# Uprating of the Czech Republic's 325 MW Pump Turbine Power station Dlouhé Stráně

Manufacturing the new runner, which was cast in two parts from martensitic stainless steel

With a rated output of 325 MW, Europe's largest pump turbines were installed at Dlouhé Stráně in the Czech Republic in 1996. After almost 20 years of operation the owner and operator decided to uprate the first unit due to the forthcoming lifetime expiration of the runner caused by high dynamic loads due to fast transitions between pumping and generating mode.

**By Michal Feilhauer, Josef Mikulášek, Aleš Skoták, Ladislav Štégner, Miroslav Varner, and Jindřich Veselý**

Pump turbines with the largest unit capacity in Europe at that time were installed at the pumped-storage hydroelectric power plant Dlouhé Stráně in the Czech Republic in 1996. This pumped-storage plant operates at heads ranging from 495 to 554 m with a rated unit pump-turbine output of 325 MW. After almost 20 years of operation, the owner and operator of the pumped-storage plant ČEZ decided upon the uprating of the first unit, TG1.

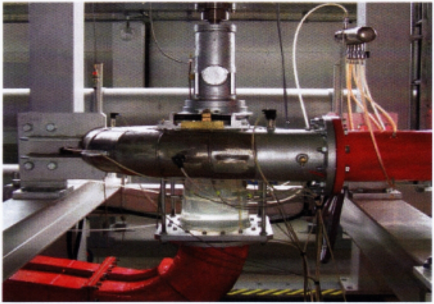
The reason for this decision was a forthcoming lifetime expiration of the runner, caused by high dynamic loads of the pump turbine unit operation due to fast transitions between pumping and generating mode and due to condenser operation in both modes.

In many cases the runners of high-head pump-turbines do not reach the required reliability due to cracks that occur in the runner. This is usually caused by resonant vibration of the runner induced by a hydraulic interference between the runner blades and guide vanes. The common casting and welding defect occurrence reduces the corrosion-fatigue properties of the runner material.

The second reason behind the uprating process was the request for a wider operational range, especially in generating mode and, of course, the improvement of the total efficiency of the pump turbine cycle.

The principle was to complete the uprating with a replacement of the existing runner with a new one. Development of the new runner with expected higher reliability was supported by an effective cooperation among hydraulic and mechanical designers. Besides fulfilling the usual criteria for functional and power parameters it was also necessary to evaluate frequency and mode shapes of the excitation dynamic pressure field, and the affinity with the eigenmodes of the runner, as well as to ensure a high level of corrosion fatigue resistance of the runner.

The main source of excitation in water turbines is RSI (Rotor Stator Interaction).



**Model tests of the new runner design were undertaken in a hydraulic laboratory. The aim of the upgrade was to improve operational reliability of the pumped storage plant.**

RSI generates an unsteady pressure field in the hydraulic machine. Using some analysis and simplifications, these fields can be described as fields with diametrical nodes. The number of the diametrical nodes k is given by a simple criterion $mz_R - nz_S = k$, as derived by several authors years ago. In this formula, the $z_R$ represents number of the runner blades and $z_S$ is the number of guide vanes. The values of m and n are arbitrary integers. As observed from the above criterion, the crucial effect on the excitation frequencies caused by RSI is represented by the number of the blades and the guide vanes. Detailed analyses of the number of runner blades' impact on the rotor vibrations and the pressure pulsations have been taken into consideration. The main evaluated parameters were rotor vibrations, high frequency pressure pulsations and turbine head cover vibration. Analyses of the whole hydraulic system, including penstock, pump turbine, draft tube and discharge tunnel loaded by high frequency pulsation have been carried out. Based on these analyses for the existing 20 guide vanes the number of runner blades was chosen as nine instead of the originally installed seven. The dominant frequency of high pressure pulsation in the rotating system $f_R$ = 142.8 Hz is the same for both the new and the original runner due to the same number of the guide vanes and the same rotational speed. The transversal modes of rotor are excited at very high frequencies $f_T$ = 587.6 Hz. The main consequences are the guide bearing load minimization and minimization of the excitation of the shaft bending modes.

Natural and forced vibrations of the new runner were analyzed by FEM (Finite Element Method) simulations. The model developed for the analysis of runner vibration behavior in water includes the complete rotor structure and the fluid domain with boundaries respecting the geometry of the turbine covers, spiral case and the draft tube. The eigenfrequencies of the runner vibration in the water were analyzed in the range from 0 Hz to 270 Hz. In the area around excitation frequency 142.8 Hz, the nearest affinity natural frequency was evaluated at 158.6 Hz, which was confirmed as being more than sufficient.

**Assembly of the new runner for the pumped-storage hydroelectric power plant Dlouhé Stráne followed a 14-month-long manufacturing process.**

An extensive hydraulic research supported by CFD (Computational Fluid Dynamics) has been realized in order to improve the efficiency level in both the turbine and pump modes. Results of the hydraulic research were confirmed at Litostroj Power - ČKD Blansko Engineering Hydraulic Laboratory in Czech Republic. The model acceptance tests were carried out with the participation of the client representatives. All pump turbine parameters, as e.g. power in pump and turbine mode, efficiency and the cavitation features, have also fulfilled the guarantees and all other tender requirements.

The new hydraulic design allows the extension of an operation range in turbine mode. With the new runner the turbine operation range is from the extremely low value of 5 MW up to the maximum of 328 MW. Basic results of the model test are compared with the original runner solution. The shift of performance Q-H curve corresponds to the expectations of increased power input in pumping mode. The efficiency increase in both modes was confirmed.

The pressure field was evaluated by measurement within the laboratory and by CFD application as well. The tests showed the maximum pulsations were found at the hub and were minimal at the shroud. This fact, among others, confirms that cracks within the pump turbine runners appear at the runner hub more frequently than at the shroud. The results of Fourier transformation confirmed the theoretically evaluated frequencies and the practical value of the pressure pulsation which was used for FEM analyses of the whole pump turbine.

The operation of pumped storage power plant is characterized by frequent starts and shutdowns of the machine in both modes of operation. Even if the runner is designed as resonance free for steady-state operation, a huge variation of the rotational speed during start and shutdown causes some short term resonances. In order to prevent possible cracks in the runner due to transients, the process of runner manufacturing must be very precise.

The fatigue cracks are usually indicated in the connection of the runner blades with the hub or shroud of the runner, i.e. in the areas of the stress concentration. This is exactly the spot, where the welds are located during a standard manufacturing procedure, which decreases significantly the runner reliability.

Requirements for reliability of the runners, new efficient milling machines, efforts to reduce costs and time required for production have led to the formulation of new concepts of runner manufacturing.

In this case the runner is executed as a semi-manufactured hub with parts of the blades and semi-manufactured shroud with the remaining parts of the blades. As can be seen from the image on page 23, these runner parts are welded at the middle of the runner blade height, where there is low stress.

The two runner parts are cast from martensitic stainless steel GX4CrNi13-4 + QT1 produced by the VOD process. The welding is performed by Metal-Arc Active Gas Welding with filler metal Böhler CN 13/4-IG.

After welding and tempering, the runner undergoes NDT tests according to CCH 70-3; indicated size of surface and internal defects are compliant with the level 1 of this standard in the exposed areas of the runner. Runner is statically balanced on the lens with hydrostatic bearing to quality grade G2.5 according to ISO 1940-1.

With knowledge gained from simulations of the runner vibration in the water, critical areas in terms of crack initiation were identified, where careful non-destructive testing during the production process are executed repeatedly. In addition to increasing the runner reliability, the new concept of the runner manufacturing process improved the technical and economic parameters of the production process. This procedure reduces material consumption, shortens production time, reduces number of tempering during welding and thereby reduces the risk of failure, in order to comply with the required mechanical properties of steel.

The entire manufacturing process of the new runner for pumped-storage hydroelectric power plant Dlouhé Stráně was finally completed in 14 months. The workshop refurbishment of the original parts, e.g. lower and upper ring or parts of the axial sealing, took approximately two months. In all, three months were necessary for completion of the task, commencing from existing unit shut down till the installation and commissioning of the new runner. At the end of 2012, the guaranteed parameters measurement was carried out by an independent organization. The measurements confirmed the guaranteed efficiency values as well as the guaranteed operation range in both modes, with a sufficiently low level of vibrations and pressure pulsations. The uprating process was completed within the planned period and the pump turbine has been in operation for two years.

A state-of-the-art review of runner reliability and sophisticated computer simulations - together with the new technology of runner manufacturing - represent essential factors in the development and fabrication of reliabile runners for plants like Dlouhé Stráně. ■

**Michal Feilhauer, Josef Mikulášek, Aleš Skoták, Ladislav Štégner, Miroslav Varner, Jindřich Veselý all work at ČKD Blansko Engineering, a.s., Czech Republic - a member of Litostroj Power Group.**