Design of Machines and Structures, Vol. 4, No. 1 (2014), pp. 77–85.
https://doi.org/10.32972/dms.2014.008

ONLINE MONITORING SYSTEM FOR STRUCTURES AT ELEVATED TEMPERATURE

SZABOLCS SZÁVAI–SZABOLCS JÓNÁS–
BALÁZS BAPTISZTA–ZOLTÁN BÉZI
Bay Zoltán Nonprofit Ltd., Department of Structural Integrity
3519, Miskolctapolca, Iglói str. 2.
szabolcs.szavai@bayzoltan.hu

OLMOST-HT project aimed to develop an integrated hardware and software system for on-line and on-site measurement of structure displacements in most critical regions in order to prevent failure due to flaw or fatigue occurred by degradation mechanism as creep, thermal ageing, and hydrogen embitterment on high temperature. Due to the unknown condition and the high consequences of any failure means that the operational risk can be extraordinary high. To prevent failure, maintenance in time requires special dedicated monitoring techniques. Having proper online global and local displacement and deformation data comparison can be done between the estimated and real data and decision can be. In this paper the previous experience of the OLMOST-HT monitoring system is presented. This study describes the main laboratory test, the trial of the monitoring system and a finite element case study of a catalytic reactor.

1. Online monitoring

Thermal power and chemical plants are highly capital intensive and hence it is necessary to ensure not only their safe operation, but also their economic viability in the long run. Integrity of important components is essential for operational safety, reliability and low cost operation. Normally, a plant is designed with a life expectancy of 30 to 40 years to produce continuous operation economically. However, because of conservatism in the design, the actual lives of these plants are expected to be much more than the estimated value. The sustained interest in the area of remaining life prediction arises from the need to avoid costly outages and to ensure safe operations, and the necessity to extend the component operation life beyond the original design life. In power generation systems, many structural components, such as steam pipes, superheater headers, and turbine rotors operate at elevated temperatures. At the same time, they are also subjected to cyclic loading due to fluctuation of process parameters. Hence, these components are exposed to a damage mechanism caused by fatigue, creep and creep-fatigue interaction. It is neither possible nor necessary to monitor the degradation effects for all the components of a plant. An in-depth understanding of the possible damage mechanism and the plant process dynamics is essential for the selection of an optimum number of components [2].

OLMOST-HT system is an on-line monitoring system for structures that operates at elevated temperatures. The system has a modular structure, which means it is possible to expand it with different additional modules (Figure 1). Sensors are equipped on the chosen components of the in-situ structure. The number of modules is determined by the number of probable failures. The different modules can be built into the system in accordance with the requirements of the structure. The measured data are constantly stored on a server. The

system has decision support software which contains a material database, several cases of hypothetic failures examined by FEA and an engineering assessment method.

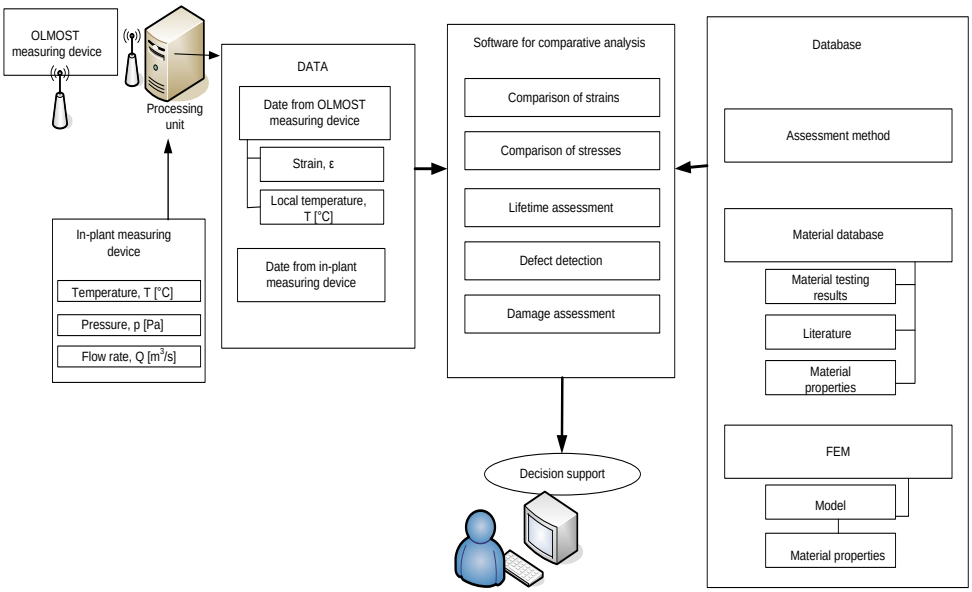


Figure 1: Block diagram of the OLMOST-HT system

The procedure described for advanced numerical analysis to calculate the expected structure response due to creep for design stage and based upon real operating temperature history. There are different creep models available:

- Combining Creep Material Models
  - This model illustrates how to combine different creep models to accurately represent the material behaviour.
- Combining Elastoplastic and Creep Material Models
  - This model shows how to combine different types of material nonlinearity, such as creep and elastoplasticity.
- Thermally Induced Creep
  - This model computes the stress history over a very long time for a material that exhibits creep behaviour.
- Primary Creep Under Nonconstant Load
  - primary creep using a Norton-Bailey law.

The monitoring system is online, so the measured values are accessible on the internet through an application called FieldLogger. The software has a pre-determined security level system. If the measured values at a component reach critical level, the system automatically sends an SMS or an e-mail to the appropriate people. Due to this function the intervention could be quick. OLMOST-HT was installed to an elbow of a steam pipeline as a test for the pilot system. Strain and temperature gauges were spot welded to the outer surface of the

elbow. The temperature of environment was also measured as a control value. In 2013 the online measurement system was installed to an elbow in BorsodChem Zrt. The Figure 2 shows the device.



Figure 2: OLMOST-HT measurement device

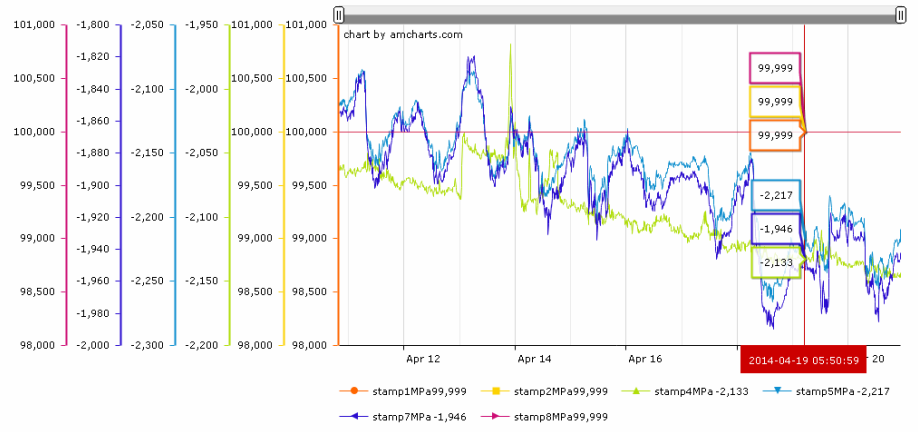


Figure 3: Measured stress values at different gauges

From the software the data can be able to export and comparable with FEA data. In the future we would like solve to connect the database with the software. Now the comparison is only works by manually, but the software development to come to an end soon. The measured values as a function of time are shown in Figure 3–4 as some results from the software. Each gauge can be examined independently. Development and testing of the pilot system was aided by laboratory tensile test results from an elbow specimen. Strain gauge layout identical to the pilot system was used during testing.The results of the test and the FEA (Figure 5) of the elbow were compared as it is shown in Figure 6. Strain 3 and strain 5 measured the same stress component, but at the opposite side of the elbow. The results are in good agreement.



Figure 4: Measured temperature values at different gauges

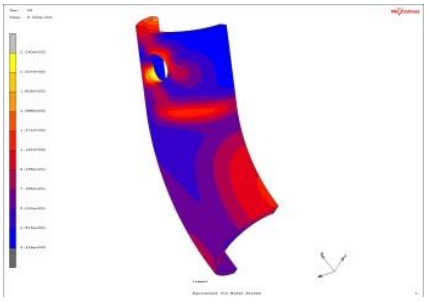


Figure 5: FEA of the laboratory test specimen

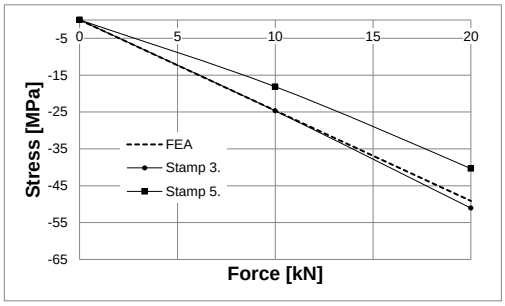


Figure 6: Comparison of the test and the FEA

2. Industrial case study for fitness for service analysis of component operates on elevated temperature

The case study is a preliminary investigation before the actual measure of creep. The reactor blows off around the perimeter and this phenomenon causes problems in the operation. The product of the reactor is NH3 so it is hazardous and can cause impair in the environment.

2.1. Parameters of the simulation

The inside pressure of the reactor pressure vessel (RPV) is 11.57 bar(a) and at the top of the RPV the temperature is 455 °C. The material of the shell, the heads, the manholes, the nozzles and the flanges are steel grade X6CrNiTi18-10. The critical part of the RPV is the upper flange, so the examination is focused for the compliance of the parts of the flange at elevated temperature. The fasteners of the flange are made of steel grade 21CrMoV 5-7+QT. The part assembly of the flange is shown in Figure 7.

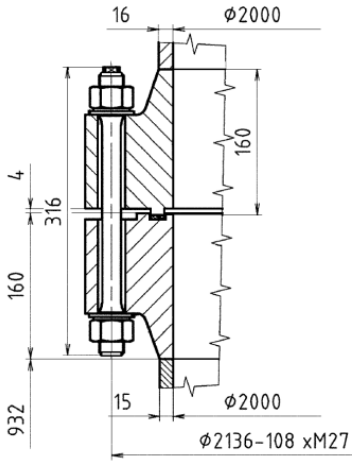


Figure 7: Geometry of the flange

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2.2. Calculation of the bolt load for gasket seating condition

The ASME BPVC III.Div.1.App. XI.was used to check the seating condition of the gasket and the bolt loads [4]. The bolt load is also a useful input parameter for the FE model. The applied gasket is a grooved gasket. Gasket parameters from Table XI-3221.1-1 of the ASME code were used for the calculations. The gasket factor m = 4.25, and the minimal seating stress y = 70 MPa (11,100 psi). From the calculations the required bolt load is F_{bolt} = 4262986.53 N (~4262.9 kN). The load distributes between the bolts equally. The flange contains 108 pieces of M27 bolts. So in the model the pre-tension force of a bolt is F_{1_bolt} = 39472.0975 N (~39.5kN).The strength calculations show that the number of bolts and the material of the gasket are sufficient and the seating condition is also suitable.

2.3. Modelling

For the simulation MSC.Marc&Mentat 2012 FE code was used. The geometry is cyclic symmetric; hence only a thin slice of the whole structure has to be modelled. Boundary conditions and the FE mesh of the flange are shown in Figure 8. The whole model is interpreted in cylindrical coordinate system. Two loadcases are set in the model. In the first loadcase the pre-tension of the bolt is computed.

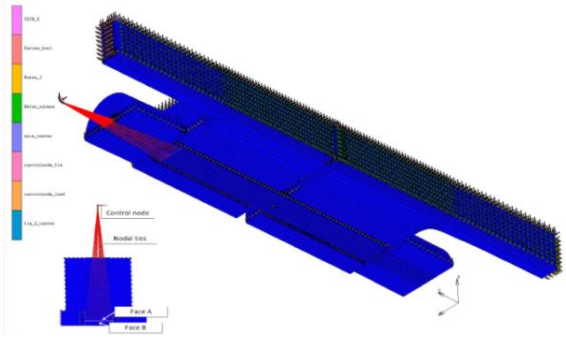


Figure 8: Boundary conditions and the FE mesh of the flange

The pre-tension was modelled according to [3]. The nodes on the new faces (Face A and Face B) are linked to the control node. The pre-tension force is transmitted by this node. The control node only moves upside (direction Z). In the first loadcase the pre-tension force of the bolt is applied to the control node. In the second loadcase the inner pressure is applied, and in the third loadcase the creep is done. The creep is considered by an exponential creep law. The total number of elements is 29696, each of them is 4-node quadrilateral element. Table 1 contains the number of elements and nodes for each part.

Table 1

Properties of FE mesh

	Number of elements	**Number of nodes**
Bolt	10784	12865
Upper part of flange	9464	11961
Lower part of the flange	9384	11844
Gasket	64	135

In the second load case the inner pressure is added. From the inner pressure originated a tensile force on the surface of the section plane of the flanges. The value of this force can be calculated by the (1). Figure 9 shows a schematic figure about the mechanical background of this relationship.

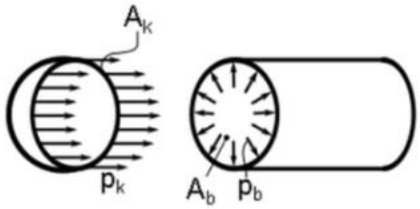


Figure 9: Illustration for the determination of the tensile force around the perimeter

$$p_k = p_b \cdot \frac{A_b}{A_k}. \tag{1}$$

2.4. Determination of the applied material properties

The material properties of the flanges and the gasket are from material database. The material properties depend on the temperature; the applied values are interpolated from the data (Figure 10–11). The material properties of the bolt are measured values. 6 specimens were tested by uni-axial tensile testing. The test temperatures are the following: 20 °C, 270 °C and 455 °C (Figure 12–13).

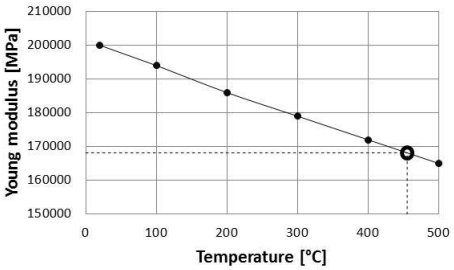


Figure 10: Temperature dependant Young modulus of X6CrNiTi18-10

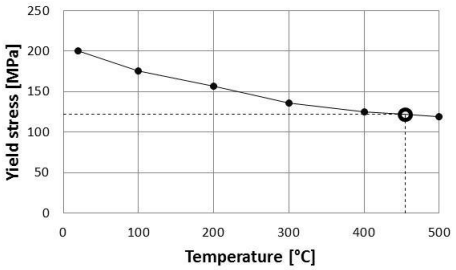


Figure 11: Temperature dependant yield stress of X6CrNiTi18-10

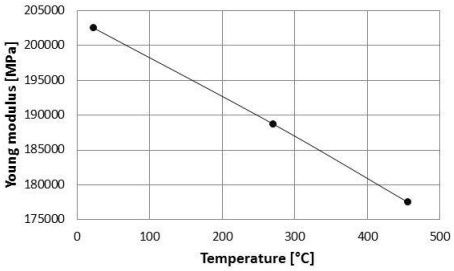


Figure 12: Temperature dependant Young modulus of 21CrMoV5-7+QT

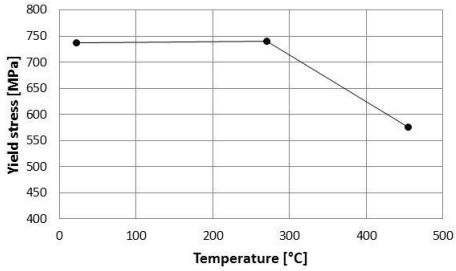


Figure 13: Temperature dependant yield stress of 21CrMoV5-7+QT

2.5. Results of the simulation

The results of the simulation show that the stress state of the bolt is high. The stress distribution at elevated temperature of the structure is shown in Figure 14. The assumption is that this stress is higher than the creep limit of the bolts. Creep data only available in literature. The creep properties of the bolt material are in Table 2. The values at 455 °C are interpolated data.

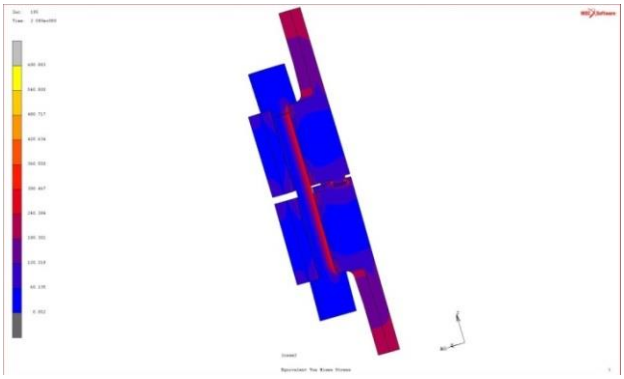


Figure 14: Equivalent Von Mises stress distribution

Table 2

Creep properties of the bolt material

Temperature [°C]	**$R_{p1/10,000}$ [MPa]**	**Temperature [°C]**	**$R_{p1/100,000}$ [MPa]**
420	429	420	365
430	407	430	340
440	385	440	315
450	363	450	288
460	339	460	262
470	314	470	235
455	349.948	455	274.805

The maximum stress of the bolt is 296.772 MPa at 455 °C. This value is higher than the Rp1/100,000. The conclusion is that the bolt is creeping and the calculation with the Larsen-Miller parameter has also supported this assumption. The determination of the creep rate needs further investigation.

3. Conclusion

The preliminary calculations and tests demonstrate that the system works. The bolts of the flanges are creeping concluded from the FE calculations. The OLMOST-HT system will be installed to the bolt, so measured values are expected later. Having proper online global and local displacement and deformation data comparison can be done between the estimated and real data and decision can be made in the frame of the OLMOST system. In case of unexpected differences between the predicted and measured response further investigation can be supported.

Acknowledgement

This research was carried out as part of the OLMOST (On-Line Monitoring of Structures and Fatigue) EUREKA_HU_08-1-2010-0021 project in the framework of the New Széchenyi Plan with support by the European Union, co-financed by the European Social Fund.

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