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WORN-OUT STEAM TURBINE BODY OVERHAUL TECHNOLOGY

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Abstract: The article presents the technology of overhauling a steam turbine body after prolonged operation at high temperatures. Before any repairs are made to such a body, preliminary material tests must be carried out, which will qualify it for scrapping or a revitalisation process, because the material undergoes degradation at creep temperatures. The purpose of the overhaul was to restore the steam turbine body (material grade L20HM) to operational condition.

Keywords: technology of repair, operation, steam turbine body.

1. INTRODUCTION

During operation, steam turbine bodies are loaded with very high forces, the source of which are [Dobosiewicz 1992; Cwilewicz and Perepeczko 2014]:

- working medium temperaturę;
- working medium pressure;
- weight of the entire turbine unit;
- vibrations, which result from the rotating mass of the turbine and from the steam flow.

The differences between steam temperatures at entry and exit from individual parts of the turbine introduce very high stresses in the material. However, the critical points in turbine operation are moments when the turbine winds down or is reactivated, when the individual parameters increase rapidly and cause deformations and thermal stresses. These conditions result in fatigue cracks in the material, while continuous turbine operation leads to creeping cracks [Dobosiewicz 1992; Cwilewicz and Perepeczko 2014].

2. SCOPE OF THE STUDY

The paper discusses the individual stages of the scope of testing, which prepare the steam turbine body for overhaul.

The repair process comprises a range of operations involving:

a) comprehensive assessment of the technical condition of the body, based on:
   - defectoscopic testing (100% internal and external surfaces) for sand or shot blasting (visual and magnetic particle inspections),
   - destructive material testing (microstructure, hardness, impact strength, etc.),
   - geometry measurements,
   - calculation of durability depletion level;
b) removal of surface cracks and rebuilding of damaged locations using a weld metal with a composition similar to the original cast material;
c) thermal treatment of the body in a furnace for the purpose of:
   - removing welding stresses,
   - removing post-operation stresses,
   - correcting the geometry,
   - regenerating the structure to a degree enabling its plastic properties to be improved;
d) mechanical processing of all planes and bores that require certification;
e) thread regeneration.

The external body of a steam turbine manufactured by Zakłady Mechaniczne ZAMECH, Elbląg, Poland, comprised an upper and lower part in the form of a steel casting using grade G20Mo5 (L20HM) steel. According to data provided by EDF WYBRZEŻE [Wieczorska 2018]:

- the turbine was commissioned in 1980;
- body operation time until the current overhaul was 232,658 hours;
- the number of activations since the last overhaul (in 2008) until the current overhaul, a total from various states, was 82.

Based on the number of turbine activations during the period 2008–2017, as stated by EDF WYBRZEŻE, the number of turbine activations since the beginning of its operation until the current overhaul was estimated. The total number activations from different states was approximately 370 [Wieczorska 2018].

The chemical composition and mechanical properties of the analysed G20Mo5 (L20HM) cast steel are shown in Table 1.

Table 1. Chemical composition and mechanical properties of turbine body G20Mo5 cast steel

L20HM according to PN-H-83157:1989 **G20Mo5** according to EN 10213 current standard PN-EN 10213+A1:2016-08						
R_e [MPa]	**R_m [MPa]**		**A [%]**		**KV [J]**	
245	420-480		22		27	
C	**Cr**	**Mo**	**Si**	**Mn**	**P**	**S**
0.15–0.23	0.4–0.7	0.4–0.6	0.6	0.5–1.0	0.025	0.020

The body was delivered for overhaul disassembled, on two different dates.

Figure 1 shows the lower part of the body after disassembly, condition as delivered.

Fig.1. Body of WP steam turbine for EC Gdynia TG1 as delivered after disassembly, lower part

3. STEAM TURBINE REPAIR PROCESS

After cleaning the body (both the upper and lower parts) by sand blasting, surface inspection was performed first using the magnetic particle method on 100% of the cast's surface.

On the upper part, 29 readings were found, and 25 on the lower part. All cracks detected were qualified for removal by milling, the recess locations were tested again using the magnetic particle method to ensure that this operation was performed properly, as all defects had to be removed until healthy material was reached [Wieczorska 2018].

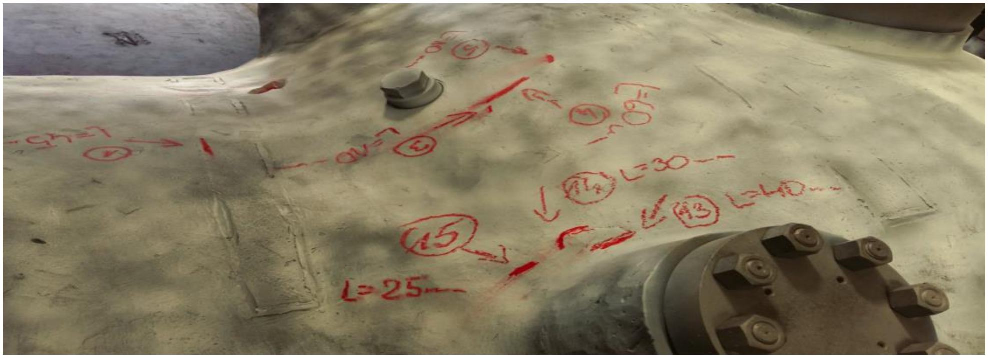


Fig. 2. Marked cracks detected during the first (preliminary) magnetic particle inspection of the upper hull part

The next step was to prepare a DDRD (defects, discontinuities – repair decisions) document. The document contains the discontinuity (defect, crack) number, crack type and discontinuity dimensions, and the method of defect removal by spreading or welding is specified. Once defects are removed by milling, the defects are measured using a slide calliper and their width, length and depth are recorded. Based on these dimensions, the repair decision is taken.

Following the magnetic particle inspection, destructive testing was performed, which included: metallographic testing of the material's microstructure, impact strength and hardness testing. All of these tests were performed on trepanation samples taken from the entire thickness of the body wall in the hot area and cold area, which were numbered consecutively:

- for the upper part – 1UH (from the hot area) and 2UC (cold area);
- for the lower part – 3LH (from the hot area) and 4LC (cold area).

Samples for strength and microstructure testing from the hot areas in the upper and lower parts of the body were taken with a trepanning tool, and cold area samples were cut out [Wieczorska 2018].

Fig. 3. Location of 3LH sample collection — external WP body, lower part, hot area

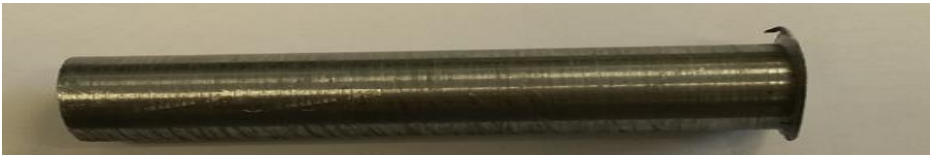


Fig. 4. Trepanation sample 3LH

Fig. 5. Location of 2UC sample collection — external WP body, lower part, cold area

Following the sampling, the samples were transferred to the laboratory and tested.

The testing scope included:

- hardness measurements;
- impact strength test;
- static tensile strength test at ambient temperature;
- metallographic tests.

The scope of testing, equipment used and test documentation is shown in Table 2.

Table 2. Test methods, test equipment, standards

No.	Test method	Test equipment	Testing conditions	Testing standards and instructions
1	Microscopic	Axioscope	zoom x100, 500, 1000 Etch Mi1Fe	MT/I-101 issue 4 of 22-01-2016
2	Vickers hardness test	Zwick 3212	Load 98,1 N	PN-EN ISO 6507-1:2007
3	Impact strength test	Zwick 5111 Charpy hammer	Temp. 23°C V-notch	PN-EN ISO 148-1:2010
4	Static tensile strength test at ambient temperature	Zwick 250	Temp. 23°C 10x10 mm	PN-EN ISO 6892-1:2010
5	Microscopic	JSM 35c	zoom x100, x500	MT/I-101 issue 4 of 22-01-2016

The hardness of the samples from the upper and lower parts of the body was measured using the Vickers method. The results are shown in Table 3.

Table 3. Results of hardness measurements, Charpy V impact energy tests, and static tensile test for post-operational state of body material

Area	Sample no.	HV10 Hardness	R_m [MPa]	R_{eH} [MPa]	KV [J]	Z [%]	A [%]
hot	1UH	160	508	277	9	58	28.9
hot	3LH	155	500	311	8	60	22.5
cold	2UC	167	511	324	17	61	24.7
cold	4LC	151	505	318	14	63	25.5

The first stage of the steam turbine repair process is a special heat treatment intended to dissolve carbides and enable repair by welding. However, before this stage was performed, both halves of the body had to be bolted together and braced, which was intended to protect the cast from major deformations during the heat treatment, as shown in Figure 6.

An equally important element is reboring the threads in the connection flanges, with the rebored holes subsequently being welded together as per the welding instruction. Small threads are destroyed during the heat treatment (the tips of the thread crests are burned), threaded holes as per design figure dimensions cannot be prepared during the calibration process, to this end, the rebored sites must be welded, and once the heat treatment is complete, the threads should be recreated according to design dimensions [Trzeszczyński and Grzesiczek 1998; Wieczorska 2018].

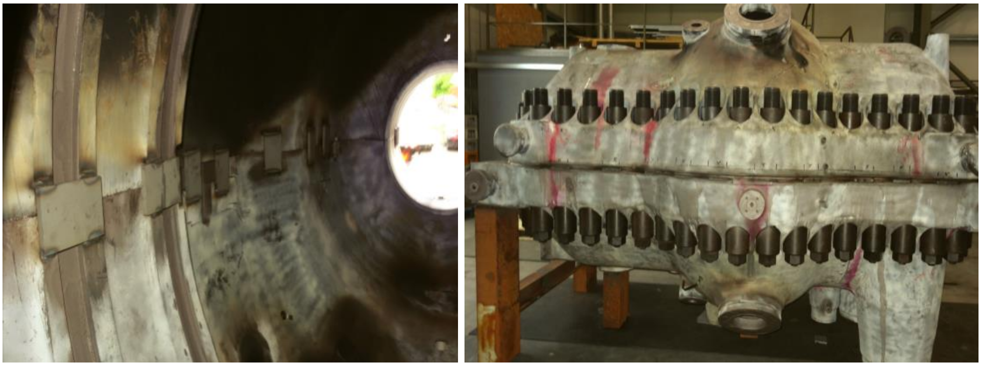


Fig. 6. Body preparation for heat treatment

The purpose of the special heat treatment is to:

- remove post-operation changes in the microstructure, e.g. by dissolving carbides;
- achieve the microstructure of tempered bainite with adequate impact strength;
- enable proper performance of welding repairs in material recesses and post-operation cracks [Rehmus-Forc 2016].

Hardening was conducted by heating the material to the temperature at which austenitisation occurs, then annealing it at this temperature, followed by cooling to achieve non-equilibrium structures — martensite, bainite, or a mixture thereof. To achieve the right results of hardening, the parameters of this treatment must be determined, which includes the austenitisation temperature, holding time and cooling rate. Heating to the austenitisation temperature is performed gradually, preventing excessive temperature differences [Cicholska and Czechowski 2013].

The body heating rate was 50°C/h. The first stop occurs at 650°C, after which the temperature again rises at a rate of 50°C/h until the austenitisation temperature of 970°C is reached. Following the hardening, the steam turbine body was cooled by a flow of air, then subjected to tempering to reduce stresses and obtain the right mechanical properties, i.e. to restore the material's plastic deformation ability. The steam turbine body was subjected to the process of high tempering to achieve as high an impact strength as possible while maintaining sufficient tensile strength. The heating rate was 60°C/h until a temperature of 620°C was reached, then the body was cooled in air [Wieczorska 2018].

Following the heat improvement, magnetic particle tests were performed, during which single cracks were detected. During the magnetic particle tests, the same acceptance criteria applied as during the initial tests. Defects (cracks) were found and marked on the upper and lower parts of the body, which were subsequently qualified for removal by mechanical processing. Once the material layers containing the marked defects were removed and the recesses were measured, it was decided to repair these areas by welding. Following the repair of the cast steel body of the steam turbine, mechanical and metallographic tests identical as for the post-operation body testing scope were performed. The results are presented in Table 4.

Table 4. Results of hardness measurements, Charpy V impact energy tests, and static tensile test after revitalisation of cast steel steam turbine

Area	Sample no.	HV10 Hardness	R_m [MPa]	R_{eH} [MPa]	KV [J]	Z [%]	A [%]
hot	11UH	155	519	342	70	63	24.6
hot	13LH	151	511	351	95	69	25.3
cold	12UC	152	509	346	59	70	28.4
cold	14LC	159	526	364	64	64	23.8

4. WELDING TECHNOLOGY

Welding repairs of the locations with removed cracks were performed in accordance with the prepared welding instruction.

Table 5 shows the chemical composition of the filler used, which was produced by BÖHLER.

Table 5. Chemical composition of filler

Filler name	C	Si	Mn	Cr	Mo	P	As	Sb	Sn
DCMS-IG	0.11	0.6	1.0	1.2	0.5	0.012	0.010	0.005	0.006

The prepared technology assumes:

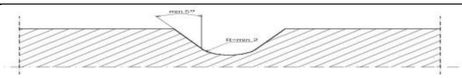
WPS (welding procedure specification) – MAG welding method, with DCMS-IG wire used as filler, the material must be pre-heated to 200˚C using a gas burner before rebuilding begins, the interpass temperature must exceed 400˚C.

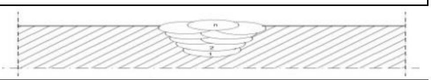
Once the welding process is complete, perform stress relief annealing by heating the cast to 670˚C at a rate of 60˚C/h, hold the piece at 670˚C for 7 h, then cool it at a rate of 50˚C/h. This technology is used as standard for the rebuilding of a recess created by removal of material discontinuities [Jaworski 2002; Wieczorska 2018].

Table 6. WPS – welding repair

WPS Welding Procedure Specification Instrukcja Technologiczna Spawania	No./Nr **ME 2805/2017**	Rev./zm. **-**
	Page/strona 1	Pages/stron 1

1. WPQR no. Nr WPQR : GDK1000330/2 2. Standard No. Norma nr : EN ISO 15614-1 3. Manufacturer Wykonawca : Metal Expert Sp. z o. o. 4. Welder qualifications ISO9606-1 Kwalifikacje spawacza : FM3-EN 5. Welding process Proces spawania : 135 6. Joint type Rodzaj złącza : BW	1. Method of preparation for welding: machining/ washing Sposób przygotowania do spawania: obróbka / mycie 2. Base material / Materiał podstawowy: acc. to ISO/TR 15608 – pos. 1 **material group** poz. 1 grupa materiałowa : 5.1 – pos. 2 **material group** poz. 2 grupa materiałowa : 5.1; 1; 2 3. Thickness of material [t-mm] Grubość materiału : 7.5 ÷ 30 4. Outer diameter [d-mm] Średnica zewnętrzna : ≥ 25 5. Welding position Pozycja spawania : PA
Preparation for welding / Przygotowanie do spawania	Run sequence / Kolejność układania ściegów





Current characteristics / Parametry spawania

Run Ścieg	Welding process Proces spawania	Size of filler mat. Wymiar spoiwa [mm]	Current Natężenie [A]	Voltage Napięcie [V]	Type of current/Polarity Rodzaj prądu/Biegun.	Wire speed Pręd. drutu [m/min]	Welding speed Prędkość spawania [mm/s]	Linear energy Energia liniowa [kJ/mm]
1÷n	135	1.2	270÷310	28÷32	DC / “+” puls	9.0÷11.0	3.5÷6.5	0.930÷2.267

1. Filler material / Materiał dodatkowy - type / typ : GCrMoSi – EN ISO21952-A - brand / nazwa : DCMS-IG - manufacturer / producent : BŐHLER 2. Shield gas / Gaz osłonowy : acc. to EN ISO 14175 - brand / rodzaj : M21 – Ar80%+$CO_2$20% - velocity / przepływ : 10 ÷ 16 l/min 3. Forming gas / Gaz formujący - brand / rodzaj : - - velocity / przepływ : - 4. Brand of tungsten electrode / Size : N/A Rodzaj elektrody wolframowej / Wymiary	**Preheating for welding / Podgrzewanie do spawania** - preheat temperature / temp. podgrzewania : **min 200 °C** - type of preheating / sposób podgrzewania : furnace - interpass temperature / temp. międzyściegowa : **max 400°C** **Post weld heat treatment / Obróbka cieplna po spawaniu** - type / rodzaj : stress relieving - heating rate / prędkość nagrzewania [°/h] : **max. 60** - holding temp. / temp. wytrzymania [°C] : **670+/-10** - holding time / czas wytrzymania [h] : **7 h** - cooling rate / prędkość studzenia [°/h] : **max. 50**

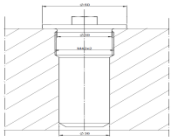
Remarks, additional information / Uwagi, informacje dodatkowe:
Shorting arc welding, inadmissible to local overheating material. Each bead cleaned precisely. Multilayer welding.
Spawać łukiem krótkim, nie dopuszczać do miejscowego przegrzania materiału. Każdy ścieg dokładnie oczyścić. Spawanie wielowarstwowe.

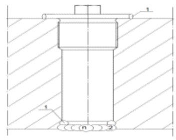
Prepared by / Opracował	Approved by / Zatwierdził	Approved by Customer / Zatwierdzenie klienta
A. Wieczorska Date / Data *05.2017*	Date / Data 05.2017	Date / Data

Table 7. WPS

WPS-Welding Procedure Specification Instrukcja Technologiczna Spawania	No./Nr **ME 3105/2017**	Rev./zm. **-**
	Page/ strona 1	Pages/ stron 1

7. WPQR no. / Nr WPQR : GDK1000330/2 8. Standard No. / Norma nr : EN ISO 15614-1 9. Manufacturer / Contractor : Metal Expert Sp. z o. o. 10. Welder qualifications / Kwalifikacje spawacza : FM3-EN ISO9606-1 11. Welding process / Proces spawania : 141/135 12. Joint type / Rodzaj złącza : BW; FW	1. Method of preparation for welding: machining/ washing Sposób przygotowania do spawania: obróbka / mycie 6. Base material / Materiał podstawowy : acc. to ISO/TR 15608 – pos. 1 **material group** / poz. 1 grupa materiałowa : 5.1 – pos. 2 **material group** / poz. 2 grupa materiałowa : 5.1; 1; 2 7. Thickness of material [t-mm] / Grubość materiału : 7.5 ÷ 30 8. Outer diameter [d-mm] / Średnica zewnętrzna : ≥ 25 9. Welding position / Pozycja spawania : PA
Preparation for welding / Przygotowanie do spawania	Run sequence / Kolejność układania ściegów





Current characteristics / Parametry spawania								
Run Ścieg	Welding process Proces spawania	Size of filler mat. Wymiar spoiwa [mm]	Current Natężenie [A]	Voltage Napięcie [V]	Type of current/Polarity Rodzaj prądu/Biegun.	Wire speed Pręd. drutu [m/min]	Welding speed Prędkość spawania [mm/s]	Linear energy Energia liniowa [kJ/mm]
1 2-n	141 135	2.4 1.2	100÷150 270÷310	17÷20 28÷32	DC / "-" DC / "+" pulse	- 9.0÷11.0	0.6÷0.9 3.5÷6.5	1.020÷4.000 0.930÷2.267

1. Filler material / Materiał dodatkowy - type / typ : 141-WCrMoSi – EN ISO21952-A : 135-GCrMoSi – EN ISO21952-A - brand / nazwa : DCMS-IG - manufacturer / producent : BŐHLER 2. Shield gas / Gaz osłonowy : acc. to EN ISO 14175 - brand / rodzaj : 141 – I1 – 100%Ar : 135-M21 – Ar80%+$CO_2$20% - velocity / przepływ : 141- 8 ÷ 12 l/min : 135-10 ÷ 16 l/min 3. Forming gas / Gaz formujący - brand / rodzaj : - - velocity / przepływ : - 4. Brand of tungsten electrode / Size Rodzaj elektrody wolframowej / Wymiary : WT20- 2x125	**Preheating for welding / Podgrzewanie do spawania** - preheat temperature / temp. podgrzewania : min 200 °C - type of preheating / sposób podgrzewania : furnace - interpass temperature / temp. międzyściegowa : max 400°C **Post weld heat treatment / Obróbka cieplna po spawaniu** - type / rodzaj : stress relieving - heating rate / prędkość nagrzewania [°/h] : max. 60 - holding temp. / temp. wytrzymania [°C] : 670+/-10 - holding time / czas wytrzymania [h] : 7 h - cooling rate / prędkość studzenia [°/h] : max. 50

Comments, additional information / Uwagi, informacje dodatkowe:
Shorting arc welding, inadmissible to local overheating material. Each bead cleaned precisely. Multilayer welding.
Spawać łukiem krótkim, nie dopuszczać do miejscowego przegrzania materiału. Każdy ścieg dokładnie oczyścić. Spawanie wielowarstwowe.

Prepared by / Opracował	Approved by / Zatwierdził	Approved by Customer / Zatwierdzenie klienta
A. Wieczorska Date / Data *05.2017r.*	Date / Data 05.2017r	Date / Data

The technology of plugging the holes created by taking trepanation samples for material testing of the body involves the performance of three operations:

- creating a thread in the hole left after collecting a trepanation sample;
- preparing a plug of ST460TS steel;
- screwing the plug into the hole, welding it from the external and internal surface sides, then testing the equality of the joint using the penetration method, in accordance with the welding procedure specification [Jaworski 2002; Wieczorska 2018].

5. STRESS RELIEF ANNEALING

Annealing is a heat treatment process involving heating the charge to a specific temperature, holding it at this temperature, then slowly cooling it in the air. The purpose of this treatment is to bring the material closer to equilibrium conditions [Cicholska and Czechowski 2013].

Once material recess rebuilding repairs were completed, the body halves were bolted together and strengthening elements were welded on, then the body was subjected to stress relief annealing.

Stress relief annealing involves heating steel to a temperature lower than Ac1 (usually no more than 650°C), holding it at this temperature, then gradually cooling it. Stress relief annealing is used to remove stresses without clear structural changes [Cicholska and Czechowski 2013].

The body heating rate was 57°C/h for 9 hours, then when the temperature of 670°C was reached, the holding time was 7 hours, followed by cooling at a rate of 48°C/h [Wieczorska 2018].

Once the last heat treatment, intended to remove welding stresses, was completed, non-destructive testing was performed, which included:

- magnetic particle inspection on 100% of the body area, with the acceptance criterion for raw (non-repaired) surfaces being identical as for the preliminary tests, while for any welding repair areas, no linear readings were accepted.

During this non-destructive testing, no unacceptable readings on the body surface were found [Wieczorska 2018].

6. SUMMARY

To summarise, it can be concluded that the body material structure following the repairs is identical to that created during the body production process from grade G20Mo5 (L20HM) cast steel. The impact strength of the upper and lower part is very high. The external body repair was performed correctly and restored the body's plastic deformation ability. The impact energy on the Charpy samples with a V-notch is 59 J to 95 J, and is consistent with the ordering party's requirements, and higher than that required by current national and industry standards. The body's mechanical properties following the repairs are consistent with the requirements specified in standards and the expert opinion on the condition of the WP steam turbine for EC Gdynia TG1 [Wieczorska 2018]. The welding repair of locations where material layers containing cracks were removed was performed correctly. During the next scheduled overhaul of the turbine, it is recommended to inspect the condition of the body again.

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