Novi Sad, Serbia 4-7 july 2011

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ECOS 2011

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ECOS 2011

Proceedings of the

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on Efficiency, Cost, Optimization, Simulation
and Environmental Impact of Energy Systems

Novi Sad, Serbia
July 4–7, 2011

Edited by:

Milorad Bojić   Noam Lior   Jovan Petrović   Gordana Stefanović   Vladimir Stevanović

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ECOS Conferences History

1987, May 25-29, Rome, Italy	4th International Symposium on 2nd Law Analysis of Thermal Systems.
1989, June 5-8, Beijing, China	Thermodynamic Analysis and Improvement of Energy Systems, International Symposium, (TAIES ´89).
1990, May 28-June 1, Florence, Italy	Florence World Energy Research Symposium, (FLOWERS ´90).
1991, June 3-6, Athens, Greece	Analysis of Thermal and Energy Systems, International Conference, (ATHENS ´91).
1992, June 15-18, Zaragoza, Spain	International Symposium on Efficiency, Costs, Optimization and Simulation of Energy Systems, (ECOS ´92)
1993, July 5-9, Cracow, Poland	Energy Systems and Ecology International Conference, (ENSEC ´93).
1994, July 6-8 Florence, Italy	Florence World Energy Research Symposium, (FLOWERS ´94).
1995, July 11-14, Istanbul, Turkey	International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS ´95).
1996, June 25-27, Stockholm, Sweden	International Symposium on Efficiency, Costs, Optimization, Simulation and Environmental Aspects of Energy Systems, (ECOS ´96).
1997, June 10-13, Beijing, China	Thermodynamic Analysis and Improvement of Energy Systems, International Conference, (TAIES ´97).
1998, July 8-10, Nancy, France	Efficiency, Costs, Optimization, Simulation and Environmental Aspects of Energy Systems and Processes, (ECOS ´98).
1999, June 8-10, Tokyo, Japan	Efficiency, Costs, Optimization, Simulation and Environmental Aspects of Energy Systems, (ECOS ´99).
2000, July 5-7, Enschede, Netherlands	International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Aspects of Energy and Process Systems, (ECOS 2000)
2001, July 4-6, Istanbul, Turkey	Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS ´01)
2002, July 3-5, Berlin, Germany	15th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2002)
2003, June 30-July 2, Copenhagen, Denmark	The 16th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2003).
2004, July 7-9, Guanajuato, Mexico	17th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy and Process Systems, (ECOS 2004).
2005, June 20-22, Trondheim, Norway	The 18th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2005).
2006, July 12-14, Aghia Pelagia, Crete, Greece	The 19th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2006).
2007, June 25-28, Padova, Italy	The 20th International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2007).
2008, June 24-27, Kraków, Poland	The 21st International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2008).
2009, August 31-September 3, Foz do Iguaçu-Paraná, Brasil	The 22nd International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems, (ECOS 2009).
2010, June 14-17, Lausanne (EPFL), Switzerland	The 23rd International Conference on Efficiency, Costs, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2010).

Following ECOS Conferences

2012, Italy (ECOS 2012)

2013, China (ECOS 2013)

Preface

It is our pleasure to host ECOS 2011, the 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, in Novi Sad, Serbia, near the magnificent Danube River that connects so many countries. Four of the major Universities of Serbia, the University of Niš, the University of Novi Sad, the University of Belgrade, and the University of Kragujevac, with the University of Pennsylvania, USA, have jointly organized this conference. The four Serbian Universities are an educational home to a total of about 174,000 students.

Hosting of ECOS 2011 gives an opportunity for Serbian scholars and students to meet colleagues from all over the world (47 countries at last count), and at the same time gives our foreign colleagues a great opportunity not only to meet others but also to enjoy the beauty of Serbia and the hospitality of its people. The ECOS 2011 motto is "*International Smart Energy Networks of Cooperation for Sustainable Development*" and we hope that the conference attendees will indeed take advantage of this precious networking opportunity to meet colleagues, learn, teach, and promote sustainable development of energy.

Apart from paper presentations, the conference includes the World Energy Panel, a Regional Energy Panel, the Symposium about the genius of Nikola Tesla, the Nuclear Energy Panel, and a panel on Ethics in Engineering and Science.

The conference is also a sad time for parting from two colleagues who have passed away last year and who made a lifetime contribution to the energy field and to ECOS conferences: Ricardo Rivero and Yehia M. El-Sayed. They will be missed.

ECOS 2011 also honors four very alive scholars who have contributed much to Serbian and world energy engineering, science, and education: Professors Naim Afgan, Simeon Oka, MarijaTodorović and Branislav Todorović.

The conference proceedings contain all of the papers presented at the conference, as well as brief biographies of the scholars who passed away and of the honored ones.

We are grateful to the Serbian Ministry of Education and Science for its professional and financial assistance, as well as to the many sponsors who helped the conference. We are also grateful to the UNESCO Foundation for providing assistance to ten young scientists from the South East European region, wich made it financially easier for them to attend this conference.

We would also like to mention the important contributions of the conference support faculty and staff, Goran Vučković, Miloš Đelić, Miroslav Džunić, Dejan Dimitrijević, Marko Ignatović, Mirko Stojiljković, Ivan Ćirić, Ana Đelić Zdravković, Nenad Obradović and Ivana Jocić. Special thanks are extended to Dr. Predrag Rašković who prepared and supervised the technical formatting of the conference papers and poster presentations, and who structured the conference proceedings volume.

Respectfully submitted,

Milorad Bojić, University of Kragujevac, Serbia
Noam Lior, University of Pennsylvania, USA
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Editorial

Testimonial, Yehia M. El-Sayed

Yehia El-Sayed was born in Alexandria Egypt on September 13, 1928. He received his Bachelors Degree from Alexandria University, and his Doctorate in Mechanical Engineering from Manchester University in England.

His academic career took him across the world. He taught and conducted research at Assiut University (Egypt), Kansas State University, Dartmouth College, Glasgow University (Scotland), Tripoli University (Libya) and The Massachusetts Institute of Technology. His legacy persists in the thousands of students and colleagues whose careers and intellectual development he has influenced. He was a recognized international authority in desalination, thermodynamics and thermoeconomics. Over the course of a highly productive career, he authored two books and numerous scientific papers. A Life Fellow of the American Society of Mechanical Engineering, he was a two time recipient of ASME's prestigious Edward F. Obert Award, in addition to a Best Paper Award from the International Desalination Association.

Dr. El-Sayed's contributions brought the fundamentals of science to usefulness in engineering practice, across the spectrum of energy conversions systems – providing principles for optimizing their technical and economic efficiency. The principal objective of his work has been the best possible use of resources. For example, among the various systems benefitting from his efforts – as a writer, teacher and consultant – is desalination, a process very energy intensive and a key to providing water when and where it is scarce. (Incidentally, this work led to a U.S. patent for his design of a unique compressor.)

To his many associates around the world the following excerpt adapted from his Obituary is not surprising: In addition to being a successful scientist, who wrote and published until the end, he was first and foremost a devoted husband of Amina El-Kholi, father of Dr. Yasser El-Sayed (Professor of Obstetrics and Gynecology at Stanford University) and Dr. Maha El-Sayed (Director of Advanced Technology at Clorox Corporation), father-in-law of Dr. William Fisher (CEO of Optwise Corporation) and grandfather of Tamara and Ramsey Fisher. Despite the professional demands on his time, he loved swimming, bowling and spending peaceful times with his loved ones. He infused his family with his contagious humor, passion for learning, and hunger for adventure and travel.

We, his professional associates, have had the privilege of having Dr. El-Sayed not only as a mentor but, it can be said, 'above all' as a friend. If only one word could be used to describe him it might be 'affable'; if two, then the second, seemingly opposed to the first, could be 'quiet' – calm, helpful, modest, always friendly and considerate, in good humor and a droll gentle-man.

On September 17, 2010, after a long battle with cancer, he passed peacefully at his home in Fremont, California surrounded by his family. Another testimony to his modesty: He never divulged his illness to associate-friends who had been communicating with him. He is and will continue to be missed not only by his family but also by all of us who have had the privilege of his friendship.

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Numerical method application for thermo-mechanical analysis of hot water boilers construction

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Abstract:

Paper presents application of the Finite Elements Method for stress and strain calculation of the hot water boiler's structure. Goal of the work was to investigate influence of the boiler scale to the thermal stresses and strain in the structure of the hot water boilers. Results show that maximum thermal stresses appear in the zone of the pipe carrying wall of the first heat diverting chamber. This indicates that most critical parts of the boiler are weld spots of the smoke pipes and pipe carrying plate, what in the case of the huge boiler scale can lead to the cracks in the welds and water leaking from the boiler. The results for two cases, the first one with temperature dependent material characteristics and the second one for the average temperature material characteristics, are compared. In order to minimize deformations and stresses, the stiffness of the rear head can be increased by increase of its thickness or by fixing stiffening girders on it. Stresses in the rear head can also be diminished by reconstruction of the flame tube supporting element.

As a reference object boiler Viessmann - Vitomax 200 HW, with installed power of 18.2 MW has been used. CAD modelling is done within Autodesk Inventor and stress and strain analysis is done within ANSYS Software.

Keywords:

Hot water Boiler, Thermal analysis, Finite Elements Analysis

1. Introduction

The paper presents application of finite elements analysis (FEA) on stress and strains analysis of hotwater boiler. The results of calculation show that extreme values of thermal stresses and strains appear in the zone of pipe carrying wall in the first heating chamber. These results imply that welded joints of smoke pipes and pipe carrying wall in the first heating chamber are the most affected parts; adding the fact that huge amount of boiler scale delivers appearance of hot/cold cracks on joint and leakage of boilers water [1,2].

Damaged places on hotwater boilers can appear as a consequence of various destructive mechanisms – in the most of cases several mechanisms act simultaneously. Since damage appearing depends from various parameters of the boiler itself (design, boiler working conditions, work medium, properties of work medium etc.) it is necessary to decompose complete system to components and work medium and investigate them separately and in detail in order to get a clear picture on real conditions of the boiler. Real assessment (about usability and life span) is real only when part-analysis is detailed and gives complete and clear glance on the effect of work.

Stress and strain analysis of the construction requires in depth analysis of its exploitation, loads and behavior while working. The main goal of the analysis is to find qualitative, complex identification of work states (function / non functional / partially functional) a behavior in determined state. This can be achieved only with development and application of numerical and experimental methods, and advanced methods for monitoring and diagnostic of behavior of construction. Furthermore, real time monitoring of exploitation and measuring of the relevant parameters behavior is a necessity in realization of the tendered goal.

The basic task of condition diagnostics and equipment behavior represents consequence-behavior and cause – consequence analysis, as well as the cause – equipment affection analysis with a goal to find optimal solutions that will provide construction / system work normally, safely, reliably, as long as it is possible with the decrease of maintenance costs.

The main purpose of this paper is to present the goal-tending analysis of a hotwater boiler: to find the most effective changes in design of the boiler to get maximal increase of the strength in the area of pipe carrying wall in the first heating chamber. For that purpose, numerical simulations for the different parameters (variable pipe diameters, ribs application etc.) are conducted on a referent model of known parameters and recognized behavior.

Referent object is the hotwater boiler Viesmann - Vitomax 200 HW M238 , of the heat power 18.2 MW. For stress and strain analysis is used Ansys Software and full FEA analysis.

2. Technical charactersitics of the - Viessmann hot water boiler Vitomax 200 HW

Vitomax 200 HW (Figure 1) is an oil or gas fired high-pressure hot water boiler for permissible flow temperatures up to 205°C and permissible operating pressures of 6.5 to 25 bar – i.e. a standard boiler for district heating and industrial applications.

The Vitomax 200-HW benefits at a glance:

- High level of operational reliability and a long service life are assured through wide water galleries and wide spaces between hot gas pipes. The clearance between hot gas pipes exceeds the minimum requirements of the applicable current (national) directives. This results in Viessmann boilers achieving the maximum permissible test periods. In addition, the large water content provides excellent natural circulation and a reliable heat transfer under all operating conditions.
- Three-pass boiler for clean combustion with low nitrogen oxide emissions.
- Economical energy consumption – boiler efficiency without Eco up to 92 %. Substantial increase in the boiler efficiency right into the condensing range through flue gas/water heat exchangers downstream of the boiler.
- Low radiation losses through 120 mm thick composite insulation and insulated flue gas collector.
- Approval according to the European Pressure Equipment Directive 97/23/EC or according to country-specific regulations.
- Low pressure drop on the hot gas side through convection heating surfaces with generously sized hot gas pipes.
- High level of serviceability through water-cooled reversing chambers without firebrick lining – large cleaning doors.
- Removable burner trolley for boilers up to 2500 kW available as accessory for easier maintenance and simplified burner adjustment.
- Walk-on cover on top of the boiler as part of the standard delivery – this simplifies the installation and maintenance and protects the thermal insulation against accidental damage.
- An intermediate flow piece for the integration of measuring, control and safety fittings is part of the standard delivery.
- The Vitocontrol control panel enables the regulation of all boiler-specific control equipment. In addition, suitable components provide operation without need for permanent supervision, a fully

automatic boiler operation with 24 or 72 hour supervision-free operation in accordance with country-specific conditions.

Table 1 - Mechanical properties of the steel St35.8

Property	Value
Elasticity module	2.1·1011 N/m^2
Poison ratio	0.3
Specific density	7850 kg/m^3
Linear expansion of material	12.5·10-6 1/°C
Yield strength	206.8 MPa (N/mm^2)

Table 2 - Mechanical properties of the steel P265GH

Property	Value
Elasticity module	2.1·1011 N/m^2
Poison ratio	0.3
Specific density	7800 kg/m^3
Linear expansion of material	12.5·10-6 1/°C
Yield strength	255 MPa (N/mm^2) for $d \geq 16$ mm

Figure 1 - Oil or gas fired high-pressure hot water boiler Viessmann - Vitomax 200 HW, (1 – Boiler with load-bearing cover; 2 – Duplex pipe with multi-layer convection heating surface; 3 – Water-cooled burner entry for low nitrogen oxide emissions; 4 – Large and light cleaning doors; 5 – Wide water galleries for good natural circulation and low thermal load)

3. Thermo mechanical calculation of the hotwater boiler

Destruction of mechanical constructions appears when extreme values of the stresses appear in the parts of the system. Very often other parameters are significant, as well, since destruction does not appear always on the places where extreme values of stresses appear. Extreme values of stresses can be determined when distribution of the stresses is estimation. Methods for stress distribution determinations are various: stress concentration factor's determination, fracture layer application, photo-elasticity method or numerical methods – FEA.

3.1. Finite Elements Analysis

The present FEA method dates from the 1956. First introduction is bonded with the work of M. J. Tuner, R. Clough, H. C. Martin i L. J. Topp, with application on simple elements (a beam and triangular plate with planar loads) for the airplane structures. Famous work of that time belong to the O. C. Zienkiewich (1966., 1967., 1971.), J. S. Przemieniecki (1968.), J. T. Oden (1972.), J. Robinson (1973.), R. D. Cook (1974.), G. N. Smith (1971.), R. G. Gallangher (1975.), K. J. Bathe (1974.), E. L. Wilson (1974.) and others [1,3,4,5].

The basic idea of FEA analysis is to find a numerical, approximate solution for a complex structural construction. Continuum of the construction is idealized and discretizied with small, regular 3D solids that we call finite elements. Finite elements are bonded one to another over mutual nodes and the number of nodes is in direct proportion with the density of finite elements in the continuum and the size of the finite elements. The higher the finite elements density is, the smaller is possibility to miss extreme values of stresses in discretization process. That is the main principle why it is necessary to increase the density of elements where extreme values of stresses are expected and vice versa.

The change of influencing parameters within finite elements is described with the simple approximation functions. Parameters of the interpolation functions are defined over values of the parameters in the nodes. Strain field of the nodes is estimated as a solution of the matrix equilibrium equation. Based on strain field, deformation and stress fields are determined as well as the stress structure points. FEA is described as a step – by – step procedure:

1. step – geometry modeling, idealization and structure discretization. Type, density, size and number of the finite elements determination and distribution of the finite elements are very important decisions on optimal and convergent solution gaining.
2. step – selection of appropriate interpolation model for strain field. Models are mostly polynomial. They have to provide required model of strain, deformation and stresses in finite elements.
3. step – stiffness matrix forming and vector of loads on finite elements determination. All properties for every finite element are calculated for the local and global system of coordinates.
4. step – determination of the global stiffness matrix, loads, loads vector and boundary conditions of the construction. Every stiffness matrix and loads vector are given to the nodes, with an adequate numeration, as well as the adequate boundary conditions
5. step – calculation of the unknown displacements from the static equilibrium eqations.
6. step – calculation of strain and stresses in finite elements.
7. step – calculation of the stress points in the structure.

3.2. Modeling, idealization and discretisation of the structure

Virtual model of the referent hotwater boiler is developed in Autodesk Inventor (CAD software). For development of the model is used documentation of the Viesmann Company. 3D model is given in the Figure 2.

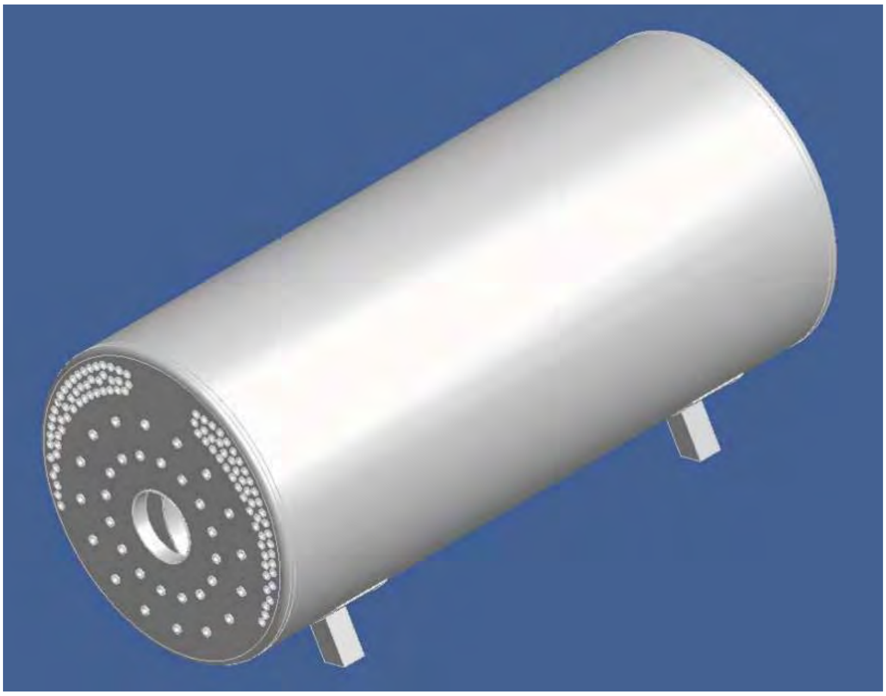

Figure 2 - Virtual model of the referent hotwater boiler

Simplified geometrical model is transformed into the discretizied FE model with the application of advanced meshing tools capable to create adaptive discrete models. Discretized model consists of 258476 nodes, which form 91248 finite elements, and 280486 nodes, which form 94337 elements in the case of reinforcement of the pipe carrying wall of the second heating chamber with a radial rib. Discretized model of the hotwater boiler is given in Figures 3, 4 and 5. Finite elements are of the identical topology for thermal and structural analysis and different types of finite elements are used for both models. Automatically, all types of used finite elements are united in a complete, complex mesh of elements that is used for the further analysis.

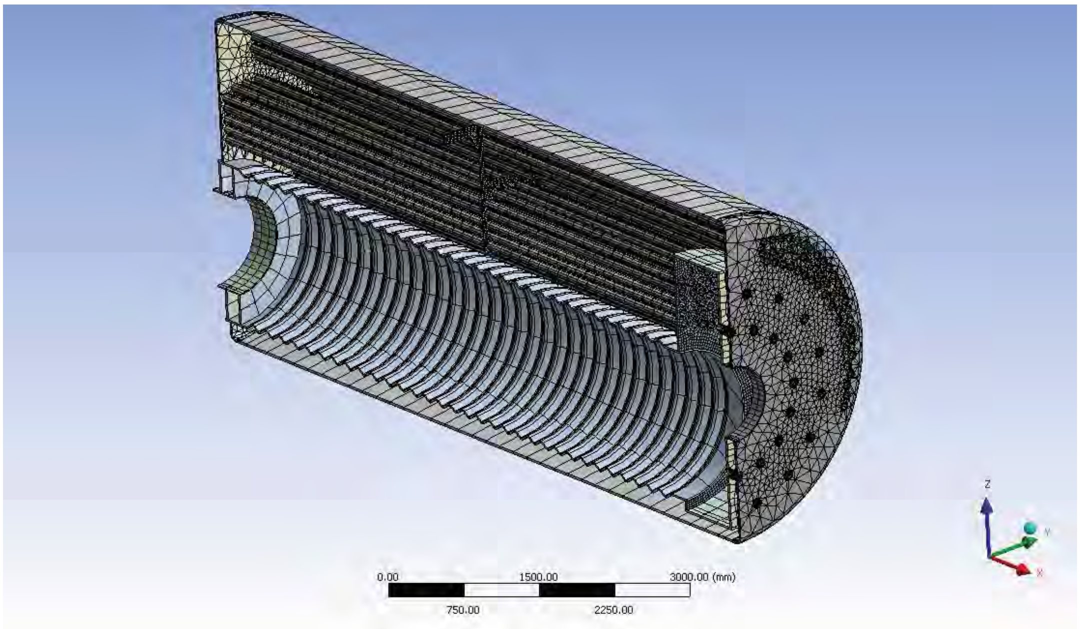

Figure 3 - Discretized structure of the hotwater boiler

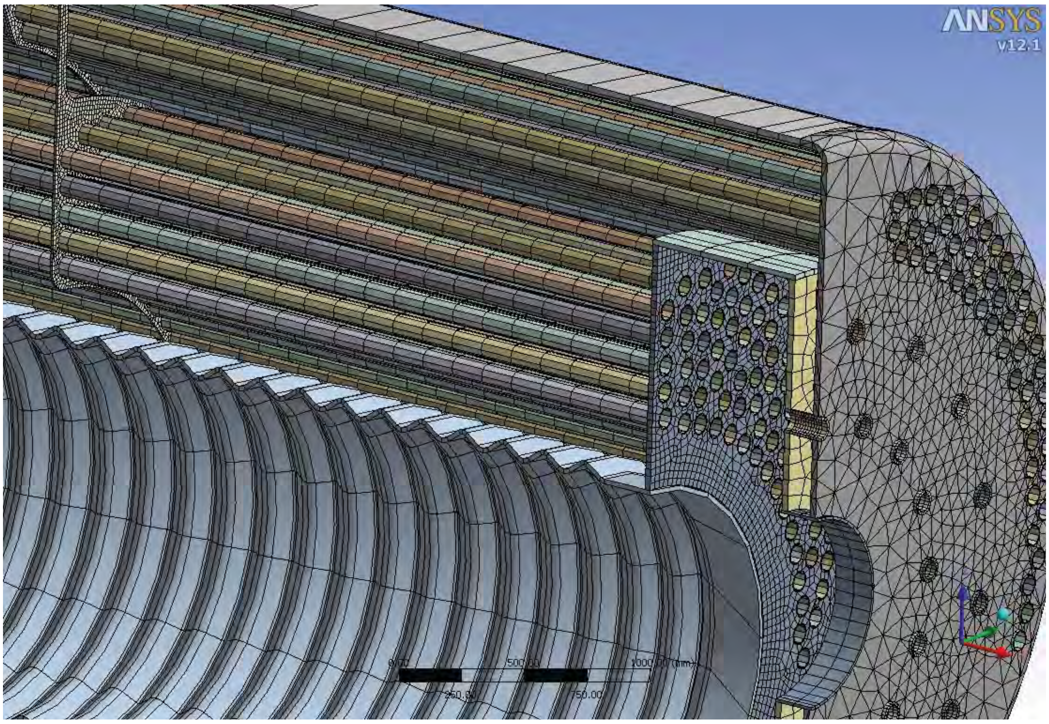

Figure 4 - Discretized structure of the hotwater boiler (detail)

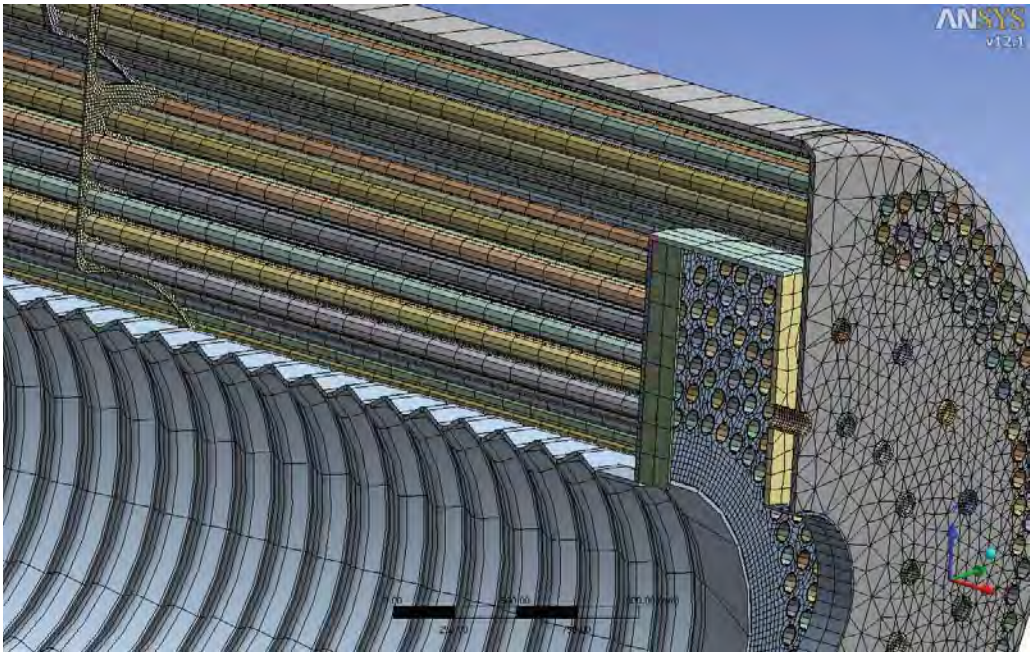

Figure 5 - Discretized structure of the hotwater boiler (detail with discretizied structure, with radial rib on the wall of the second chamber)

3.3. Boundary conditions

Thermal calculation of the hotwater boiler is done basing on the median temperatures of the construction on the side of smoke gasses and on the side of the boiler where water flows – data about boiler without boiler scale, according to the Viessmann (Figure 6).

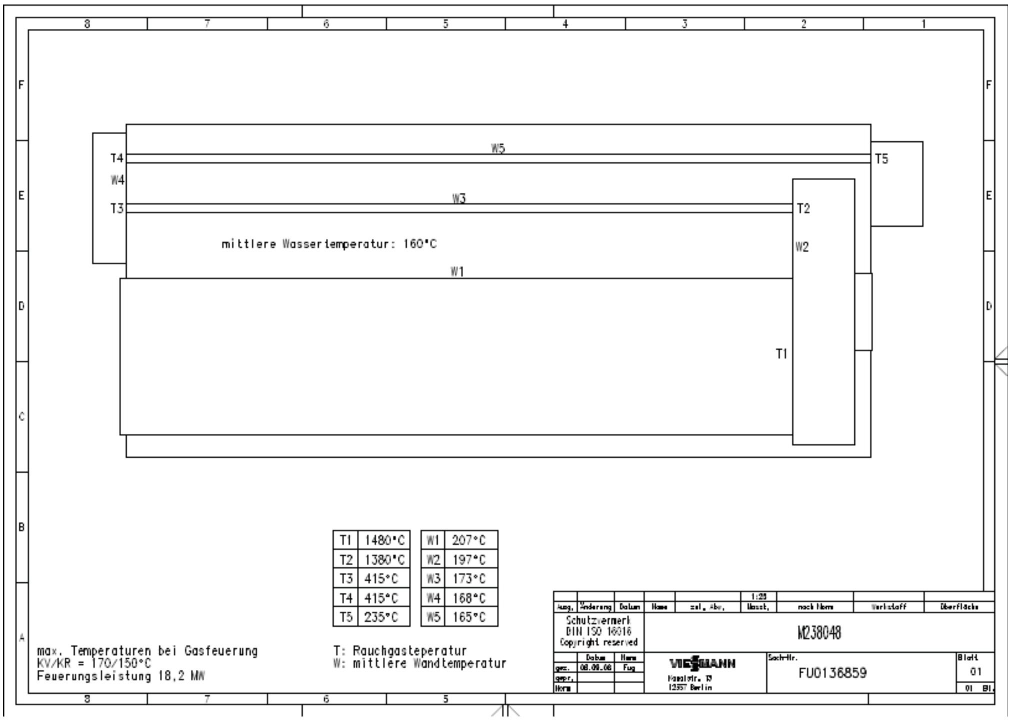

Figure 6 - Median temperature used for calculations

Based on this data thermal loads of the model have been defined (Figure 7).

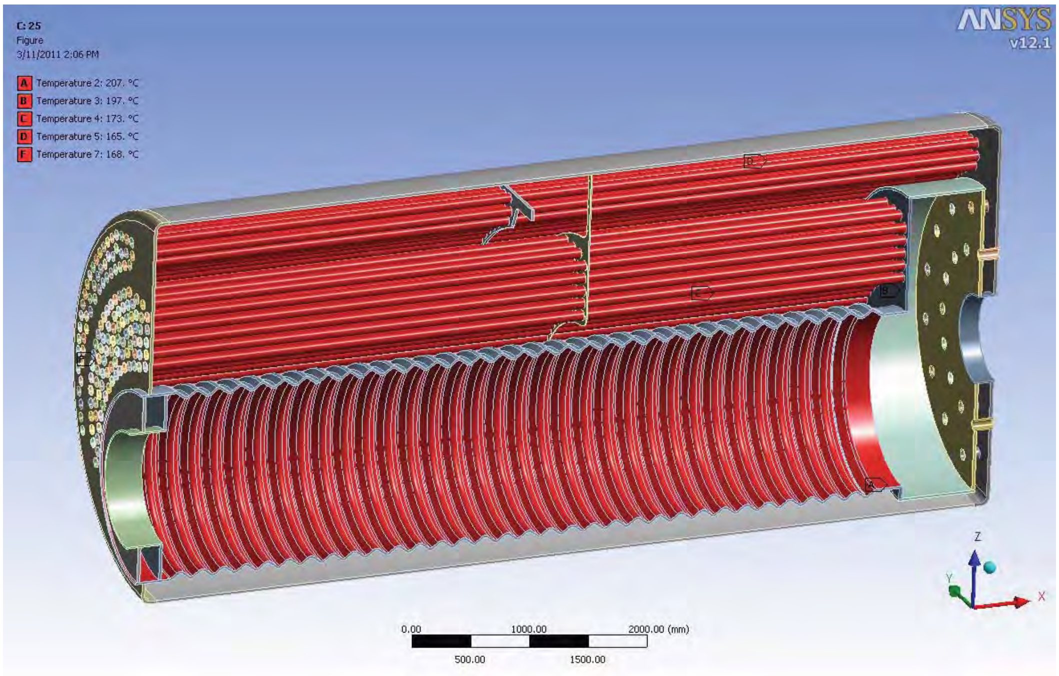

Figure 7 - Defined input median temperatures of the hotwater boiler

4. Thermomechanical analysis of the hotwater boiler's structure

"On field" expertise has shown that destruction of the hotwater boiler appears on pipe carrying wall of the second chamber and several different constructional changes have been investigated. Beside increase of the pipe thickness of pipe carrying wall of the second chamber, it is analyzed the influence of the inserted radial (welded) ribs in the area of pipe carrying wall of the second chamber. Complex structure of the pipe carrying wall gives the possibility to insert only one rib, in the plane of symmetry of the of pipe carrying wall. Four different cases have been analyzed:

- Basic structure of the hotwater boiler (thickness of the of pipe carrying wall 21 mm) – no changes in referent design,
- Construction with the increase to the 23 mm,
- Construction with the increase to the 25 mm
- Construction with the increase to the 21 mm with the inserted radial rib (Figure 9).

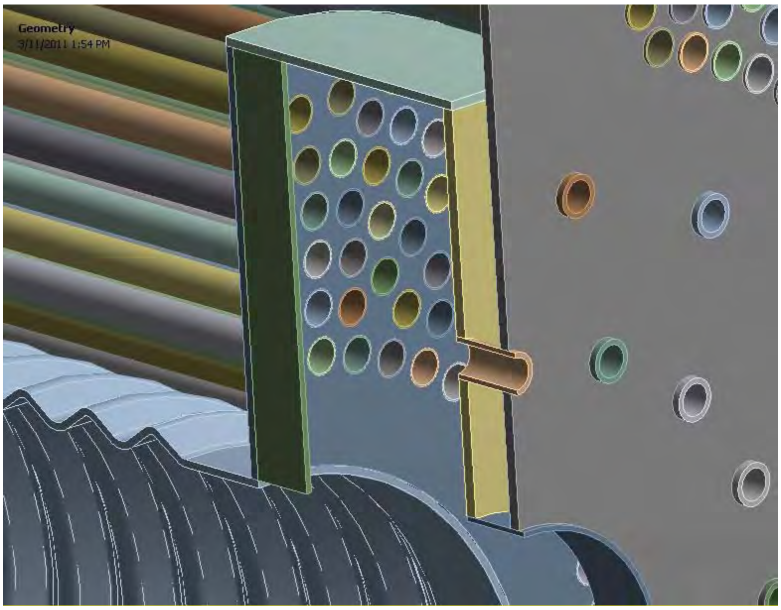

Figure 8 - Radial rib inserted in the hot water boiler

Analysis of structural loads delivered to the boiler shows two different types:

- Loads from the mass of the construction and
- Loads resulting from the thermal dilatations on higher temperatures

Results of the thermal analysis are given – temperature field and thermal flux are shown in Figures 9 and 10.

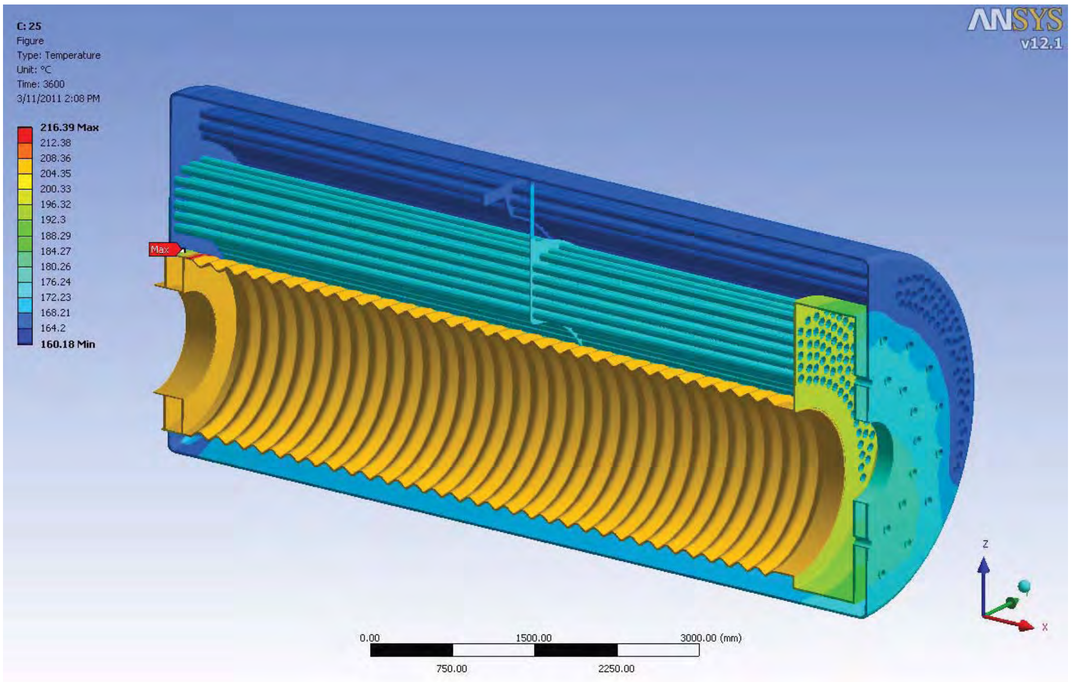

Figure 9 - Temperature field of the structure

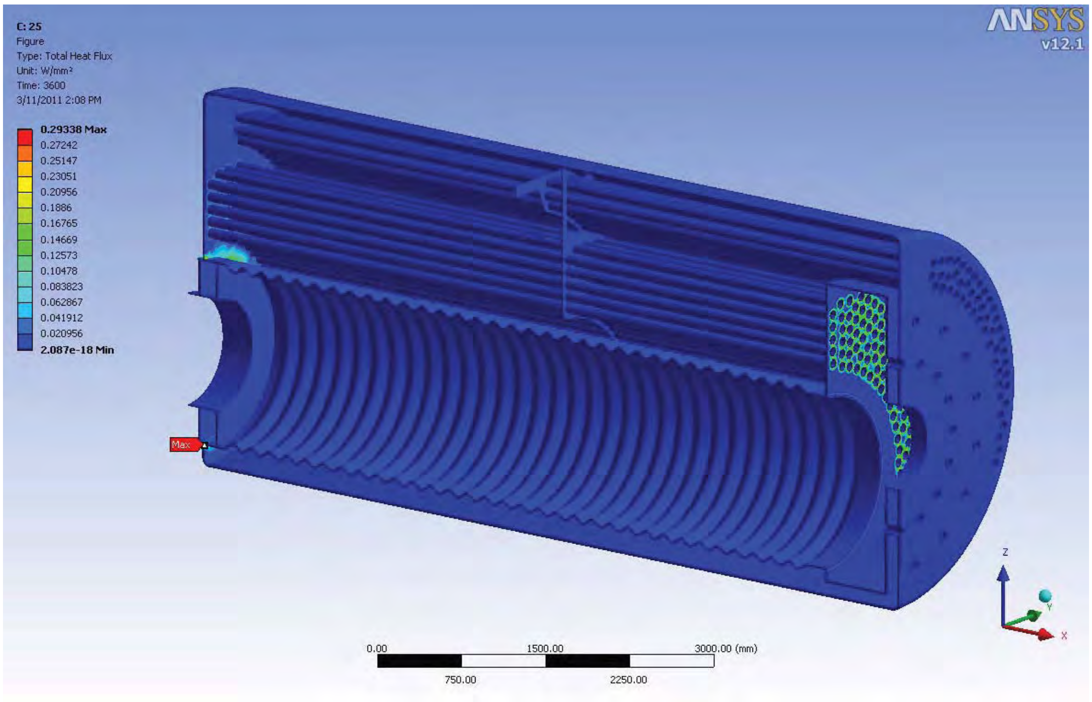

Figure 10 - Temperature flux field of the structure

Based on the thermal analysis of the boiler, structural analysis of the boiler is conducted. Anchorage system is shown in Figure 12.

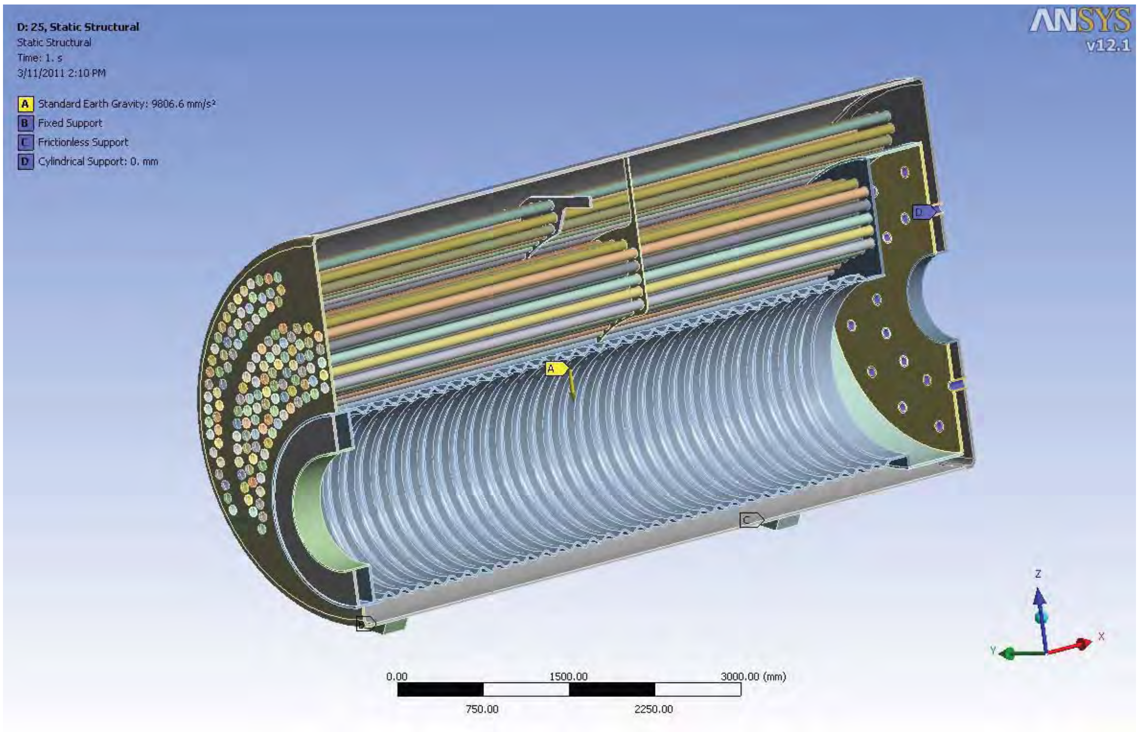

Figure 11 - Anchorage system of the hotwater boiler

Results from the stress and strain analysis of the boiler, for the previously mentioned cases are given in Figures 12 to 15.

As seen from the noted figures, the maximum stresses occur on the between pin key and the bolster at the back wall of the boiler. The contact stresses are byproduct of the Finite Element Method. Those are a consequence of the simplifications of design features (omitting of chamfers, fillets and radiuses) due to high computational demands and model complexity. Stress contraption occurs in sharp edges which in reality do not exist in the structure. In such case it is appropriate to perform the more detailed analysis with usage of actual geometry without simplifications or to use non linear material model in order to include strain-hardening effects. But noted procedures are very computational demanding and will be object of research in future. Maximum stresses were omitted as they occur on the place which is not interesting for analysis, as the boiler defects due to thermal loads occur on the pipes carrying wall [1].

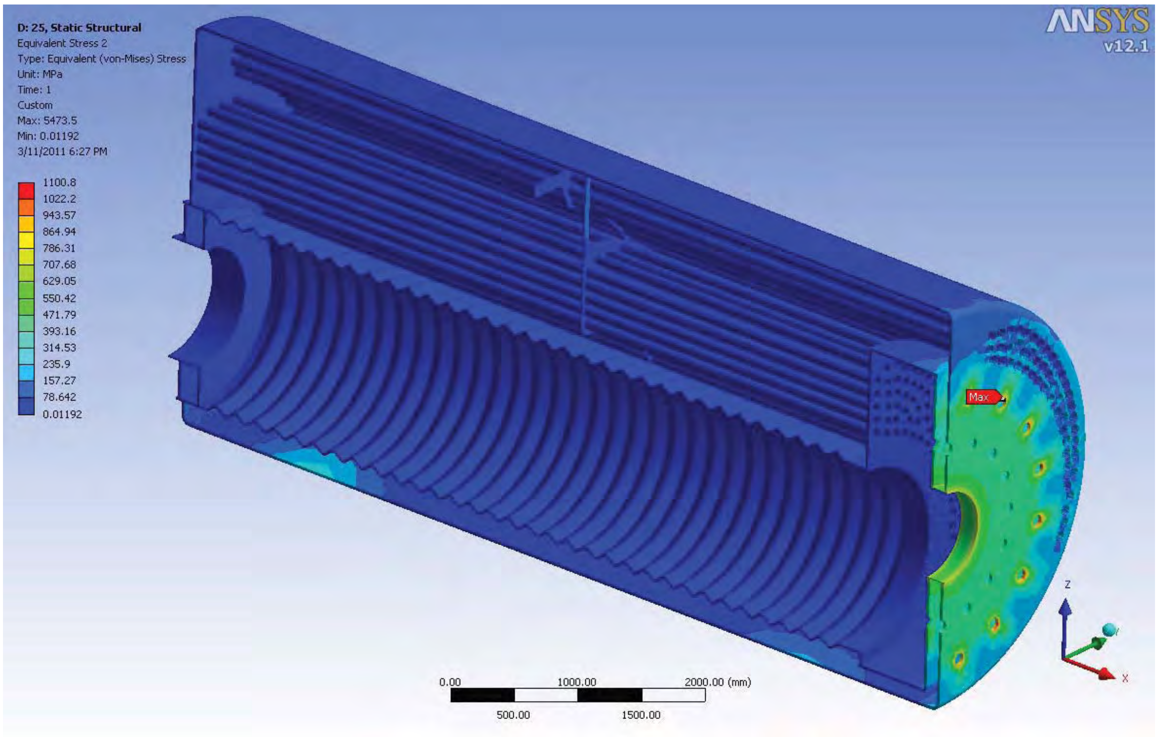

Figure 12 - Stress and strain of the boiler, case: (pipe carrying wall - 25 mm)

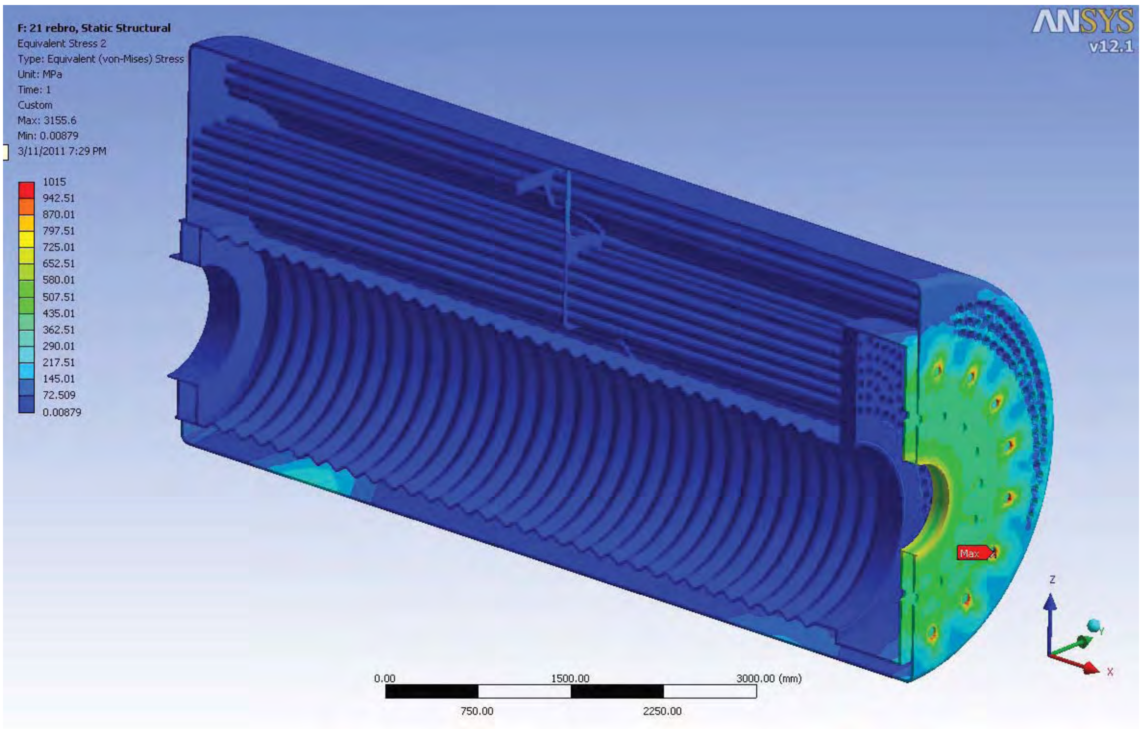

Figure 13 - Stress and strain of the boiler, case: with the radial rib

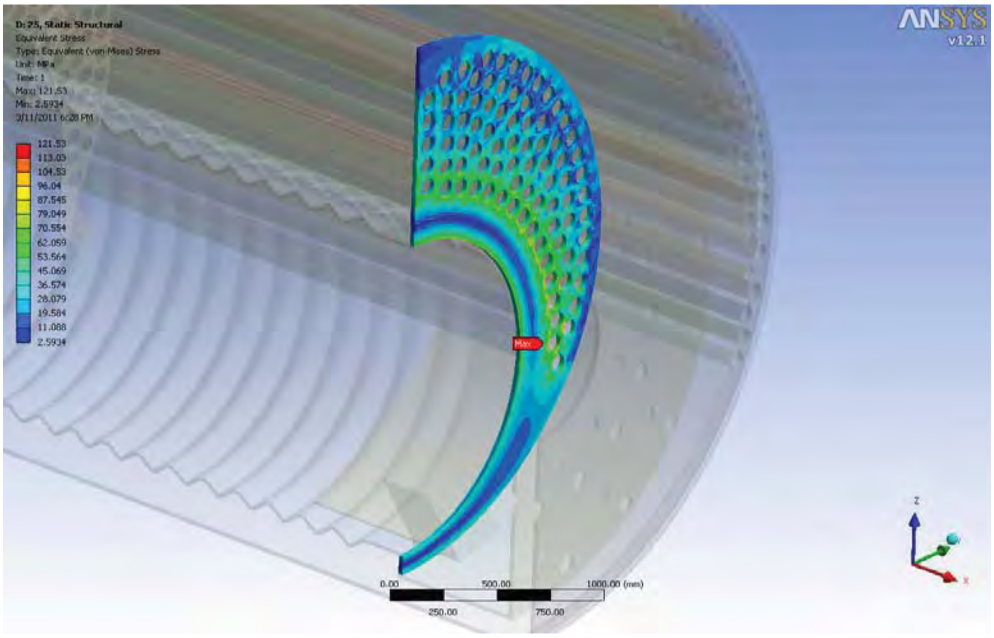

Figure 14 - Stress and strain of the boiler, case: (pipe carrying wall - 25 mm)

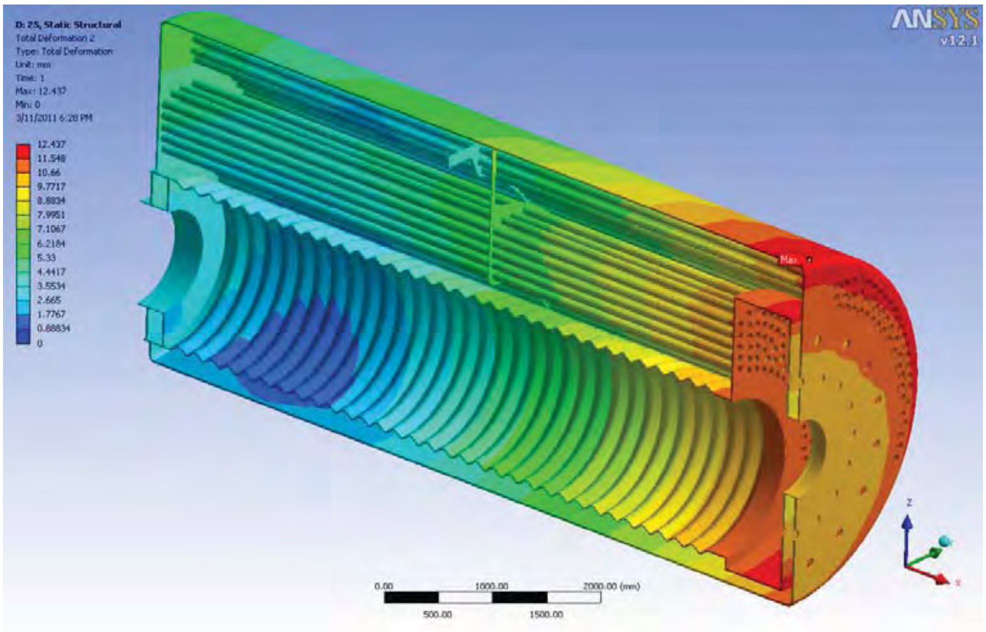

Figure 15 - Deformation of the boiler, case: (pipe carrying wall - 25 mm)

Table 3 gives representative values of stress and deformation of the pipe carrying wall of the second chamber for all analyzed cases.

Table 3 - Stress and deformation – comparison of the results for different cases

	pipe carrying wall ≠21 mm	pipe carrying wall ≠23 mm	pipe carrying wall ≠25 mm	pipe carrying wall ≠21 mm, with the radial rib
Stress N/mm^2	146.51	136.66	121.53	143.01
Deformation in mm	11.186	11.218	11.265	11.098

Results show that maximal thermal stresses and deformation appear in the zone of pipe carrying wall in the first chamber. This endangers welded joints of smoke pipes and pipe-plate what in the case of significant boiler scale could cause hot / cold cracks appearance and leakage of the water.

5. Conclusions

Based on the results of the thermomechanical calculations done by FEA, it can be said that:

1. Maximal stresses appear in contact between pin key and the bolster at the back wall of the boiler. Values of the stresses are extremely large which is a byproduct of Finite Elements Method. Simplifications on model and stress extreme values in noted region have no credibility for the analysis stress and deformations of boiler.
2. Stresses at the carrying wall of the second chamber, where referent model has shown the weakness, reach the value up the 147 N/mm^2.
3. Properties of the material P265GH DIN EN 10028-2, used for the pipe carrying wall, are R_m=410 - 530 N/mm^2, yield strength R_p=265 N/mm^2, yield strength at T = 200 °C, R_{p200} =200 N/mm^2, and allowed stresses σ_{doz} =133 N/mm^2 are less than resulting stresses and destruction of the hotwater boilers made by company Viessmann are inevitable even without boiler scale.
4. Possible leakages may appear on the welded joints of pipe wall and pipes, what is already found on the referent model.
5. Deformations of pipe carrying wall are about 11 mm.
6. Based on the numerical results, it can be concluded that better results about the carrying strength of pipe carrying wall can be achieved with the increase of the pipe wall thickness rather than radial rib.
7. Insertion of the radial rib minimally increases strength of the pipe carrying wall and it is recommended, based on specific design of the hotwater boiler and it should not be considered considering the complexity of the boiler.

6. References

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