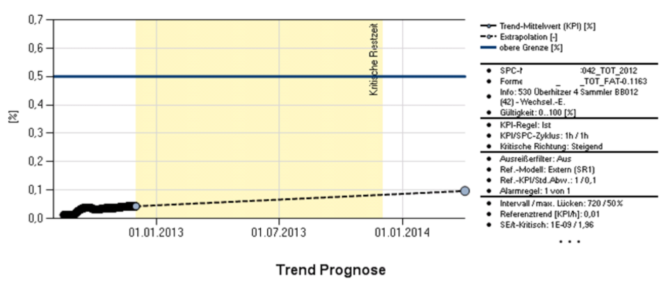

Figure 7: Continuous extrapolation of the alternating fatigue – scenario "base load"

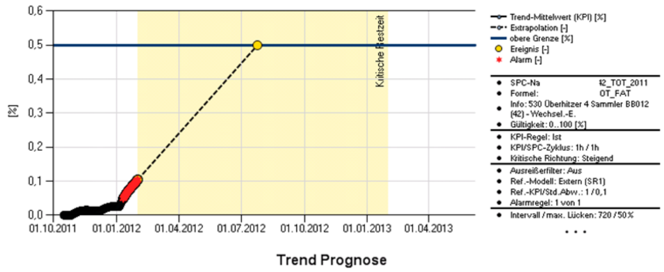

Figure 8: Continuous extrapolation of the alternating fatigue – scenario "energy turnaround"

SUMMARY AND OUTLOOK

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 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.

In addition, the continuous trend analysis monitors the stress of thick-walled components. If the expected fatigue is transgressed during the projection period due to the current mode of operation, one can react with a more moderate mode of operation, or the additional consumption can be economically assessed and tolerated if applicable.

The continuous monitoring of the component 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 SR1 and 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.

Recently performed comparative calculations show that DIN EN 12952 and FEM calculations are in good accordance regarding the calculated thermal stress. The results of the calculations and the approaches on how to combine both online and offline assessments will be reported in future publications.

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