THE NEW PENSTOCK FOR THE HIGH-HEAD HYDROPOWER PLANT KAUNERTAL

Part 1

MEASURES FOR QUALITY CONTROLLED COMPONENT PRODUCTION

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Abstract: TIWAG renews the underground steel-lined pressure shaft in the high head power plant Kaunertal with a diameter of 4,3 m and a construction pressure of 100 bar. We describe the main aspects of quality assurance and testing as well as the crucial parameters for high quality.

1 Project overview

The hydropower plant Kaunertalkraftwerk was built by TIWAG-Tiroler Wasserkraftwerke AG from 1961 to 1965, at that time it was Austria's largest plant with a maximum power output of 392 MW under a head of 890 m. Actually TIWAG erects a new underground pressure shaft with a 1,4 km long steel lining, with bifurcations to the existing power house and to the planned parallel new stage.
The capacity for the nominal flow is increased from actual 52 m^3/s to 122 m^3/s.

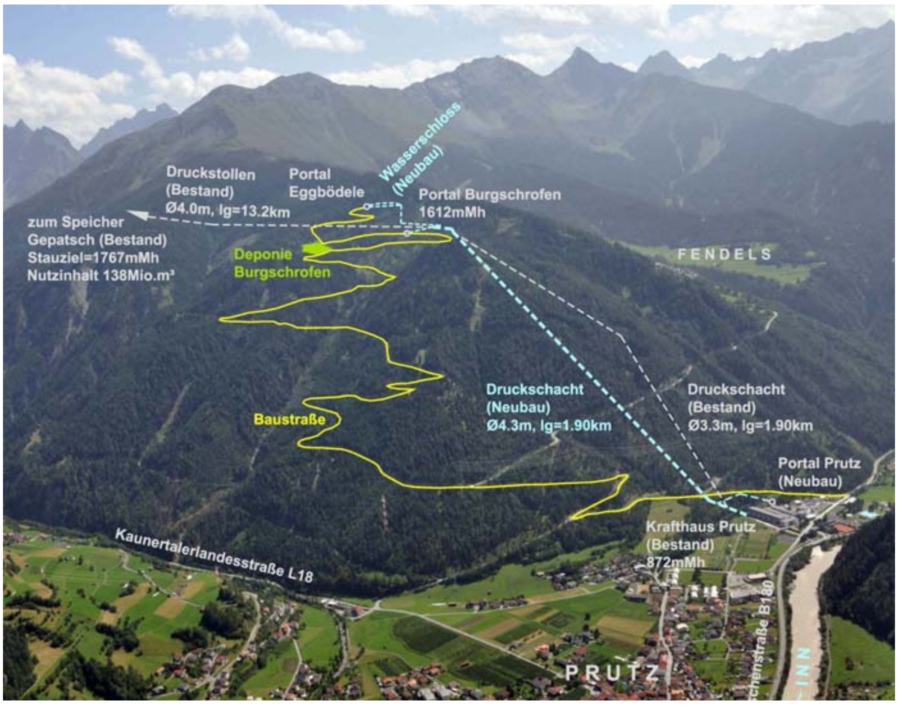

Figure 1: Project Overview

The civil work has started in March 2012, actually the steel lining is three-quarter done. The beginning of operation is planned in 2016.

2 Quality measures for reliable steel structures

The steel-lining of the pressure shaft comprises some 9.300 tons of steel plates, the structure (diameter 4,3 m, maximum pressure 100 bar, dynamic pressure ±5 bar with $8*10^7$ load cycles within 100 years) is among the highest stressed ones of this kind. TIWAG's engineers laid high emphasis on the reliability of the whole structure.

In Europe the reliability of technical structures has its common basis in the Eurocode, which allows for a specific differentiation of a structure's reliability depending on its risk-potential. The general concept, described in Eurocode 0 (EN1990 [1]), is a design concept built on "partial safety factors" against "limit states". It comprises classes of reliability (RC1 to RC3) and levels of consequences (CC1 to CC3, high number high consequences), the combination of which results in different values of the "partial safety factors" on the loading side and on the resistance side.

Eurocode allows for an increase of reliability, either by higher "partial safety factors" or by more intensive measures during the planning (design supervision levels DSL1 to DSL3) and/or during the erection (inspection levels IL1 to IL3, high number low probability of failure). It also provides rules for the consideration of deviations from "usual conditions", reaching from loads and calculation of stresses up to geometrical abnormalities, but also from materials properties up to defects detected with testing measures. A well-established information is given in [2].

The Eurocode requires the structural elements to provide for certain resistances, the bases are the properties of materials and structural elements described in EN1090 [3]. It defines classes of execution (EXC1 to EXC4) describing the individual production steps from design and choice of materials to the manufacturing of the single parts including the welding and testing, depending on the service categories (SC1 to SC2) and the production categories (PC1 to PC2).

For the Kaunertal pressure shaft, TIWAG decided to specify the measures for its reliability according to Eurocode and EN1090. The structure certainly belongs to RC3 and CC3 and requires EXC4. This calls for a high quality level, it comprises different elements, from straight pipes to bendings and bifurcations, embedded in concrete or free-standing, with thousands of tons of steel plates and kilometres of welding and with the necessity of testing procedures in factory shops, on-site shops and inside the mountain. From the beginning of the works, when all the specifications and contracts with suppliers, supervisors, authorities etc. had to be cleared, the compliance with the codes was the common rule, and also all the abnormal conditions and situations that could happen during such a project – and for sure they will happen.

The Austrian National Appendix to Eurocode 3, EN1993-4-3, provides the rules for pressure pipes in hydropower plants up to a limit in diameter and pressure. The Kaunertal structure is far outside from these limits, but as Eurocode provides for rules even for such conditions, TIWAG executed quite a lot of tests for the properties of materials and structural elements and thus was able to comply with the Eurocode.

3 Quality measures previous to the contract specifications

The preliminary engineering comprised an investigation of the available steel grades for plates and welding filler and a pilot test simulating welding and mounting at near-site-conditions. TIWAG participated in an Austrian research project Betriebssicherheit von geschweißten hochfesten Pipelines und Druckrohrleitungen. The understandings and experiences gathered are described in [4].

The steel lining requires high ductility in base material and weld to compensate for eventual weak bedding conditions. It also requires over-matching, which means that the minimum yield strength of the deposited weld shall be higher than the maximum yield strength of the plates, allowing for eventual movement of the surrounding rock.

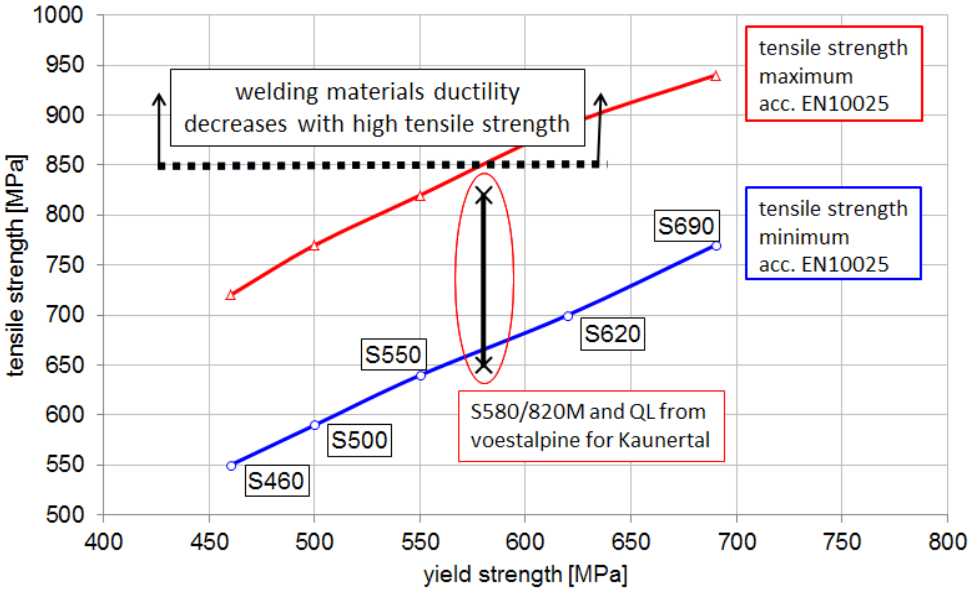

Fig. 1 Standard specification of strength according to EN10025

The diagram depicts minimum and maximum tensile strength versus yield strength for steels according to EN10025.

Material (GW) specification Kaunertal:										
		mechanical properties longitudinal					toughness transverse		fracture mechanics	
							guarantee	goal	guarantee	goal
sign VOEST Alpine	Thickness [mm]	$R_{p0,2}$ min [MPa]	R_m min [MPa]	R_m max [MPa]	A_{gt} min [%]	(R_e/R_m) max	MW / EW AV [J] (0°C)	MW / EW AV [J] (-40°C)	$J_{0,2}$ min [kJ/m²] (0°C)	CTOD min SEB10 [mm] (0°C)
Dillimax 620 QL	100 - 151	560	630	820	5	0,93	130 / 100	70 / 50	150	0,56
Dillimax 620 QL	50 - 101	580	650	820	5	0,93	130 / 100	70 / 50	150	0,56
Aldur 560/820 QL	101 - 140	560	630	820	5	0,95	130 / 100	70 / 50	120	0,56
Aldur 580/820 QL	50 - 100	580	650	820	5	0,95	130 / 100	70 / 50	120	0,45
Alform 620/820 M	46 - 51	620	690	820	6	0,93	200 / 175	100 / 70	120	0,45
Alform 580/820 M	30 - 50	580	650	820	5	0,93	200 / 175	100 / 70	120	0,45
Alform 500/770 M	20 - 50	500	560	770	6	0,93	200 / 175	100 / 70	120	0,45
Alform 460/700 M	20 - 50	460	515	700	6	0,93	200 / 175	100 / 70	120	0,45
Alform 355/630 M	20 - 30	355	400	630	6	0,93	200 / 175	100 / 70	120	0,45

Table 1: Base Material Specification for Kaunertal penstock and surge tank

The properties for steel plates are shown in the upper table, those for welds with different processes in the lower table.

Weld (SG) specification Kaunertal:									
strength class welded connection	welding process	mechanical properties guaranteed				hardness guarantee	toughness guarantee	fracture mech. goal
		PWHT (°C)	R_{p02} min [MPa]	MW/EW R_m min [MPa]	A_{gt} min [%]	MW/EW HV10 max	MW / EW AV min [J] (0°C)	$J_{0,2}$ min [kJ/m²] (0°C)
≤ S460 / 700	UP	510±10	580	700 / 680	5	350 / 380	130 / 110	110
	MAG	510±10	580	700 / 680	5	350 / 380	100 / 80	120
	E	510±10	580	700 / 680	5	350 / 380	100 / 80	120
	WIG-man	510±10	580	700 / 680	5	350 / 380	130 / 110	120
	WIG-HD NG	510±10	580	700 / 680	5	350 / 380	130/110	120
≥ S500 / 770 ≤ S620 / 820	UP	510±10	710	830 / 810	5	350 / 380	130 / 100	80
	MAG	510±10	710	830 / 810	5	350 / 380	120 / 90	80
	E	510±10	710	830 / 810	5	350 / 380	80 / 60	70
	WIG-man	510±10	710	820 / 800	5	350 / 380	130 / 100	120
	WIG-HD NG	510±10	710	820 / 800	5	350 / 380	130 / 100	120

Table 2: Specification for the weld connection for Kaunertal penstock and surge tank

The results: ductility and over-matching require for the base material a constraint of EN10025, in particular the steel grade S620 limited with $R_{m/max} \leq 820$ N/mm^2, notch impact test at 0° C and CTOD-test for crack initiation must be executed. The optimum welding procedure for site-work is gas tungsten arc welding with hot wire/narrow gap.

4 Quality measures during production and mounting

TIWAG mandated an accredited quality inspector with the supervision of the quality measures. The inspector has a team of experts tracing the complete process during production and mounting. He is responsible for quality testing, approval and document management. His works comprises the melting of the bars to the rolling of the plates, the fabrication of the pipes and bifurcations at the supplier's workshops and the site-shops, and the final welding on the installation site inside the mountain.

Testing of the welds:
The primary testing of the welding is done by the quality inspector of the supplier, it comprises UT of 100 % of the welding seams, executed with classical hand testing apparatus. The approval testing is done by TIWAG's inspector, executed with a rather new testing apparatus, TOFD/PA, which allows for a 3-dimensional scan of the whole weld and the neighbouring zones of the pipes. The scans result in digital data that can be filed to PC.

As the testing apparatus was new for the inspector and since International Standards do not provide enough information on the detection and approval/reject of faults, it was decided to produce probes of near-reality structural elements with pre-fabricated faults of well determined geometry, location and orientation. The scan of these probes provided calibrated scan-results for typical faults as references.

The testing of the welds inside the mountain requires two scans with different calibration of the testing sensors for areas near the back side and the inner side of the pipe. An instant judgement of the welding quality is done at the site, the decision whether to proceed with the welding or to repair is available within three hours.

Documentation of the quality:
The consequent evaluation of the scans and the writing and filing of the testing report is done in the inspector's office within a few days.

The length of the pressure shaft is 1.400 m. The total length of the welds, including longitudinal and circumferential welds, is 14.300 m, they are tested and scanned as per 100 %. The welds on bifurcations etc. comprise some 1.700 m, they are scanned as per 44 % as not all of them are accessible with TOFD/PA (the rest is tested conventional). The files with the scans comprise some 600 GB of data, filed in a structured database on TIWAG's server with definite assignment to the element of the structure and the phase of its production or mounting.

The advantage of this kind of testing is that the results are available immediately in digital form, whereas with conventional testing a huge amount of paper documents was available months after the testing with difficulties to which document belongs to which part and step of production.

5 "Management" of quality

The management of quality is an essential task during the erection of the structure. The partners in the project team not only comprise the planner, the contractor and the customer, but also the sub-contractors, the inspectors and the representatives of the authority as well as the construction company's site managers.

It is not sufficient to have an inspector for the quality testing, who is obliged to approve or reject the work. The inspector needs criteria enabling him to decide. These criteria must be developed in a process, as there is no International Standard or similar rule that complies with all the situations that might be encountered.

Very exciting experiences were the discussions among experts having knowledge in specific professional disciplines, when they were forced to make it understandable to other persons, and above all, to make it compatible with the restrictions of the daily work for production, mounting and testing of a real structure.

The client himself, the planning engineers and the representatives of the authority need to have possibilities to check single steps during production and mounting and to intercept the process if necessary.

It is necessary to supervise the inspector (two-man rule).

Regulations for the workflow of the quality documents were developed and brought into operation with continuous improvement:
- the supplier's quality personnel produce documents
- the inspector judges their results and produces documents himself

- the approval of all these results is done by the planning engineers
- the permission is given by the representative of the authority

If there are situations questioned by either one of the partners, then it is necessary to have a forum where aspects can be discussed and settled.

6 Conclusions

The steel-lined pressure shaft of the Kaunertal power plant is among the highest stressed structures of this kind. The International Standards EN1990 and EN 1090 provide the basis for the reliability of the steel structure.

The most important recognition from the preliminary engineering was that all the measures regarding quality must be started at the very beginning of the project, before the writing of the specifications for the contract, then they must be subsequently executed during all the processes and, not to forget, they have to be communicated to all the partners in the project team.

The quality testing with 3-D scanning of the weld and its surrounding provides digital information which can be accessed immediately and is unique assigned to the single element and the phase of its production. For the coming phase of operation of the conduit it will also be possible to compare the results of future testing with the initial state of the structure.

References:

[1] EN1990: Eurocode: Basis of structural design;
EN1993: Eurocode 3: Design of steel structures

[2] Greiner, R.: Reliability of penstocks of hydropower plants – new concepts and strategies; 16th International Seminar on Hydropower Plants 2010, Vienna

[3] EN1090: Execution of steel structures and aluminium structures;
Part 1: Requirements for conformity assessment of structural components;
Part 2: Technical requirements for steel structures

[4] Maldet, R.: The renewal of the pressure shaft for the high head hydropower plant Kaunertal: preliminary testing for the constructional steelworks; 17th International Seminar on Hydropower Plants 2012, Vienna

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