Piottino Powerplant

Upgrading study

Contents

1 EXECUTIVE SUMMARY

This study investigated the consequences of renewing the existing turbines and valves of units 1-3 in Piottino Hydro Power Station. The basis of the study is as follows:

- The existing maximum flow will be maintained, 3*8 m^3/s.
- The existing waterway system and surge shaft system will be maintained.
- The existing draft tube bend, extension and lower part of draft tube cone will be maintained.
- The pressure relief valve outlet will be maintained.
- New turbines, pressure relief valves, inlet valves, penstock protection valves, governors and oil pressure systems will be supplied.

The performance of upgraded turbines is summarized in the following table:

Estimated Performance of Upgraded Turbines

	Existing Units	Upgraded Units
Rated Head (m)	320	320
Output at Above Head (MW)	22.7	
Maximum Discharge (m^3/s)	8	8
Nominal Speed (rpm)	750	750
Max efficiency (%)	90.5**	
Efficiency at max output (%)	90.5**	

* Figures based on original contract
** Figures based on article from 1933 about the existing units when they were new as explained below.

Upgrade & Rebuild Benefits:

- Increased maximum output
- State of the art efficiency
- Reduced maintenance costs

2 BACKGROUND

This upgrading study has been performed to study the possibilities for renewal of the turbines in Piottino Hydro Power Plant.

The powerplant with existing turbines was constructed between the years 1928 – 1931. The plant has three vertical Francis units, each one with a rated flow of 8 m^3/s.

The purpose of the study is to quantify the efficiency and output gains and the associated costs connected with replacing the turbines, valves and governors with new equipment.

The present runners are subject to wear from particle erosion and cavitation and are repaired regularly. The study has assumed that new runners will be designed to operate with cavitation damage not exceeding the lower recommended limit in IEC 60609 (41 cm^3 in 8000 hours).

3 PERFORMANCE ESTIMATE OF EXISTING UNITS

The efficiency of the existing units has been estimated based on an efficiency curve published in Schweizerische Bauzeitung in May 1933 and an estimate of normal wear and tear of this type of units. The peak efficiency in this curve is 91.4 %.

It is assumed that the efficiency has deteriorated by 0.01 % each year due to normal wear and tear of the unit, giving a total reduction of about 0.9 %. It is observed that the units are well maintained, however erosion by cavitation and hard particles in the water is present and various parts are repaired approximately every 45 000 operating hours.

Thus the present peak efficiency is estimated to 91.4 – 0.9 = 90.5 %.

4 DEFINITIONS OF SCOPE OF SUPPLY

The objective of the upgrading project is to achieve reliable operation and good efficiency over a large operating range. To achieve this the following new parts will be supplied:

- 3 off Francis Turbines
- 3 off Pressure Relief Valves
- 3 off Main Inlet Valves
- 3 off Electronic Governors
- 3 off Oil Pressure Systems
- 3 off Penstock Protection Valves, located in separate valve chamber
- 3 off Maintenance Valves upstream of the Penstock Protection Valves
- 1 off Oil Pressure System to operate the valves in the separate valve chamber
- 1 Spare Runner
- Additional Spare Parts as listed
- Technical Advisor for Installation and Commissioning

A turbine model test will be conducted to ensure that the guaranteed efficiency is reached.

New pressure relief valves (PRVs), connected to the turbine spiral case, will be supplied. The PRVs will be linked to the turbine servomotors through the pressure oil system. This will guarantee that the guide vanes and pressure relief valves always operate together to maintain the penstock pressure within its design limitation.

New penstock protection valves will be supplied.

New electronic governor and new 16 MPa oil pressure system will be supplied.

Technical advisor for installation and commissioning is included in the price estimates.

5 BUDGETARY PRICES

The budgetary prices include the following scope of supply as defined in chapter 4. The prices considers deliver DAP (Incoterms 2020) Piottino powerstation. The prices are in CHF and based on the price level of 2020:

Item	Price (CHF)
Engineering and administration	1 700 000
Francis Turbines	2 700 000
Model test	630 000
Spare runner	460 000
Pressure Relief Valves	300 000
Main Inlet Valves	870 000
Electronic governors	80 000
Oil pressure systems	540 000
Penstock Protection Valves	750 000
Other spare Parts	130 000
Technical advisor and commissioning	260 000
Total	**8 420 000**

6 ASSUMPTIONS

This study has been based on information provided by the owner in form of clarifications, tables, drawings and pictures of the equipment. A visit to the site was also made on January 21, 2020. During the site visit, unit 3 was under refurbishment and it was possible to inspect the inside of this unit.

This study is based on limited information on the condition and characteristics of the existing equipment in the power plant. In order to arrive at a definition of the scope of supply and a complete assessment of the upgrading potential, the following assumptions have been made:

6.1 General:

- The existing inlet pipes provides suitable distribution of water to the new equipment.
- The capacity and condition of existing auxiliary systems / balance of plant equipment is sufficient to secure safe operation with new installation.
- An order is placed for all units at the same time

6.2 Installation:

- The supplier will provide one technical advisor for the mechanical installation and commissioning work.
- The removal of existing equipment and concrete will be performed by the owner before the arrival of the technical advisor.

6.3 Condition for Site Works:

- The owner will do the mechanical and electrical works, arrange accommodation and local transport.
- Working hours: Normal working hours is 8 hours per day, 5 days per week.
- The owner will supply normal tools
- The supplier will supply special tools and test equipment
- Site work is assumed being done at one unit at a time, with an interval of one year between the units.

6.4 Turbine operating range

- Maximum discharge through existing tunnel is 24 m^3/s, i.e. 8 m^3/s for each turbine. We have chosen to design the turbine for maximum 8 m3/s over the complete head range.
- HWL can vary between el. 945.00 and 940.60
- The drawing 651_1 “Sfioratore prefabbricato presa Piottino” shows a weir in the tailrace at elevation 603.55. It also indicates a tailwater elevation of 604.14 m at Q = 8.0 m^3/s. The normal operating range of the tailwater according to measurements in the outlet channel is between elevations 604.00 and 605.00.
- An original hand calculation shows losses in the waterways are 34.47 mwc at flow of 8 m^3/s through each turbine. These are relatively high losses.
- This gives the following head range:
    - o Hn,min = 301.1 m (HWL= 940.60, TWL= 605.00, Hl = 34.47 mwc at 3*8 m^3/s)
    - o Hn,max = 340.5 m (HWL= 945.00, TWL= 603.55, Hl = 1 mwc at 1*4 m^3/s)

6.5 Penstock pressure rating

- The existing penstocks will be able to handle a maximum pressure of 354 mwc at the elevation of turbine centerline (604.35). This corresponds to an overpressure of 4% over maximum static pressure. Please note that a higher pressure rating is recommended (see chapter 8).

7 OVERALL DESCRIPTION OF UPGRADING

7.1 General

The objective of this study is to achieve good reliability, efficiency and maintainability with a reasonable expense of capital. To achieve this, we suggest replacing the complete turbine, inlet valve and pressure relief valve with new equipment. The existing lower part of the draft tube cone, draft tube bend and draft tube extension will be maintained. The existing pressure relief valve outlet will also be maintained.

In addition, we suggest to replace the existing penstock isolation valves, located in a separate valve chamber.

In some upgrading projects the existing spiral case has been reused in order to save costs. For Piottino we have considered to supply new spiral case also. The main reason is that the principal dimensions of the existing spiral case, designed about 90 years ago, will influence the efficiency of a modern turbine very negatively. Replacing the existing spiral case also gives us the opportunity to optimize some aspects of the civil works. This will result in the following additional advantages:

- Stresses in the stay vanes will be more uniform.
- Vertical stresses in the concrete will be reduced.
- Horizontal stresses in the concrete will be well defined and absorbed in two separate portions by the existing inlet pipe and the new spiral case.
- Assembly and disassembly of the unit for future maintenance will be easier.
- The radial position of the lower labyrinth seal will be independently adjustable, which will make it easier to obtain optimal performance in practice.
- The lower guide vane bearings and seals will be easily accessible for maintenance.
- Any water leakage onto the head cover will be fully drained by gravity.

We have performed a hydraulic analysis of the draft tube parts that we propose to keep, please see figure 7.1. The shapes of the existing draft tube bend and extension are quite good with almost no negative impact on the efficiency. Since they also appear to be in good mechanical condition, we judge that it is not economically feasible to replace them.

It is suggested that the existing draft tube and extension should be sandblasted and painted.

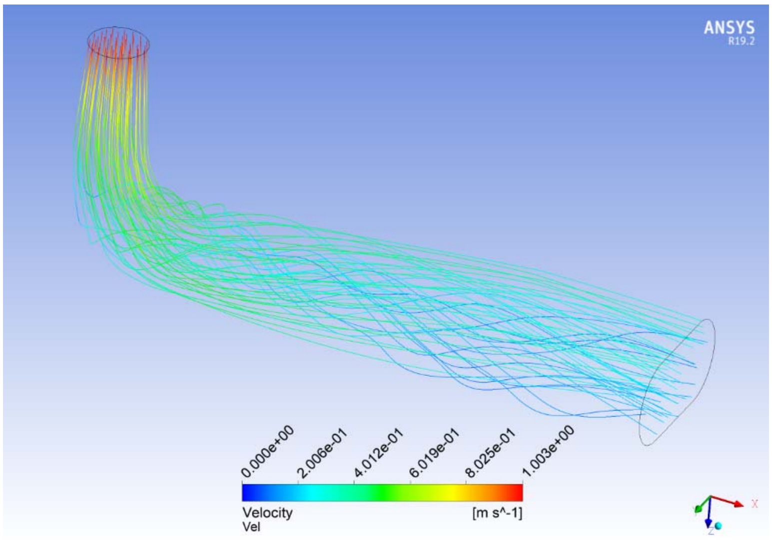


Figure 7.1. CFD analysis of existing draft tube shape.

7.2 Scope of supply

The following components are included in the supply:

- 3 sets of new turbines including a short draft tube cone.
- 3 sets of new inlet valves with inlet pipe and expansion box.
- 3 sets of new pressure relief valves.
- 3 sets of new electronic governors.
- 3 sets of new oil pressure systems
- 3 sets of new penstock protection valves in separate valve chamber. Two valves with nominal diameter 1550 mm and one valve with nominal diameter 1800 mm.
- 3 sets of new maintenance valves for the penstock protection valves. Two valves with nominal diameter 1550 mm and one valve with nominal diameter 1800 mm.
- 1 set of oil pressure based operating system for the penstock protection valves in the valve chamber.

7.2.1 Turbines

Nominal data for the new turbines are as follows:

Variable	
Power output	22.5 MW
Rated head	320 m
Rated discharge	8 m^3/s
Speed	750 rpm
Runner outlet diameter	950 mm

The performance of the new turbines is assumed to be verified in a homologous model acceptance test, which is included in the scope of supply. A thermodynamic efficiency test of the prototype units can also be made, but is not currently included in the price estimate.

7.2.2 Pressure relief valves

To meet the required pressure rise in the existing penstocks, new pressure relief valves will also be supplied and integrated with the turbine control system. The pressure relief valves will be designed together with the turbines in order to meet the pressure rise requirements. More details can be found in the transient analysis chapter.

7.2.3 Main inlet valves

New spherical main inlet valves will be supplied. While the existing inlet valves have a diameter of 1000 mm, we recommend 900 mm valve diameter as most appropriate with today's state of the art technology.

The inlet valves will be closing by counterweight and opening by a hydraulic oil servomotor. The hydraulic oil will be supplied by the new oil pressure system.

7.2.4 Electronic governors

New electronic governors are included in the scope. It is noted that the existing electronic governors are relatively new. It may be possible to reuse the existing electronic governors. However, this may create additional interface issues. The study includes separate price estimate for the electronic governor.

7.2.5 Oil pressure systems

New 160 bar oil pressure systems are included in the scope.

The current oil pressure systems are low pressure systems of obsolete design. In our experience it can be challenging to procure spare parts for such systems. In addition high pressure systems will reduce the necessary amount of oil.

The price estimate includes new oil piping and mechanical / hydraulic overspeed switch.

7.2.6 Valves in the upstream valve chamber

The existing powerstation incorporates three penstock protection valves and three maintenance valves in a separate valve chamber, located just downstream of the surge shaft. Two of the penstocks are Ø = 1550 mm and one is Ø = 1800 mm with the valves having corresponding diameters.

New penstock protection valves and maintenance valves, with the same sizes as the existing, are included in the scope. It is suggested to supply standard valves available on the market.

The penstock protection valves will be opened by hydraulic oil servomotors and closed by counterweights. The maintenance valves will be manually operated by handwheels.

The valves will be delivered with new bypass lines, inlet pipes and expansion boxes.

Technical descriptions of typical commercially available butterfly valves, suitable for the upstream valve chamber, are in appendix 3.7.

7.2.7 Oil pressure system for valve chamber

The existing valves in the valve chamber are operated by water pressure. It is proposed to supply a new oil pressure system to operate the valves. Since these valves are operated very infrequently, we propose one oil pressure system to operate all three penstock Protection Valves.

The system will have 16 MPa rated pressure. Each penstock protection valve will have a dedicated bladder accumulator to keep the servomotor in open position in case of a small leakage over the servomotors.

The oil pressure system includes an electric control cabinet with pump control and control of the shutdown valve for automatic closing upon too high water velocity in the penstocks.

The penstock protection valves will be operated manually by pushbuttons for open and close. The maintenance valves will be operated by hand, same as today.

7.3 Spare parts

The following spare parts are included in the budgetary price:

7.3.1 Turbine

- Runner – 1 off
- Stationary and rotating labyrinth seal rings – 1 complete set
- O-rings and gaskets – 1 complete set
- Guide vane mechanism bearings – complete set for 5 guide vanes
- Guide vane servomotor – 1 complete set of seals
- Electrical instruments – one of each kind

7.3.2 Inlet valve

- Bearing seals – 1 complete set
- Servomotor seals – 1 complete set
- Main sealing ring – 1 off
- Electrical instruments – one of each kind

7.3.3 Pressure relief valve

- O-rings and gaskets – 1 complete set
- Electrical instruments – one of each kind

7.3.4 Oil pressure system

- AC motor – 1 off
- Proportional valve – 1 off
- Coil for pilot valve – 10 off
- Filter – 4 off

7.3.5 Electronic governor

- Electronic module – 1 off
- Power supply – 2 off

7.3.6 Penstock protection valves

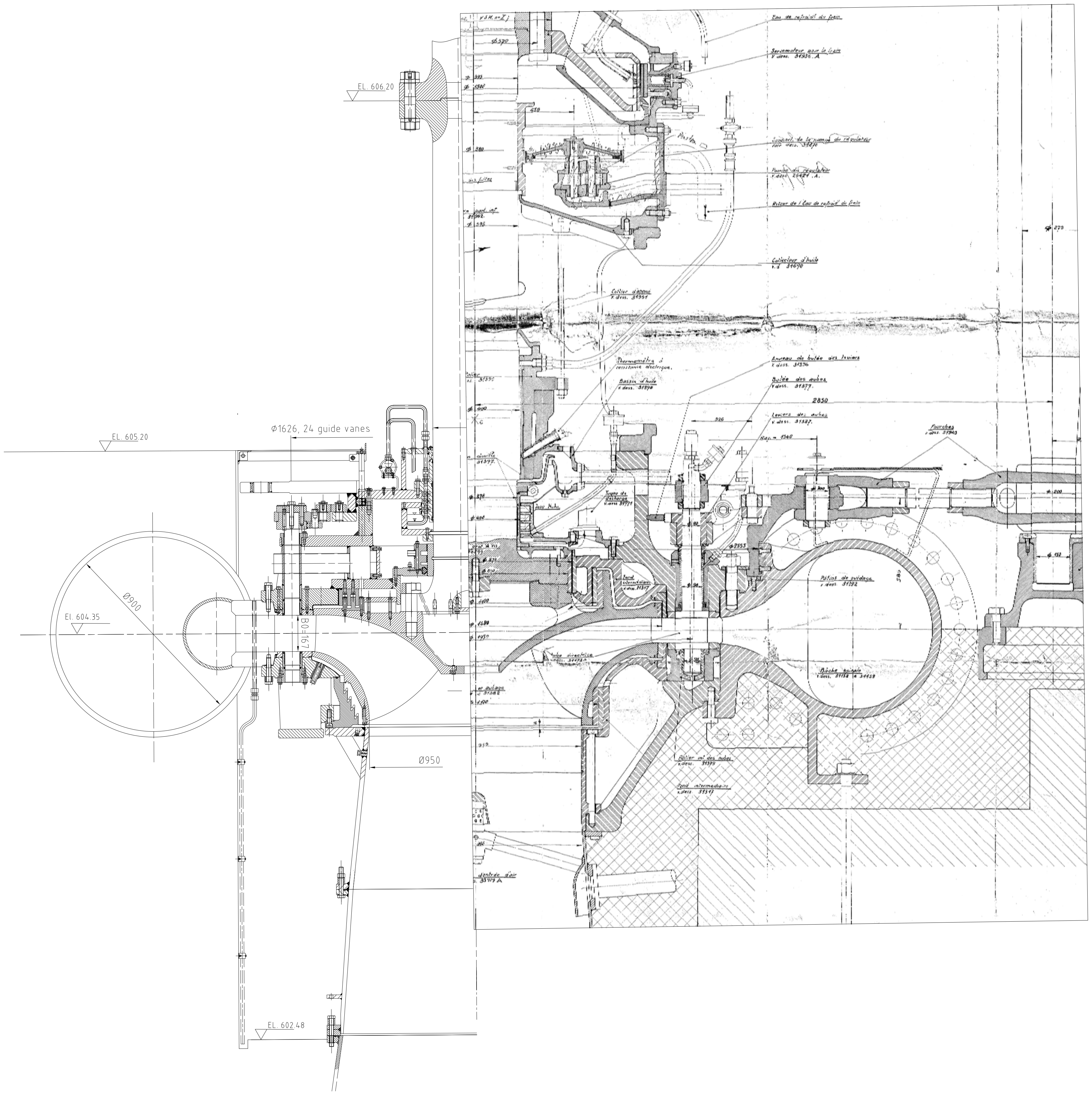
- No spares recommended

7.3.7 Oil pressure system for valve chamber

- Pump/Motor – 1 off
- Solenoid valve – 6 off
- Coil for solenoid valve – 1 off
- Manometer – one of each kind
- Pressure switch – one of each kind
- Relays – 3 off
- Limit switches – 1 off
- Filter elements – 1 off

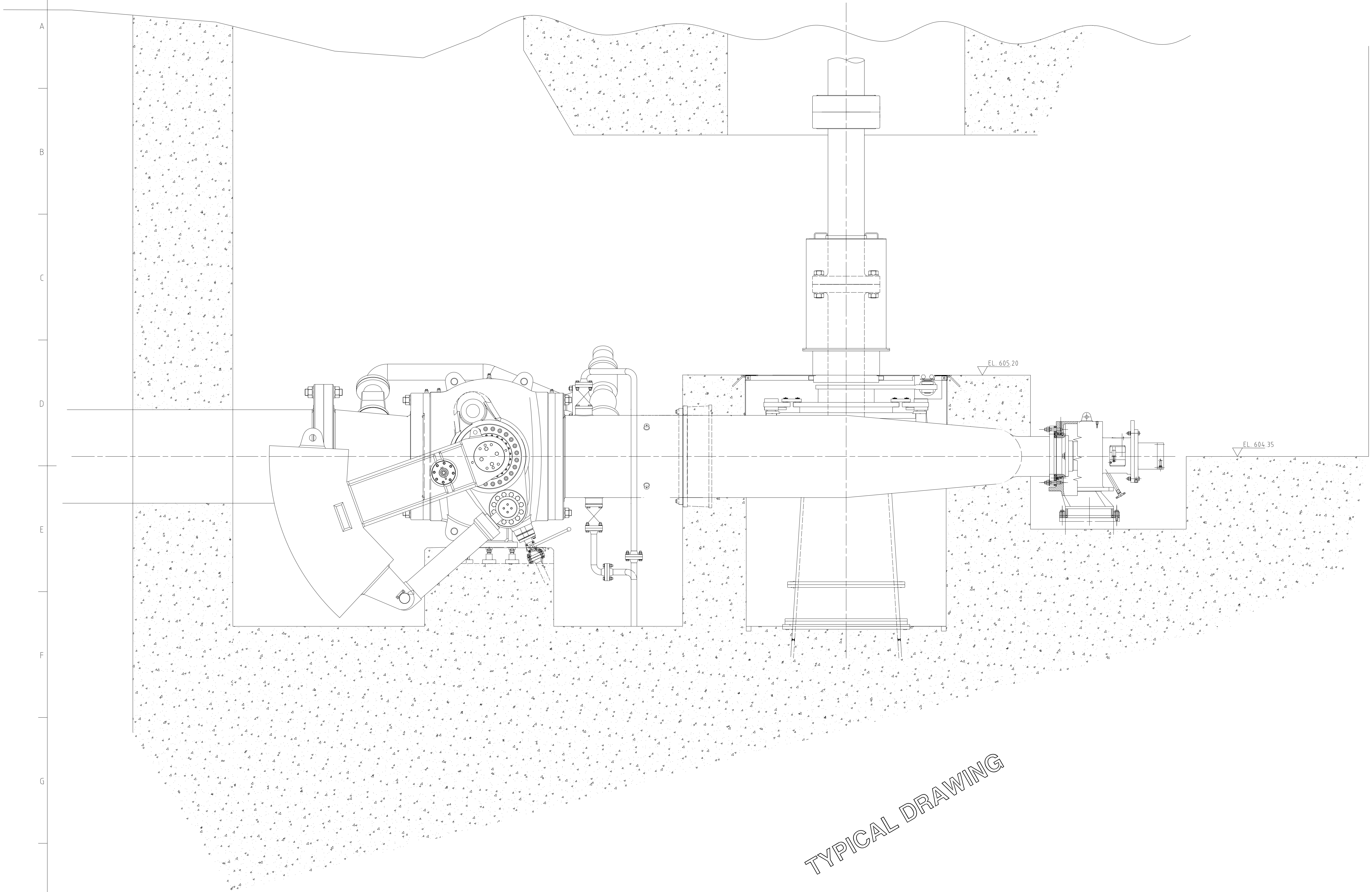
7.4 Preliminary layout drawings

See following pages



TYPICAL DRAWING

All dimensions are preliminary



All dimensions are preliminary

8 TRANSIENT CALCULATIONS

The following was noted:

- The original aim has been to keep the penstock pressure rise within 4% of the maximum static pressure. The values for worst case are close to 4% with the Pressure Relief Valve in operation. However, if the Pressure Relief Valve fails to operate, the value is approximately 7% in the worst case. Considering a reasonable margin, we recommend that the penstocks should be able to withstand 10% higher pressure than maximum static pressure (i.e. maximum 390 mwc). Since this failure case is very unlikely it may be discussed what penstock design safety margins to apply for it.
- The maximum elevation in the surge basin is 946.7 msl in the worst case. This value agrees well with the study made by Ingg. Gellera e Pfetsch in 1974. This water level is only 0.3 m below the surge tank upper edge. Since the real water level depends on the estimated waterway headlosses, we recommend verifying the actual water level upswing at the site. We also recommend implementing restrictions on restart of the units after load rejection to avoid amplification of the surge basin swing.

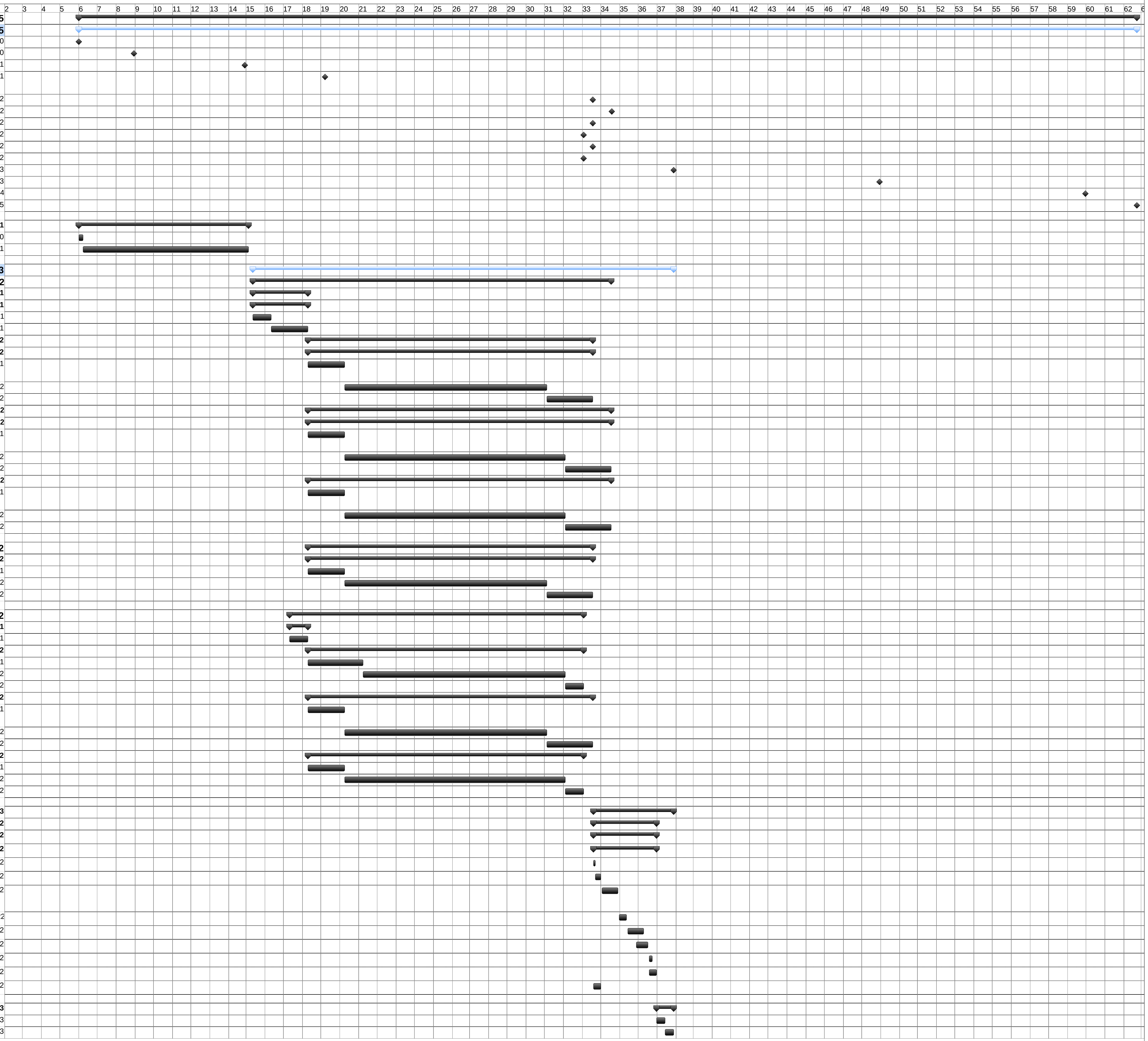
9 PRELIMINARY TIME SCHEDULE – MANUFACTURING AND INSTALLATION

This chapter contains an estimated time schedule for the supply and installation of new equipment.

The schedule only indicates the detailed supply and installation schedule of the first unit. It is assumed that the remaining two units will be installed with one year in between.

Proposal Time Schedule for Main Components and Installation - Vertical Francis Turbines

ID	Task Name	Duration	Start	Finish
1	**Piottino - Project Schedule**	**1235 d**	**on 01.06.20**	**Fri 21.02.25**
2	**Milestones**	**1235 d**	**on 01.06.20**	**Fri 21.02.25**
3	1. Contract date	0 d	Mon 01.06.20	Mon 01.06.20
4	2. Delivery documentation	0 d	Sun 30.08.20	Sun 30.08.20
5	3. Model test completed	0 d	Sat 27.02.21	Sat 27.02.21
6	4. Main PO's issued (draft tube, spiral casing, Guide Apparatus, OPS, MIV, etc.)	0 d	Wed 07.07.21	Wed 07.07.21
7	5. Delivery of Spiral Casing (U1)	0 d	Sun 18.09.22	Sun 18.09.22
8	6. Delivery of Guide Apparatus and the rest of turbine parts (U1)	0 d	Tue 18.10.22	Tue 18.10.22
9	7. Delivery of MIV (U1)	0 d	Sun 18.09.22	Sun 18.09.22
10	8. Delivery of Turbine Governor (U1)	0 d	Sat 03.09.22	Sat 03.09.22
11	9. Delivery of Pressure Relief Valve (U1)	0 d	Sun 18.09.22	Sun 18.09.22
12	10. Delivery of Valves in Valve Chamber	0 d	Sat 03.09.22	Sat 03.09.22
13	11. End of commissioning Unit 1	0 d	Fri 27.01.23	Fri 27.01.23
14	12. End of commissioning Unit 2	0 d	Fri 29.12.23	Fri 29.12.23
15	13. End of commissioning Unit 3	0 d	Fri 29.11.24	Fri 29.11.24
16	14. As-built ad quality documentation	0 d	Fri 21.02.25	Fri 21.02.25
17				
18	**Model Test**	**199 d**	**Mon 01.06.20**	**Fri 05.03.21**
19	Hydraulic Design and Engineering	1 ew	Mon 01.06.20	Mon 08.06.20
20	Production of parts and test	9 emo	Mon 08.06.20	Fri 05.03.21
21				
22	**Engineering, Manufacturing and Transport**	**491 d**	**Fri 12.03.21**	**Fri 27.01.23**
23	**Turbine**	**417 d**	**Fri 12.03.21**	**Tue 18.10.22**
24	**Hydraulic Design**	**64 d**	**Fri 12.03.21**	**Thu 10.06.21**
25	**Turbine Hydraulic Design and Conseptual design**	**64 d**	**Fri 12.03.21**	**Thu 10.06.21**
26	Hydraulic Design	1 emo	Fri 12.03.21	Sun 11.04.21
27	Conseptual Mech. design	2 emo	Sun 11.04.21	Thu 10.06.21
28	**Turbine Embedded Parts**	**332 d**	**Thu 10.06.21**	**Sun 18.09.22**
29	**Spiral Casing**	**332 d**	**Thu 10.06.21**	**Sun 18.09.22**
30	Spiral Casing - Engineering and Review of Drawings, Procurement	2 emo	Thu 10.06.21	Mon 09.08.21
31	Spiral Casing - Manufacturing and FAT	11 emo	Mon 09.08.21	Tue 05.07.22
32	Spiral Casing - Transportation (U1)	2,5 emo	Tue 05.07.22	Sun 18.09.22
33	**Guide Apparatus**	**353 d**	**Thu 10.06.21**	**Tue 18.10.22**
34	**Guide Apparatus**	**353 d**	**Thu 10.06.21**	**Tue 18.10.22**
35	Guide Apparatus - Engineering and Review of Drawings, Procurement	2 emo	Thu 10.06.21	Mon 09.08.21
36	Guide Apparatus - Manufacturing and FAT	12 emo	Mon 09.08.21	Thu 04.08.22
37	Guide Apparatus - Transportation (U1)	2,5 emo	Thu 04.08.22	Tue 18.10.22
38	**The rest of turbine parts**	**353 d**	**Thu 10.06.21**	**Tue 18.10.22**
39	The rest of turbine parts - Engineering and Review of Drawings, Procurement	2 emo	Thu 10.06.21	Mon 09.08.21
40	The rest of turbine parts - Manufacturing and FAT	12 emo	Mon 09.08.21	Thu 04.08.22
41	The rest of turbine parts - Transportation (U1)	2,5 emo	Thu 04.08.22	Tue 18.10.22
42				
43	**MIV**	**332 d**	**hu 10.06.21**	**un 18.09.22**
44	**MIV**	**332 d**	**Thu 10.06.21**	**Sun 18.09.22**
45	MIV - Engineering and Spesifications for Procurement	2 emo	Thu 10.06.21	Mon 09.08.21
46	MIV - Manufacturing and FAT	11 emo	Mon 09.08.21	Tue 05.07.22
47	MIV - Transportation (U1)	2,5 emo	Tue 05.07.22	Sun 18.09.22
48				
49	**Turbine Governor**	**344 d**	**ue 11.05.21**	**Sat 03.09.22**
50	**Interface and General Engineering**	**22 d**	**Tue 11.05.21**	**Thu 10.06.21**
51	Turbine Governor - Interface Engineering (Lay-out, I/O lists etc)	1 emo	Tue 11.05.21	Thu 10.06.21
52	**Turbine Governor**	**322 d**	**Thu 10.06.21**	**Sat 03.09.22**
53	Turbine Governor - Engineering and Spesifications for Procurer	3 emo	Thu 10.06.21	Wed 08.09.21
54	Turbine Governor - Manufacturing and FAT	11 emo	Wed 08.09.21	Thu 04.08.22
55	Turbine Governor - Transportation (U1)	1 emo	Thu 04.08.22	Sat 03.09.22
56	**Pressure Relief Valve**	**332 d**	**Thu 10.06.21**	**Sun 18.09.22**
57	Pressure Relief Valve - Engineering and Spesifications for Procurement	2 emo	Thu 10.06.21	Mon 09.08.21
58	Pressure Relief Valve - Manufacturing and FAT	11 emo	Mon 09.08.21	Tue 05.07.22
59	Pressure Relief Valve - Transportation	2,5 emo	Tue 05.07.22	Sun 18.09.22
60	**Valve Chamber**	**322 d**	**Thu 10.06.21**	**Sat 03.09.22**
61	Valves in Valve Chamber - Engineering and Spesifications for Pro	2 emo	Thu 10.06.21	Mon 09.08.21
62	Valves in Valve Chamber - Manufacturing and FAT	12 emo	Mon 09.08.21	Thu 04.08.22
63	Valves in Valve Chamber - Transportation	1 emo	Thu 04.08.22	Sat 03.09.22
64				
65	**Supervision and commissioning**	**95 d**	**Mon 19.09.22**	**Fri 27.01.23**
66	**Supervision**	**75 d**	**Mon 19.09.22**	**Fri 30.12.22**
67	**Installation before embedment of spiral casing**	**75 d**	**Mon 19.09.22**	**Fri 30.12.22**
68	**Turbine U1: Intallation before embedment**	**75 d**	**Mon 19.09.22**	**Fri 30.12.22**
69	Weld new flange on draft tube	3 d	Mon 19.09.22	Wed 21.09.22
70	Installation of spiral casing MIV, and expansion joint	7 d	Thu 22.09.22	Fri 30.09.22
71	Embedment og spiral casing (Customer responsibility)	20 d	Mon 03.10.22	Fri 28.10.22
72	Intallation of turbine before generator assembly	10 d	Mon 31.10.22	Fri 11.11.22
73	Generator Installation	20 d	Mon 14.11.22	Fri 09.12.22
74	Final assembly	15 d	Mon 28.11.22	Fri 16.12.22
75	Assembly safety valve	5 d	Mon 19.12.22	Fri 23.12.22
76	Complete assembly GOPS w/piping (U1)	10 d	Mon 19.12.22	Fri 30.12.22
77	Installation of valves in Valve Chamberwith operation sys	10 d	Mon 19.09.22	Fri 30.09.22
78				
79	**Commissioning**	**20 d**	**Fri 30.12.22**	**Fri 27.01.23**
80	Turbine Dry Test	2 ew	Fri 30.12.22	Fri 13.01.23
81	Turbine Wet Test U1	2 ew	Fri 13.01.23	Fri 27.01.23



10 RECOMMENDED ADDITIONAL WORK

10.1 Site tests

- It is recommended that a thermodynamic efficiency test should be made on the existing equipment to establish detailed conditions for upgrading and to have a baseline to compare the actual upgrading result against. At the time of writing a thermodynamic efficiency test of unit 3 is being prepared.
- It is recommended that the exact design pressure of the penstocks is verified, since the calculated pressure rise exceeds the current estimates of the penstock design pressure. See also chapter 8.
- It is recommended that the actual water level upswing at the site is verified, see chapter 8.

11 APPENDIX 1. RECOMMENDATIONS FOR PARTICLE ABRASION PROTECTION

The existing units are subject to abrasion from solid particles in the water and are overhauled regularly. In order to increase the time between overhauls certain technical measures can be considered. The recommendations in this appendix are to large extent based on IEC standard 62364 and adapted to the conditions for Piottino turbines.

It should be noted that the performance and price estimates earlier in the report consider a turbine supplied without implementation of the recommendations in this appendix.

11.1 Option 1. Thicker runner blades

Design the runner with thicker blades in order to have some wear margin before the blades become too thin for structural reasons. The thickness should be increased towards the outlet edge and around twice more at the band compared to the hub.
Benefits:

- Longer time between overhaul of the runner.

Drawbacks:

- Slightly higher cost of the runner due to more blade material and larger weld volumes
- Lower efficiency due to thicker blade. For example an additional blade thickness of 5 mm would reduce the efficiency by 0.1 - 0.2 %.
- The risk of cavitation on the runner band, downstream of the blades (so called “mouse-ear” cavitation) would increase due to thicker blades

11.2 Option 2. Guide vane sand seals

Guide vane sand seals that protect the guide vane stem by sealing towards the end face of the guide vane. Please see figure A1.

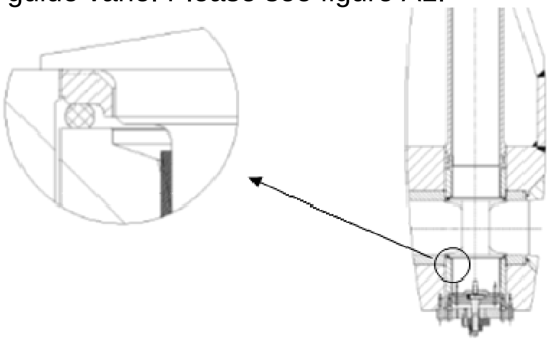


Figure A1. Sand seal that seals towards guide vane end face.

This type of guide vane sand seal has negligible impact on both price and performance, if the covers and guide vanes are manufactured new anyway.

11.3 Option 3. Guide vane end seals

Guide vane end seals are located in grooves in the end faces of the guide vanes and seal against the facing plates of the head and bottom covers. They reduce the crossflow over the guide vane ends, which in turn reduces abrasion on the guide vane ends and facing plates. In addition to have a beneficial effect on the abrasion, guide vane end seals are also beneficial for the turbine efficiency. Estimates of price earlier in this report suppose that guide vane end seals are used when new guide vanes are included.

11.4 Option 4

Facing plates, fastened from the dry side, outside the covers. Please see figure A2

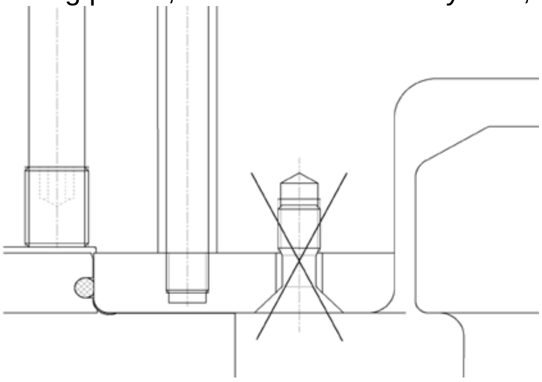


Figure A2. Facing plate, fastened from outside the cover.

Benefits:

- Less wear on the facing plate due decreased turbulence from uneven surface
- Easier coating of facing plates with hardface coating
- Easier dismantling of worn facing plates and reassembly of new facing plates from / to the covers

Drawbacks:

- Small additional cost since the stainless steel facing plates must be thick enough for screw threads.

The price estimates earlier in this report suppose that facing plates, fastened from the dry side, are included

11.5 Option 5

Design for easy removal of the unit. The main purpose of this option is to reduce the outage time for removal and reinstallation of components. The proposed new unit layout will result in easier assembly and disassembly.

A further reduction in outage time can be achieved by disassembly and reassembly of the covers, guide vanes, guide vane mechanism and runner outside of the turbine pit.
Benefits:

- Short outage time
- Much of the installation and adjustments can be performed while the unit is still in operation

Drawbacks:

- Complete set of spare parts (covers, guide vanes, guide vane mechanism and runner) is required.
- Additional installation tools are required
- Proper space for assembly of a unit outside of the turbine is required.

11.6 Option 6

Hardface coating with tungsten carbide thermal spray HVOF on selected components. Tungsten carbide is a very hard material that can withstand abrasion much better than stainless steel.

The following components can be protected with hard face coatings:

- Labyrinth seals, both rotating and fixed
- Guide vanes
- Facing plates

It is also possible to coat certain areas of the waterway inside the runner with hardface coating. However, the most critical portion of the runner (the outlet edge towards the runner band) is not accessible for hardface coating. Coating of the runner inside the waterway, therefore gives limited benefit.

Benefits:

- Longer time between overhaul. It is reasonable to expect that the components, except runner, can have 2 - 3 times longer time between overhaul with hardface coating than without.
- The efficiency of the turbine will be maintained over a longer period of time. Worn labyrinth seals, guide vanes and facing plates represent a substantial efficiency loss that will be avoided if the components are coated.

Drawbacks:

- HVOF coating is expensive. As an order of magnitude, the price of the turbine equipment may increase by CHF 150,000 with HVOF coating applied (total for three units).
- The coating has a certain roughness and tolerance of the thickness. These will combine to reduce the initial efficiency of the turbine. Depending on the extent of the coating, this may reduce the efficiency by 0.2 - 0.5%. However, as the abrasion progresses the efficiency of an uncoated turbine will decrease, while the coated turbine will maintain close to its original efficiency during the entire overhaul interval.