Application of Modern SHM Methods in Electric Power Industry

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ABSTRACT

In this paper an application of up-to-date Structural Health Monitoring systems based mainly on optical fibre sensors for various applications in power plants is presented. Real working solutions and ideas of the SHM systems were applied to fluid power boilers, installations of environmental protection (the so called desulphurisation systems) and main frames of construction (130m high). The measured values were compared with the design ones, as well as with the calculated values. It enabled evaluation of the inhomogeneous loads distribution and increased safety of the construction during its repair and operation.

INTRODUCTION

A nowadays, modern power plants requires advanced sensor systems which support its everyday operation. The trend has not been related to a „fashion" for building modern „intelligent" or "smart" objects. First of all it results from the real and measurable effects coming from continuous monitoring of responsible and strategic industrial objects. Measurement and control systems have been extensively used in various applications for verifying the state of objects which could be exposed to conditions endangering their continuous failure-free operation. Complete evaluation of power structures efficiency is a difficult task.

It results from high complexity of the structures themselves and their operation frequently in the extreme conditions (high temperature and pressure, high and variable in time loads). Complexity of static schematics, unpredictability of loads, natural

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environment hazards, progressing degradation of materials, and frequently also significant geometrical dimensions present numerous problems and cause that opinions formulated by engineers controlling condition of an object are based at uncertain assumptions.

Safety and continuity of operation of power objects (boilers, generators, installations of environmental protection) constitutes an essential problem for their owners and operators. Frequently, even small malfunction in any of the system components causes measurable economic effects for an owner (temporary shut-down, loss in transmitted raw materials, compensations for environmental pollution), as well as for the natural environment (possible contamination in case of failure). In relation to the above the improvement of procedures regarding power objects management and increasing safety of their use becomes necessary, which in consequence will lower the economic (decrease in maintenance costs) and environmental loses related to their break-downs [1, 2].

One of the methods supporting the work of experts is installation of monitoring systems on the selected structures (Structural Health Monitoring Systems, SHMS). Systems of that type perform continuous measurement of various physical quantities (most frequently displacement and temperature), enabling that way determination of others, indirect physical quantities (such as strain, stress, deflection, curvature radius, pattern of stress/temperature field, recording of creeping process, crack appearance, leakage etc.), and their subsequent comparison with the critical values. A defect in SHM is defined as a change in material or geometrical properties of an object, which at present or in future could disturb operation of the system. The changes should be detected at the possibly earliest stage of their development. General assumptions for structure monitoring systems may be brought to:

- recording behaviour of a structure in the period of its use (verification of assumptions and models adopted at the object design stage and defining efforts of particular components),
- increasing an object safety during its use (continuous measurement enables control of the structure work in time and under the influence of changing loads),
- informing on hazards appearing from the side of structure itself (determining progress in degradation processes in a structure condition, as well as forecasting the generally understood durability of an object),
- localisation of failure and operation control of the monitored object (determining the place of malfunction and possible shut-down of equipment),
- supporting overhaul works in the structure area (undertaking rational decisions enabling optimal use of means designated for objects maintenance, i.e. optimisation of the necessary overhauls and repairs planning),
- extending knowledge on real behaviour of an object.

STRUCTURAL MONITORING OF POWER BOILER

Institute of Materials Science and Applied Mechanics at Wrocław Univeristy of Technology, jointly with RAFAKO S.A., have performed the reference design of structural monitoring at fluidal boiler type OFz-425 (Figure 1a). In relation to the planned repair concerning among others: exchange of part of bulkhead superheaters, rear zone of hermetic wall and parts of ceiling, it was decided to introduce monitoring of the strain state in selected parts of the boiler structure: strings and walls of combustion chamber (Figure 1b).

a) ***b)***

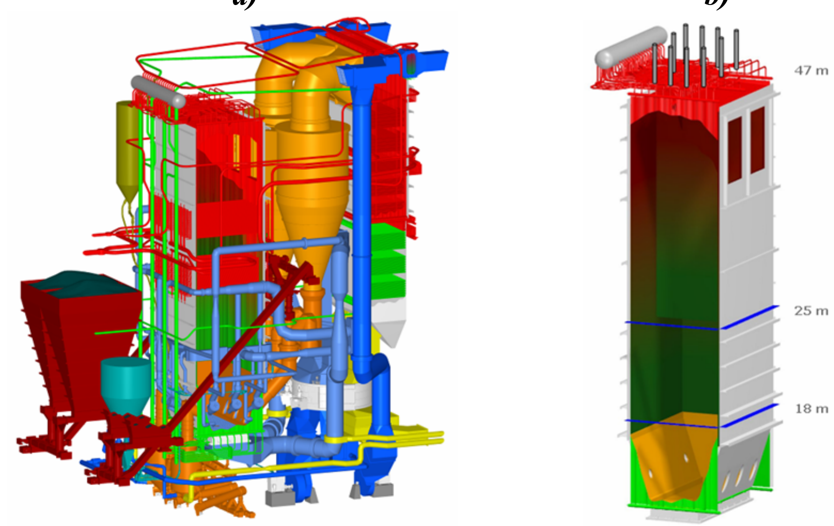

Figure 1. Simplified schematic of complete boiler type OFz-425 (a) and of combustion chamber (b) with marked areas subjected to monitoring during repair works (level 18m – exchange of hermetic wall zone, level 25m – exchange of superheaters, level 47m – strain monitoring of chamber suspension strings of the first sequence), courtesy of RAFAKO S.A.

Investor, and also the supervisor, of the repair works (RAFAKO S.A.) was set on real-time control along the work progress whether the conducted works do not endanger safety of the boiler structure and workers during the repair. It was mainly caused by screen cut outs creating communication windows for the time of works that were weakening the total strength and rigidity of the combustion chamber. The suggested plan of repair works was not forecasting hazards, however the additional knowledge would allow for their speeding up (parallel works in several places; conscious undertaking of strategic decisions concerning the overhaul), and at the same time enable comparison of the structure state to the initial status before the repair works on completing the overhaul [3].

Therefore, it was proposed that during the repair works measurements of strains and displacements using SOFO interferometric fibre optic sensors from Smartec be performed. A measurement system based at that technology was supposed to locally monitor the structure in its most strenuous places and inform on appearing hazards. Places of sensors installations (e.g. in the vicinity of the holes made) were determined after joint agreement of parties involved in the project: Siersza Power Plant, RAFAKO S.A. and Wrocław University of Technology. Localisation of sensors was supported by development of the proper numerical model of the boiler structure in RAFAKO S.A. Moreover, a www service was initiated where the influence of repair works on behaviour of the structure could be observed in real time. Exemplary measurement results performed during overhaul works have been collected in (Figure 2).

a) *b)*

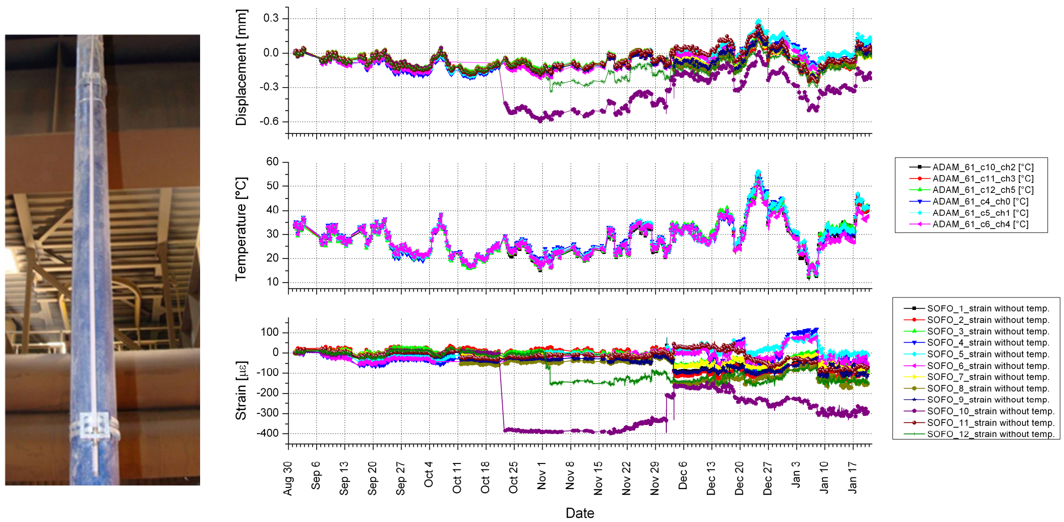

Figure 2. View of the SOFO type sensor installed at steel string (a) and diagrams presenting work of the boiler chamber suspension strings during repair works (b): displacements, temperature changes and strains without temperature influence [3].

STRUCTURAL MONITORING OF FLUE GAS DESULPHURISATION INSTALLATION

Subsequent application of the structural monitoring systems, SHM, in power plants is their use for monitoring composite pipelines of absorber in the Flue Gas Desulphurisation Installation (FGDI), being part of the newly built power unit in the Bełchatów Power Plant (Figure 3). The project has been implemented jointly by the Institute of Materials Science and Applied Mechancs of Wrocław Univeristy of Technology, as well as the companies: RAFAKO S.A. and QuantumSHM [4].

a) *b)*

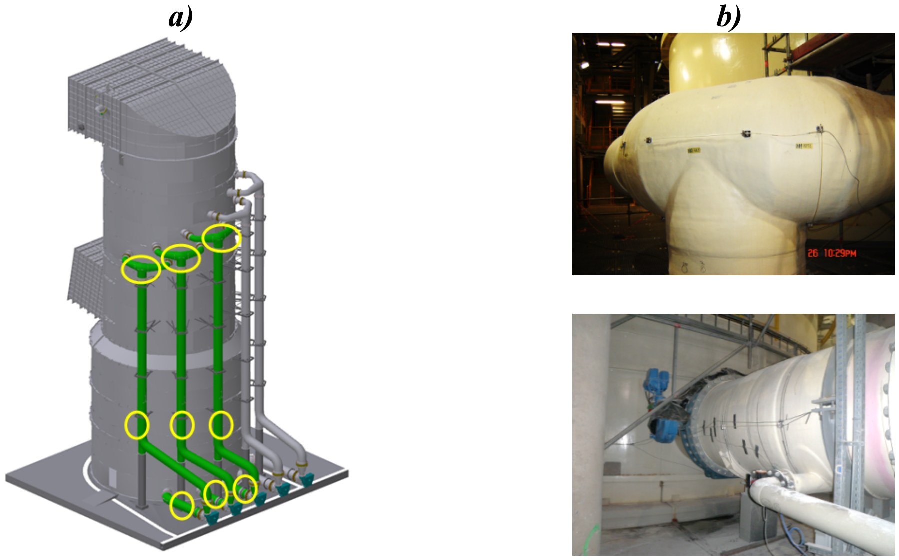

Figure 3. Sensor arrangement diagram (marked with circles) at absorber circulation pipelines and their view as installed directly at the suction part and T-pipe of the circulation pipeline.

Purpose of the measurements was verification of the action correctness of FGDI absorber circulation pipelines manufactured of polymer liners reinforced with the glass-polymer composite winded up at their external parts. For that reason measurements of pipeline surface strains using two available fibre optic measurement methods (SOFO and FBG) were applied.

The monitored circulation pipelines were of 1.4m in diameter, and their height reached up to 33m. At each pipeline 7 strain converters and additionally 3 thermocouples were installed at selected places. Their localisation was determined based at numerical simulations, with consideration for suggestions from the object operator. The most critical areas were located at the suction part of the pipeline (in the vicinity of circulation pomp), at its vertical section (in the area of connecting their individual segments), and at the T-pipe located at the very top of the pipeline. Arrangement of the sensors at the absorber circulation pipelines has been presented in Figure 3.

The most important task for the developed SHM system was supervising of the structure and FGDI workers safety during its filling up, trial start-up, as well as every-day operation (in temperatures of the 75 °C order). For that purpose it was necessary to monitor behaviour of critical areas of the structure including joints of component parts and its particularly strenuous fragments, e.g. elbows and tees.

Below, exemplary results of measurements performed at the FGDI circulation piping installation being part of the supercritical block during static (pipeline filling up) and dynamic (start-up trial) tests have been collected in Figure 4.

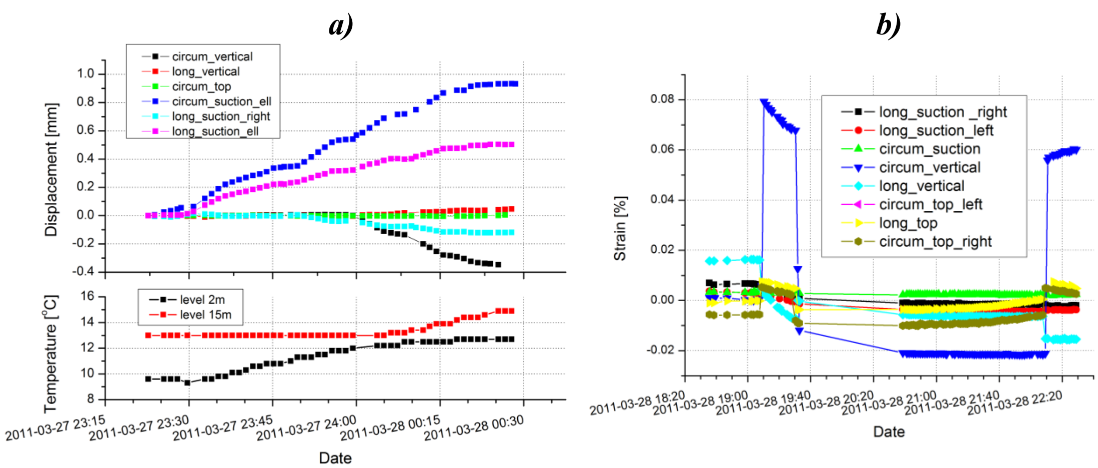

Figure 4. Exemplary results of total strains registered by SOFO sensors during static test.

The applied solution enabled real verification of behaviour compliance with the design assumptions and the numerical model developed by the producer (RAFAKO S.A.) (Figure 5). Continuous measurement of strain values enabled control of composite material degradation process (through a change in strain susceptibility to internal pressure in time) and defining the period of safe use. Moreover, because of the working medium (the so called milk of lime necessary for the process of exhaust gases purification in the FGDI unit), it was possible to control flow capacity and localisation of possible places of pipelines clogging through measurements of circumferential strains.

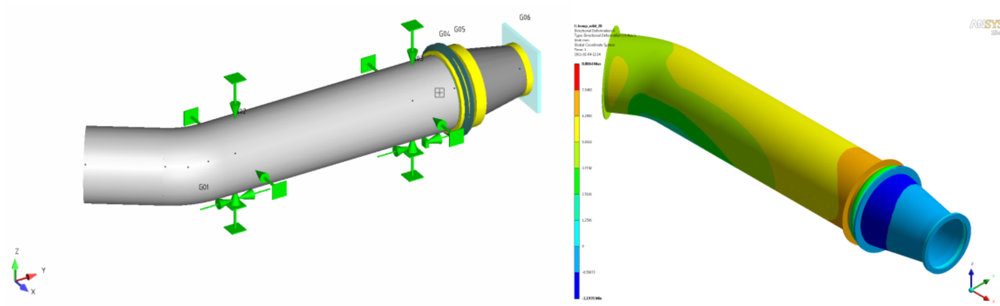

Figure 5. Numerical model and exemplary results from FEM analyses.

STRUCTURAL MONITORING OF MAIN FRAMES

A separate issue in the field of modern power plants, and in particular the boilers operating at supercritical parameters (so called: *supercritical power* boilers), is the need for monitoring the supporting structures of those objects. First of all, it results from their geometrical dimensions. Standard heights of *supercritical power* boilers reach even 140 meters, and their transverse dimensions amount to 20 x 20 meters. Inside the truss structure the combustion chamber and remaining parts of power systems (e.g. superheaters, combustion gas ducts, steam pipelines etc.) are suspended at steel strings. Work parameters of high-power supercritical units of the power of 800-900 MW order are: fresh steam pressure of the 28,5 MPa order, temperature of the fresh steam at least 600 °C, and that of the re-superheated steam within the 600 °C to 620 °C range.

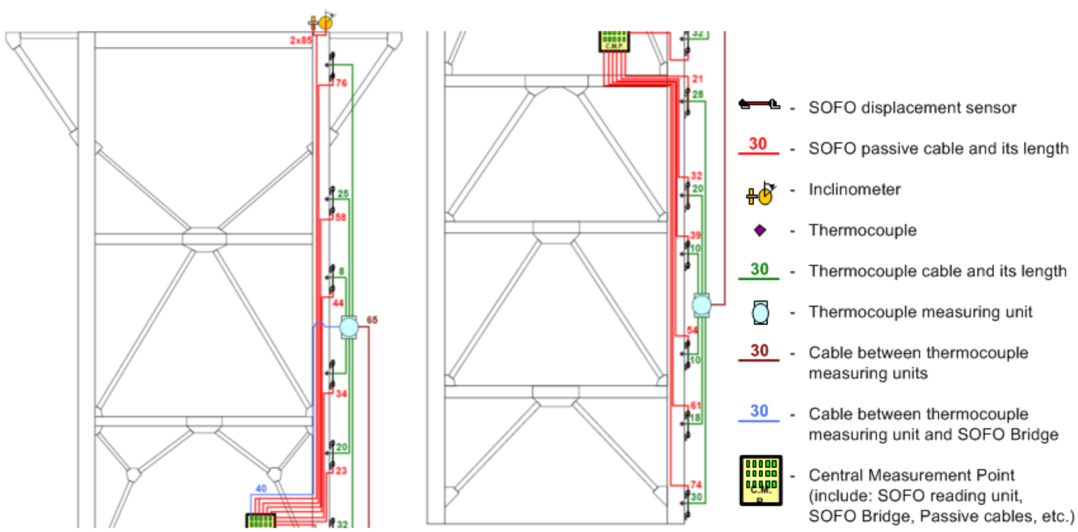

Figure 6. Schematic diagram of a system for monitoring the support structure of a power boiler.

Monitoring of a support structure is particularly important in objects localised at territories exposed to seismic phenomena (natural earthquakes, as well as those frequently caused by nearby mining works). The knowledge concerning condition of a structure after seismic phenomenon will allow evaluation of the necessity of performing repair works and adjustment of suspensions without shutting down the boiler. Estimated costs of holding the production of electrical energy for one unit of 1000 MW power amount to 1.5 M€ / day.

RAFAKO SA expressed interest in the SHM system enabling monitoring of displacements (compression, tension, angular deflections) at the main posts, and being compatible with the earlier suggested solutions from the field of power boilers and installations of combustion gas desulphurisation. This could enable creation of one coherent system of Prognostic and Health Management (PHM) in the area of power unit.

For that purpose, similarly as for strings, application of a measurement system based at interferometric SOFO® sensors installed superficially at steel beams and carrier posts along with thermocouples has been proposed. This could enable evaluation of strains related to the applied loads. Moreover, positioning of fibre optic inclinometers at the structure top which would enable continuous measurement of the structure deflection in two planes has been planned. Schematic diagram of the measurement system has been presented inFigure 6.

SUMMARY

Among others, monitoring of conventional power industry objects (SHM) using fibre optic based measurement systems enables:

- performing measurements in many structure locations, which otherwise could be inaccessible in terms of technology or economy,
- monitoring changes taking place in components during operation and by that enabling fast reaction to possible hazards, additionally improving safety of object and workers,
- conscious undertaking of decisions concerning repair works strategy which could effect in shortening the time necessary for performing all works.

Furthermore, the suggested solutions of PHM systems may find application in other areas of professional power industry, like evaluating condition of pipeline during many-years operation, monitoring vibrations in rotating equipment, monitoring leaktightness of boiler installations and installations of environmental protection, as well as detection of fires with the use of scattered sensors.

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