Hydraulic Design of the Horizontal Double Runner Variable Speed Pump-turbine for Reißeck II Plus Pumped Storage

Presented by:
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Praktikerkonferenz Wassekraft – Graz 2021

Basic Project Data

CLIENT: Verbund Hydro Power GmbH
Europaplatz 2
A-1150 Vienna
Austria

Supplier:
Litostroj Power d.o.o.

Subcontractor: Litostroj Engineering – hydraulic development, model test

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Kraftwerk R2plus, above Kolbnitz, Carynthia, Austria

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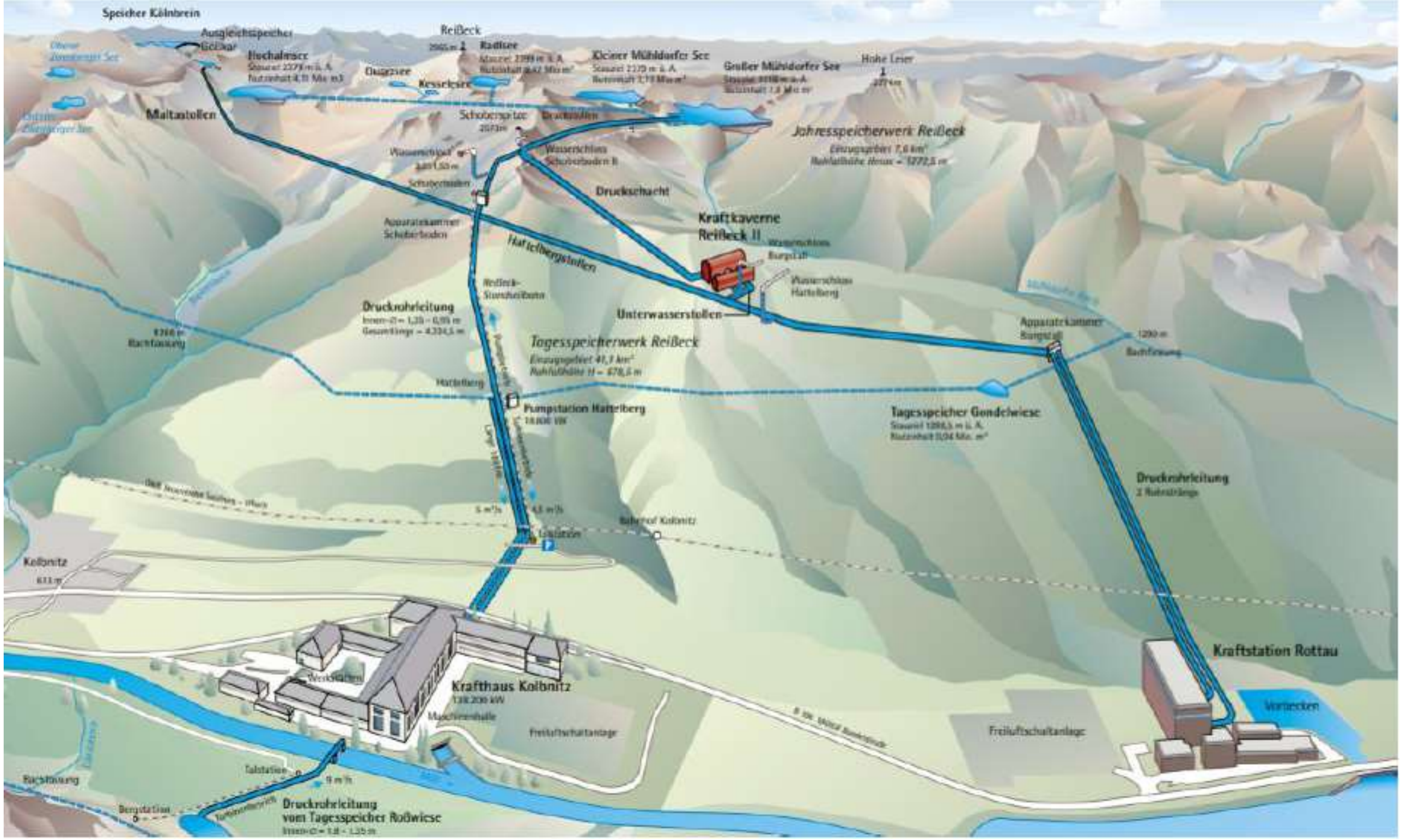

Kraftwerksgruppe
Reißeck-Kreuzeck

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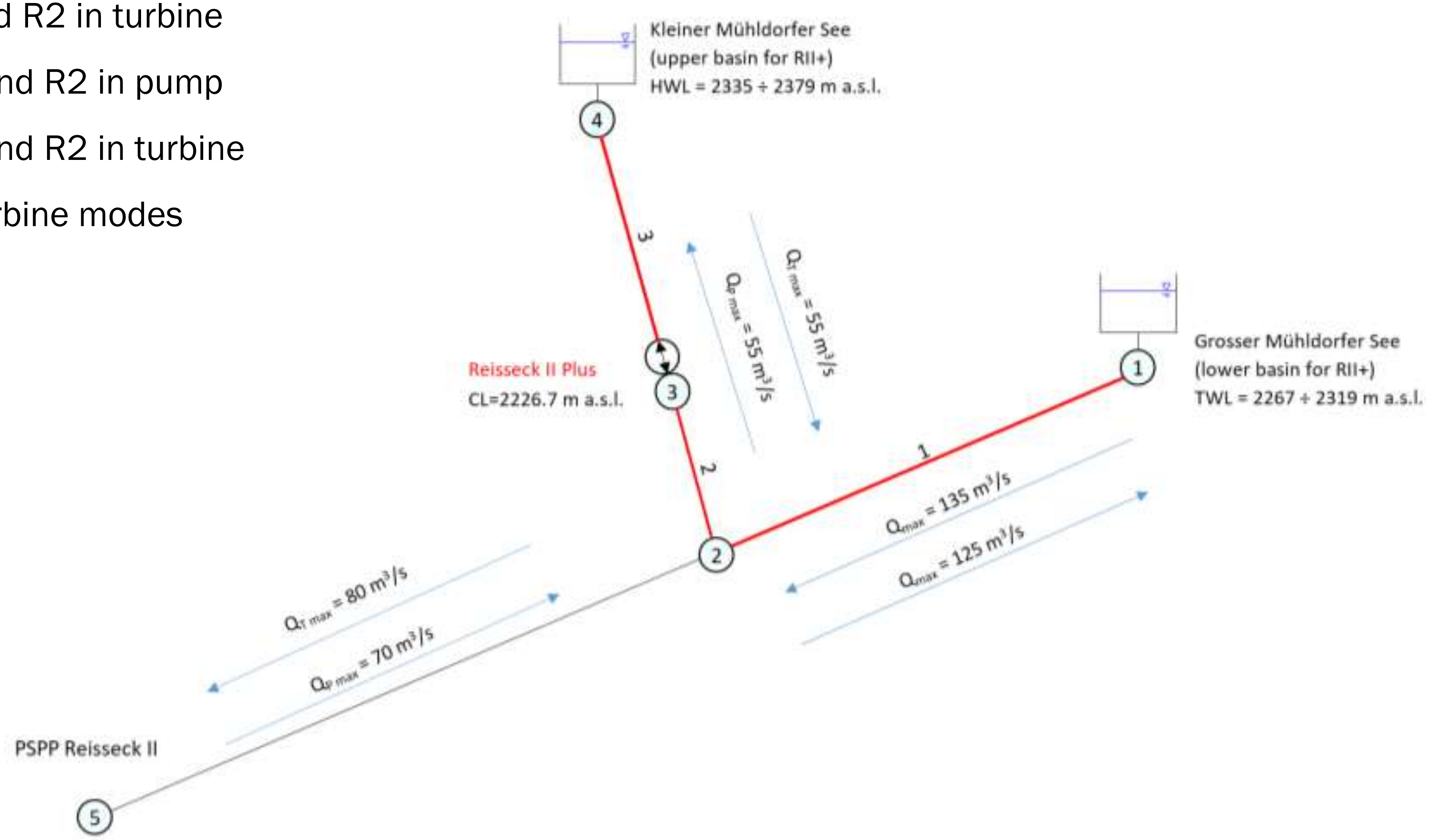
1. New hydraulic design of complete pump-turbine
2. Model mechanical design
3. Model manufacturing
4. Model testing
5. Model acceptance test
6. Model test report
7. CFD optimization of suction piping

Philosophy of operation

- Simultaneous operation of R2P in pump and R2 in pump
- Simultaneous operation of R2P in pump and R2 in turbine
- Simultaneous operation of R2P in turbine and R2 in pump
- Simultaneous operation of R2P in turbine and R2 in turbine
- Individual operation of R2P in pump and turbine modes

R2P Pump mode	
Head range	45 ÷ 115 m
Discharge range	15 ÷ 55 m^3/s

R2P Turbine mode	
Head range	35 ÷ 110 m
Discharge range	15 ÷ 55 m^3/s



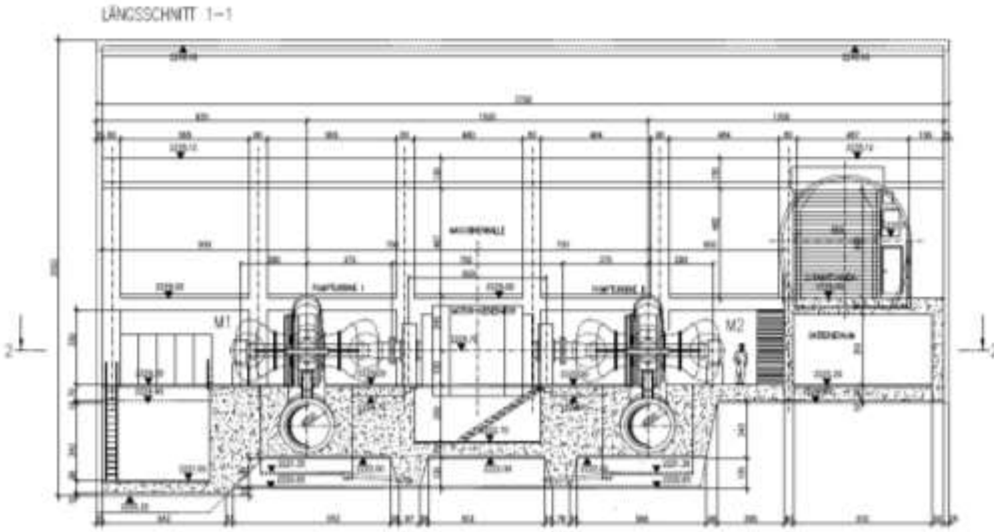
Configuration of the powerhouse

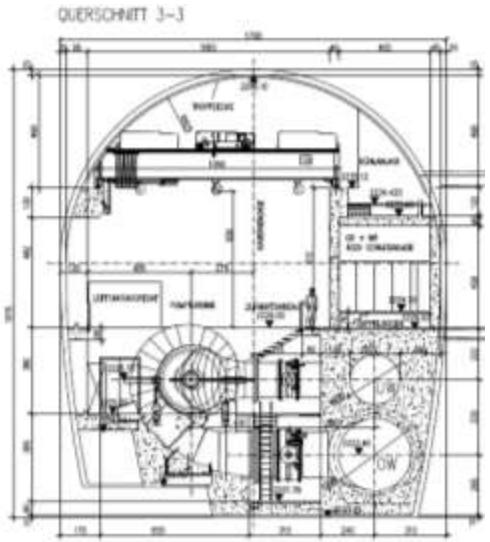
Concept

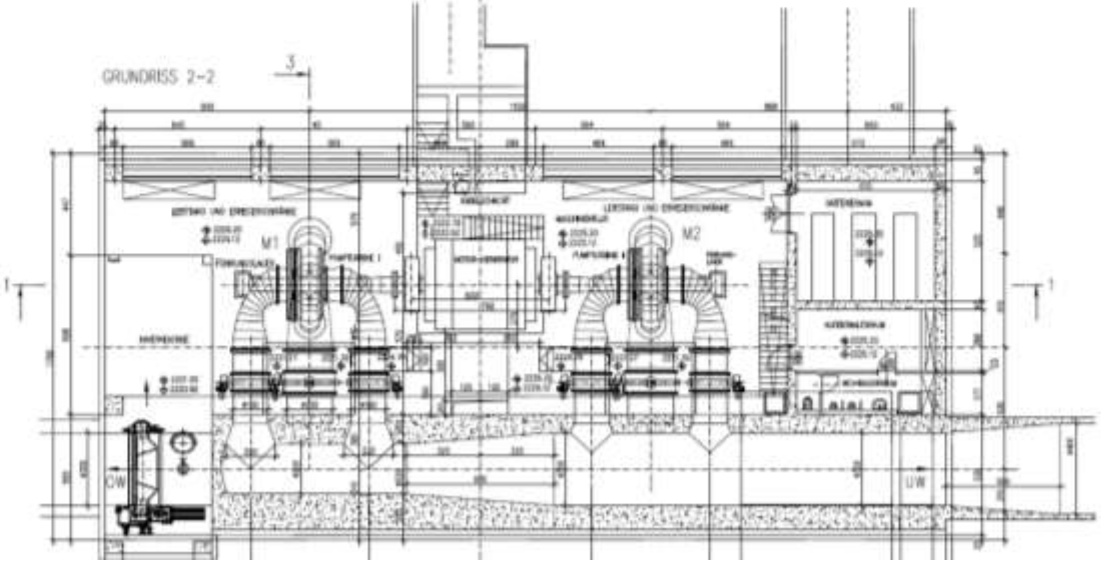
- One unit with one motor-generator
- Two pump turbines with double runners
- Frequency converter for speed variation

Advantages

- Possibility to operate only one pump-turbine
- Wide range of operation in both modes
- Regulation of pump input
- Compact solution







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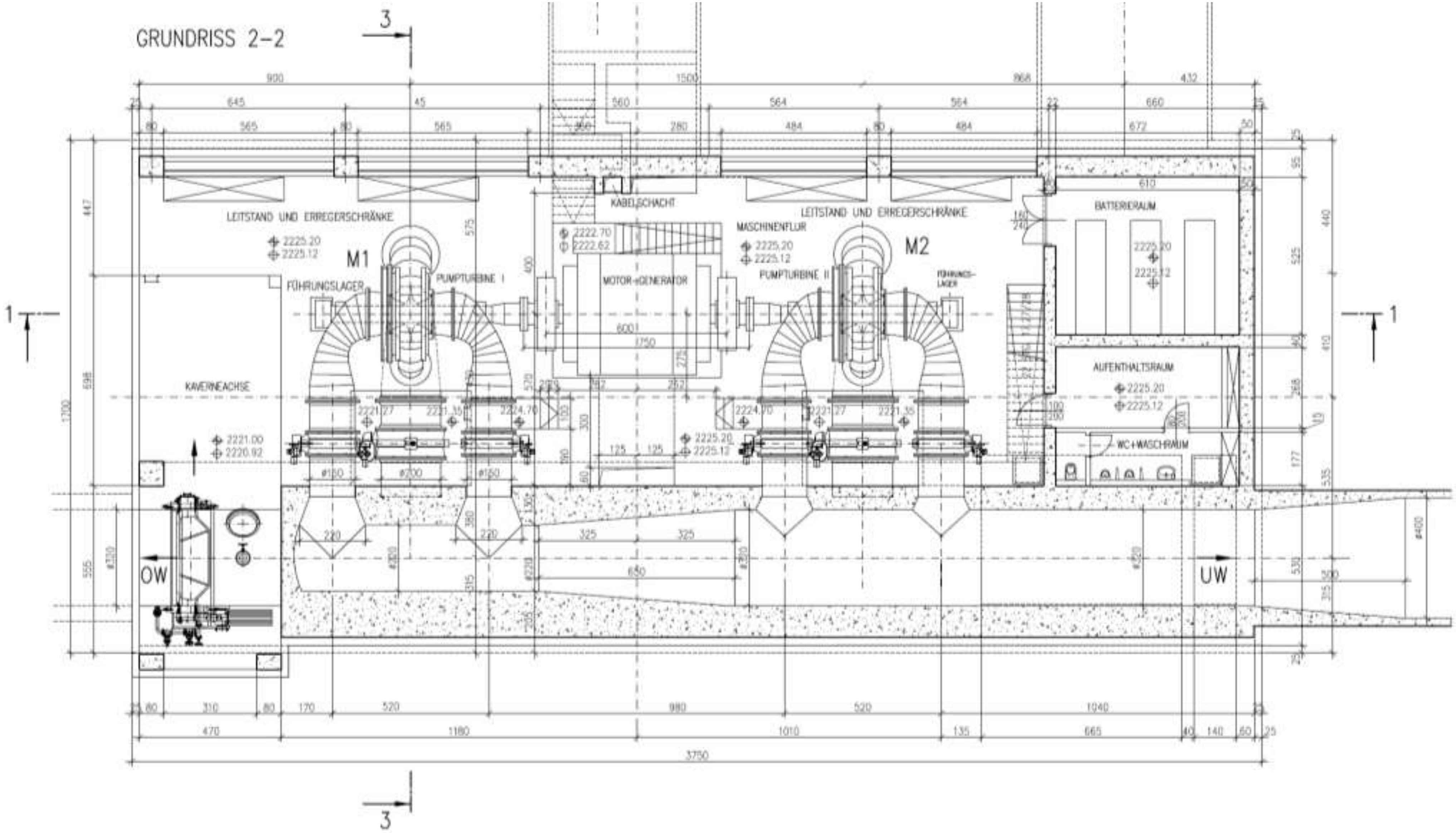
Assembly of the unit



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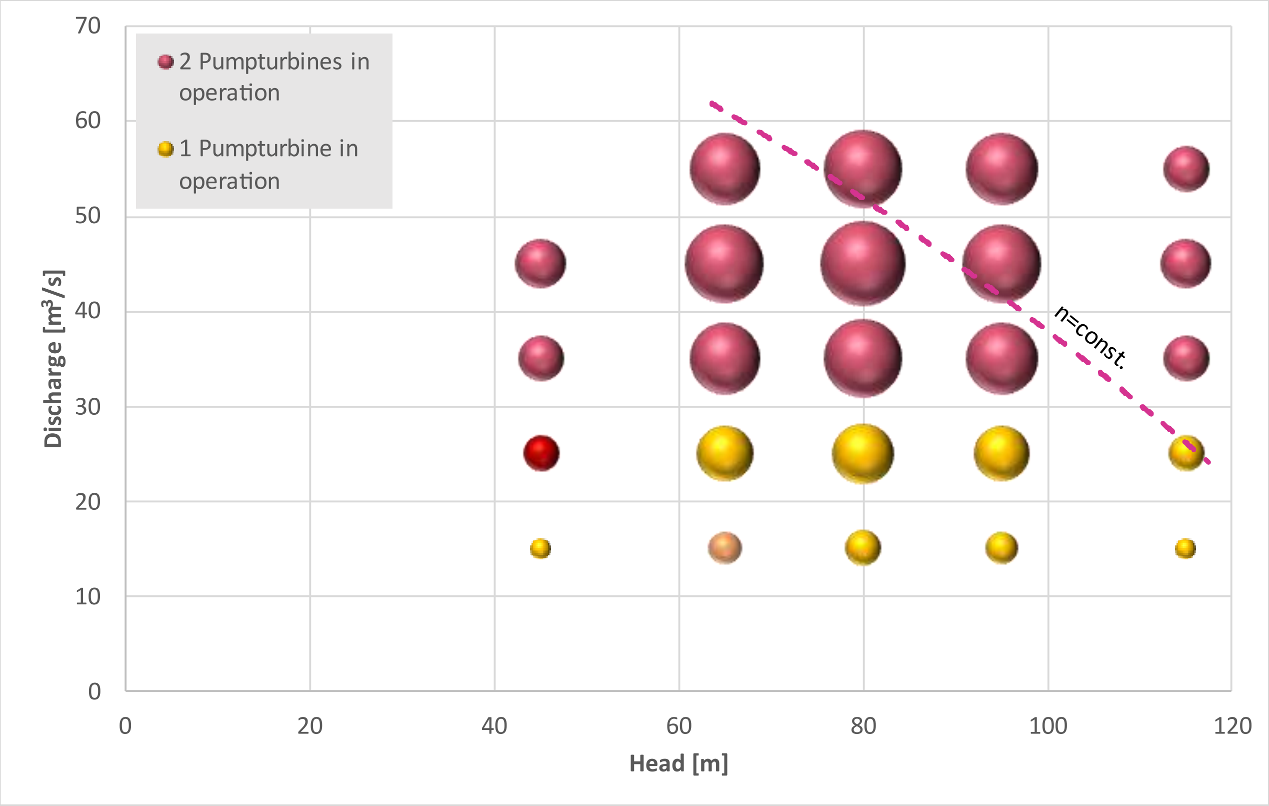
Basic pump-turbine parameters

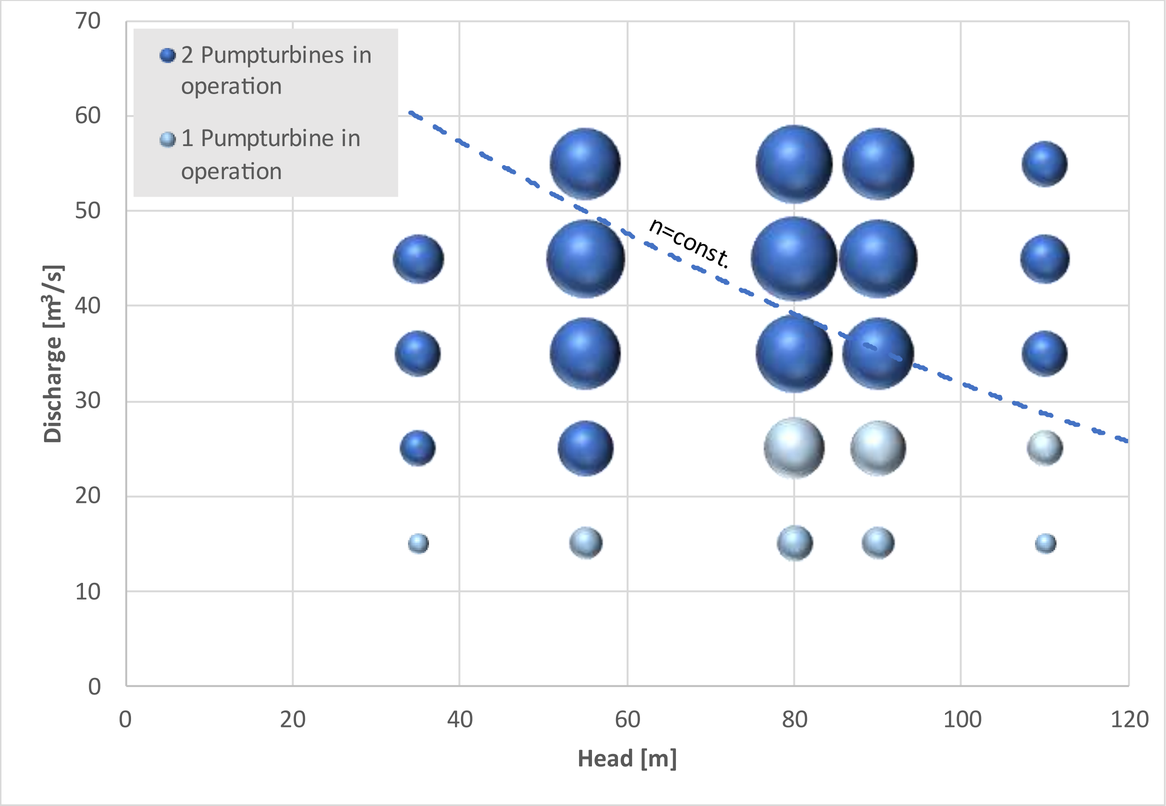
Pump-turbine basic data		
Specific speed of one single runner in pump mode (BEP)	145 m-kW	
Specific speed of one single runner in turbine mode (BEP)	160 m-kW	
Runner reference diameter	1352 mm	
Runner outlet diameter	1830 mm	
Number of runner blades	7 + 7	
Rotational speed (variable)	250 ÷ 550 rpm	
Number of guide vanes	20	
Number of stay vanes	20 (Alt. 10)	
One pump-turbine output	22.5 MW	
Total output of unit	45 MW	
	Pump mode	**Turbine mode**
Net head range	45 ÷ 115 m	35 ÷ 110 m
Discharge range	15 ÷ 55 m^3/s	15 ÷ 55 m^3/s
Discharge range of one single runner	3.75 ÷ 13.75 m^3/s	3.75 ÷ 13.75 m^3/s

Operation range of the unit

Pump mode



Turbine mode



Size of points represents value of weighting factors for average efficiency calculation

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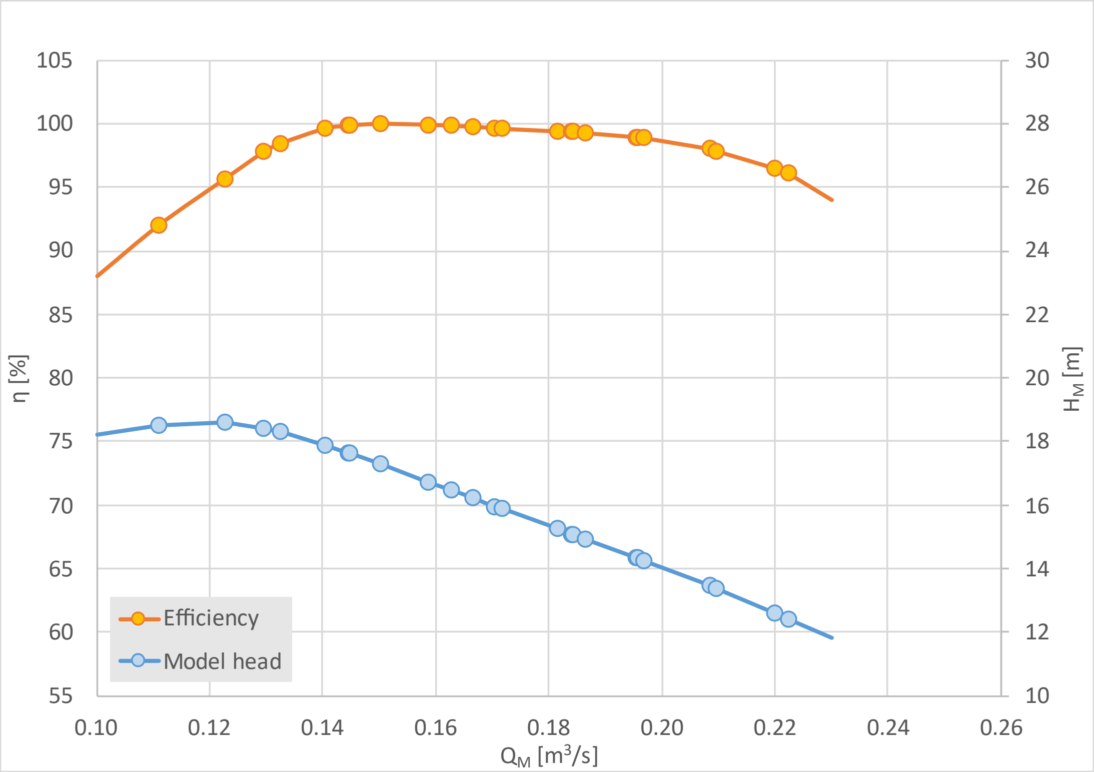
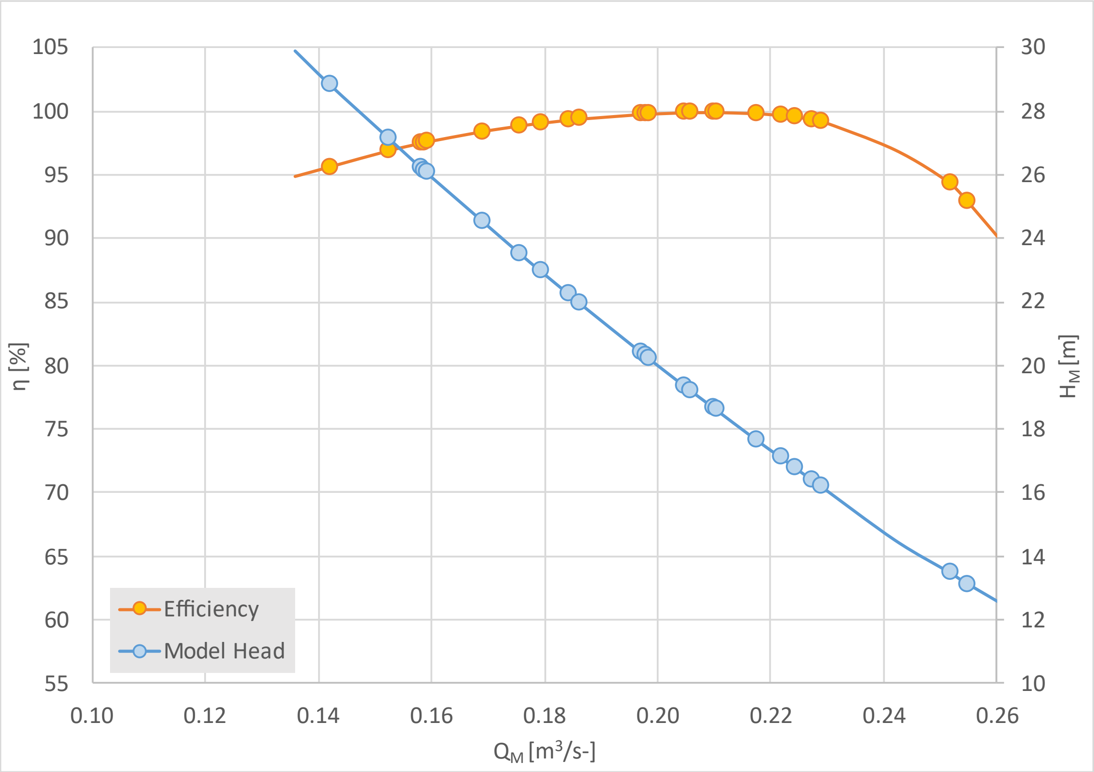
Single runner performance of model pump turbine (constant speed curves)



Target Pump mode performance curve



Target Turbine mode performance curve

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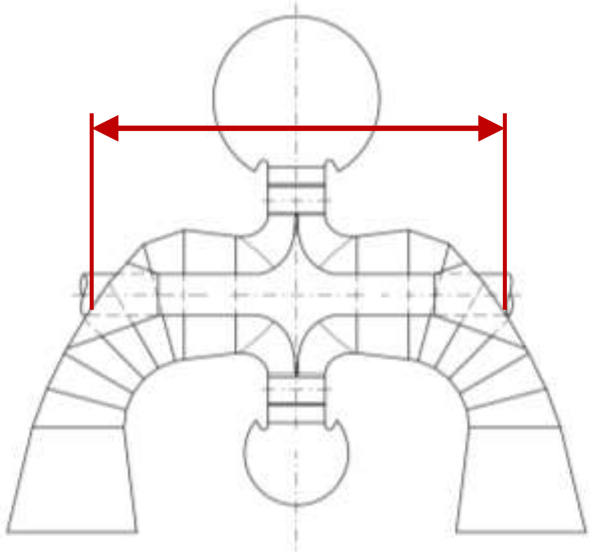
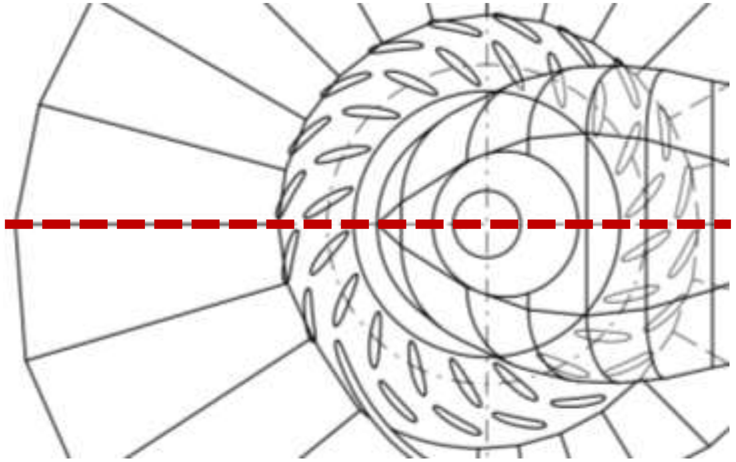
Mechanical constrains

- Limited space for draft tube elbow
- Horizontal dividing plane of spiral case and stay ring



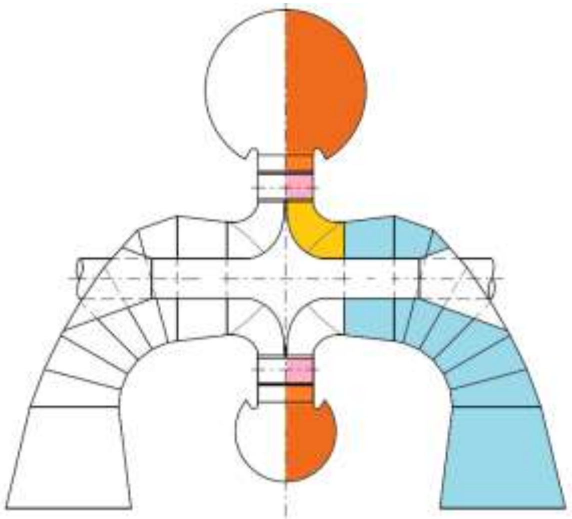


Hydraulic design challenges

- Wide range of operation in both modes
- High efficiency level in both modes
- Cavitation in pump operation at highest heads
- Instability of pump operation at highest heads
- Performance at maximum discharge in turbine operation

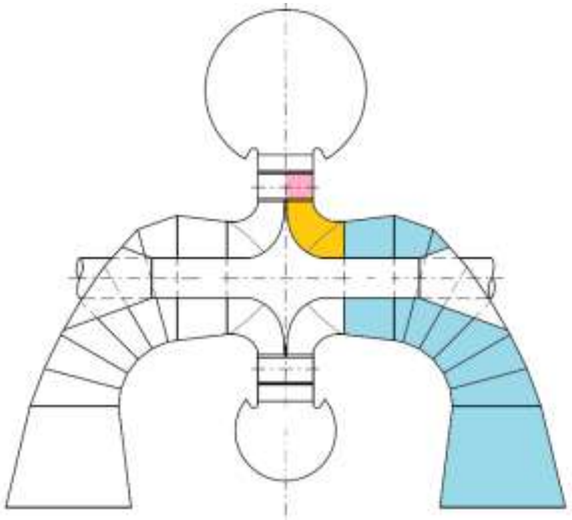
Large simulation

- Complete one half of the pump-turbine
- One single runner segment (1/7)
- All guide vanes and stay vanes
- Draft tube
- Used for complete flow analysis (8.250 k cells)

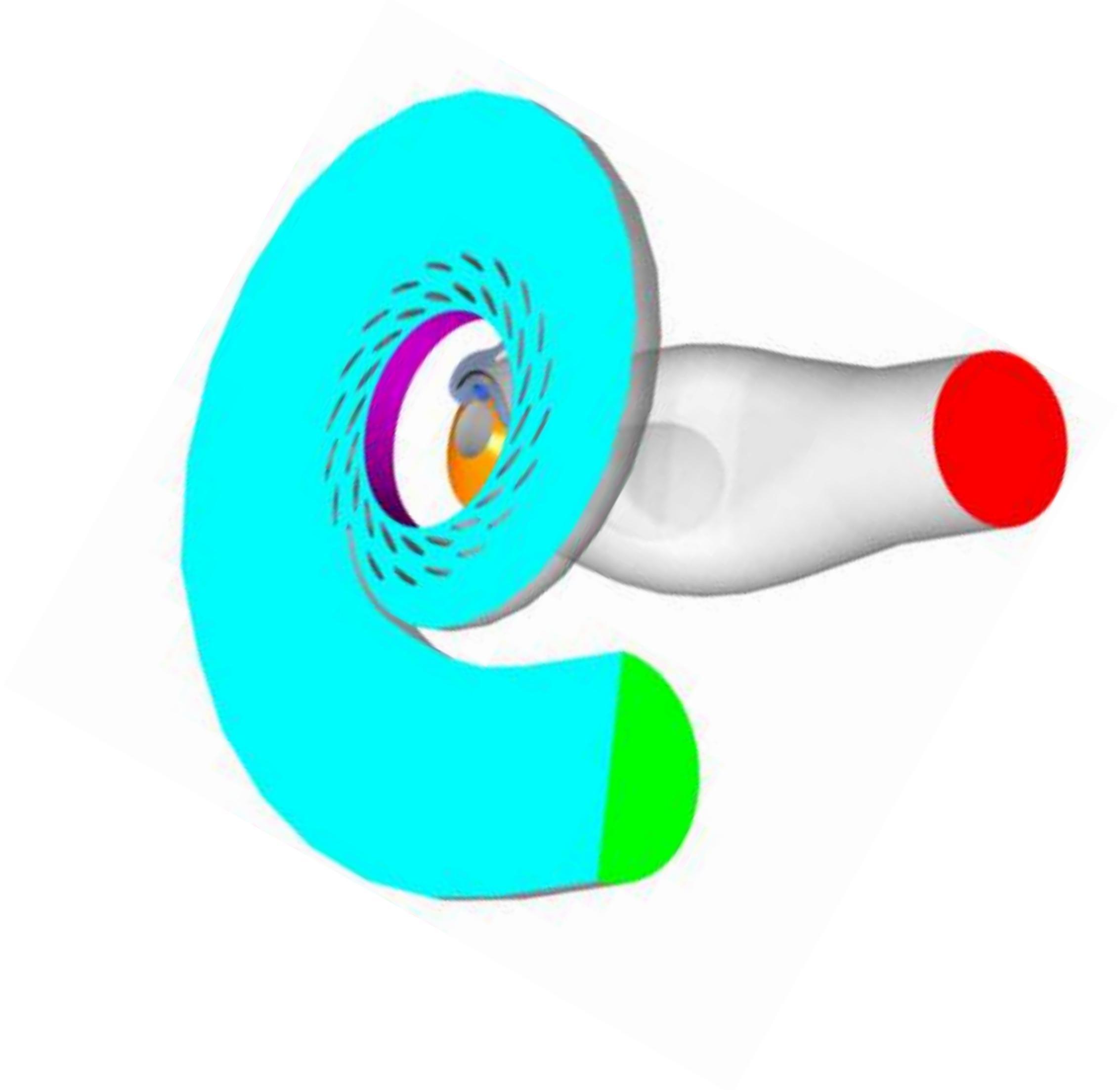


Small simulation

- One single runner segment (1/7)
- One guide vane channel (1/20)
- Draft tube
- Inlet turbine boundary condition from "big simulation"
- Used for runner blade optimization loop (600 k cells)



Hydraulic design of pump-turbine components



Initial design of individual components

CFD Flow analysis

Engineering CFD optimization of individual components

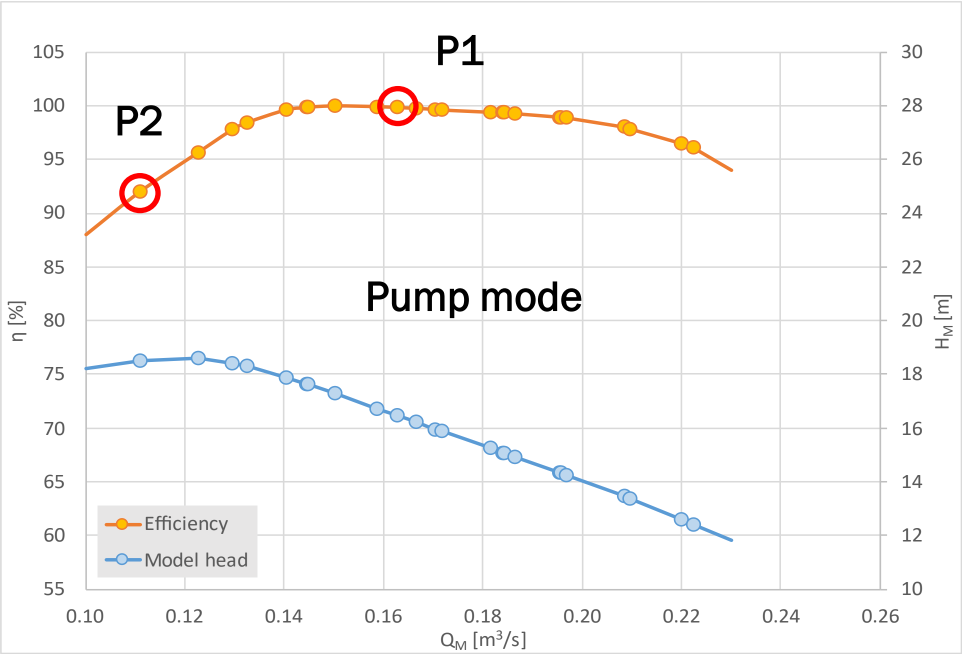
Automatic CFD mathematical optimization of runner blade

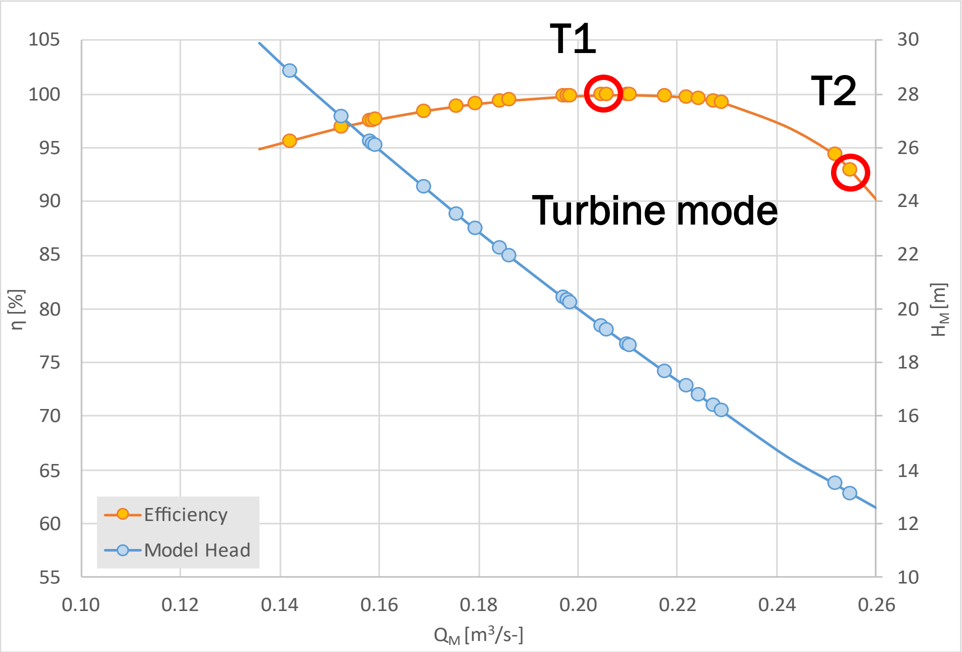
Final design of pump-turbine

Model tests at Hydraulic laboratory

Critical operational points for hydraulic design

- Best efficiency point at pump mode (P1) – efficiency and head at specified discharge
- Best efficiency point at turbine mode (T1) – efficiency and head at specified discharge
- Maximum head at pump mode (P2) – head and cavitation at specified discharge (stability)
- Maximum discharge at turbine mode (T2) – efficiency and head at specified discharge





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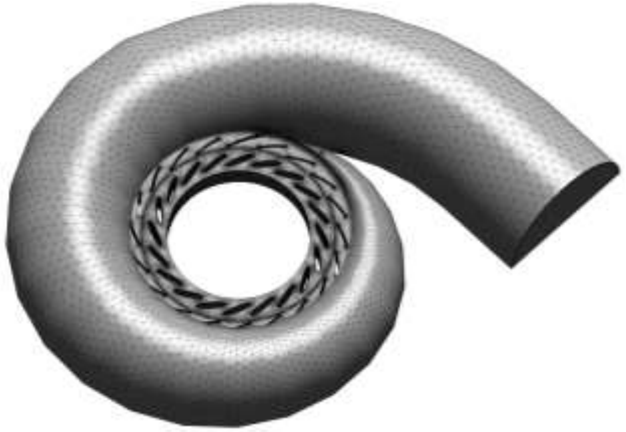
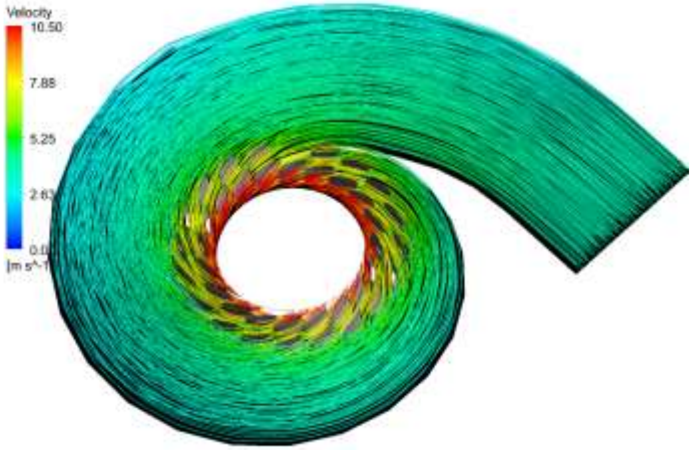
Hydraulic design of spiral case

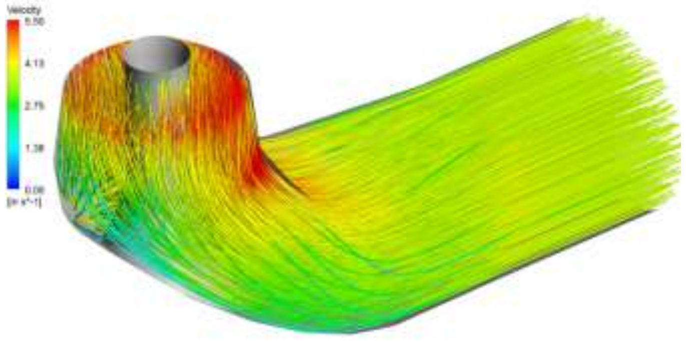
- Spiral case sections designed for design flow angle
- Testing of alternative heights of the distributor channel





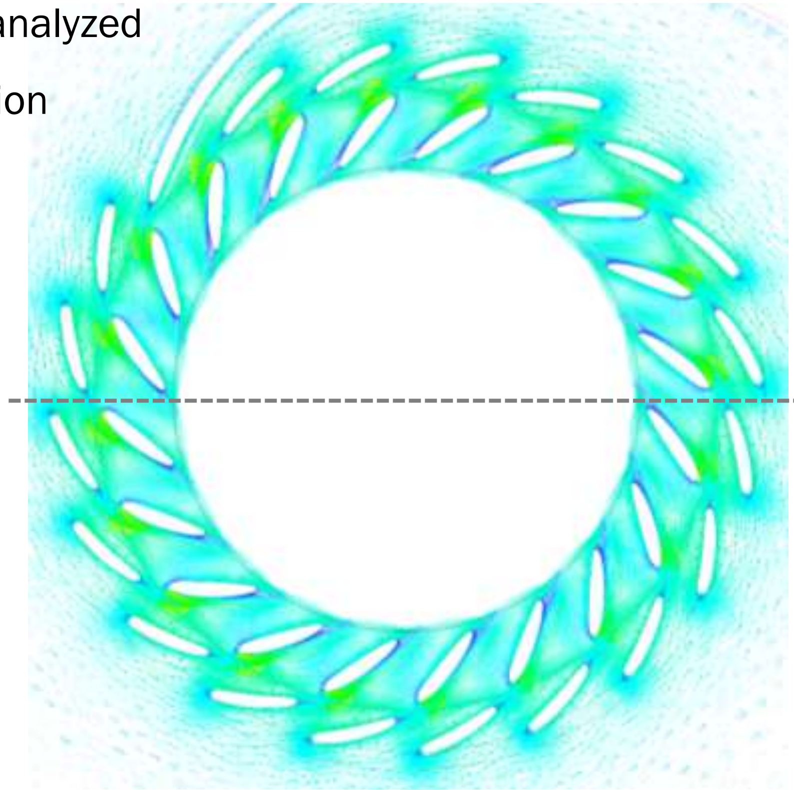
Hydraulic design of draft tube

- Manually optimized for turbine BEP velocity profile
- Cover for bearing housing are source of turbulences

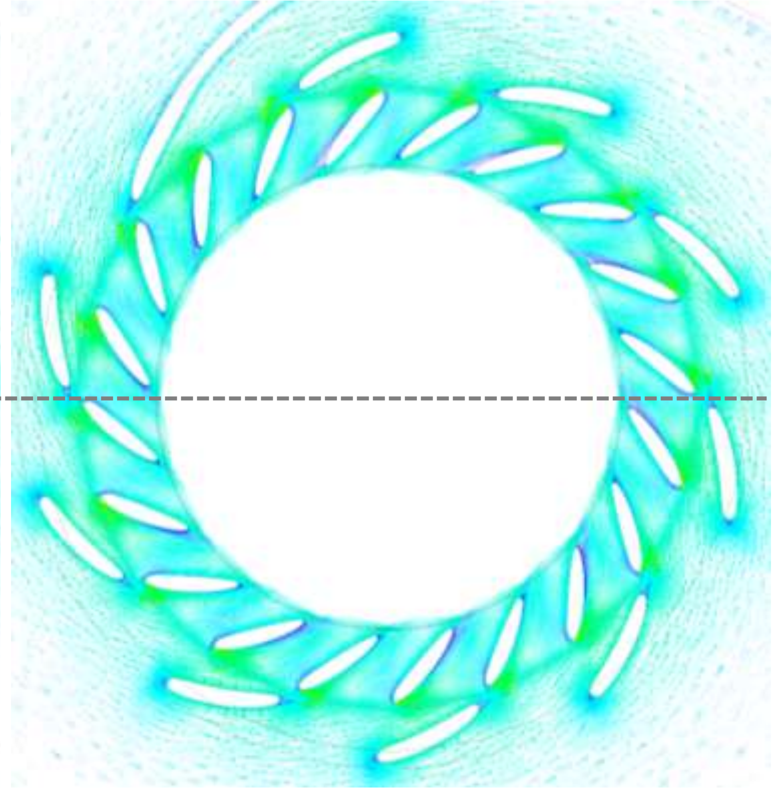


About number of stay vanes

- Alternatives with 20 and 10 stay vanes were analyzed
- Similar hydraulic performance after optimization
- 20 stay vanes → better performance at T2
- 10 stay vanes → better performance at P2
- Both solutions allows horizontal dividing plane



20 stay vanes - 20 guide vanes



10 stay vanes - 20 guide vanes

Turbine mode – Hmin, Qmax

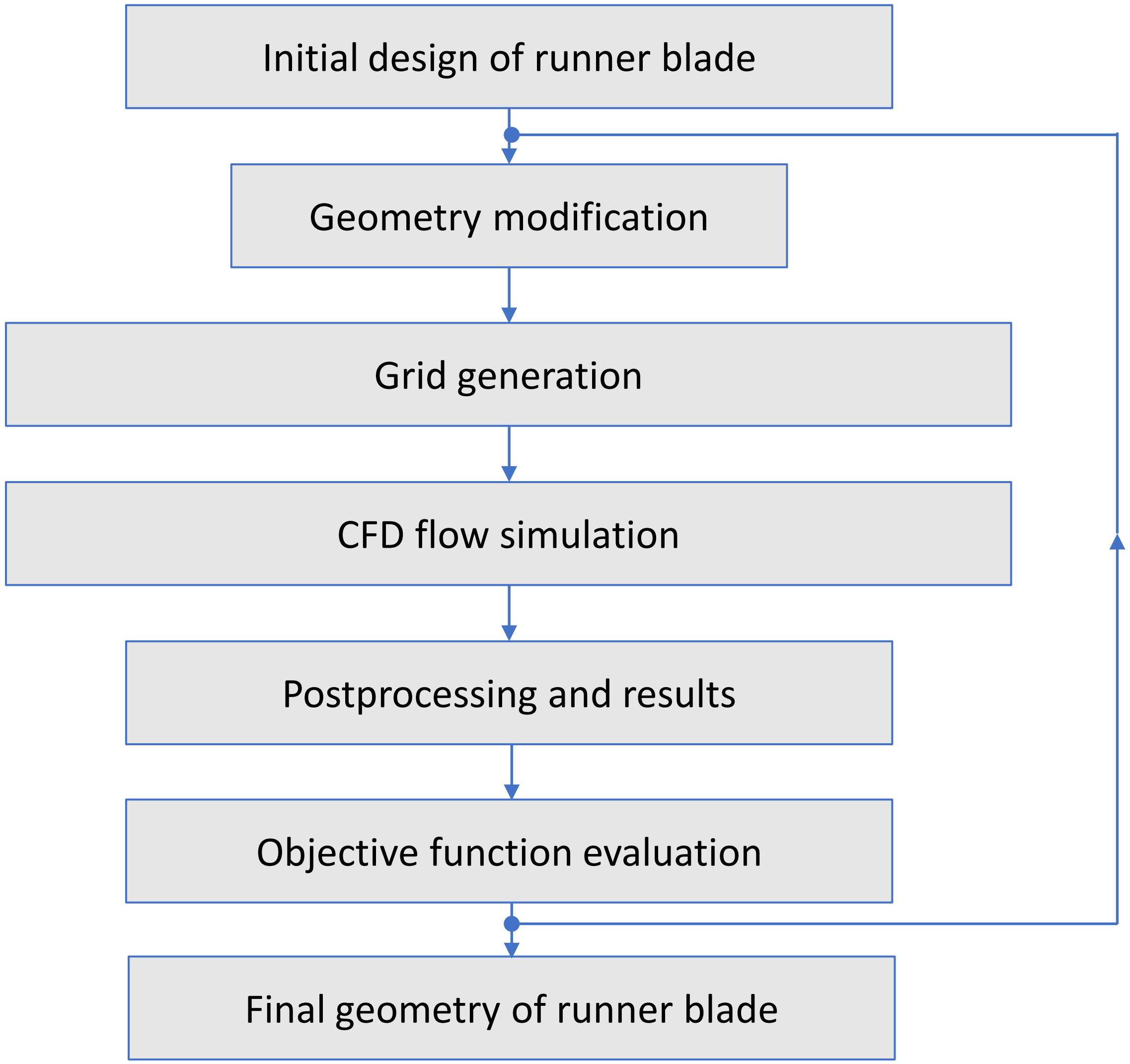
Automatic process for optimization of runner blade

- Nelder-Mead simplex optimization algorithm (in-house)
- Multi-objective function minimization
- Multi-Initialization run (partial random globalization)
- Parametrical modelling of the runner blade (in-house)
- Ansys TurboGrid ®
- Ansys CFX ®
- Definition of multi-objective function:

$$f(Xi) = \sum \Delta E_i . WE_i + \Delta H_i . WH_i + \Delta C_i . WC_i$$

ΔE_i Efficiency term
ΔH_i Head term
ΔC_i Cavitation term

WE_i, WH_i, WC_i weighting factors



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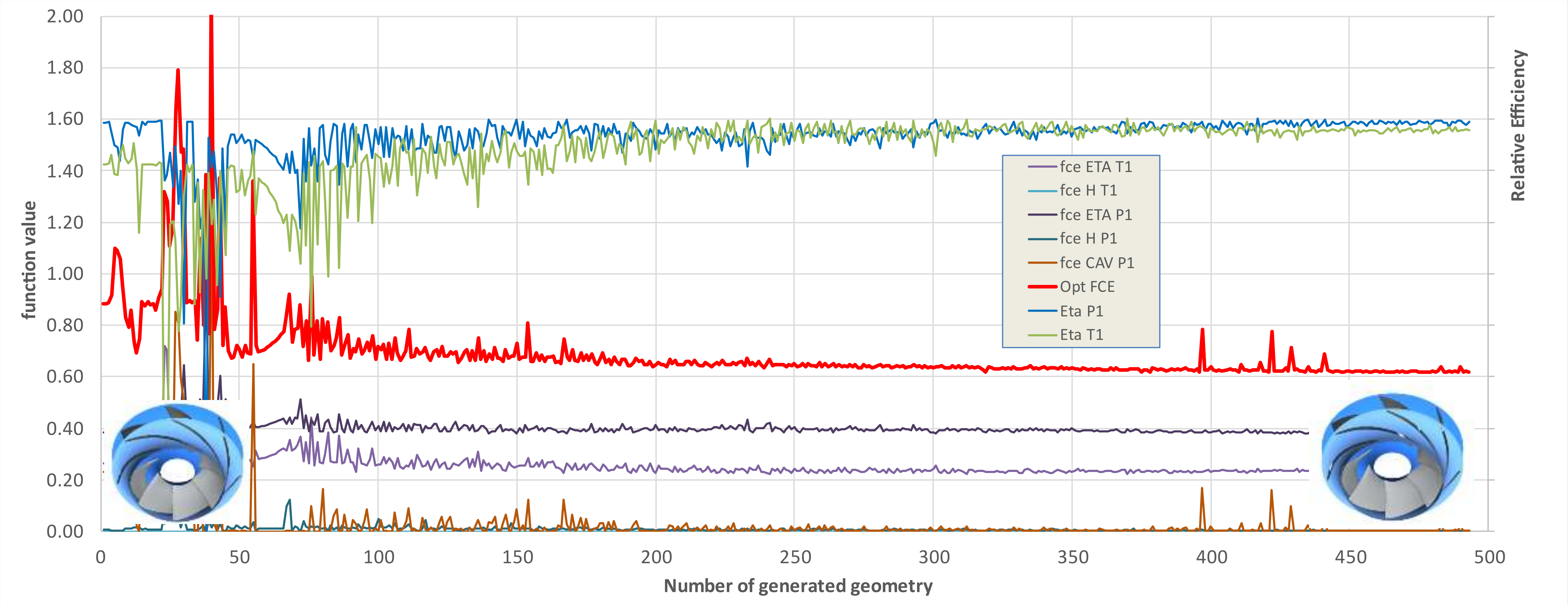
Optimization of Pump and Turbine BEP

$$f(Xi) = \sum \Delta E_{P1}.WE_{P1} + \Delta H_{P1}.WH_{P1} + \Delta C_{P1}.WC_{P1} + \Delta E_{T1}.WE_{T1} + \Delta H_{T1}.WH_{T1}$$



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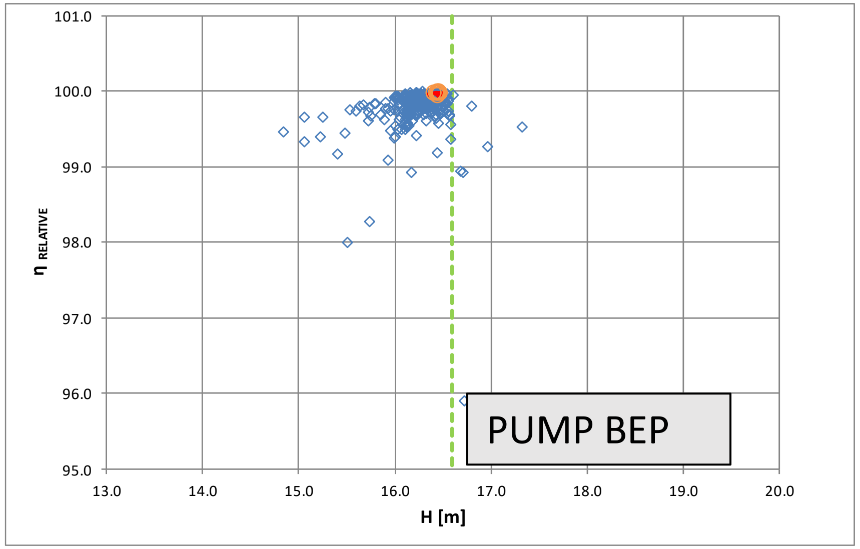
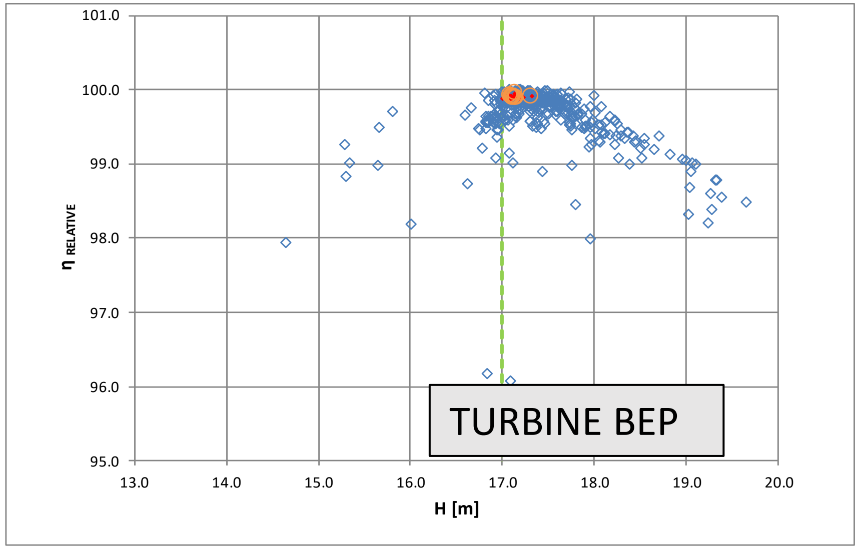
Optimization of Pump and Turbine BEP

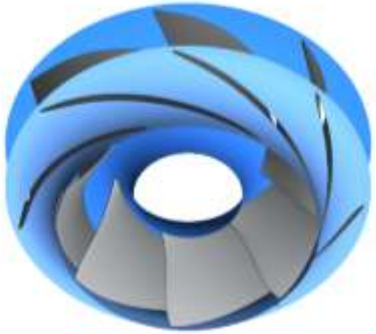
- HP Z6 G4 Workstation 96 GB RAM Intel ® Xeon ® Gold 6152 2.1 GHz (22 cores)
- 30 geometrical parameters optimized
- 2 parallel runs (Pump BEP + Turbine BEP) each on 10 cores
- 8 minutes for one geometry converged CFD analysis (2 operational points)
- 72 hours needed for converged optimization process
- During design process almost 50 realized optimization processes





Hydraulic design of pump-turbine

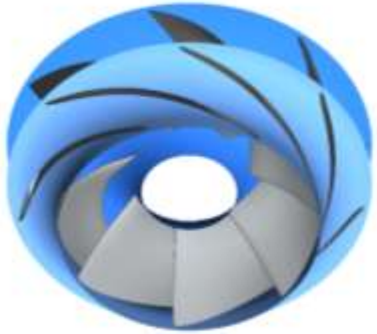
Initial design



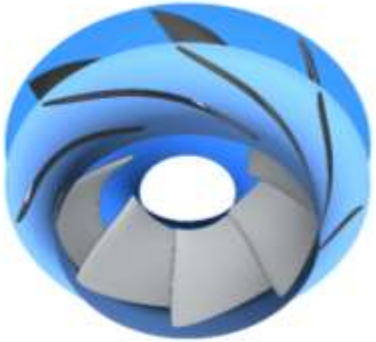
Optimized P1
(pump BEP)

Optimized T1
(turbine BEP)

Optimized P1+T1
(pump + turbine BEP)



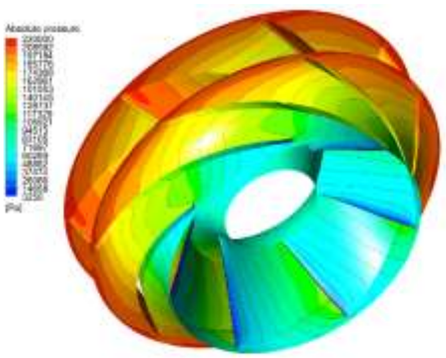
Optimized P1+P2+T1+T2
(pump + turbine all)

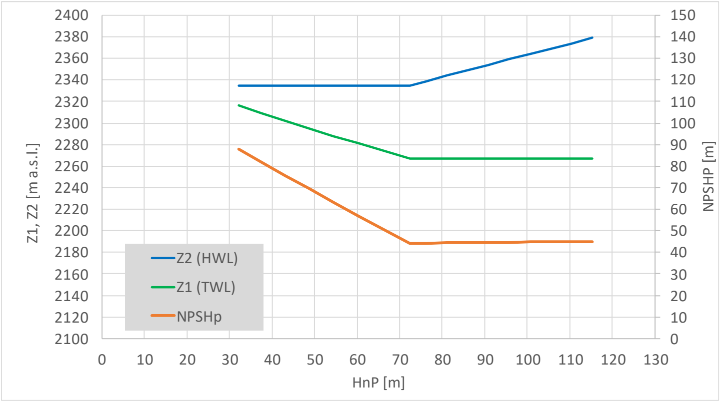


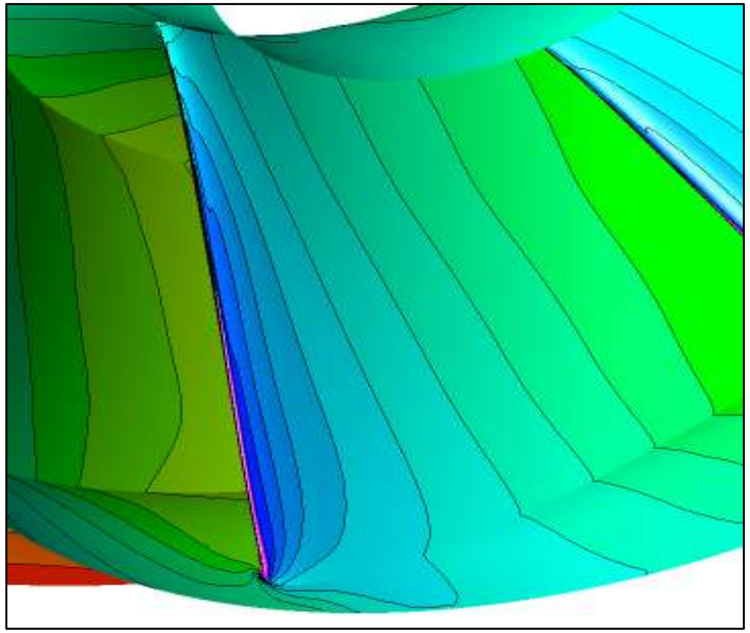
Final design
(after manual finishing)

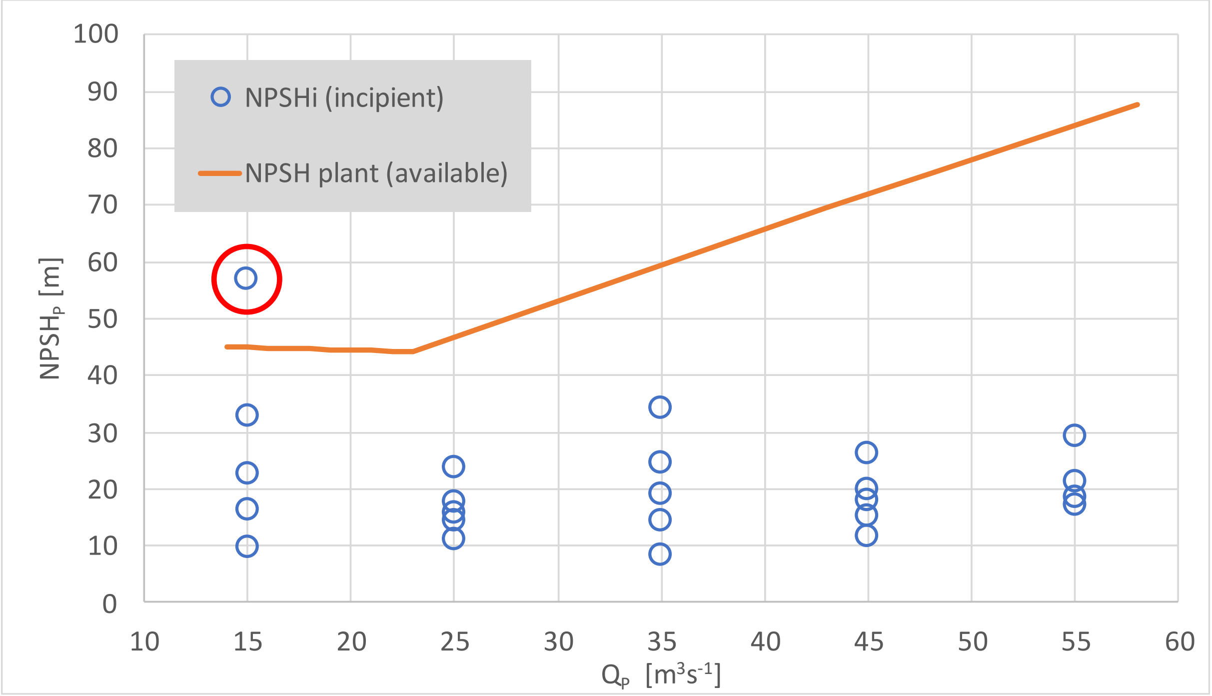
Analysis of cavitation features

- Not any cavitation expected at turbine mode
- One phase CFD static pressure-based evaluation
- Cavitation strip at pump on suction side at H_{max}, Q_{min}
- Not expected any effect on performance
- Not expected deep material removal (low head H≈100m)









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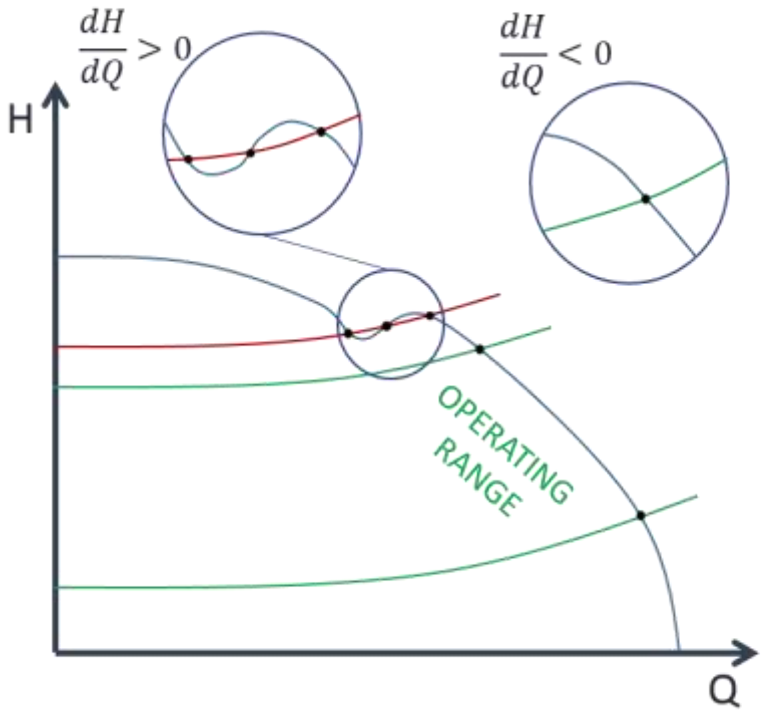
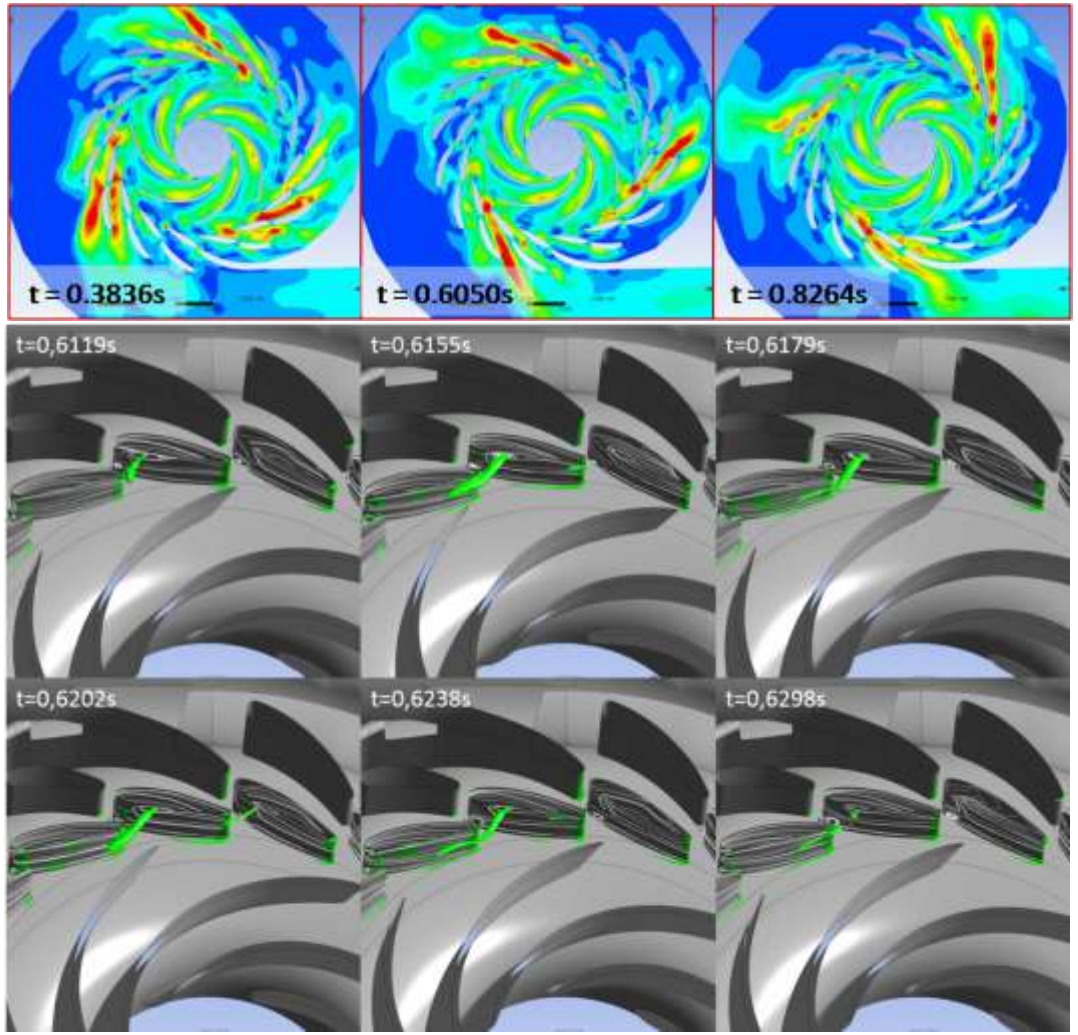
Analysis of pump operation instability

- Pumps should be designed to operate out of "hump zone"
- Best numerical results by unsteady CFD
- Unsteady CFD not suitable in design process – too long CPU

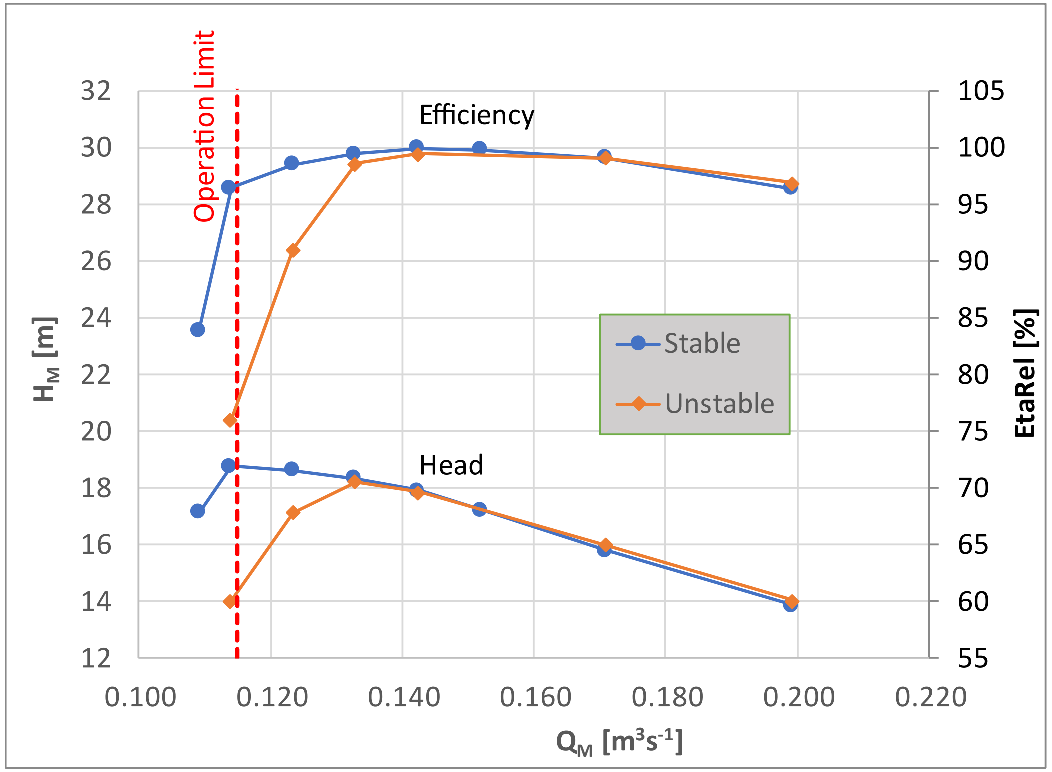


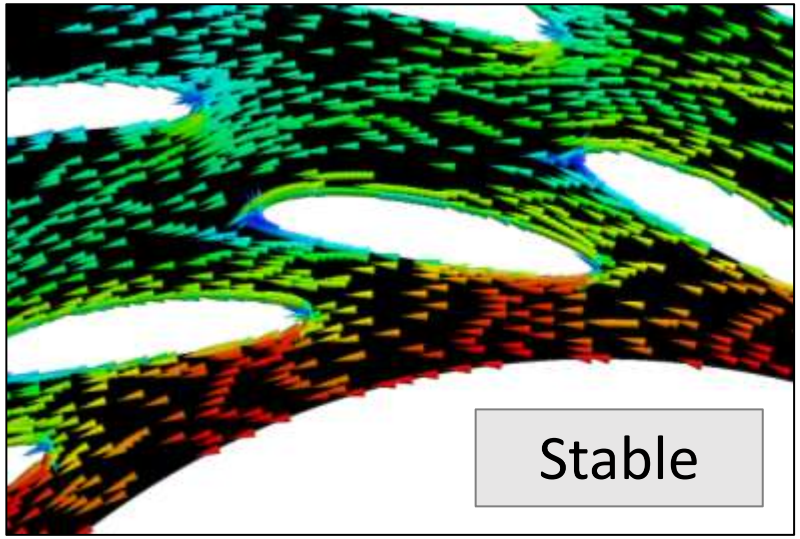


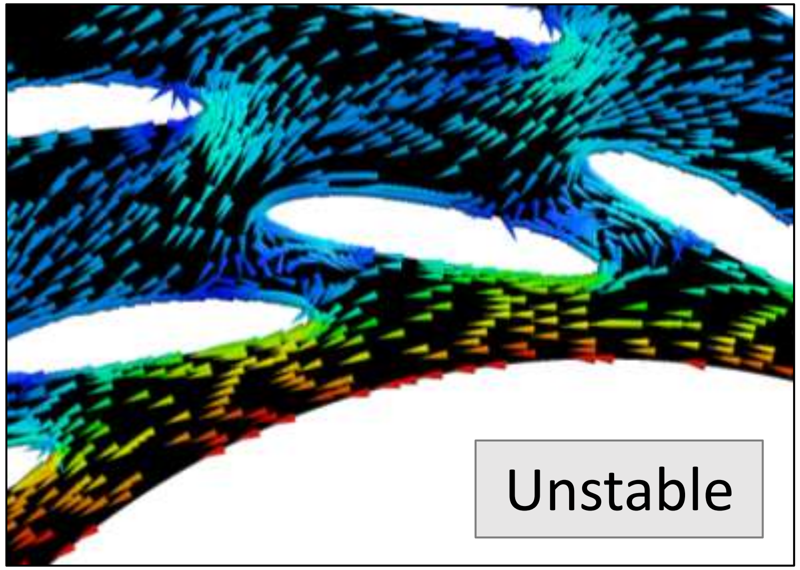
Ješe, Novotný, Skoták – 29th IAHR Symposium (Kyoto, Japan, 2018)

Analysis of pump operation instability

- Steady state CFD – satisfactory for identification of phenomena
- Blockage of the flow in area of distributor
- Fall of head and efficiency even at “Small simulation”

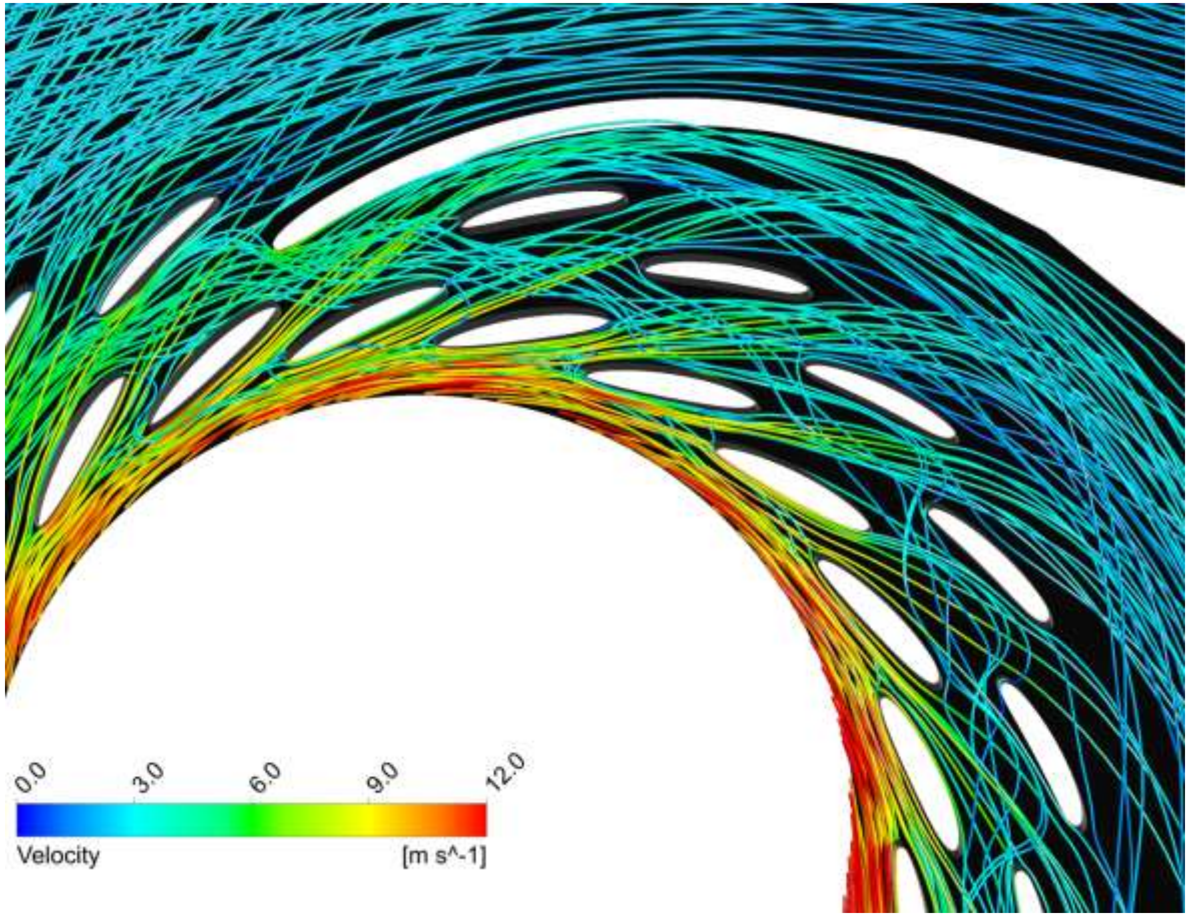


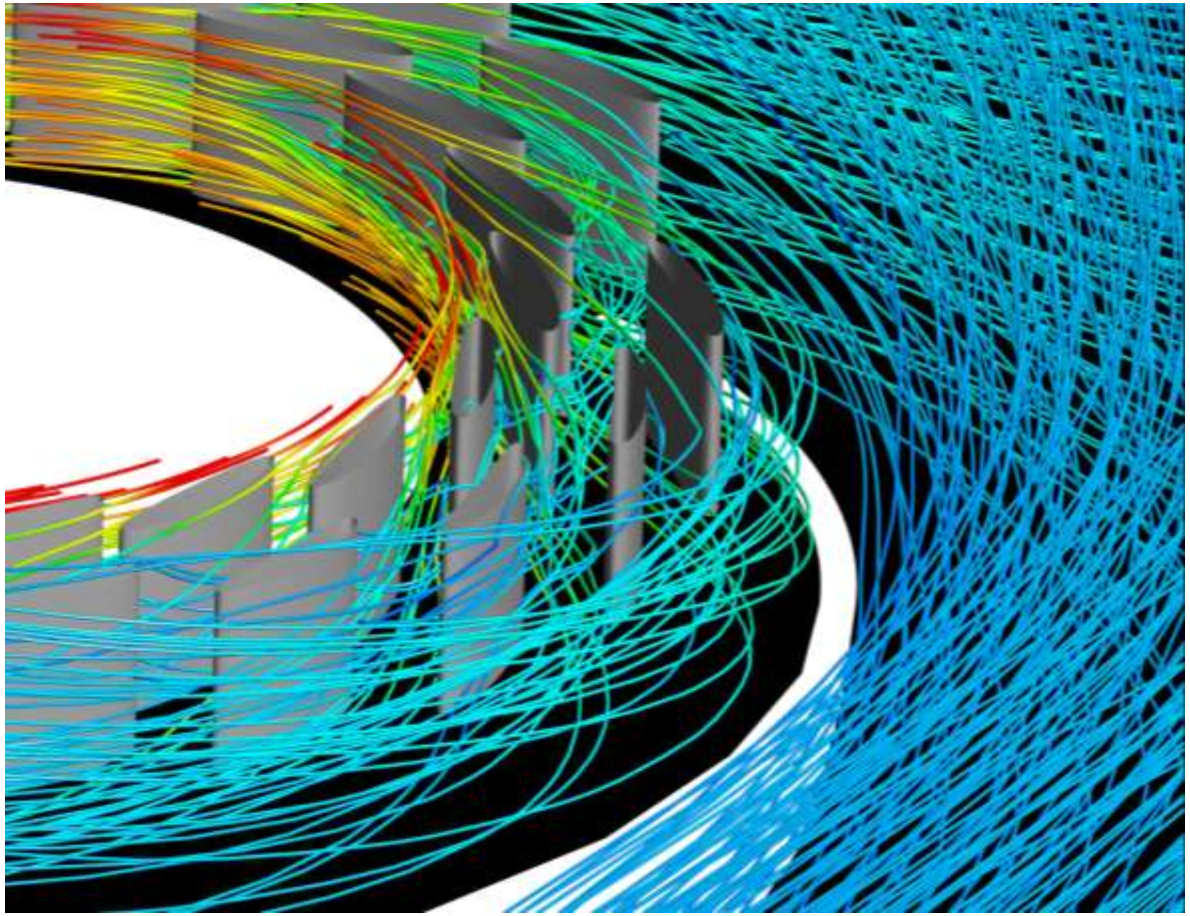




Analysis of pump operation instability

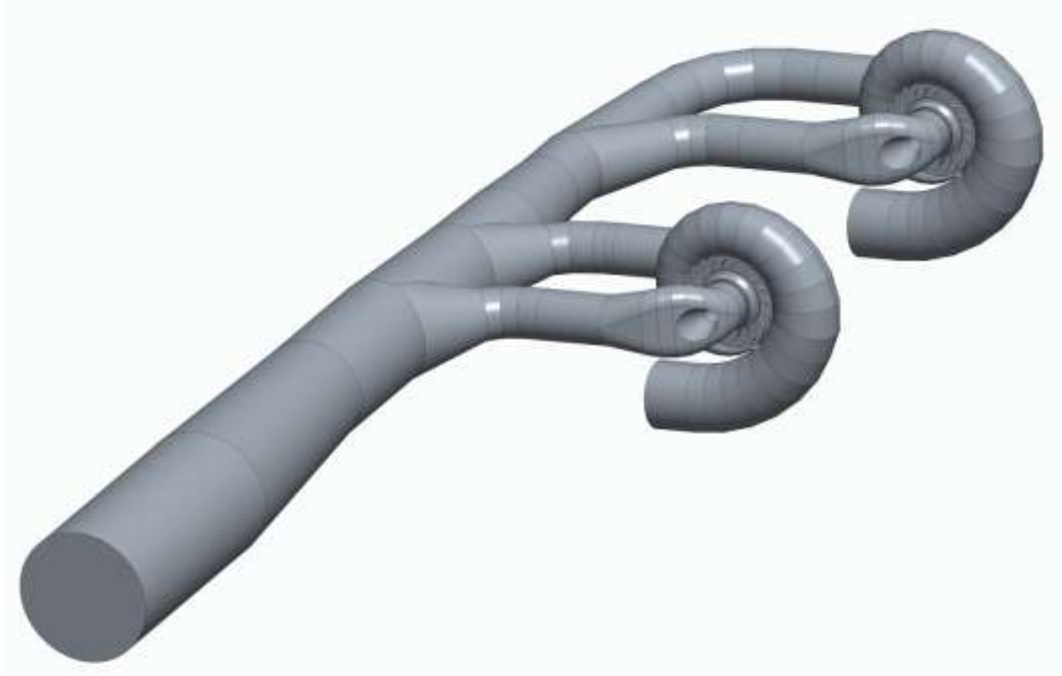
- Steady state CFD – “Large simulation”

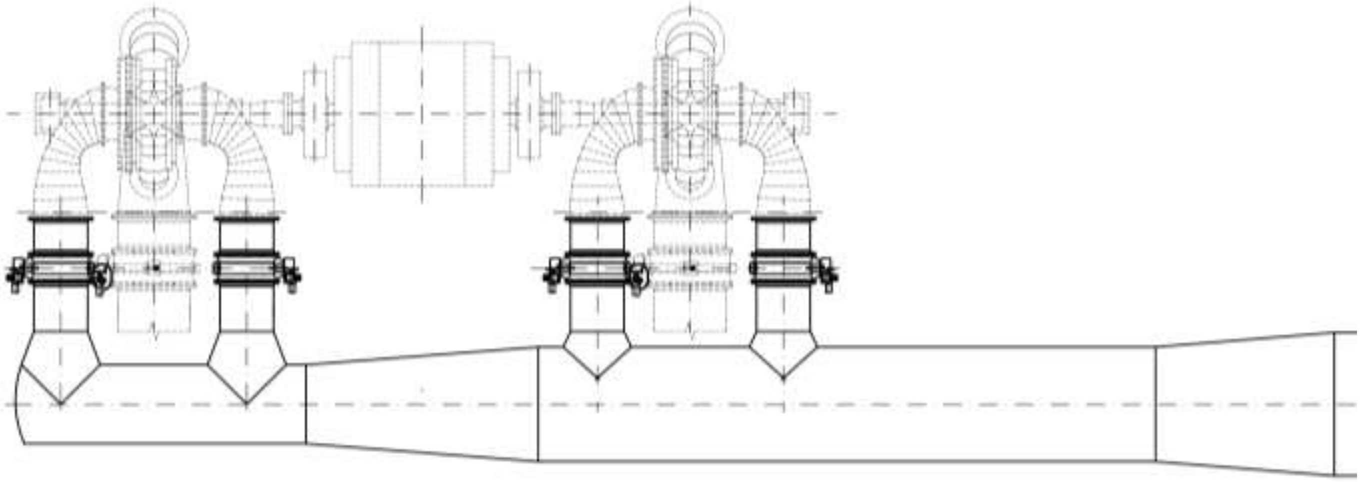




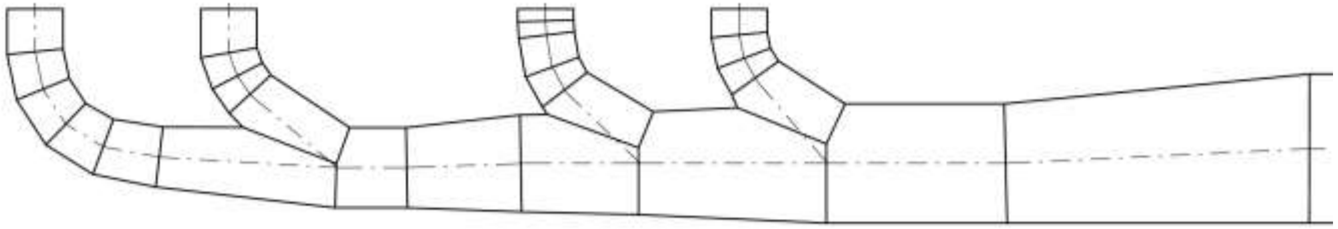
Hydraulic design of Quadrifurcation

- Initial orthogonal design
- Pump and turbine flow directions
- Respecting space inside power plant





Initial design



Optimized design

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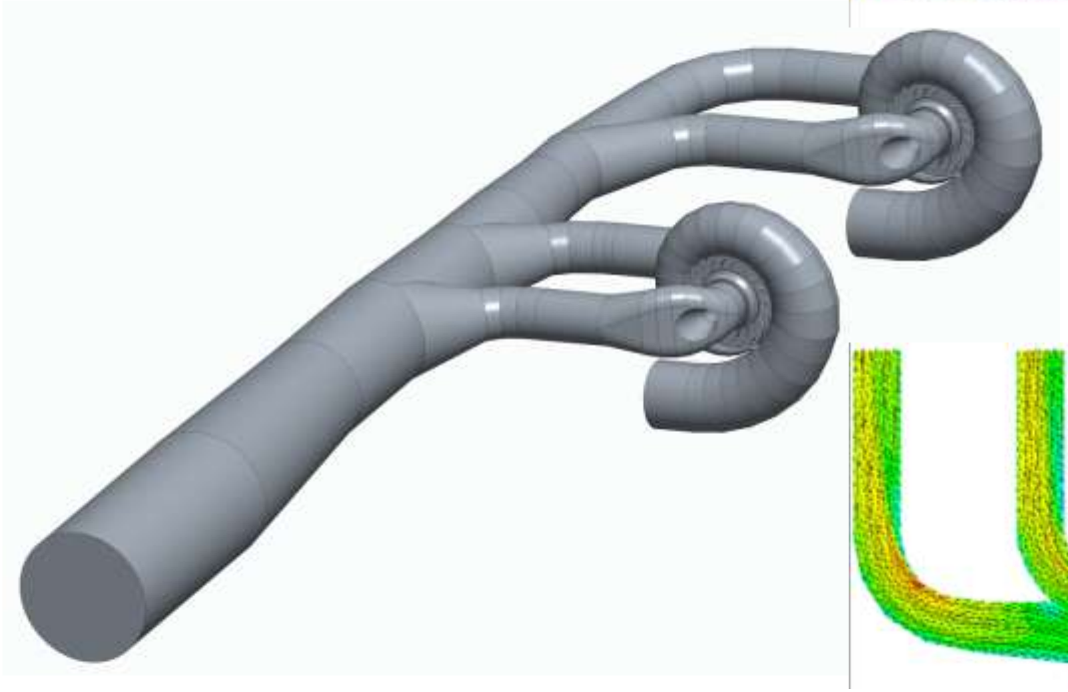
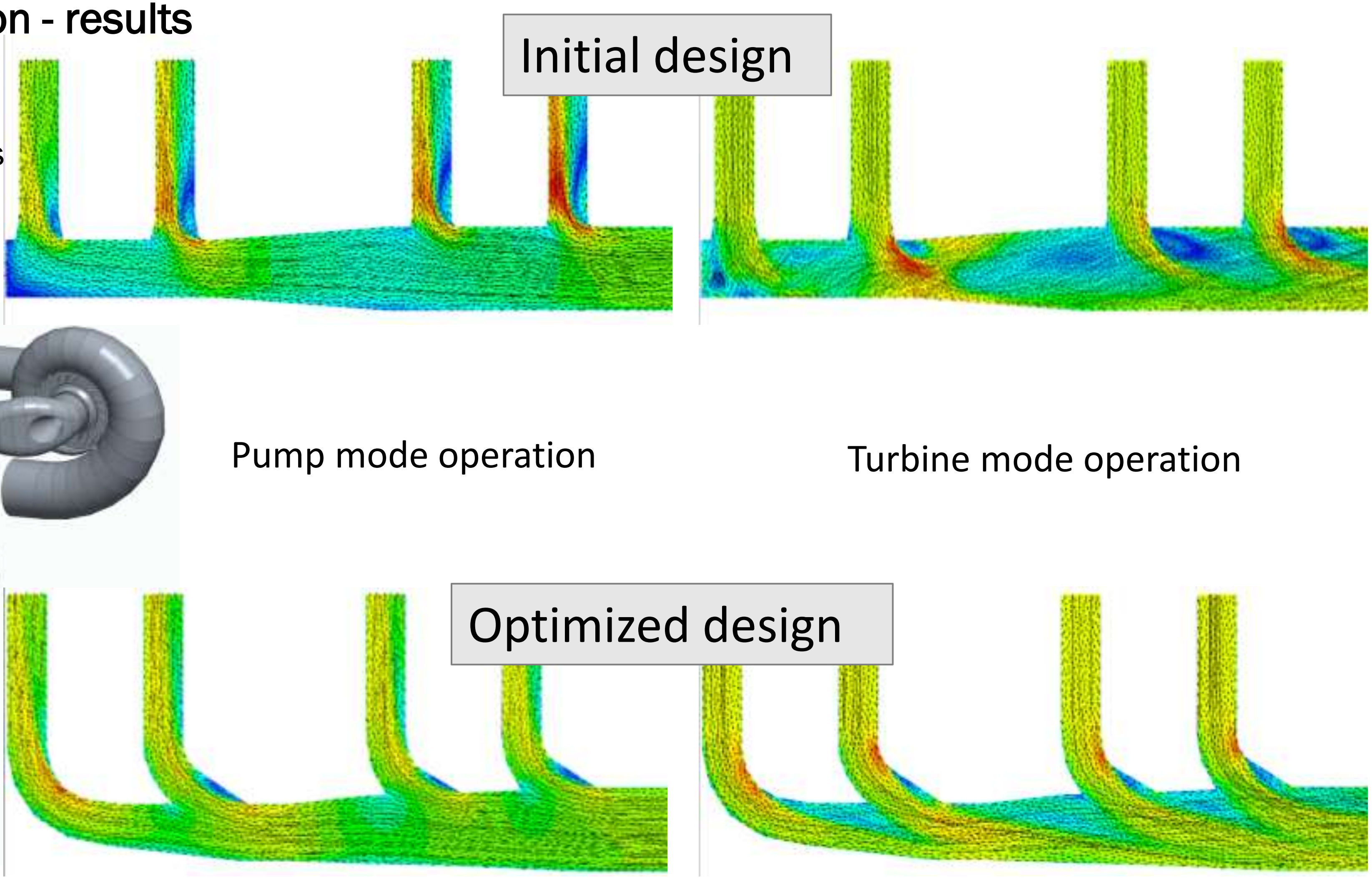
Hydraulic design of Quadrifurcation - results

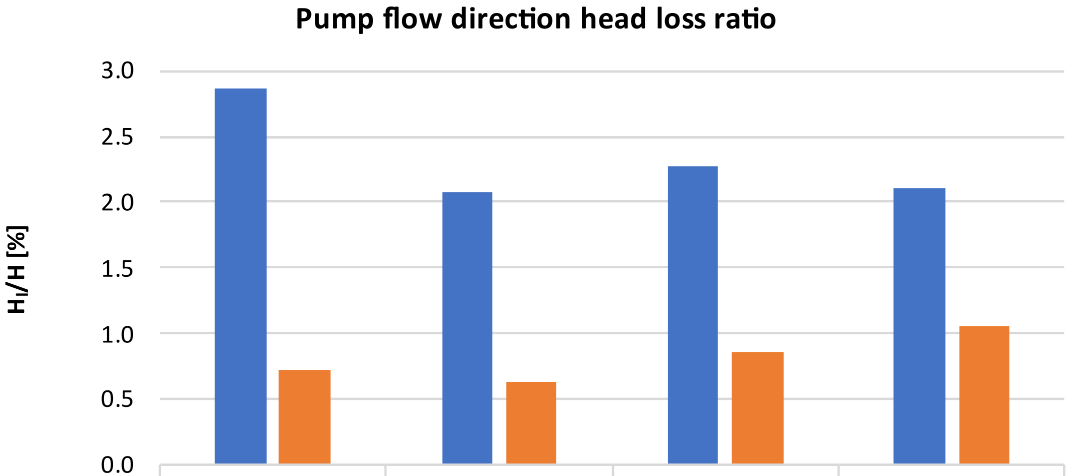
- Minimization of hydraulic losses
- Uniformity of flow at individual branches
- Uniformity of flow across branches



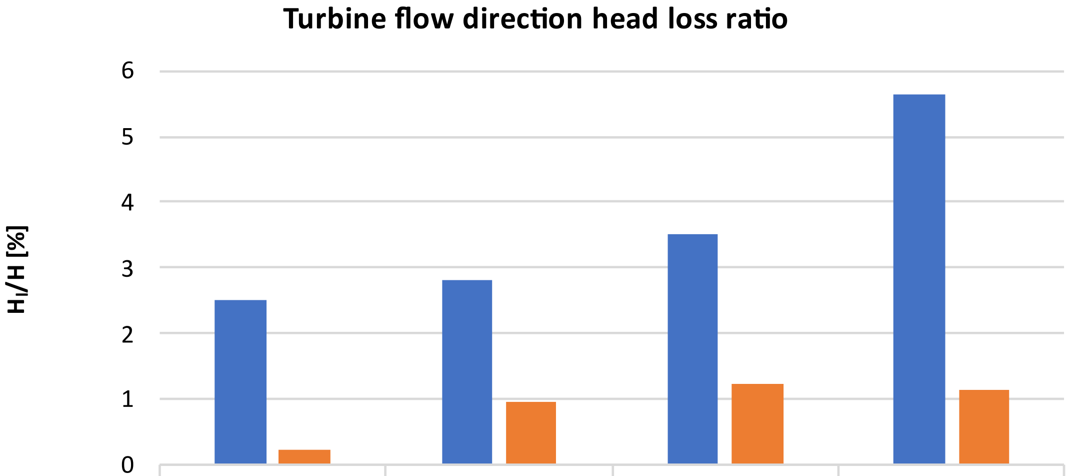


Hydraulic design of Quadrifurcation - results

- Losses in evaluated in percentage of pump-turbine head



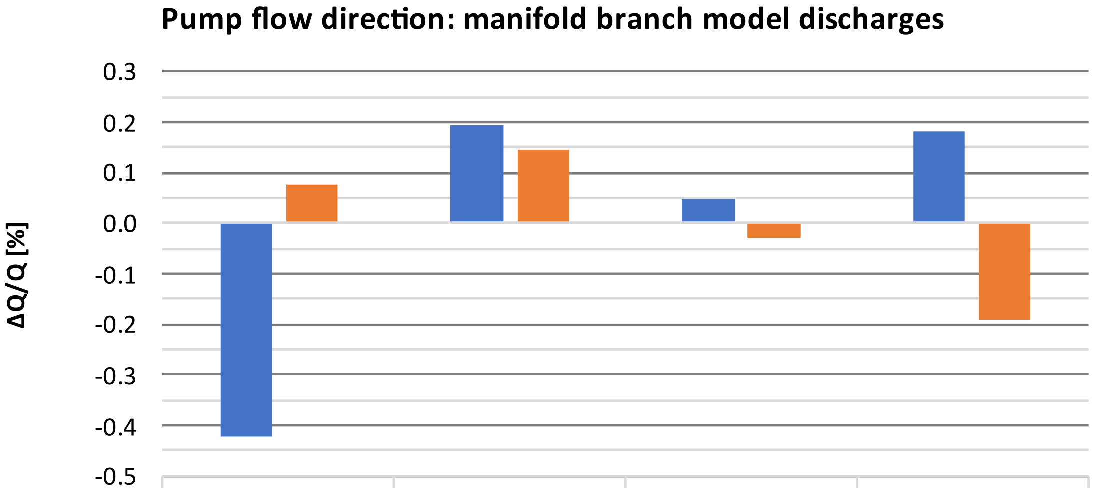
Branch nuber	1	2	3	4
Initial	2.86	2.08	2.27	2.10
Optimized	0.72	0.63	0.85	1.06



Branch nuber	1	2	3	4
Initial	2.51	2.82	3.50	5.64
Optimized	0.22	0.96	1.21	1.14

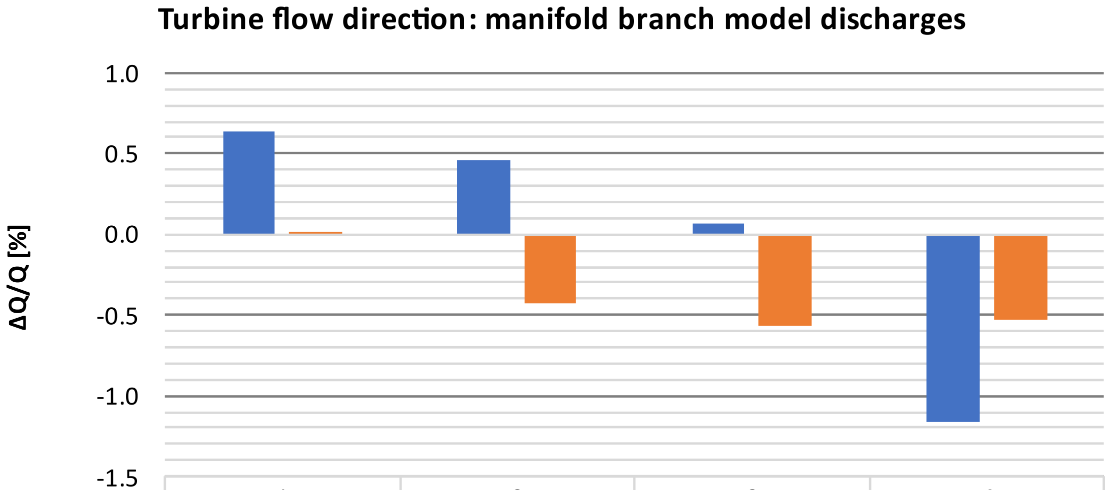
Hydraulic design of Quadrifurcation - results

- Flow distribution evaluated in percentage of average flow



	1	2	3	4
Initial	-0.42	0.20	0.05	0.18
Optimized	0.07	0.14	-0.03	-0.19

Branch nuber



	1	2	3	4
Initial	0.64	0.46	0.07	-1.16
Optimized	0.00	-0.43	-0.57	-0.53

Branch nuber

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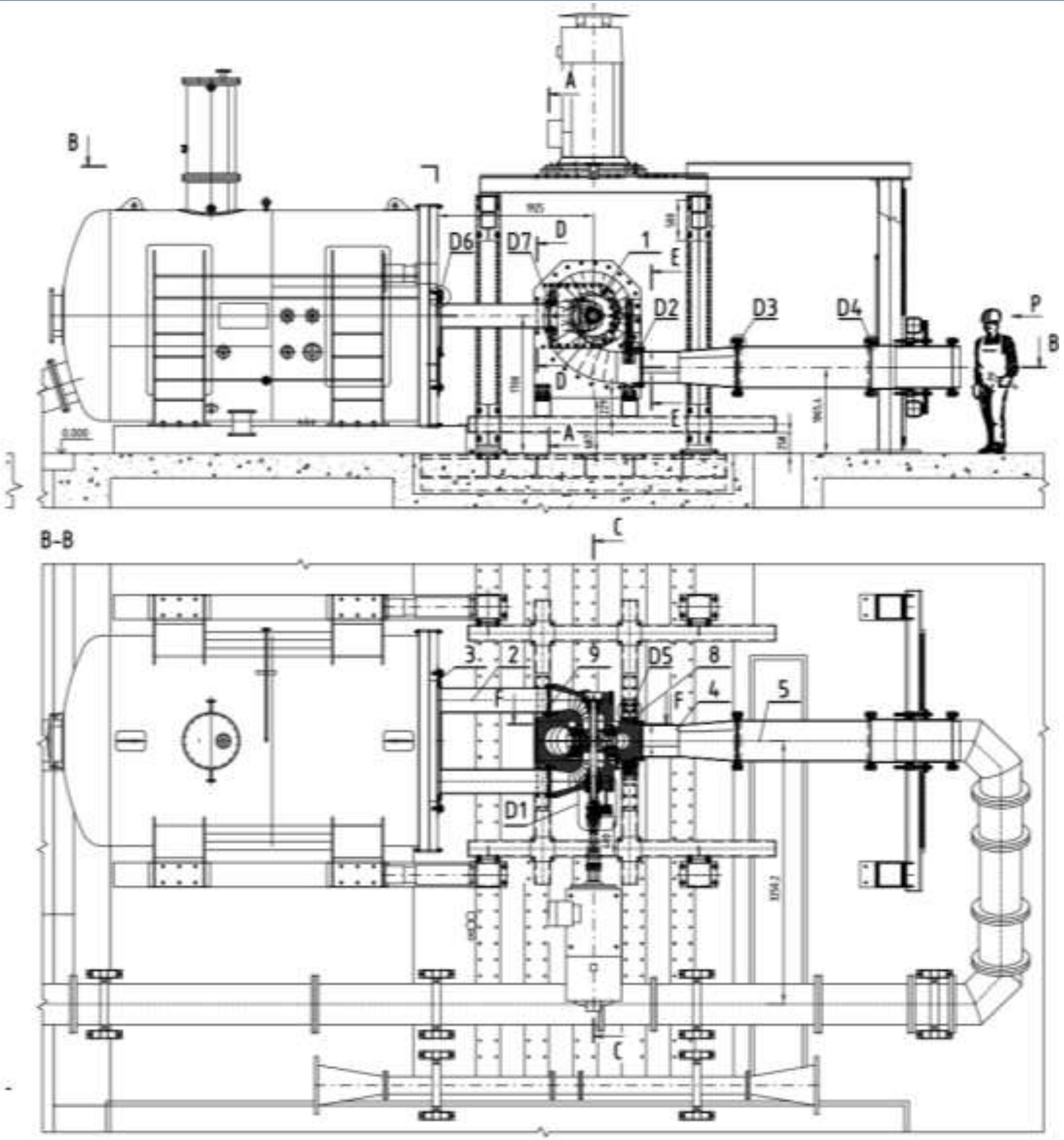
Model tests at hydraulic laboratory

- Double runner configuration will be tested
- Model runner reference diameter D_{REF}= 260 mm
- Two sets of stay vanes (20/10) will be ready
- Model tests will be carried out till end of 2021



Thank you for your attention.