Hongrin-Léman pumped-storage plant, Veytaux II powerhouse: Engineering, erection and commissioning of a new generation of multistage storage pumps

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Abstract

In order to double the total installed capacity of the Veytaux pumped storage power plant, the existing plant, put into operation in 1970, will be enhanced by two ternary sets. Both plants are owned by the Swiss-located FMHL (Forces Motrices Hongrin–Léman SA) belonging to Romande Energie SA, Alpiq Suisse SA, Groupe E and the city of Lausanne. The FMHL representative is Alpiq Suisse SA and the operator is Hydro Exploitation SA. Each set, rated at 120 MW, consists of a five-stage storage pump coupled to a motor/generator with a gear coupler and a Pelton turbine. The lower reservoir is the "Lac Léman" - the "Lac de l'Hongrin" will be used as upper reservoir for both power stations.

In early 2011, Voith Hydro GmbH & Co. KG in Heidenheim was awarded the contract for the two five-stage storage pumps. The model acceptance test was conducted in the "Brunnenmühle" hydraulic laboratory of Voith Hydro Holding GmbH & Co. KG and successfully finished at the end of 2011.

Hydropower multistage pumps are a solution for high head storage projects. These types of projects are rare worldwide, with only a few installations per decade. As such, experience in execution, a set of references, and operational behaviour are required. In addition, hydraulic model tests of such multistage pumps are necessary to generate the optimum hydro-mechanical design.

Several challenging design methods and solutions are required in order to guarantee and achieve the highest performance values. Tight tolerances and complex seal arrangements were designed in order to reduce leakage flows and therefore minimize additional losses. The combination of a long pump (due to its five stages) with small runner clearances was demanding for the dynamic shaft line behaviour. A newly developed design solution needed to be chosen. State-of-the-art tools and methods — commercially available as well as developed in-house — were applied in respect to all necessary engineering calculations.

Following the current industrial standard, a global sourcing concept was managed by a project team consisting of Project Management, Engineers, Sourcing, Quality Experts, and various other Subject Matter Experts. Components were simultaneously engineered and ordered and shipped to site; however, stationary and rotating parts were assembled in the workshop to verify dimensions and ensure adequate fit before these pieces continued onto the power plant. Pressure tests for the housing, spiral case, deflectors, and covers were performed to 175 bars in Voith's workshop in Germany.

Logistical challenges had to be overcome when shipping the parts to site. Pre-assembly at Voith's workshop laid the basis for a flawless execution by the erection team. Precise planning of work in the powerhouse as well as consistent project management for all involved led to a collaborative situation at site.

The units are scheduled to be commissioned and field tested within 2016.

This paper describes the highlights of the process of mechanical engineering, manufacturing, logistics, erection, and commissioning of multistage pumps.

1. Introduction

The decision to build a five-stage pump was made because the new power plant FMHL+ -in a newly bored cavern- reused the existing penstock of Veytaux 1, resulting in a design with strong requirements for the maximum transient pressure in the penstock. The correct specific speed, as determined through a combination of rotational speed and number of stages (i.e. delivery head per runner stage), must be selected in order to ensure cavitation-free operation in the first runner stage. Typical trend curves were utilized to forecast the required counter pressure (sigma value) in order to operate without any issues. Model testing is typically performed to provide visual verification of cavitation performance for these types of large pumps. Such model tests, including a customer acceptance test, had been performed in the Voith laboratory in Heidenheim / Germany [1].

This design is more demanding to shaft dynamics when compared to, for example, a three-stage pump (like the Voith-built Kops II). In addition, a high efficiency level and very small labyrinth clearances required a new design for impeller pretension and high-precision machining of parts that weigh up to 100 tons.

2. Shaft Dynamics

The five-stage configuration of the pump required a guide bearing distance of approximately 8,800 mm. The shaft outside diameter of 700 mm was defined by the impeller inlet diameter. These geometrical boundary conditions and the runaway speed (in reverse rotation) of 664 rpm led to a critical bending speed with inadequate safety margin. Because of this margin, the stiffening effect of the impellers in the shaft line calculation was considered. An ANSYS simulation showed that the combination of the impellers and spacer led to an increase of approximately 10% of the effective shaft diameter in both bending and torsional stiffness.

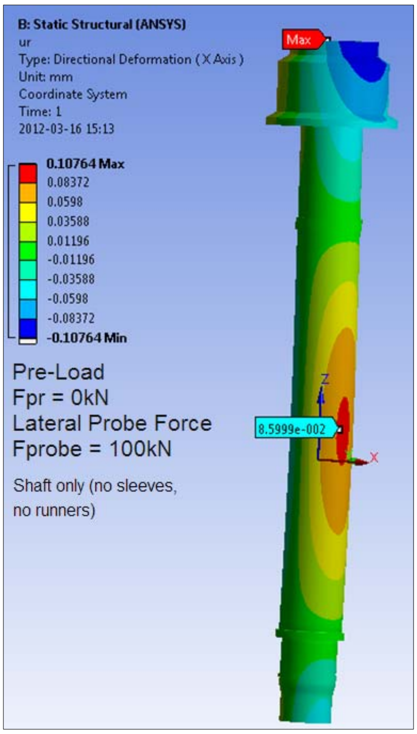

Figure 1: Lateral Probe Force - Preload 3300 kN, No Axial Preload Considered

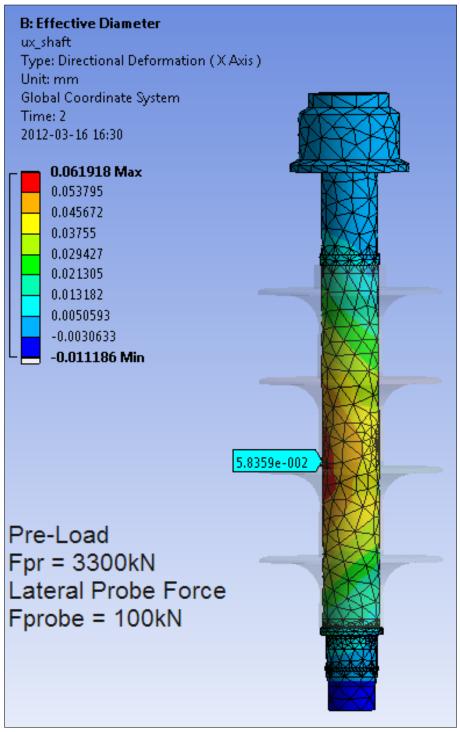

Figure 2: Lateral Probe Force - Preload 3300 kN, Axial Preload Considered

The modification of the effective diameters sufficiently increased the safety margin of the critical speeds. However, this effect can only be considered as long as the axial preload is high enough to ensure a gapless arrangement of the impellers and sleeves under any operating conditions.

The typical industrial standard of pre-tensioning through hydraulic jacks and heating the shaft was too imprecise to obtain a reliable preload of the rotor. Therefore, during the workshop erection of the rotor, an integrated device consisting of piston, cylinder and a spacer ring that was adapted for pre-tensioning was designed (Figure 3).

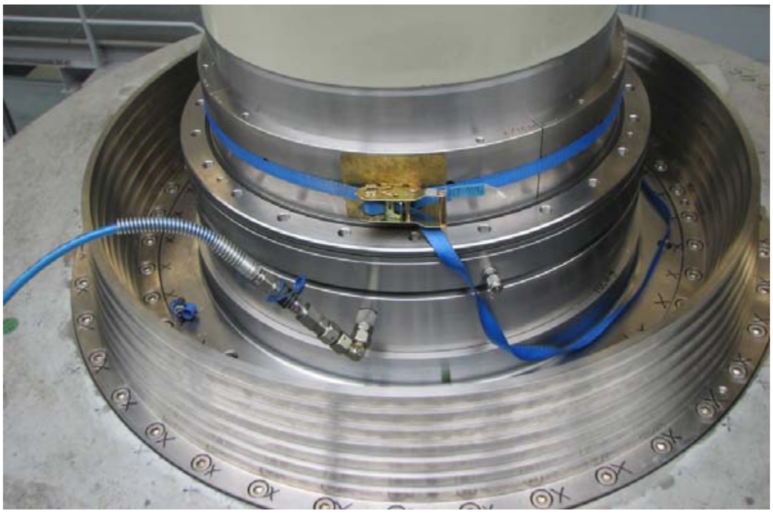

Figure 3: Hydraulic Pre-tensioning of the Rotor in the Workshop

3. Compensation Pipe

It is necessary to be able to move the pump to a central pit in order to maintain the ternary set pump without having to dismantle the turbine and generator that are situated above it. Consequently, the pump itself cannot be embedded. For a non-embedded unit, the hydraulic force at the spiral case's outlet is transmitted via the relatively small casing supports, which in turn cause very high compressive loads on the civil works when compared to the conventional pump-turbine transmission to the civil works via the anchor plates.

Traditionally, the elongation of the penstock (mostly from temperature expansion) is eliminated by a sliding joint, which also generates tremendous foundation loads. To avoid such loads in this kind of application, Voith used its standard device, the "Force Compensation Joint" (Figure 4). Two opposed rings are placed on the outlet pipe; one is fixed to the spiral case and another to the pipe. They built a chamber that has the same surface as the inside of the pipe and that is flooded through holes in the pipe. Since the two chambers have the same surface area and the same pressure, they eliminate the hydraulic force at any pressure and thus avoid a remarkable hydraulic force on the foundations and the pump casing. Yet, thermal expansion of the pipe can occur free of resistance and without generating constraining forces within the arrangement. In this way, undesirable asymmetrical distortions are eliminated, keeping the pump aligned to the turbine and making the behavior of the arrangement more predictable.

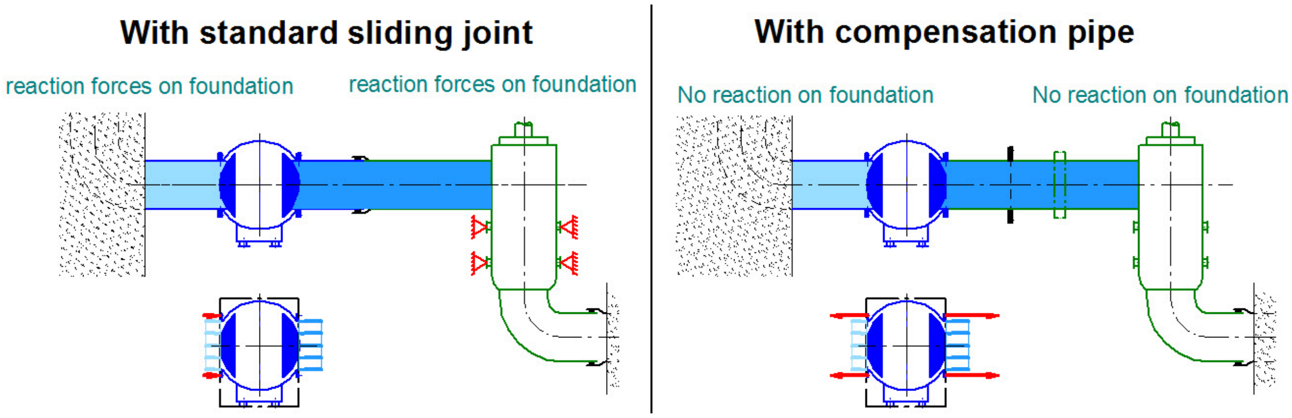

Figure 4: Reaction Forces from Sliding Joint and Compensation Pipe

4. Mechanical Coupler

A hydraulic torque converter with a no-slip gear coupling can be used in ternary units (for example KopsII) that have a demand for high flexibility in operation. The hydraulic torque converter has adjustable vanes to allow its use for starting and stopping of a water-filled storage pump. For startup, the hydraulic torque converter is filled with water that can then be emptied dynamically after synchronization and gear coupling engagement and then it rotates in air.

Its variable speed and dynamic water fill feature allows for transmission of initially high acceleration torque, allowing for fast startup of the pump without sudden load surges to the grid. As the hydraulic torque converter is a variable speed device, the water-filled pump starts and rotates to speed, providing load as it starts. Within ten seconds after start of rotation, about 60% of the pump power is already on the grid. The no-slip gear coupling is engaged when the unit is near synchronous speed to maximize efficiency of power transmission during steady state operation of the pump.

The hydraulic torque converter is also used to smoothly decouple/recouple the pump from the rotating system while the turbine is in operation, allowing for transition of the unit from power absorption to power production and back. A schematic of the torque converter is provided in Figure 5. For more information on comparison between various pumped storage concepts and torque converter, please refer to [2] and [3].

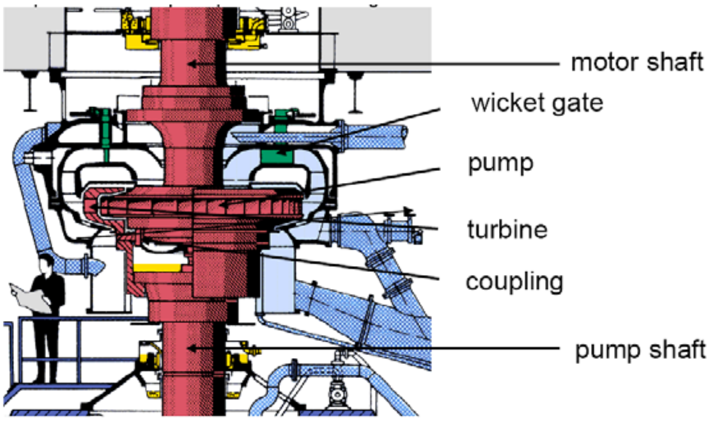

Figure 5: Typical Arrangement of a Hydraulic Torque Converter

In the case of FMHL+, the unit is prepared to be upgraded with a torque converter but it is currently still started in a conventional way (i.e., the turbine ensures the acceleration of the pump). This means that the engaging and disengaging of the coupler can only occur at standstill, which ensures smooth meshing of the gear teeth but there is a chance that the coupling is blocked because the gears become “tooth on tooth” due to the missing slip.

For this situation, Voith developed a feature, similar to a retractable ballpoint pen: a built in linear movement sensor in the actuator detects if the movable spline wheel is stopped in a “tooth on tooth” position and retracts the spline wheel a predefined amount. During this movement, a cylinder mounted on the movable wheel slides along a guide mounted on the pump side toothed wheel and turns the movable wheel out of the “tooth on tooth” position, then the coupling can be engaged.

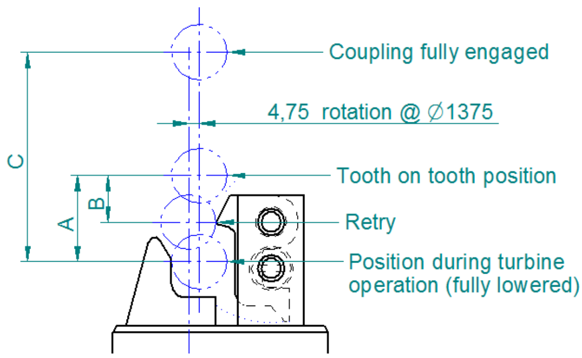

Figure 6: Coupling Synchronisation Device

5. Workshop Assembly and Tests

In order to ensure a smooth and fast assembly at site, the stationary and rotating parts were assembled in the workshop and dimensional controls were conducted on the assemblies.

The rotor, inclusive of the shaft, the five impellers, spacers and thrust head, was assembled in Voith’s workshop in Heidenheim and a runout test was performed with Voith Paper equipment that is typically used to check the runout of the paper rolls. The test confirmed accurate machining with runout of the different impeller wearing rings of maximum 0,11 mm.

Figure 7: Dimensional Check of the Rotor in Voith Paper's Workshop

In order to achieve a perfect fit of the deflectors and wearing rings in the casing, Voith procured the pre-machined parts from high-end suppliers and conducted the final machining in its own workshop. The wearing rings have been final machined while mounted (and pinned) in the respective deflector together with the centering diameter.

During the erection, each stationary wearing ring was measured with a laser tracker since the weight of this assembly (more than 200 tons) made the runout test on a machine impossible. The maximum measured runout was 0,12 mm.

The stationary parts consisting of the casing, the spiral case, the four deflectors, the covers (suction side and pressure side) and the compensation pipe were pressure tested at 175 bars, which corresponds to 1,5 times the zero flow head at 51,5 Hz grid frequency.

The clearances between the deflectors and the casing were monitored during the workshop pressure test to verify the FEA results. The behaviour of the deflectors when lying on the fitting rings of the casing was also observed. The measurements showed a good correlation and symmetrical movement of the deflectors in the casing. This measurement is still in place in the prototype and confirms the stable behaviour of the machine.

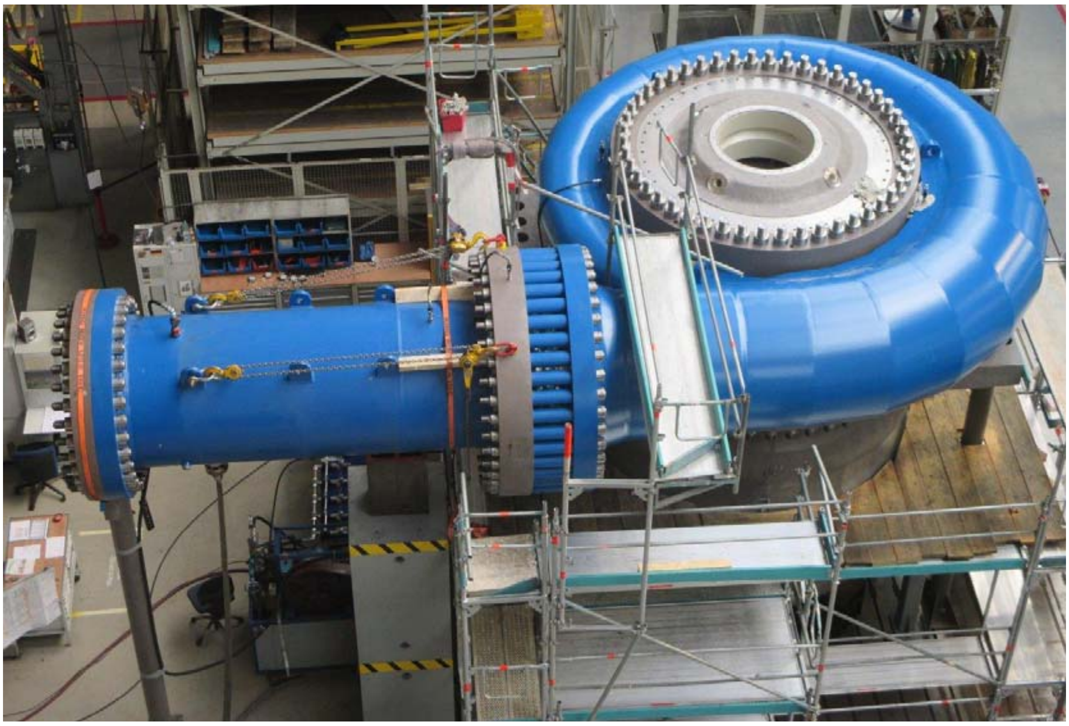

Figure 8: Pressure Test in the Workshop

6. Assembly at Site

The location of the site is in a downtown area with extremely limited storage capacity. The parts were disassembled at the workshop and sent to a warehouse close to the site to ensure a just-in-time delivery method.

Figure 9: Pump Casing (100 tons) Parked in Front of the Site Entrance

Positioning the deflectors in the casing is the most demanding task during on-site assembly. Tight centering of the deflectors is essential to avoid fretting and galling of the labyrinths in operation despite the very small radial gap (smaller than 1 mm). For this, Voith realized a very small play between the casing and the deflectors. Lowering the 30 tons deflector with the exact position and levelling with 40 m of crane cables (due to the ternary unit) required extremely skilled erection personnel.

Figure 10 & Figure 11: Lowering of the Last Deflector

A misalignment between the pump and the turbine was reduced to less than 0,2 mm to lessen bearing forces and vibrations in the coupler. The perfect fit was achieved through hydraulic jacks and the SICLAV checking device of EDF.

7. Commissioning

The commissioning of the first pump of FMHL+ was successful, with the five-stage pump performing as desired.

Additional sensors, such as a temperature sensor in the pressure relief pipe of the pressure side cover, have been added in order to monitor the water temperature in the wearing rings area. As soon as the unit is close to nominal speed, only a small portion of the energy delivered by the turbine is converted in acceleration and the rest is dissipated as vibration, noise, and heat. The measurements showed that the temperature rise is about 35 K per minute. Since the impeller has more filigree extension than the cover, with the built-in stationary labyrinths, it is crucial that the heat does not act too long on the parts; otherwise, an unequal expansion of the parts would result in a reduced gap between the labyrinths, which would increase the risk of seizure. Therefore, the seal of the Pump Discharge Valve (PDV) is opened as soon as the pressure in the spiral case is higher than the pressure in the penstock. This immediately stops further heating and the temperature stabilizes to an acceptable level. After the PDV is open, the water cools to approximately 2 K warmer than the tailrace water and no further temperature rise can be observed, except in long time hydraulic short cut.

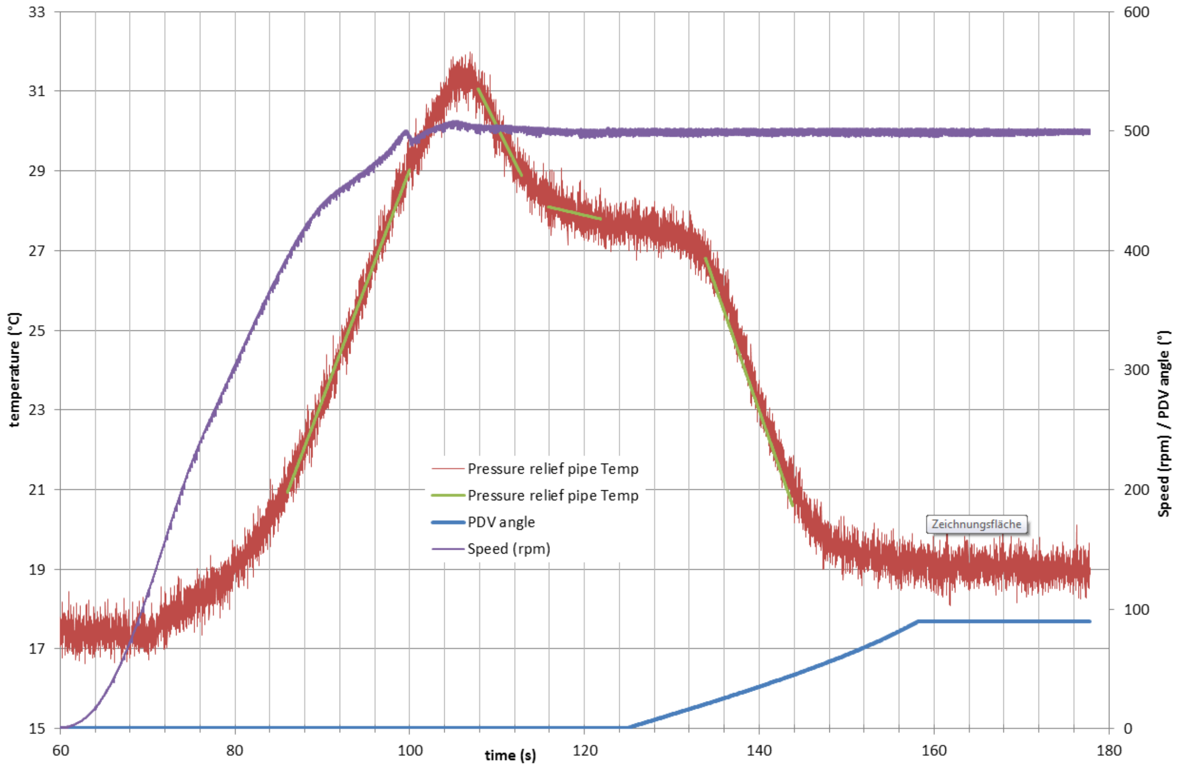

Figure 12: Temperature in the Pressure Relief Pipe During Pump Start

Various tests were conducted during commissioning, even a reverse runaway run: the ternary unit is stabilized in pump mode and tripped by opening the circuit breaker. The consequence in normal operation is the closing of the PDV. For this test, the closing is inhibited and the water column starts to go downwards. This slows the unit down to 0 rpm within 11 sec and then accelerates it to a runaway in reverse sense of rotation (636 rpm) within a further 11 sec.

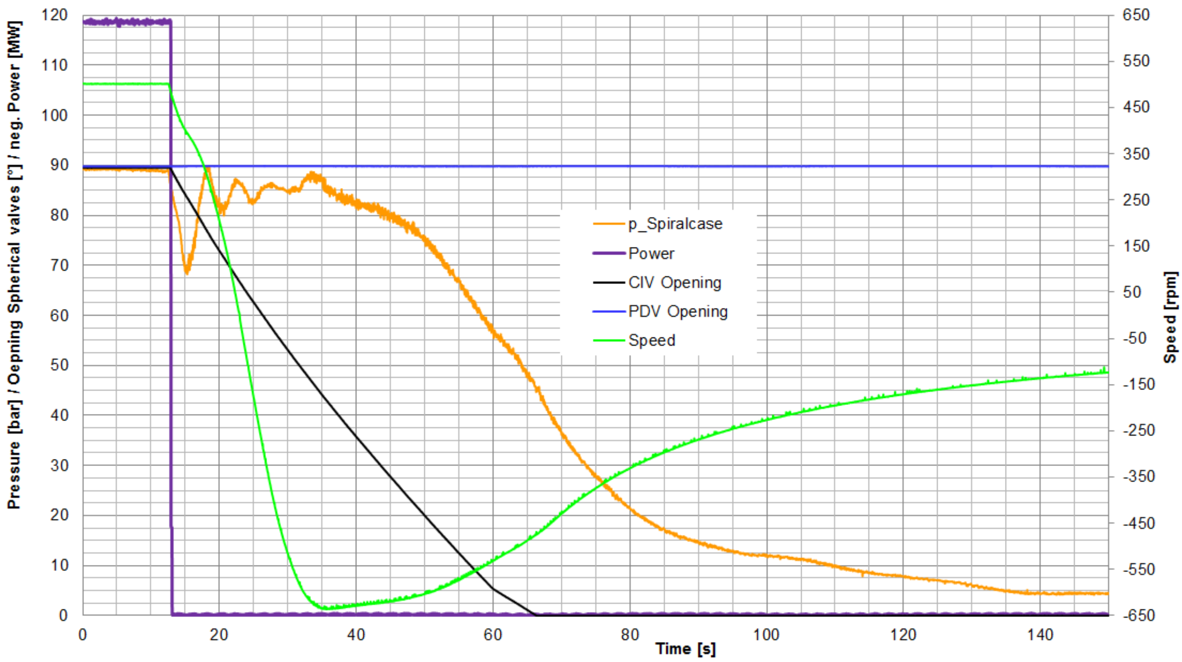

Figure 13: Speed of the Unit and Spiral Case Pressure During Runaway Test

8. Conclusion and Outlook

The commissioning of the first pump of FMHL+ was successful, with the five-stage pump performing as desired, even in reverse runaway at -664 rpm. Special design measures, like the pre-tensioning of the rotor and the compensation pipe, that have been applied showed positive results. The intensive design review process and the precise manufacturing and erection enabled the smooth execution of this unusual project without delay. The tight manufacturing tolerances in the range of IT2 (i.e. 0/+0,1 mm on a diameter of 3200 mm) makes us proud of our “450-ton Swiss watch”.

The efficiency measurements are planned to take place by the end of 2016.

Figure 14: The Five Stage Storage Pump at a Glance

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As lead engineer for mechanical System Engineering he was involved from the first to the final mechanical layout of the multistage pump of FHML.