NDT TESTING AND DETERMINATION OF THE STATE OF THE MATERIALS OF THE HEADERS OF THE BOILER UNIT 5 IN THE THERMAL POWER PLANT KAKANJ

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ABSTRACT
In order to examine the state of critical components of the boiler of Unit 5 of Kakanj Thermal Prema wer Plant, headers were tested in order to undertake appropriate technological measures and activities on the basis of insight into the current state of affairs, and to make recommendations for further exploitation. From first commissioning in 1969 to 30 April 2019 the Unit 5 boiler had 271.403 operating hours in operation and was designed for 100.000 hours. During the exploitation so far, several modifications and revitalizations have been carried out on the block, although some components from the installation period are still in operation (superheater headers Pr 5 and Pr 6). The testing program was made on the basis of analysis and evaluation of the results from previous tests and records of performed repairs on the tested components (repair of individual cracks on welded joints, created during exploitation in the previous period). The paper presents the most important data on past exploitation, the results of the NDT tests, as well as the hardness and structure tests on the replicas.
Material condition assessments of critical components of Pr 5 and Pr 6 superheaters, unit 5 boiler, and recommendations for further exploitation were made based on NDT tests, as well as hardness and structure tests, in accordance with prescribed, norms and applicable standards, and structural degradation assessment and the hardness drop from the commissioning of the block to the tests carried out in the course of this work on the same or similar components.

1. INTRODUCTION

In order to assess the condition of the critical components, which have been in operation for the longest time on boiler block 5 in the Thermal Power Plant Kakanj, tests were carried out on the following headers during regular overhaul:

a) Mixing header of superheater Pr 5 (KP 13),
b) Outlet headers of superheater Pr 5 – left (KP 14L) and right (KP 14D),
c) Exit header Pr 6 (KP 16).

According to the test program, the following non-destructive tests are planned according to valid standards, regulations, and methods:

a) Visual and dimensional control of headers,

b) Ultrasonic measurement of the thickness of the header walls,
c) Examining the microstructure of the material by taking replicas and the hardness at the place where the replicas were taken,
d) Examination of welded joints by magnetic and ultrasonic methods and measurement of hardness.

2. BASIC DATA ON THE BOILER OF BLOCK 5

Unit 5 is a 110 MW steep tube condensing unit with natural water circulation in the evaporator, liquid slag removal, and a triple bypass, delivered from the former Czechoslovak Republic. From the first commissioning in 1969. until the overhaul on April 30, 2019. 271.403 h in exploitation working hours were achieved. In the course of exploitation so far, several modifications and revitalizations have been carried out on the unit, and there are some parts of the boiler that are still in use, and have not been changed since the unit was put into operation [1].

3. MATERIALS

3.1 Basic data on the materials of the tested boiler headers of block 5

Basic data on the material of the tested headers from the block 5 boiler superheater are given in Table 1.

Table 1. Basic data on the materials of the tested boiler headers of block 5

Ordinal number	The name of the component	Material	Dimension [mm]	Installation time
1.	Pr5-KP13	15128.5	Ø 273 x 25	1987
2.	Pr 5 - KP 14L i KP 14D	15128.5	Ø 324 x 36	1987
3.	Pr 6 - KP 16	15128.5	Ø 273 x 46	1981

3.2 Properties of the steel from which the tested headers are made

The tested headers of the boiler of block 5 are made of low-alloy chromium-molybdenum-vanadium steel of the designation 15128.5 according to the standard ČSN 41 5128 [2] in a normalized state. Steel 15128.5 is designed to withstand long-term loads at an elevated temperature of 545 ˚C, and the designed service life is approx. 100.000 hours. The microstructure of steel 15128.5 consists mainly of ferrite with a smaller proportion of softened bainite and pearlite in the amount of 4 to 15 %. Alloying elements influence the course of material degradation and the primarily formed coherent carbides under the long-term influence of temperature change into another non-coherent form, as a result of which the process of forming new carbides from elements dissolved in the ferrite solid solution begins. In the further process, coagulation and solidification of carbides occur, which leads to the degradation of the structure and a decrease in mechanical properties. The described processes take place in the stationary region of creep and are observed by observing the microstructure on a microscope. Degradation processes in the stationary area dominantly affect the creep flow in the tertiary phase, in which the formation of microcracks and fractures occurs [3].

Table 2 shows the chemical composition and mechanical properties of steel 15128.5 according to the standard ČSN 415128 [2] and steel 14MoV63 according to the standard DIN 17175 [4], because the regulation for the evaluation of structure degradation VGB-S-517 [5] applies only to steel 14MoV63, which according to its chemical composition and mechanical properties is almost identical to steel 15128.5, so this regulation can also be used for steel 15128.5.

Table 2. Chemical composition, tensile strength, and hardness of steel 15 128.5 and 14MoV63

Steel	Content of elements, %								R_m	Hardness
	C	Si	Mn	P	S	Cr	Mo	V	MPa	HB
15 128.5*	0,10 - 0,18	0,15 - 0,40	0,45 - 0,70	Max 0,04	Max 0,04	0,50 - 0,75	0,40 - 0,60	0,22 - 0,35	490- 690	140 - 197
14MoV63	0,10 - 0,18	0,10 - 0,35	0,40 - 0,70	Max 0,035	Max 0,035	0,22 -0,32	0,25 - 0,35	0,22 - 0,32	450 - 690	135 - 181**

** Steel 15128.5 in a normalized state (normally cooled and quenched) according to ČSN 41 5128 [2]*
***Hardness is derived from tensile strength according to standard DIN 50150 [7]*

4. PROGRAM AND EXAMINATION SCOPE

The following tests were performed on the boiler superheater headers of block 5, KP 13, KP 14L, KP 14D, and KP 16:

4.1. Visual inspection of header ovality, corrosion damage, and cracks,
4.2. Ultrasonic measurement of wall thickness on each header,
4.3. Microstructure with replicas on each header,
4.4. Assessment of the degree of degradation of the microstructure according to VGB-S-517,
4.5. Measurement of hardness at all points of taking replicas,
4.6. Examination of the welded joints of the headers with magnetic particles and ultrasound,
4.7. Measurement of the hardness of welded joints.

5. OBJECTIVE OF THE TEST AND ANALYSIS OF PREVIOUSLY PERFORMED TESTS

The analysis was done with the aim of comparing the obtained results with previous tests, especially with the previous results performed on the same components as with the tests conducted in 2019. The assessment of the condition of the tested components was carried out based on the characteristics of the materials taken from the standard, treated as the initial state of the material, and the results obtained by testing in 1997, 2002, and 2019.

6. EXAMINATION

As part of this work, a visual inspection, measurement of the ovality and thickness of the header walls, and testing of welded joints were performed, as these are the methods used to detect imperfections according to the requirements of standards and acceptance criteria. Testing the degree of degradation of the microstructure using replicas, testing the hardness at the place of taking the replicas, and measuring the hardness of welded joints are methods that, based on the results and analysis of previous tests, indicate the degradation of the material of the tested components. The following tests were conducted on the superheater headers of boiler 5: KP 13, KP 14L and KP 14D, and KP 16 during the overhaul period of block 5 in 2019, and the obtained test results are listed in Table 3.

Table 3. Header test results

Ordinal number	Test method	Test result
6.1.	Visual inspection	Visual inspections determined that all tested headers, welded joints, suspensions, supports and other elements meet the acceptance criteria.
6.2	Measuring ovality (dimensional control)	Measurements confirmed that the ovality of chambers KP 13, KP 14L, and KP 14D, KP 16 meet the requirements of the EN 10216-2 standard.
6.3	Measurement of wall thickness using ultrasound	Measurements of the thickness of the header walls KP 13, KP 14L and KP 14D, and KP 16 with tolerances according to standards showed that there is no significant deviation from the nominal thickness of the header walls.
6.4	Examination of welded joints with magnetic particles	The tested butt-welded joints on the headers and fillet welded joints of headers KP 13, KP 14L and KP 14D, and KP 16 with headers meet the acceptance criteria.
6.5	Examination of welded joints using ultrasound	The tested butt welds on headers KP 13, KP 14L and KP 14D, and KP 16 meet EN ISO 17640/EN ISO 5817 - B, with the level of acceptance according to EN ISO 11666 Level 2. – On the header, KP 16 at the welded joint FW 1-1, a defect of length 12 mm at a depth of 8 mm was detected, with an excess of the registration curve of 1 Db, and as such it meets the acceptance criteria. – On the welded joint FW 1-5, a 25 mm long defect was detected at a depth of 48 mm, exceeding the registration curve by 2 Db, and as such it meets the acceptance criteria.

6.1 Examinationof the degree of degradation of the microstructure using the method of taking replicas

The results of testing the degree of degradation of the steel microstructure on the header KP 13, KP 14 L, KP 14 D, and KP 16 are similar, and therefore we show the microstructure and images on the header KP 13 as an example of the degree of degradation of the imputed chambers.

All tested microstructures of the replica headers KP 13, KP 14L and KP 14D, and KP 16 of the block 5 boiler superheater were evaluated according to VGB-S-517 regulations with degradation level 3a, which indicates the beginning of complete degradation of the structure due to long-term loading. The tested microstructures on the replicas are completely degraded and consist of ferrites with coarse carbides segregated along the grain boundaries and locally connected in arrays. The presence of bainite and pearlite, which are common microconstituents in the delivery state of this type of steel, was not observed in the microstructures.

Figure 1 shows the place where the replica was taken, and Figure 2 shows the microstructure of replicas R1 and R2 of the chamber of KP 13.

Figure 1.Place of taking the replica at the header of KP 13

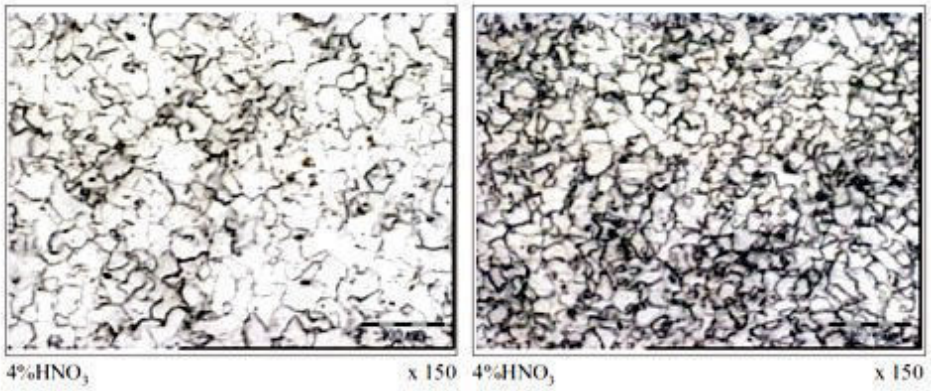

Figure 2.Microstructure of replicas R1 and R2 of header KP 13

6.2 Hardness test at the point of taking replicas

The prescribed values for the hardness of steel 15 128.5 in the normalized state according to the standard ČSN 41 5128 are in the range of 140 to 197 HB. The results of the hardness test at the place of taking the replica headers KP 13, KP 14L and KP 14D, and KP 16 are given in Tables 4, 5, and 6.

Table 4. Hardness at the place of taking replicas of chamber KP 13

Label replicas	Position pipes	Hardness, HB Individual values					Middle HB	VGB-S-517
R1	Left	148	151	149	153	142	149	3a
R2	Middle	151	154	151	148	145	150	3a
R3	Right	142	141	142	146	140	142	3a

Table 5. Hardness at the point of collection of header replicas KP 14L and KP 14D

Label replicas	Position pipes	Hardness, HB Individual values					Middle HB	VGB-S-517
R1	Left	154	161	158	160	164	159	3a
R2	Left	169	170	170	162	172	169	3a
R3	Left	141	142	140	140	140	141	3a
R1	Right	134	139	137	136	136	136	3a
R2	Right	150	150	155	147	152	151	3a
R3	Right	146	151	154	156	156	156	3a

Table 6. Hardness at the place of taking replicas of chamber KP 16

Label replicas	Position pipes	Hardness, HB Individual values					Middle HB	VGB-S-517
R1	Left	142	145	140	138	142	141	3a
R2	Middle	135	139	135	135	132	135	3a
R3	Right	136	138	142	140	142	140	3a

Based on the results from Tables 4, 5, and 6, the following can be observed:

- All measured hardness values on the KP 13 header are close to the lower prescribed limit of 140 HB.
- The measured hardnesses on the KP 14D header with the R1 replica have values below the prescribed lower limit (average value 136 HB), and with the R3 replica on the left side on the KP 14L headers they are at the very lower limit (average value 141 HB). The measured hardnesses at the places where the replicas were taken, along with the other replicas, are above the prescribed lower limit.
- Measured hardnesses at the measurement points in the header of KP 16 at the replicas R1 and R3 are at the lower prescribed limit of 140 HB, and at the place at the replica R2 they are with an average value of 135 HB below the prescribed limit.
- The measured hardnesses are fully in line with the ratings of the high degree of structural degradation of 3a.

6.3 Measurement of the hardness of the welded joints of the headers

The hardness test was performed on the welded joints of chambers KP 13, KP 14L and KP 14D, and KP 16 of the boiler superheater of block 5. The hardness was measured on both sides of the welded joint on the base material (BM), heat-affected zones (HAZ), and weld metal (WM). The test results for the mean values of the measured hardness in all zones of the welded joint are given in Tables 7, 8, and 9.

Tables 7. The hardness of welded joints on header KP 13

Place of examination	The hardness of the welded joints, HB						
	FW1-1	FW1- 2	FW 1-3	FW 1-4	FW 1-5	FW1-6	FW1-7
BM	143	145	149	150	155	154	135
HAZ	173	231	222	302	222	230	216
WM	223	229	225	329	304	219	213
HAZ	227	219	231	305	253	212	201
BM	157	151	144	152	138	138	140

Tables 8. The hardness of welded joints on headers KP 14L, and KP 14D

Place of examination	The hardness of the welded joints, HB					
	FW1-1	FW1-2	FW 1-3	FW 1-1	FW 1-2	FW1-3
	Left side			Right side		
BM	144	146	170	159	153	142
HAT	257	272	241	236	277	216
WM	239	254	225	225	262	214
HAZ	240	286	232	239	277	228
BM	146	170	138	147	148	142

Tables 9. The hardness of welded joints on header KP 16

Place of examination	The hardness of the welded joints, HB							
	FW1-1	FW1-2	FW1-3	FW1-4	FW1-5	FW2-1	FW2-2	FW2-4
BM*	196	140	149	139	140	152	164	165
HAZ	270	191	206	184	234	***	***	***
WM	251	189	194	180	222	205	191	201
HAZ	246	192	213	200	238	***	***	***
BM**	141	150	137	150	195	146	138	140

Basic material of the vestibule, ** Exit chamber, * Not measured because the weld, the angle between the pipes is 90⁰*

Analysis of the results of measuring the hardness of welded joints on the superheater headers is given in Table 10.

Tabela 10. Analysis of the results of measuring the hardness of the welded joints of the headers

Tested header	Results of hardness testing of welded joints
KP 13	Based on the test results from Table 7, it can be concluded that in all welded joints and zones, the hardness is above the lower prescribed limit, except for welded joint FW 1-7, which in the base material has one value at the lower limit, and the other below the lower prescribed limit. values.
KP14L and KP14D	Based on the test results from Table 7, it can be concluded that the hardness of the welded joints in all zones is above the lower prescribed limit, with the conclusion that the hardness in the base material of the welded joints is FW 1-1, FW 1-2, on the left side and of the welded joint FW 1-3 on the right side near the lower border.
KP 16	Based on the results from Table 9, it can be concluded that the hardness of the welded joints in the base material is close to or below the prescribed values, although differences in the measured values from different sides of the welded joint in the base material were also observed. Welded joint FW 1-3 has the worst results.

7. CONCLUSIONS AND RECOMMENDATIONS

a) In all tested components, an increased level of microstructure degradation and a significant decrease in hardness was found.
b) Through the conducted tests and comparison with the results from previous tests, it can be concluded that there was progress in the initial degradation of the microstructure and a significant drop in hardness.
c) The results of testing the hardness and degree of degradation of the structure are given in Table 11.

Table 11. Hardness and structure of the examined components during the period of exploitation

Year	KP 13		KP 14L		KP 14D		KP 16	
	Hardness	Structure	Hardness	Structure	Hardness	Structure	Hardness	Structure
1997	187	2a	161/174	1	149/161	1	174	1
	182	2a	*	*	*	*	174	1
2002	*	*	139	2a	145	2a	*	*
2019	149	3a	136	3a	159	3a	141	3a
	150	3a	151	3a	169	3a	135	3a
	142	3a	153	3a	141	3a	140	3a

d) Changes in hardness values are given in Figure 3 for chamber KP 13 with a diagram of hardness changes.

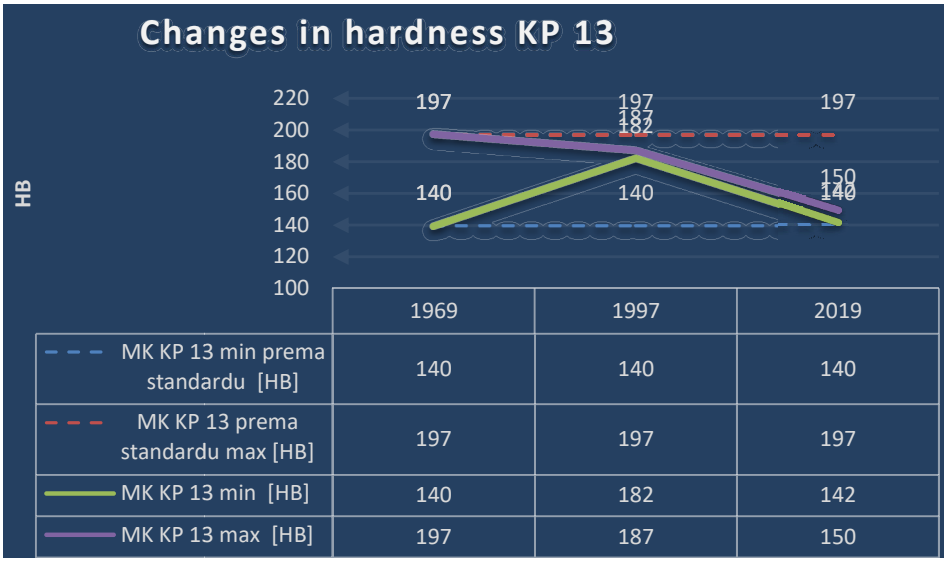

Figure 3. Change in the header of the KP 13 during the period of exploitation

e) Based on the data from Figure 2 and Table 10, it can be concluded that there has been a significant degradation of the microstructure, since the initial test in 1997, with a grade of 1 for headers KP 14L and KP 14D, and header KP 16, and grade 2a for header KP 13, up to a grade of 3a for all headers examined in 2019.
f) In the entire exploitation life, the largest drop in hardness since 1997 was recorded in the KP 13 header, in the amount of approx. 55 HB, compared to the KP 14D and KP 14L headers, and the KP 16 header, where this drop amounted to approx. 20 HB.
g) The summary analysis of test results is briefly described for all tested components in Table 12.

Table 12. A descriptive evaluation of test results for the chambers KP 13, KP 14L, KP 14D, and KP 16

Header	Visual and dimen.	Wall thickness	Hardness HB	Structure	Magnetic tests	UT	The hardness of welds HB
KP 13	Acceptable	No deviation	Acceptable (142-150)	Degradation Grade 3a	Defect repair on FW3	Acceptable	Acceptable (143-152)
KP 14L	Acceptable	No deviation	Partially acceptable (136-159)	Degradation Grade 3a	Acceptable	Acceptable	Partially acceptable (142-150)
KP 14D	Acceptable	No deviation	Acceptable (141-159)	Degradation Grade 3a	Acceptable	Acceptable	Acceptable (142-159)
KP 16	Acceptable	No deviation	Not acceptable (135-141)	Degradation Grade 3a	Acceptable	Defect repair on FW1	Partially acceptable (137-196)

Table 13 lists the recommendations for the times for which the tested components can be safely used under normal operating conditions.

Table 13. Recommendations for further exploitation

Unit 5 boiler component	Recommendation for exploitation, h	Remark
Header KP 13	15.000	Monitor the development of defects on FW 3
Header KP 14L	10.000	Tighter control
Header KP 14D	15.000	
Header KP 16	10.000	Monitor the development of defects on FW 1.Tighter control.

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