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Steam pipelines' effort and durability

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Analysis and modelling

ABSTRACT

Purpose: The main problem addressed in the paper is the description of an effort and durability of steam pipelines under the conditions of mechanical and thermal interactions.
Design/methodology/approach: The FEM modelling has been used to determine the stress and strain fields in the pipelines and to describe their behaviour under mechanical and thermal loading.
Findings: An appropriate model description has been developed. So far, experimental verification of the usefulness of the model description to determine the stress and strain patterns in particular object and for chosen operation conditions has been made. The analysis made has shown that the most probable cause of cracks occurrence on the analyzed chosen pipeline' inner surfaces are thermal deformations and constraints of their dislocations.
Research limitations/implications: The developed description should be useful in problems of behaviour predictions of high temperature components and their durability assessment under different mechanical and thermal loadings in industry practical applications.
Originality/value: The method, which more precise description of power industry components behaviour makes possible have been shown in the work. The work is addressed to researchers interested in problems of component behaviour prediction under different loadings that we can meet in the operation practice and to power industry engineering maintenance staff.
Keywords: Numerical techniques; Residual life analysis; Applied mechanics

1. Introduction

The technical condition of the installations working in the power industry which have exceeded the so-called "calculated operation time" may very, depending on their type and history of service. Frequently, admission of such installations for further operation after expiry of their durability period assumed in the project is entirely reasonable. In any case, however, an evaluation of the actual technical condition of the installation is necessary and so is the forecast of the date of its next technical inspection or withdrawal from operation. This problem becomes exceptionally complex in the case of changes in the geometric features of individual elements and characteristics of external influences. It is then necessary to apply computer strength calculations with taking into account the actual properties of the objects investigated. This approach to calculations necessitates the development of appropriate uniform procedures for evaluating the installations' technical condition in order to make the results of such evaluations (carried out by different teams) as objective as possible.

Among the most widely applied procedures and European standards are the TRD regulations [1], standard R5 [2,3], used by the British Energy Generation Ltd and standards [4], whose considerable parts are devoted to thick-walled elements. They provide for the designing and verifying calculation methods for fittings subjected to variable loads in cycles.

However, the methods and procedures provided for in the above-mentioned standards do not account for all the issues connected with the evaluation of the technical condition of individual objects worked under mechanical and thermal loadings [5-8]. Due to the specificity of their operation, a majority of components requires an individual approach after long-term usage. The evaluation of the condition of each of such plants becomes a research task, where the research methodology depends on the specific operational conditions and loading history [9-12]. This paper presents an example analysis of the condition of high-pressure (HP) and mean-pressure (MP) intermediate pipelines of a turbine working in one of our domestic power stations.

A preliminary evaluation of the pipelines' material lifespan was made based on the TRD standards, the material properties quoted in the specialist literature and the boundary conditions, given the most unfavourable variant of load. In this way, a conservative estimation was made on the degree of material's weakening after many years of service. Next, this approach was compared with a different approach, where the evaluation of material effort and durability was carried out by applying the finite element method; the real operational parameters and boundary conditions were determined based on their characteristics obtained in industrial conditions.

2. The object of research

The objects of the research were intermediate high-pressure and medium-pressure pipelines connecting the valve chambers with the high- and medium-pressure parts of a turbine. The analyzed pipelines were made of the 13HMF steel and the components connecting the pipelines with the turbine housing were made of the L17HMF cast steel. For those pipelines, the connections between welded pipes and fittings showed cracks in a number of cases. In order to determine the cause of cracks' occurrence and to evaluate the durability of the discussed pipelines, strength calculations were made using different methods.

The following nominal parameters of intermediate pipelines' operation were assumed:

- intermediate high-pressure (HP) pipeline: temperature 535^{o}C, pressure 17.6 MPa,
- intermediate mean-pressure (MP) pipeline: temperature 535^{o}C, pressure 4.3 MPa.

The operation time of the investigated intermediate pipelines was 105,000 hours. In that period, the pipelines were shut down 278 times. The degree of weakening caused by creep is determined by the TRD 508 procedure [1], which is based on the *creep resistance* value. On the basis of an experimentally determined creep resistance characteristic as a function of time until failure, $R_{z/T}(T)$, a diagram parallel to it is determined, 0.8 $R_{z/T}(T)$, where T means time until failure. The points lying on the 0.8 $R_{z/T}(T)$ characteristic curve correspond to the standardized boundary states.

The calculations carried out showed a varied degree of the intermediate pipelines' damage, in the range of $0.04<\omega_p<0.34$. In accordance with the guidelines included in the TRD 508 regulations, it is necessary to assess the material wear based on metallographic investigations as well as to examine the internal surface's condition by an endoscopes' method, and to check for possible cracks in the components by applying either a magnetic or ultrasonic method. The calculations of durability based upon constant load originating from the pressure constitute the primary information on the predicted time of further plant components operation.

3. Models of pipelines' components

According to the TRD 301 standard guidelines, only the load caused by internal pressure was taken into account when calculating the pipelines' material creep wear. In actual turbine operational conditions, the following factors also influence the intermediate pipelines' effort:

- thermal elongation of the pipelines,
- thermal dislocations of valve chambers and the turbine itself,
- intermediate pipelines' deadweight.

Since the influence of the enumerated factors on the creep wear degree may be significant, the effort calculations were also made applying the finite element method. The models prepared account for the basic geometric features of the investigated elements, in compliance with the technical documentation. The geometric form of WP and SP pipelines' models with a finite elements' lattice is presented in figures 1 and 2.

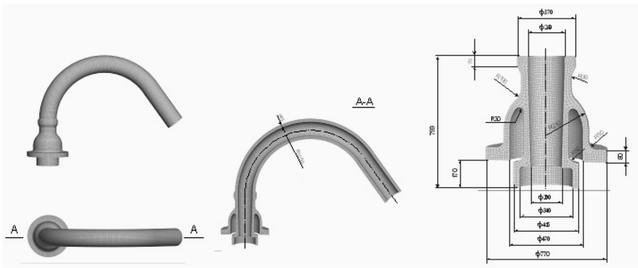


Fig. 1. High-pressure turbine pipeline model

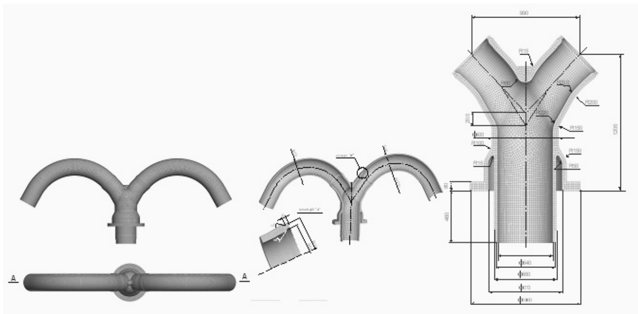


Fig. 2. Middle-pressure turbine pipeline model

The boundary conditions were defined through the values of dislocation in the direction of X, Y and Z axes of pipelines' ends attached to the valve chamber ferrules and of components securing the pipeline to the turbine housing.

Nominal operation parameters were assumed for the calculations and the action of pressure p_2 in the area between the external connecting element and the pipeline was taken into account, as indicated in Fig. 3. The boundary conditions were determined in the analyzed models through the thermal dislocation values of the turbine housing which forced the dislocation of HP and MP pipelines and the valve chambers, to which the intermediate pipelines' ferrules are connected. The chambers' dislocations results from thermal expansion and mechanical forces in the pipelines connecting the boiler with valve chambers (Fig. 4).

The turbine's thermal expansion causes dislocation of the pipelines' connection points with the turbine in Z axis direction (direction: boiler – turbine) and in a vertical direction (axis Y). The values of dislocations in the direction of axis Z were assumed based on the data recorded by a system monitoring the turbine operational parameters.

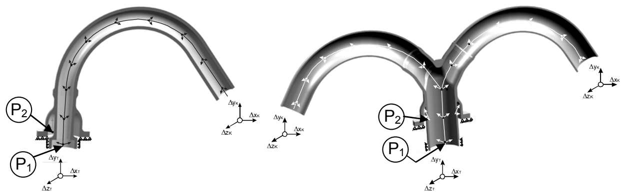
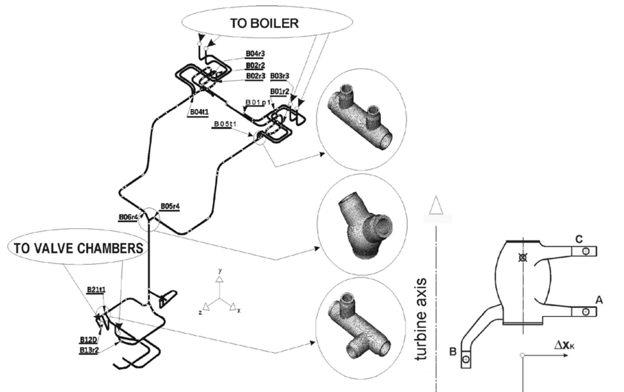


Fig. 3. Boundary conditions and pressure assumed for HP and MP pipelines' models

In turbine operational conditions, after major overhauls, measurements are made of the valve chamber clamping arms dislocations, based on which the dislocation values for the intermediate pipelines' outlet ferrules have been determined in the study. The dislocation directions are presented in Fig. 4b.



(a) (b)

Fig. 4. Example of the re-superheated steam pipeline - (a); valve chamber draft with dislocation directions indicated - (b)

The wear evaluation was made for two variants of boundary conditions defined through the valve chambers' dislocation values:

- in variant 1, the pipelines' effort calculations were made for an average value of the valve chambers' dislocations,
- in variant 2, hypothetical dislocation values were assumed, which values may be real after carrying out repair works on the power unit, where the live steam pipeline and the reheated steam pipeline have been fixed to the valve chambers in a faulty way.

The values of pipeline ends' dislocations at the turbine in the direction of axis Z were assumed based on the data recorded by a system monitoring the turbine operational parameters. The values of connecting elements' dislocations in a vertical direction (Y) were determined with taking into account the thermal expansion of the turbine's external housing, in accordance with the dependence:

$$\Delta y = H \cdot \alpha \cdot \Delta T \qquad (1)$$

where: H – turbine's height from its bed to the pipeline fastening place,

α – turbine housing thermal expansion coefficient,

ΔT – difference in temperatures of the turbine's external housing between cold and hot states.

4. HP and MP pipelines local effort

The pipelines' effort calculations were made by applying the finite element method with the use of a professional version of the ALGOR program. Examples of stress distributions calculation results for the pipelines' models are presented in Fig. 5.

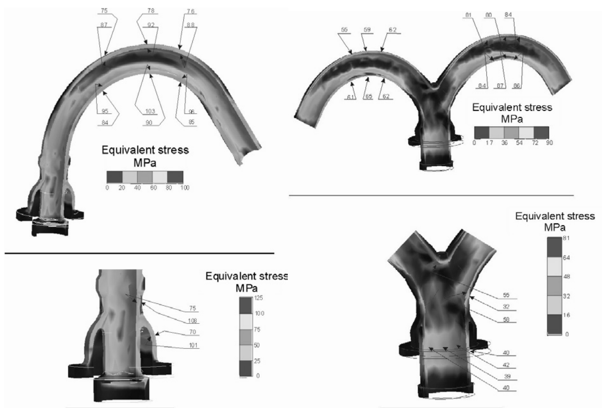


Fig. 5. Reduced stress distributions determined given limited freedom of thermal dislocations of HP and MP pipelines

5. Pipelines damage

The operational creep damage - ω_p, the total calculated operation time - T_o, and the remaining operation time - ΔT of the pipelines were determined in compliance with the $R_{z/T}(T)$ curve described in TRD standards [1]. In the wear calculations, the average reduced stress value - σ_{red} was determined as an arithmetic mean of reduced stressed on the component's inner and outer surfaces. Reduced stresses in the pipelines' arcs and connectors were determined in accordance with the Huber-Mises hypothesis. The maximum stress value in a given component was assumed as a criterion forming the basis for predicting the duration of further operation. For the HP and MP pipelines' arcs, the higher of two reduced stress values in the tensioned (σ_I) and compressed (σ_{II}) part of the arc was taken into consideration for durability calculations. Figure 6 presents the location of the fittings' areas under the highest effort. The average reduced stress values in those areas were used for the fittings' damage calculations.

The creep damage (**ω_p**) calculations for intermediate pipelines, performed with taking into account the additional forces originating from thermal dislocations of pipelines' fittings to turbine housing and valve chambers, have shown that the operational wear degree compared to the wear determined according to the TRD standard does not show significant differences where the valve chambers' mean dislocation values observed during operation are taken into account. In such case, the **ω_p** coefficient ranges between 0.03÷0.39.

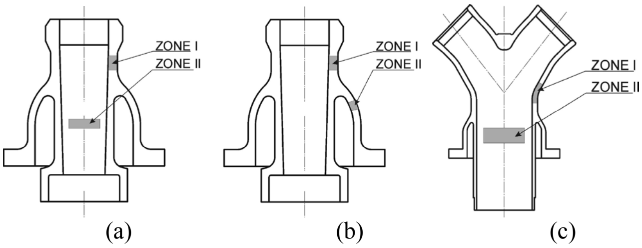


Fig. 6. Zones of the highest effort in the HP pipeline for variant 1 (a) and 2 (b) of limited freedom of pipeline dislocation; location of the MP pipeline zones subject to the highest effort (c)

The calculations made have also shown a very significant influence of the valve chambers' dislocation values on the theoretical damage of the pipelines. Limitation of freedom of the valve chambers' dislocation, caused e.g. by improper allowances for power pipelines' expansion or a poor condition of pipeline suspensions, may lead to a multiple increase of the damage coefficient (ω_p>1) and to a considerable concurrent decrease of the pipelines' durability.

6. Conclusions

When making calculations in compliance with TRD standards and given only the load caused by internal pressure, the estimated pipeline material damage degree reaches a level of less than 0.4 for all the elements discussed. When making calculations by applying the finite element method for the first of the given variants of boundary conditions, with taking into account the mean valve chambers' dislocation value, convergence of their results with the results of calculations performed in accordance with TRD standards has been shown. For the dislocation values in fixing points, assumed for the discussed case, the calculated exhaustion coefficient assumed values higher than unity.

The calculation results show high sensitivity of the facility to limitation of the dislocations of its components. The analysis made has shown that the most probable cause of cracks occurrence on the HP pipeline' inner surfaces are thermal deformations and limitation of their dislocations. However, the influence of the above factors is the most significant in structurally inhomogeneous areas of welded joints.

Analysis shows the influence of constructional features, which undergo changes during operation, on pipelines' effort and durability. This factor is frequently neglected when analyzing the actual condition of installations subject to mechanical and thermal interactions. At this stage of the research, focus has been placed on the evaluation of effort and durability, without considering possible cracks in such facilities. Such approach should be treated as a preliminary study, preceding a more detailed analysis which will make use of the fracture mechanics method and in particular, of the new SINTAP and FITNET procedures, where one of possible approaches to the failure criteria and durability evaluation provides for applying FADs (Failure Assessment Diagrams) [2,13-15].

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