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APPLICATION OF NON-DESTRUCTIVE TESTING METHODS TO DIAGNOSTICS AND REPAIR OF ELEMENTS OF THERMO-ENERGY SYSTEMS

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ABSTRACT

The paper treats the application of various non-destructive testing methods to preventive examinations of vital elements of thermo-energy systems operating at elevated temperatures and pressures. The elevated pressures and temperatures produce thermal stresses in the material of a device, i.e. a system, which may result in material creep.
On the occasion of a preventive inspection of a steam line some critical flaws were detected. They could easily result in a failure of an element of the device if the system continued to operate.
In a visual examination of the link pipeline between two stages of a steam reheater cracks were detected at the surface of the pipeline close to a drillhole for the tube attachment supplying cold water. The presence of such cracks at the steam reheater not being admissible, repair of the pipe was required. The location of the cracks detected had to be confirmed additionally by other methods so that the location and extent of damage and repair could be determined. Based on non-destructive testing performed it was decided to remove the tube attachment supplying cold water to the system. The surface was examined with liquid penetrants. The metallographic replicas taken made it possible to determine the extent of damage to the material. Based on additional non-destructive testing a decision was taken concerning the extent and method of repair. It was decided to locally repair the area of the tube attachment by first grinding and then surfacing the crack area. After welding the welded joint obtained was thermally treated, the state of the material surface was visually examined, and the welded area and its surroundings were additionally examined with liquid penetrants.

Keywords: Material testing, Non-destructive testing, Maintenance, Thermo-energy systems, Repair, Metallography, Replicas

1. Introduction

In order to ensure reliable and safe operation of thermo-energy systems it is of great importance that all devices operate with the operating parameters designed for their operation and that on delivery preventive periodic inspections are specified. The system inspections are less frequent at

the beginning of their operation and get gradually more frequent. The inspections should be performed in accordance with the shut-downs of the device and the system scheduled.
The materials and components built into the apparatus are subjected to various kinds of loads during their life. In addition to high temperatures and pressures they operate in corrosion aggressive environment. Because of thermomechanical processes in materials and under corrosion effects, the microstructure will change and, consequently, the mechanical properties of the pipelines will deteriorate, which will produce crack formation and corrosion damages. Both phenomena should be treated as complementary in testing although their repair may differ.
The process of material *creep* due to the operation at elevated thermomechanical loads is a common phenomenon but to which particular attention should be paid. An analysis of the changes in the material microstructure is a basis for action if necessary to ensure the life scheduled for the device or the system under the same operating conditions. It is often seen that local imperfections resulting from inappropriate structural and technological solutions producing considerable reduction of loadability and creep resistance produce even greater difficulties. This type of deficiency may lead to damages produced by leakage at the joints. *Overheating* of the device or the system may be due to an uncontrolled process of combustion in the burners, insufficient water or steam flow or to deposits formed at the pipe inside wall, which reduces the heat transmission from the pipe wall to the medium in the pipe. Overheating of the system, accompanied by other effects, may additionally influence in material creep. The latter may produce, with the lack of appropriate control, catastrophic damages. The third important phenomenon is *thermal fatigue* of the material or the components occurring with frequent short-time, but rapid changes of the operating temperature.
The main purpose of periodic inspections, which include numerous non-destructive material inspections, is to establish the condition of the components so that damages or cracks, which may jeopardize the reliable and safe operation of the system if the latter continued to operate to the next shut-down scheduled, may be detected in time. The data on component testing should also take into account the remaining life and the time period to elapse to the next inspection. In this way a user may obtain information on the condition of the components and make a decision on their repair or replacement.
Efficient operation of the system as a whole requires careful scheduling of periodic inspections of the system and the determination of critical components requiring careful inspection. All findings should be suitably recorded. Based on the knowledge of individual components of the device or the system, the individual types of damages and/or cracks occurring during normal or inadequate operation should be anticipated. In the system it is possible to determine the locations particularly sensitive to damages due to the operating conditions or short-time overloads of the system. Consequently, suitable non-destructive testing methods may be determined. They should be so efficient that the type and size of a damage can be determined from the indication given. In case of an erroneous assessment of the importance of individual components and/or non-consideration of the operating conditions, including short-time or long-term overloads, very important data on the condition of the component may get lost. Depending on the size and risk of a damage or a crack at individual, particularly critical components of the device or the system, the consequences in terms of failure of the thermo-energy system or even human casualties may be catastrophic.

2. Description of component elements of the pressure part of the steam power station

The pressure part of the steam power station using fossil fuels consists of a steam boiler, steam pipelines, a steam turbine, and a condenser.
In the steam boiler, which is the largest and most expensive device in a steam power station using fossil fuels, the chemically bonded energy of fossil fuels will transform into heat of flue gases, which in pipe heat transmitters will be transmitted to water. Water will heat, evaporate,

and reheat to the operating conditions required by the steam turbine, which will transform the steam energy, in combination with the generator, into the electrical energy.

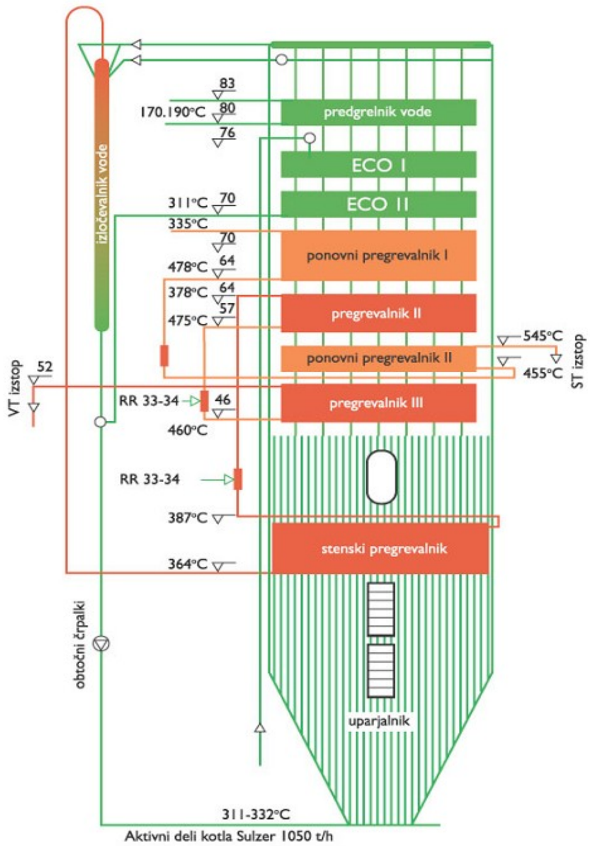

Fig. 1: Schematic of boiler Sulzer, block V. of TE Šoštanj [1].

The steam having passed through the turbine it condenses in pipe condensers and the steam circuit is thus closed.

The pipe heat transmitters are the pipes of a water heater. They are mounted just before the entrance of flue gases into a chimney or a cleaning appliance for flue gases and a steam generator surrounding the burners and one-stage or two-stage steam reheater mounted above the burners, where the temperature of flue gases is the highest. In addition to the pipe transmitters, where the heat of flue gases is transmitted to water or vapour, the elements of steam boilers are also drums, to which steam-generator pipes are connected at the lower side and those of the reheater at the upper side, steam collectors, link pipes between boiler elements and steam pipelines supplying the steam from the boiler to the turbine, and back.

For reliable and safe operation of a power station, impeccable operation of pressure pumps, regulation, high-speed shut-off and safety valves is of equal importance.

3. Operating parameters and choosing of materials

The operating parameters of the elements of the pressure part of the steam power station are given in Table 1.

The kind and quality of the material are chosen with reference to the operating parameters (temperature and pressure) and to the designed life of the individual boiler elements.

The life of the thermo-energy system and its individual devices can be mainly influenced by the user by carefully monitoring the operating conditions and the measures taken to correct as fast as possible inappropriate operating conditions which might cause damages or cracks, which would result in a shorter remaining life of the device.A critical area of the entire system are the boiler burners. The process of combustion, which is heating the inside of the system, is taking place at the inside and is difficult to monitor. Monitoring is done with a suitable sensor system and the mode of process control so that in a comparatively short time the temperature of the flue gases may be adjusted to the upper admissible level of operation. This may happen occasionally in the steam reheaters with regard to the planned and specified upper temperature level. The screen pipes surrounding the burners and the reheater pipes are not critical boiler elements since they are replaced several times during the life of the boiler. The untightness occurring due to damages or cracks resulting from thermomechanical overloads due to a short-time or even long-term excessive boundary temperature may cause damages to the system. The material damage is due to the boiler shut-down and the necessary replacement of a larger number of damaged pipes. Major attention should be paid to the vital elements of the boiler, at which damages or cracks may occur in the material due to overloads. Considerable material damage can be caused by the necessary repair and a longer shut-down of manufacture. Such elements are steam lines, steam collectors, and drums.

Table 1: Operating parameters of the steam boiler [1].

Boiler element	Operating temperature [°C]	Operating pressure [bar]
Water heater	from 257 to 311	-
Steam generator	311 to 364	-
Wall reheater	364 to 387	-
Reheaters II and III	387 to 540	-
Fresh steam supply	540	184.4
Additional reheater	from 335 to 545	41.3
Supply of reheated steam	545	41.3

Table 2: Boundary operating temperatures of steels for elevated temperatures [4].

Steel designation	Boundary temperatures of use [°C]
St 35.8	≤ 350
St 45.8	≤ 350
15Mo3	≤ 460
13CrMo44	≤ 545
10CrMo910	≤ 545
14MoV63	≤ 545
15NiCuMoNb5-6-4	≤ 450
X20CrMoV121	≤ 585
X10CrMoVNb9-1	≤ 585
X11CrMoWVNb9-1-1	≤ 630

In order to prevent the occurrence of excess temperatures, steam coolers are being built-in into the devices (Figs. 2 and 3). They regulate the temperature in the system by supplying cold water so that the steam coming from the boiler can be cooled down. Thus the temperature in the steam line supplying steam to the steam turbine is controlled. The cold water is supplied to the steam line by the pipe (Fig. 2, pos. 1) running through the steam-line wall (Fig. 2, pos. 4) and the sheath pipe (Fog. 2, pos. 5) in the steam-line inside. In the middle of the steam line there is a nozzle (Fig. 2, pos. 6) that is to spray cold water uniformly into the steam flow at an angle of 90° in the direction of flow and thus make sure that the steam temperature remains below the upper admissible level. In case of incorrect operation of the cooling system due to cracks or shut-down of the sensor or monitoring system, the operating temperature will vary and produce thermal fatigue of the material. A sheath pipe is built in the steam line to prevent the contact between the cooling water and the steam-line pipe.

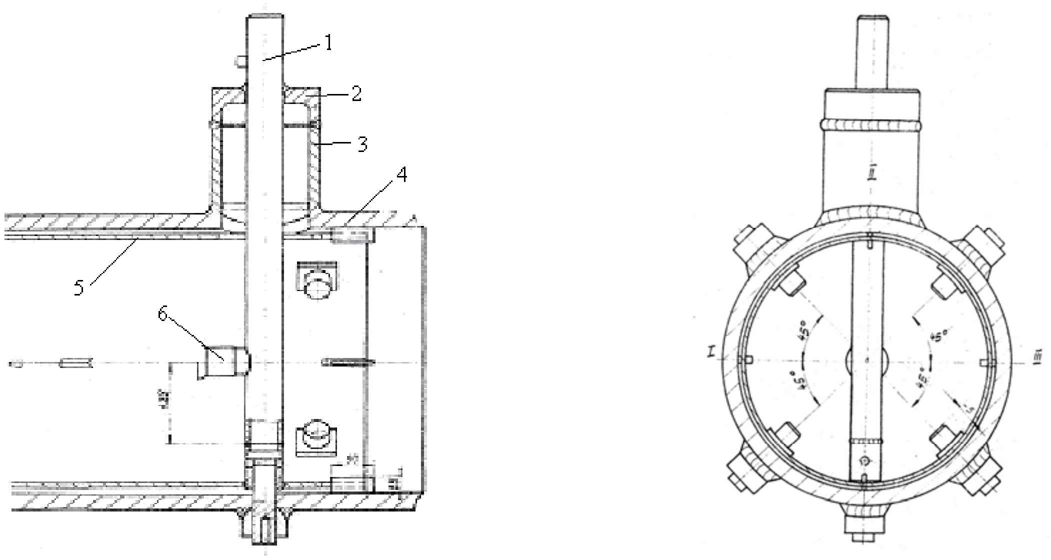

Fig. 2: Longitudinal and cross sections of steam cooler.

4. Inspecting the steam cooler

The steam cooler is examined visually using accessories permitting remote visual examination of difficult-to-access points. If there are any doubts with regard to the presence of damages or cracks some other non-destructive methods stated in the specification of periodic inspections are used. The use of such methods requires dismantling of the entire tube attachment (Fig. 2, pos. 2). The position of the nozzle and the condition of the sheath pipe inside in the direction of steam flow are examined visually. Also the area close to the drillholes in the steam-line wall (Fig. 3, positions 3 and 4) and the sheath pipe shall be examined visually. The pipe supplying cold water passes through the two steam-line parts. At these locations damages or cracks in the material due to material creep or thermal fatigue may occur. An ideal solution is to take metallographic replicas of the critical steam-line areas. The creep process can thus be easier monitored from its initial state to the detection of cracks due to thermal fatigue of the material. These areas, however, are very difficult to access and examine. Examinations are, therefore, made through a special opening obtained by dismantling two elements (Fig. 2, positions 1 and 2). Both elements are positioned at the area of the attachment supplying the coolant when the system is overloaded.

4.1 Visual examination of the steam-cooler inside

The remote examination of the steam-cooler inside was performed using a videoscope, a product of EVEREST, with a diameter of 8 mm and a length of 6 m. The device enables the visual examination, measurement of lengths, areas of certain locations, and depth of damages. A special stereo probe was used for the purpose. The videoscope was used to examine the steam-line area hatched in Fig. 3. The steam line is a critical location. All the damages and cracks found at the steam-line surface and cracks at the sheath pipe (Fig. 4) were detected. In the examination the cracks due to thermal fatigue of the sheath pipe were not detected, although they were initially expected. Several cracks were found at the steam line where the tube attachment was welded to the steam line and some cracks at the drillhole of the sheath pipe.

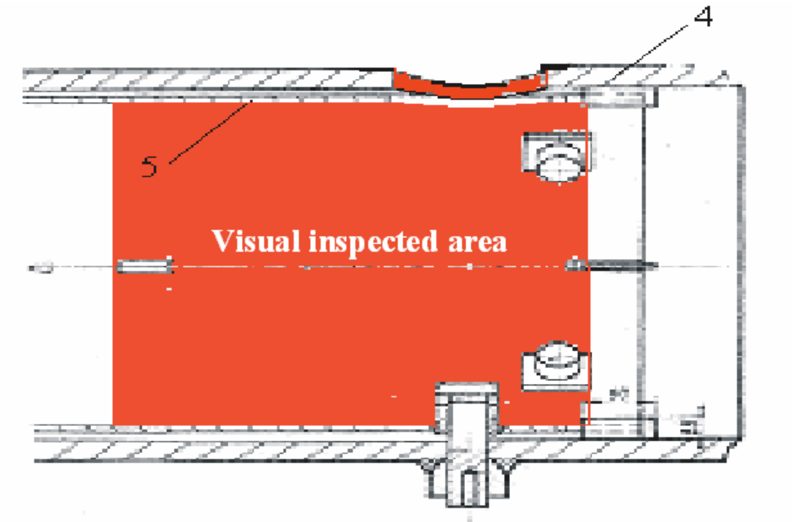

Fig. 3: Visually examined locations of steam-cooler inside.

Fig. 4: Appearance of cracks inside of tube attachment; 5 x [3].

4.2 Liquid penetrant testing

The depth of the crack located at the built-in tube attachment (Fig. 2, Pos. 3) could not be measured due to its inaccessibility. The occurrence of cracks at the steam line is not admissible; therefore, a decision was taken, to separate the tube attachment by grinding the fillet weld connecting the tube attachment to the steam line. The liquid penetrant examination was then employed to determine the number and size of cracks.

The crack lengths were measured up to 8 mm in the radial direction of the drillhole (Fig. 5). In Fig. 5, left, the entrance of the cooling pipe to the steam line, including the cracks in the steam-line wall and the protective plate, is shown. In Fig. 5, right, the same location is shown from another viewing angle and magnified so that the crack size and the deformation at the protecting plate could be assessed.

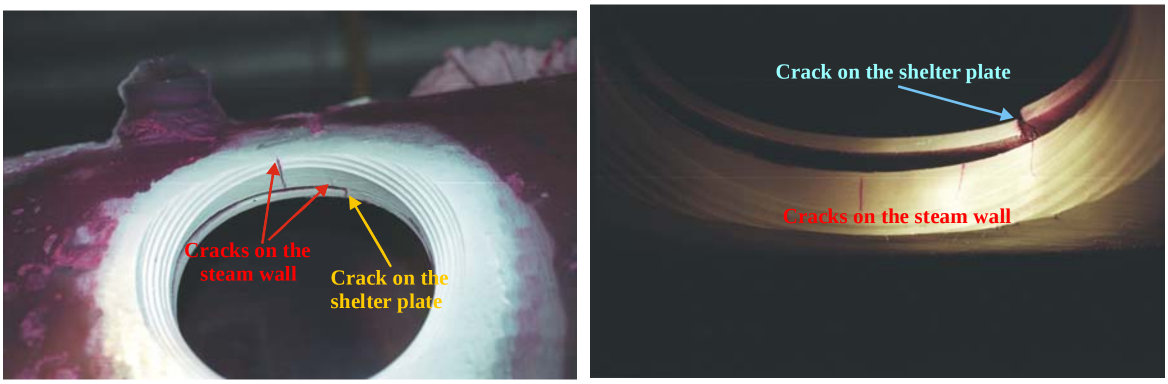

Fig. 5: Cracks made visible in liquid penetrant examination.

4.3 Taking metallographic replicas

The final decision regarding the mode of repair was made after taking and assessing metallographic replicas. The replicas showed no changes in the material microstructure close to the drillhole that would require a replacement of the entire pipe segment of the steam line. A local repair was decided upon.

Fig. 6: Microstructure of replica taken from undamaged pipe section; 150 x.

Fig. 7: Microstructure of replica showing a crack and single gas pores; 300 x.

Figures 6 and 7 show the microstructure of the metallographic replica taken at the location 15 mm off the drillhole. The image clearly shows very fine, single gas pores. In accordance with the guidelines of the German association of operators of large power stations (VGB) the microstructure was grouped in class 2a, in the early stage of the creep process. These guidelines are very helpful in the assessment of the material microstructure subjected to thermomechanical loads. They also suggest, with reference to the class, further measures to be taken in terms of scheduled inspections and repair measures.

5. Repair of the steam-cooler steam line

Because of the defects close to the opening where the pipe for cold-water supply is inserted there were three options for its repair, i.e.:

- repair welding in the surroundings of the cracked areas around the drillhole in the radial direction;
- increase of the drillhole and surfacing of an additional ring;
- increase of the drillhole and building-in of a new tube attachment.

It was decided to increase the drillhole in the steam-line wall by groove preparation. The entire cracked area at the steam-line was eliminated. After preparing the groove by grinding a liquid penetrant examination was repeated. Cracks were detected at two locations shown below. The cracks ran in the tangential direction of the pipe and in the surroundings of the opening. The cracks were hidden and appeared only after grinding the weld groove, i.e. the crack was detected only thanks to the groove preparation. It was decided to eliminate cracks at these locations by local grinding of the steam line (Fig. 8).

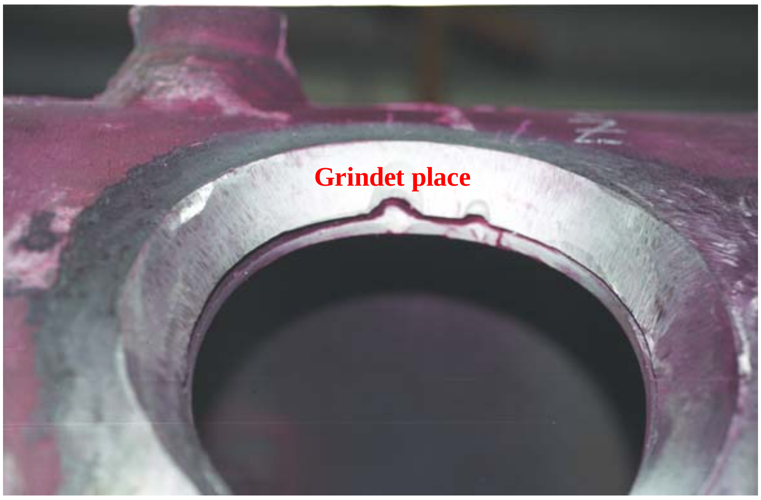

Fig. 8: Weld preparation by grinding close to cracks.

The next step was surfacing at two locations to obtain the geometry desired. For the repair of the steam line made of common CrMo steel, i.e. 13CrMo44, a special thermal regime of preheating was chosen. The second important technological phase was monitoring of the temperature cycle during and after welding in order to prevent the occurrence of too high internal stresses that could produce deformation of the attachment area that could reduce operating efficiency of this part of the steam line. In accordance with the welding technology the surroundings of the welded joint shall be thermally isolated and preheated at a temperature from 200 °C to 250°C. This temperature shall be maintained during the welding process itself as well. Immediately upon welding completion the temperature at the bell-shaped measuring point shall be raised to 675 ^{o}C and be kept constant for a minimum of 20 minutes, a cooling rate 250 ^{o}C/h during heating being

specified. The temperature cycles were measured with two thermocouples mounted at the steam-line wall surface at a distance of 80 mm from the location of repair, i.e. the new welded joint. An interphase non-destructive examination during heat treatment could not be carried out.
The welding process was carried out at a temperature lower than the transformation temperature of steel and at a cooling rate ensuring as low as possible internal stresses during welding and as low as possible residual stresses after welding. Thus the influence of subsequent material fatigue and the risk of crack formation may be reduced. Welding was carried out by an approved welder for manual metal arc welding with filler material DCMS-Kb following the welding procedure specification.

6. Weld testing after repair

The final testing of the weld made was performed after repair welding and heat treatment. After repair welding visual examination of the weld and its surroundings was performed. It was followed by the magnetic particle examination to confirm the quality of the material condition and of the steam line after welding. The material condition after surfacing and heat treatment can be efficiently assessed by measuring hardness of the weld and its surroundings The measuring points for hardness were prepared with surface grinding. The measurements were made employing a portable hardness tester EQOTIP. Both examinations showed that repair welding and heat treatment were efficient. The hardness measured being appropriate, repair was completed and the steam line put back to operation. If inadmissible hardness values were found, additional inspection of the microstructure with the replicas from the repaired area would be performed to confirm whether undisturbed operation with respect to the inspection schedule would be possible.

Fig. 9: Appearance of steam line with welded area and completed magnetic particle examination supplemented by hardness measurement.

7. Conclusions

The problem presented shows that the preventive inspections of the steam line at the location of the steam cooler were performed efficiently. Knowledge of non-destructive testing and of the mode of operation of the device was required to determine the type and size of the damages occurring during operation. It is of great importance to know well the operating conditions when searching for solutions of repair. The repair made was efficient. The steam-line section repaired is operating normally.

8. References

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