High Power Francis runner – upgrade with a new design runner

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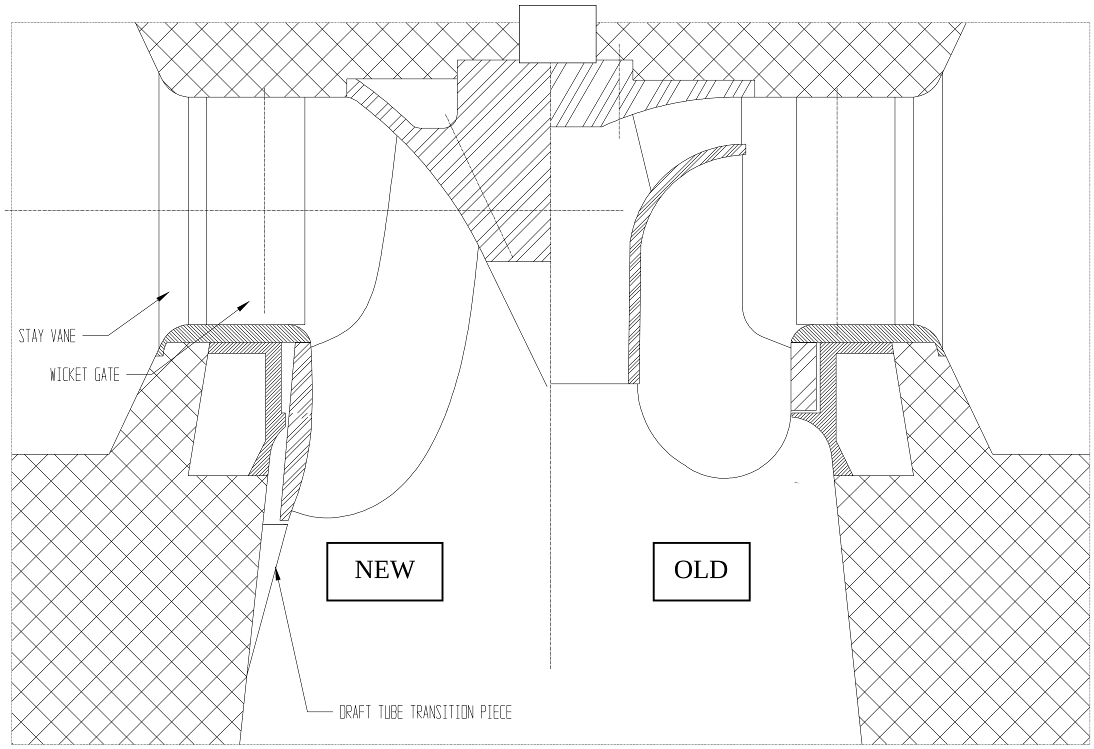
Preamble

New hydropower developments must satisfy environmental requirements, which include the “environmental impact”. This means any influence of a new powerplant with its concrete structure, variations of water levels and the life of species living in the river.

The environmental standards have become “show stoppers” for several potential new hydropower developments. The existing stations, however, are treated as…part of the existing environment. The crisis in the demand for electric power in North America along with the above mentioned environmental constraints, has influenced development of modern hydropower industry for the last several years. The advancement in the design optimisation methods, which happened recently thanks to the Computational Fluid Dynamics (CFD), allowed for another look at the existing hydropower stations from the performance improvement viewpoint. The “sleeping potential” of existing power stations became obvious. Recent history of modern-way refurbishments, shows that newly designed runners installed inside existing turbine structures (spiral casing, stay vanes, wicket gates, draft tube) can improve power output of the plant by 10 to 30%.
This is the economically, environmentally, technically justified alternative for hydropower nowadays.
The paper presents an example of a modern refurbishment, where the runner replacement resulted in 25% maximum power output increase.

Salmon Falls Power Station

The SF power station is equipped with three identical vertical Francis turbines. Semi-spiral case is fed by the large diameter short penstock, distributor has 8 stay vanes and 12 regulated wicket gates, runner is a Leffel “F” type having double cascade of blades (8 and 14). The Leffel "F" model runner was tested at the Holyoke laboratory and later become famous for its high unit power. According to the authors, many attempts to replace the Leffel "F" runner with any of the runners developed later have not been successful in terms of power increase.



DWG 1. Salmon Falls Power Station – runner replacement

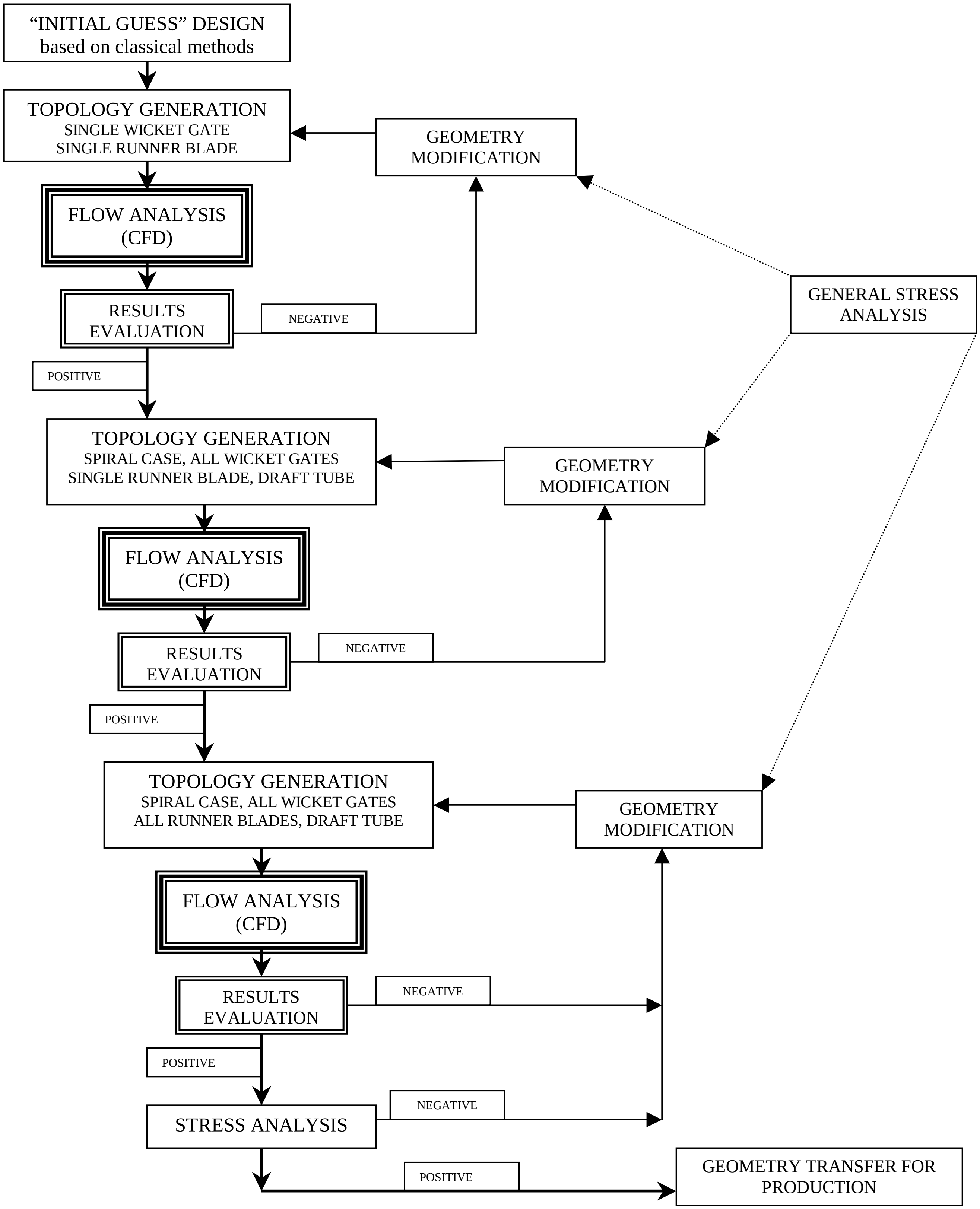
New runner

Approximately 2.5 years ago Norcan Hydraulic Turbine Inc. decided to start their own R&D project, aiming towards development of modern runner designs. This was a necessity: the technologies available at that time were not sufficient for the changing market. A business decision was made by Norcan to commit to the implementation of the Computational Fluid Dynamics to the design practice, which was a necessity if the company was to stay competitive in the upgrade and refurbishment market. After development of the geometry editors and grid topology configuration, the development team was ready to run the virtual hydraulic laboratory.
The NOR_F runner, one of seven recently developed, was designed and optimised based on the viscous flow analysis of the entire turbine (including spiral case, 12 wicket gates, 13 runner blades, draft tube).
Design procedure starts with the "initial guess design" – a blade geometry design based on 2D classical approach. At this stage also final refinement of the topology is conducted. Wicket gate angle is set to the expected peak efficiency position (here 40deg was anticipated). The first run of the flow analysis program allows to draw first conclusions regarding the quality of the initial guess geometry, as well as the adequacy of the nodes distribution. After final refinement of the nodes distribution (at this stage the grid is coarse and for example in the blade-to-blade space it has only 5,000 to 7,000 nodes).

Both, calculated power output of the runner and observation of the flow entering the draft tube, suggest first geometry modifications to undertake. The modification of the blade shape is done on the computer screen by dragging-and-dropping selected control points. Runner blade shape is controlled by positions of 20 control points, and double - stage surface interpolation. The blade thickness is controlled by the thickness distribution functions. The geometry editor updates the database for the CFD program automatically, after the geometry change is completed. During the initial design stages it takes approx. 2 to 3 minutes to perform the shape modification and all files for the CFD solver to restart. Progressing deeper into the design refinement grid density and complexity (mostly due to repeated blocks/grids) of the entire domain becomes higher, as does the time required by the solver to achieve the assumed accuracy. If , during the first stages, following “initial guess design”, solver’s CPU time is 5min to 10 minutes, then the final, most complex problems are solved in 10 to 15h.

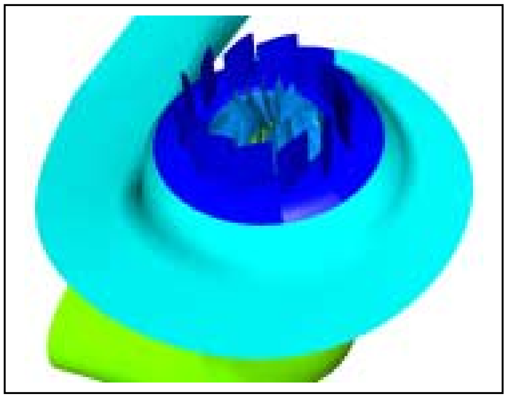
It took approximately 25 modifications (including blade shape and the crown and skirt outlines) to arrive to the satisfactory solution in the presented case.

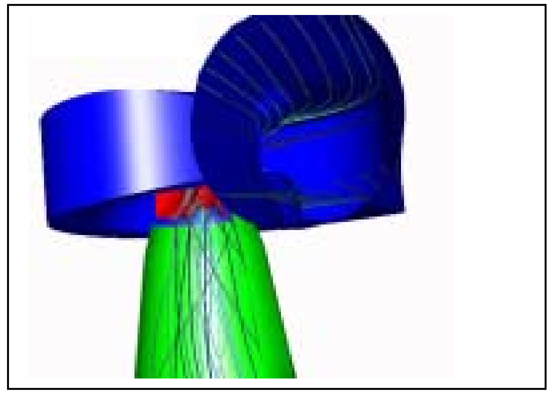
The design procedure is shown on the DWG 2.

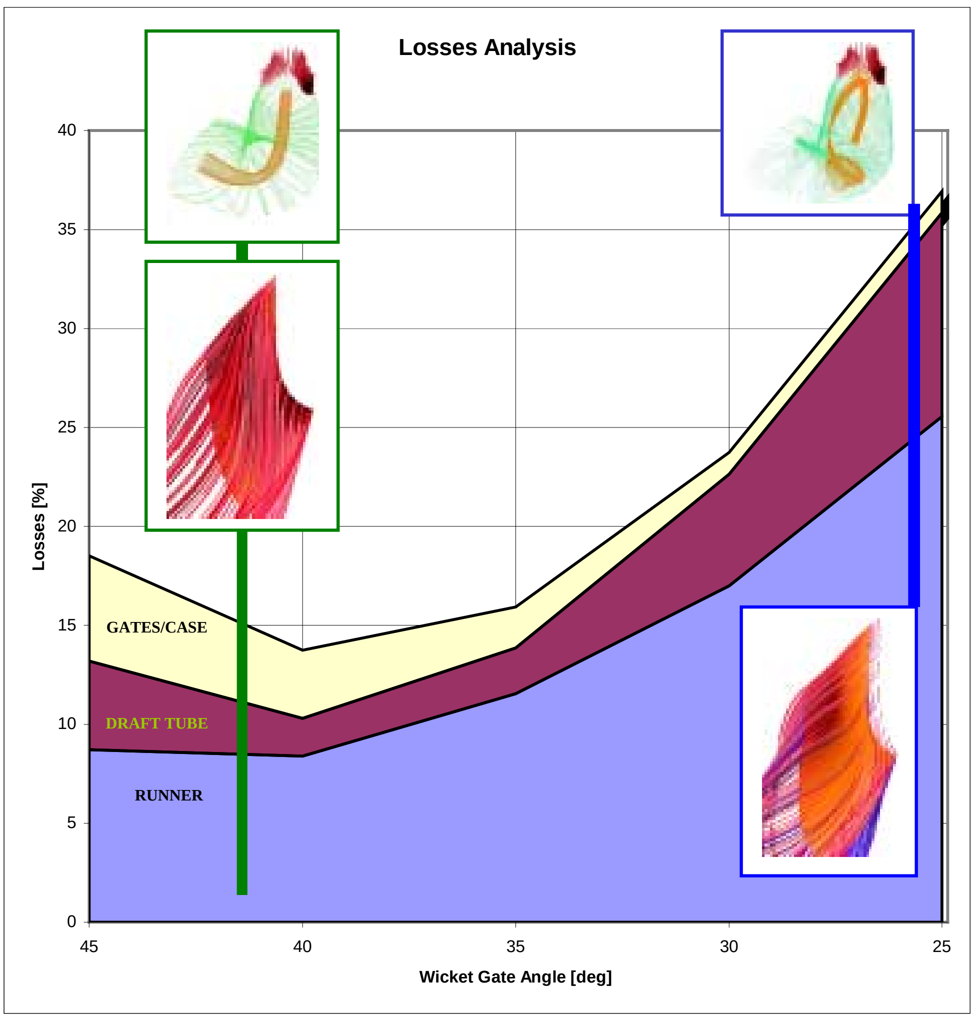


DWG. 2. Runner blade design methodology

Results of the CFD analysis of the final design

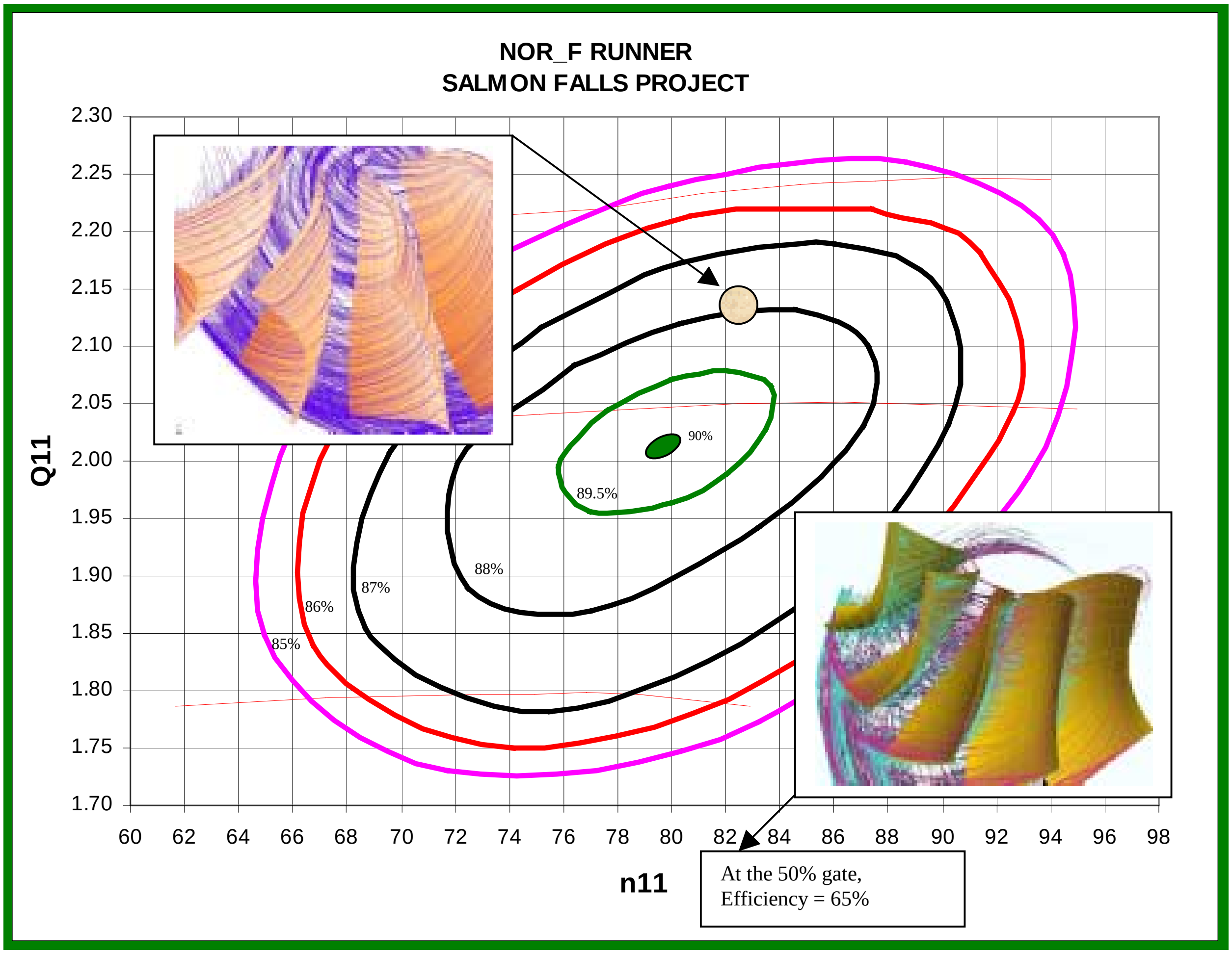






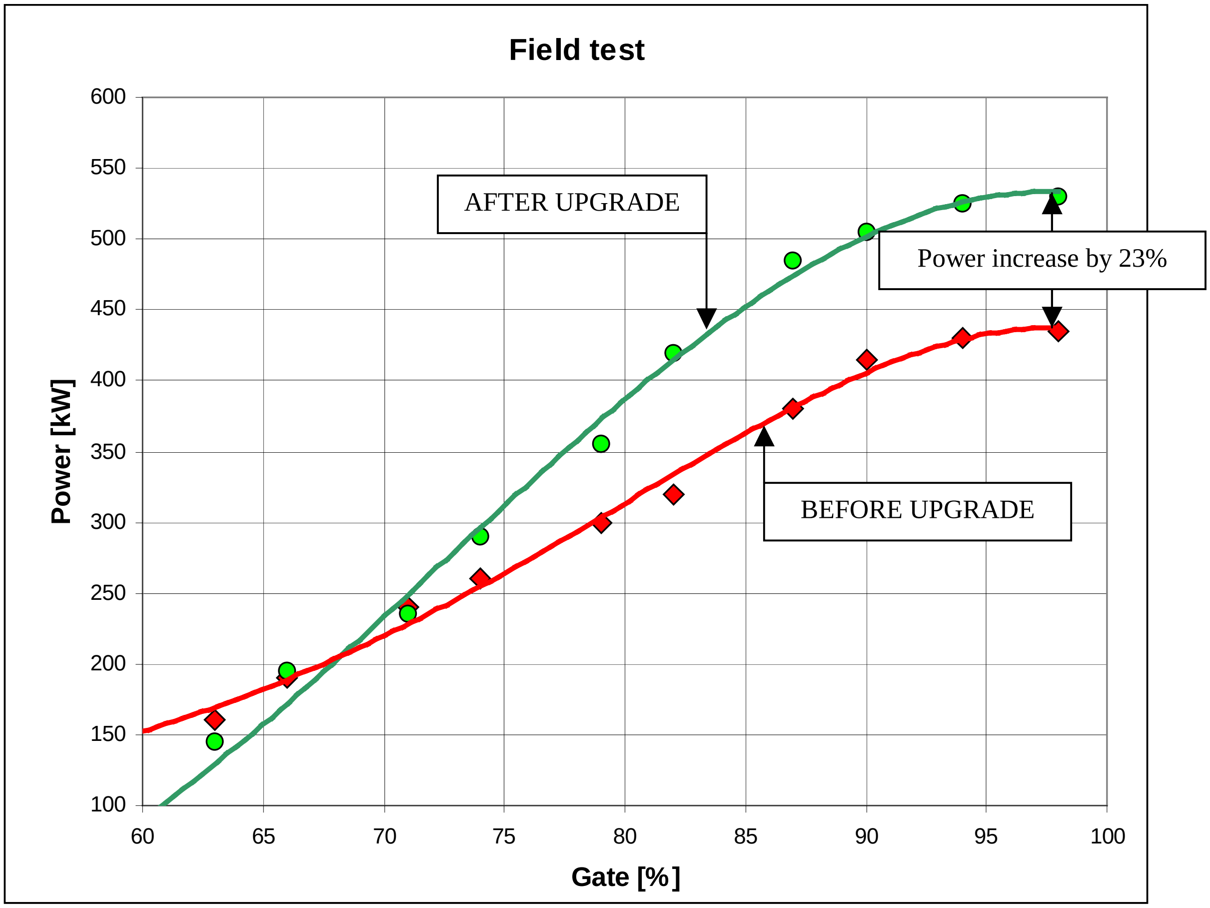
DWG. 3. Losses analysis

The above graph presents results of the CFD analysis for the configuration as shown on the DWG. 3. It is worth noting that the draft tube losses cannot be represented as a function of Q^2. Also the highest hydraulic losses are calculated at the runner area.



DWG. 4. Hill chart predicted by the CFD

Hill Chart predicted theoretically. At the area of high Q11 values, lowest pressure point of the entire turbine has been moving away from the runner blade surface. After tracing the travel of the particles passing through the lowest pressure point, it was concluded that should the cavitation bubbles be created, they must collapse away from the turbine walls.



DWG. 5. Comparison of the turbine performances with old and new runner

The presented above field test, was conducted by the owner of the station in January/2000. Performances of the new unit are compared to the performances of the unit identical to the one upgraded.