Experimentální Analýza Napětí 2010
Experimental Stress Analysis

Analysis of stress states in critical parts of supporting structure of steam boiler and determination of its residual life span

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Abstract: Steam boiler as a whole, but mainly it's supporting structure, has to ensure longtime life span in the long time term reaching almost half of century. During this period occur considerable decrement of material due to aggressive environment but also influence of heat mainly in locations of damaged thermo insulation. The changes during life span of boiler, but also further additional loading of structure that have influence to boundary conditions, require, in order to solve the questions of reliability, experimental or potentially experimental-numerical treatment.

Key words: Supporting structure, Strain gage measurement, Residual lifespan

1. Introduction

Steam boilers in heating plants or energetic systems are often in operation several decades and during this time there were provided general overhauls, or they were reconstructed in such way that the system of work on technological equipments was modernized. It results to changes in loading of supporting structures of steam boilers that are in many cases modified during reconstruction works. During assessment of structure it is necessary to know possible failures in individual elements of supporting structure as a result of corrosion and thermal influences (mainly in case of damaged thermo insulation) invoke additional stresses.

In locations of external loading, where is possible form technological point of view to provide application of strain gages was realized strain gage measurement of time-dependent changes of stresses. For the assessment of strength of structure and their residual life span was necessary to know also residual stresses invoked by assembly, operation, structural overloading during their operation as well as to know

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mechanical properties and their degradation as result of longtime mechanical and thermal loading.

As result from charts of stresses from simulated and operational regimes as well as from the values of residual stresses determined on the base of damage accumulation theories or according to standards was determined residual lifespan of the supporting structure. Identification of the most loaded parts of structure requires full knowledge of geometry. Geometry is necessary condition for analysis and the crucial role play primarily thicknesses [1,2].

Analysis of loading by the finite element method requires precise knowledge of boundary conditions. Their definition is not easy and assessment of structural state only on the base of such computation would be only orientational. The structural changes that were provided during reparation works and including of their influence into strength computation by FEM is also problematic. Assessment of life span has to be unambiguously bounded to time-dependent changes of stresses (their amplitudes, middle values, number of cycles and so on), degradation of mechanical properties of material, loading history, residual stresses and loading invoked by thermal influences [3,4,5]. These parameters allow using experimental methods that are in common use on the workplace of authors.

2. Description of boiler supporting structure

In Fig. 1 is shown original structure of boiler made of steel [6]. The main structural members of this structure are supporting columns, bracing of combusion chamber, frames on individual high levels as well as overhead beams.

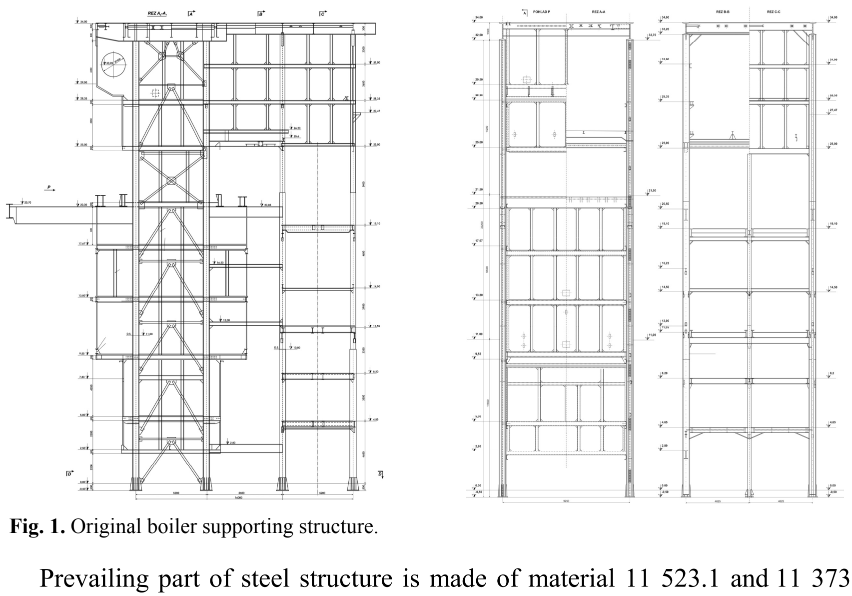


Fig. 1. Original boiler supporting structure.

Prevailing part of steel structure is made of material 11 523.1 and 11 373.0. The whole mass of supporting structure in accordance to data given in drawings is 264 848 kg. The drawings were elaborated in 1961.

By the photographs on the figures are documented possible impacts to loading of individual members due to corrosion and not appropriate structural interventions that were required by new equipments, technologies or changes realized in supporting structure.

In Fig. 2 is shown sheet of framework joint of brace strut in the high level 3.3 m on the left side. During the inspection was found out that from the sheet of the framework joint was burned-out middle part with interruption to outer profile. From the Fig. 3 is obvious that the webs of closed beam are not plannar that can invoke increased levels of loadings and problems with stability.

Fig. 2. Burned-out of framework joint sheet.

Fig. 3. Deformed webs of beam.

After visual inspection in the high level 20.5 m as found out that double I beam of high 800 mm on the left frontal side of boiler is deformed in its cross-section so that its web is moved from vertical line by 50 to 60 mm that substantially changes statical scheme of supporting structure and it is necessary to stabilize the beam on this side by transversal member. The same beam on the other end is also moved from in vertical direction but its deformation is substantially smaller and it is not considered to be critical.

In Fig. 4 is shown loining of U-profile to the column. It is obvious that it is not positioned in center of mass and nor in the centre of shear of U-profile that can be considered as inappropriate. Even more interesting is a fact that there were removed bracings 2 x U 100 in high 29.5 m on the left and right side of supporting structure of boiler, see Fig. 5.

Fig. 4. Joining of U-profile to the column S2L.

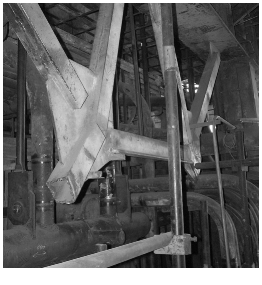


Fig. 5. Removed struts from left side of boiler (U-profile web is on right side).

3. Determination of static components of stresses in columns by the hole drilling method

The methodology for determination of residual stresses can be used also for assessment of stresses in columns S1P and S2P (see Fig. 6) that are invoked by self-weight or other not defined forces.

Only the method of hole drilling allows determine stresses induced by self-weight, without disassembly and assembly after application of strain-gages to the strain-gage apparatus. The strain-gages were applied on the columns from foot ribs S1P in distance 1.1 m and on column S2P in distance 0.6 m (see Fig. 7).

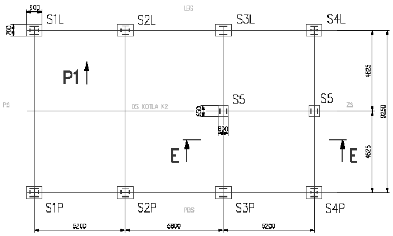


Fig. 6. Labeling of column of supporting structure and approximate locations of strain-gage application.

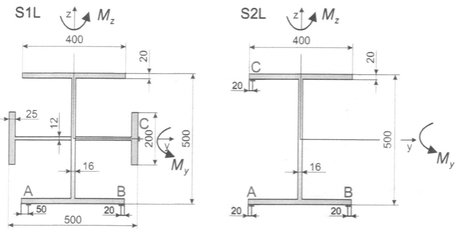


Fig. 7. Locations of strain-gages for hole drilling method.

Locations of measurements on individual specimens were prepared by prescribed technological procedure. After degreasing were applied on the surface strain-gage rossettes 1 – RY21-3/120 with *k*-factor 2,08.

For gluing was used two-component cement X 60 and protective coat SG 250 made by fy Hottinger Baldwin Messtechnik.

By the hole drilling method were in locations of applied strain-gages on columns S1P and S2P determined normal stress components in directions of column axes. These are given in Tables 1 a 2 [7].

As can be see from the Table 1 and 2, the stresses in columns S1P and S2P on the right side reach in absolute values 254 resp. 221 MPa. High stress levels with respect to material 11 523 can not be considered as dangerous, because they contain beside statical loading also residual stresses.

Despite of relatively high levels of statical stress components can be stated that for assessment of life span of supporting structure is crucial time-dependent variable stress component that can be read from time-dependent stresses during operation.

Measurement chain consists of strain-gages XY91 10/120 with $k = 2.06$. Connection of strain-gages was realized such way that active branch consists of strain-gage grid with axis parallel to column axis and compensative strain-gage was oriented perpendicular to active one. For simple uniaxial tension was, with respect to location of strain-gage application, influence of transversal deformation expressed by Poisson ratio.

Table 1. Stress values in location SP1

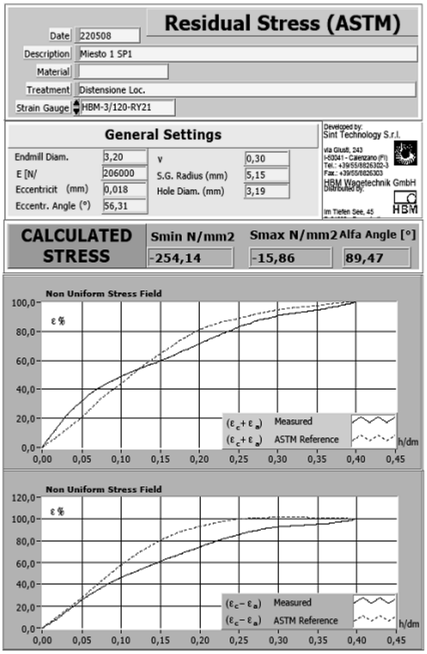
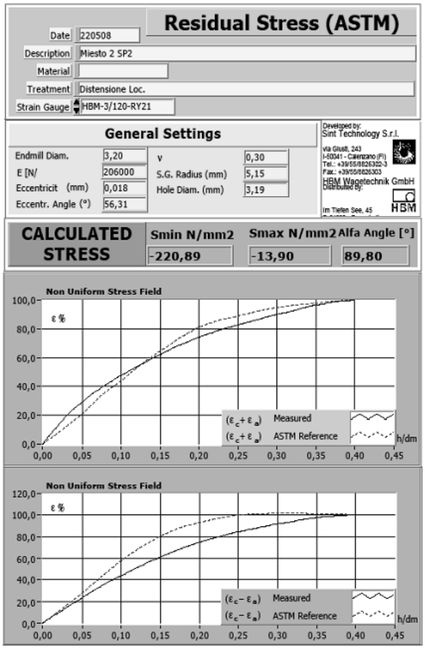


Table 2. Stress values in location SP2



The measurement chain consists of, beside of above mentioned strain-gage in half-bridge connection for thermal compensation also strain-gage apparatus SPIDER8, notebook, computer with program system CATMAN and a printer [8].

4. Determination of internal force quantities in columns from measured values of normal stresses

Application of three strain gages in one cross-section of each column allows determining influence of axial force and bending moments separately [9]. If we consider cross-sections of supporting structure columns according to Fig.7, positioning of strain gages in locations A,B,C allows us to determine the magnitude of axial force N and bending moments M_y, M_z from relations

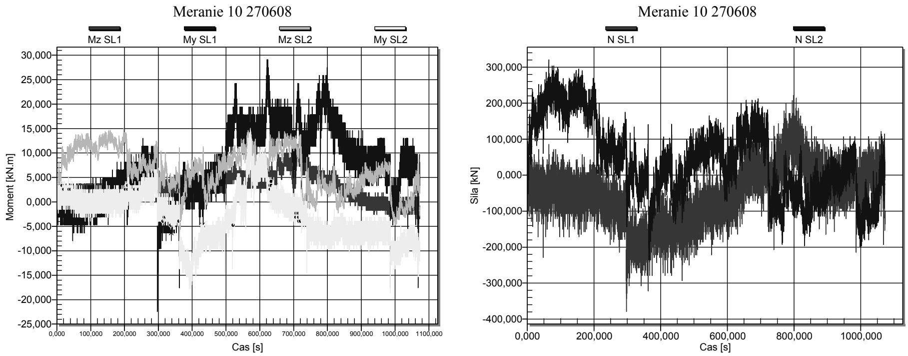
$$N = A\left[\begin{array}{l}\left(1-\frac{z_A}{z_A-z_C}\frac{y_B-y_C}{y_B-y_A}+\frac{y_A}{y_B-y_A}\right)\sigma_A+\left(\frac{z_A}{z_A-z_C}\frac{y_A-y_C}{y_B-y_A}-\frac{y_A}{y_B-y_A}\right)\sigma_B \\ +\frac{z_A}{z_A-z_C}\sigma_C\end{array}\right],$$

$$M_y = \frac{2J_y}{z_A - z_C}\left[\frac{y_B - y_C}{y_B - y_A}\sigma_A - \frac{y_A - y_C}{y_B - y_A}\sigma_B - \sigma_C\right],$$

$$M_z = \frac{J_z}{y_B - y_A}\left(\sigma_A - \sigma_B\right)$$

where y_B, z_A, z_B, z_C are coordinates of strain gages A, B, C; A, J_y, J_z - area, inertial moments of column cross-section, respectively; $\sigma_A, \sigma_B, \sigma_C$ - stresses in locations of strain gages A,B,C [10,11].

Time-dependent charts of integral internal force quantities determined from measured stress charts are given in Fig. 9.



a) b)

Fig. 11. Time-dependent a) increments of moments, b) increments of axial forceduring measurement No. 5.

5. Discussion of results

On the base of visual inspection, modeling of chosen supporting members of original supporting and modified structure, assessment of mechanical properties, determination of statical stress components and residual stresses, but also on the base of strain-gage measurements of stress increments and resulting internal force quantities can be stated:

- Supporting structure of boiler is after modifications loaded by relatively low stress increments caused by thermal loading and also due to dynamical influences evoked during operation. Stress levels increments for ten measurement regimes did not exceed 34 MPa.
- The magnitudes of statical stress components (including residual stress) do not reach the design strength, which is determined to be 284 MPa for material 11 523 and for considering coefficient of material reliability. Level of safety for given case is also sufficient.
- The modifications of supporting structure are not fully correct.

- As inappropriate can be considered:
  - lacking diagonals on the left and right side of upper part of boiler supporting structure,
  - insufficient length of welds between diagonals and sheets of joins on the left and right side in upper part of supporting structure,
  - inappropriate joining of U-profile of frame to columns S2L and S2P, where the joining is positioned not on the side of shear, but on the other side. It results to additional loading of frame (torsion) and column (bending.
  - inappropriate intervention can be seen on joining sheets (on both sides of supporting structure), where are even welded members that stabilize railway system,
  - modifications of truss in high level 3.3 m that are in drawings were not realized and despite of fact that the design is not perfect, the authors tip off that this part of supporting structure have to be solved.
- Insufficiently treated surface of supporting structure, in some cases there is no even the basic coating.
- The authors after visual inspection found out that the beam on which lie piping under barrel declines from vertical position of web by several centimeters The authors believe that it is necessary to stabilize this beam by welding of transversal reinforcement into beam and also stabilize beam in question by triangular reinforcement. The corners of transversal and triangular reinforcement have to be free in length 40 mm on the side of triangular opening.

Despite of high levels of statical stress components (self-weight, content and residual stresses) with respect to extremely low stress level dispersion, it is not necessary to consider according to STN 73 1401 history of boiler loading and damage cummulation for determination of boiler supporting structure state. Life span of supporting structure can be assessed only according to levels of statical stress components and accordingly its life span is limited only by structural state as a result of corrosion damage or degradation of material properties due to thermal influences.

6. Conclusions

Supporting structure after modifications, despite of some documented inappropriate solutions, is suitable for further operation.

In case there will be ensured anticorrosive protection of boiler supporting structure and the supporting structure will not be loaded locally by thermal fields of intensity higher as is during normal operation, it can be considered to be fully functional without limitation in time.

Acknowledgement

The authors acknowledge by project VEGA 1/0004/08.

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