Numerical Investigation of Pelton Turbine Distributor Systems with Axial Inflow

INSTITUTE OF ENERGY SYSTEMS AND THERMODYNAMICS

Univ.Ass. Dipl.-Ing. Franz Josef Johann Hahn

Senior Scientist Dr. Anton Maly*

Univ.Prof. Dr.-Ing. Christian Bauer

Tel.: +43-1-58801-302413 Email: anton.maly@tuwien.ac.at

Motivation

Storage, pump-storage and distributed small hydropower plants help to stabilise the volatile electricity market. They must provide excellent controllability and part-load operability. Their wide operating range and high part-load efficiency makes multi-injector fed Pelton turbines highly suitable for this type of operation, as long as a high-quality free-surface jet can be maintained. With conventional Pelton turbine distributors, a high-quality free surface flow is only achievable when the turbine is operated close to its design conditions. In off-design operation tear up and deformation of the jet may reduce turbine efficiencies. A high manufacturing effort for conventional distributors is a burden for small hydropower plants where construction and manufacturing costs are a decisive factor. Therefore, a design providing the same inflow conditions to every injector yet all the same made up of simple, standardisable pipe sections is desirable. One example of a novel design for a Pelton turbine distributor system is shown in [1]. Our project focusses on the assessment of the flow quality in such novel Pelton turbine distributor systems with axial inflow. We derive criteria to compare the losses of the entire system and to rate the amount of secondary flow at distinct evaluation stations. Also, we discuss the impact of parametric design changes on the flow in the distributor system.

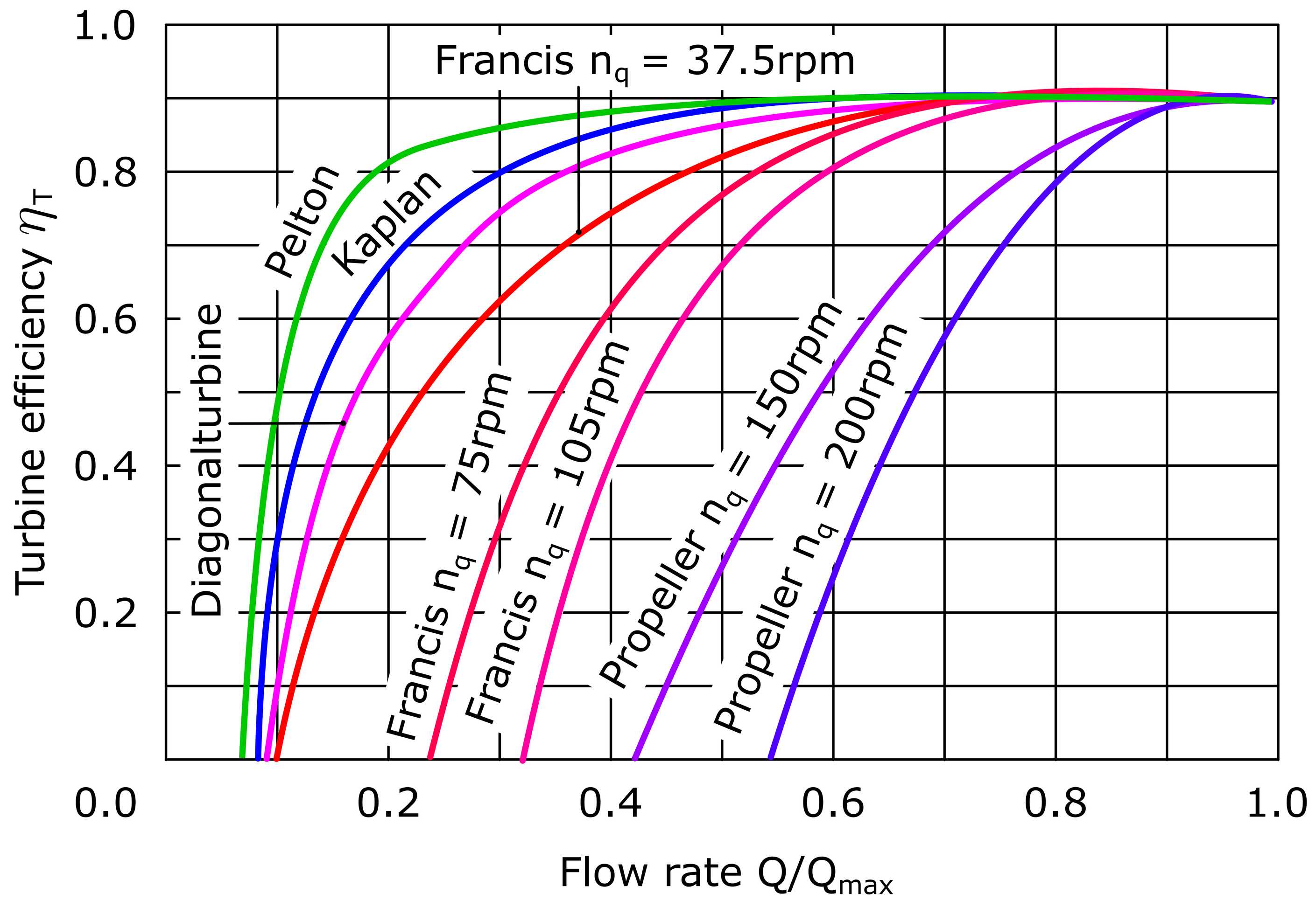

Figure 1. Efficiency curves for common turbine types, recreated from [2].

Flow Quality Criteria

For Pelton turbine distributors, the flow quality is determined by pressure losses and flow disturbances, which are generated mostly at bends and bifurcations. Following [3], we define the power loss coefficient between a reference station and station i

$$\zeta_{PmTE1i} = \frac{\int_{A_{\text{ref}}} \left(p + \frac{\varrho}{2}\vec{u}^2\right) \vec{u} \cdot d\vec{A} - \sum_{i=1}^{n} \int_{A_i} \left(p + \frac{\varrho}{2}\vec{u}^2\right) \vec{u} \cdot d\vec{A}}{\int_{A_{\text{ref}}} \left(\frac{\varrho}{2}\vec{u}^2\right) \vec{u} \cdot d\vec{A}} \quad (1)$$

and the secondary velocity ratio at station i is defined as

$$\phi_{II,i} = \left(\frac{||\vec{u}_{II}||}{||\vec{u}_I||}\right)_i = \left(\sqrt{\frac{u_{II}^2 + v_{II}^2 + w_{II}^2}{u_I^2 + v_I^2 + w_I^2}}\right)_i . \quad (2)$$

Here, $||\vec{u}_I|| = \vec{u} \cdot \vec{n}$ represents the magnitude of the primary flow velocity $\vec{u}_I = (\vec{u} \cdot \vec{n}) \cdot \vec{n}$ and $||\vec{u}_{II}||$ the magnitude of the secondary flow velocity $\vec{u}_{II} = \vec{u} - \vec{u}_I = \vec{u} - (\vec{u} \cdot \vec{n}) \cdot \vec{n}$.

Parametric Study

Four different fully parametrised distributor designs were investigated by numerical flow simulations. These four designs mainly distinguish themselves by the manifold body, which was either shaped as a diffuser, a sphere or a cylinder. Figure 2 exemplarily shows the basic model with a diffuser-shaped manifold, where the branch lines are connected to the manifold through a conical frustum.

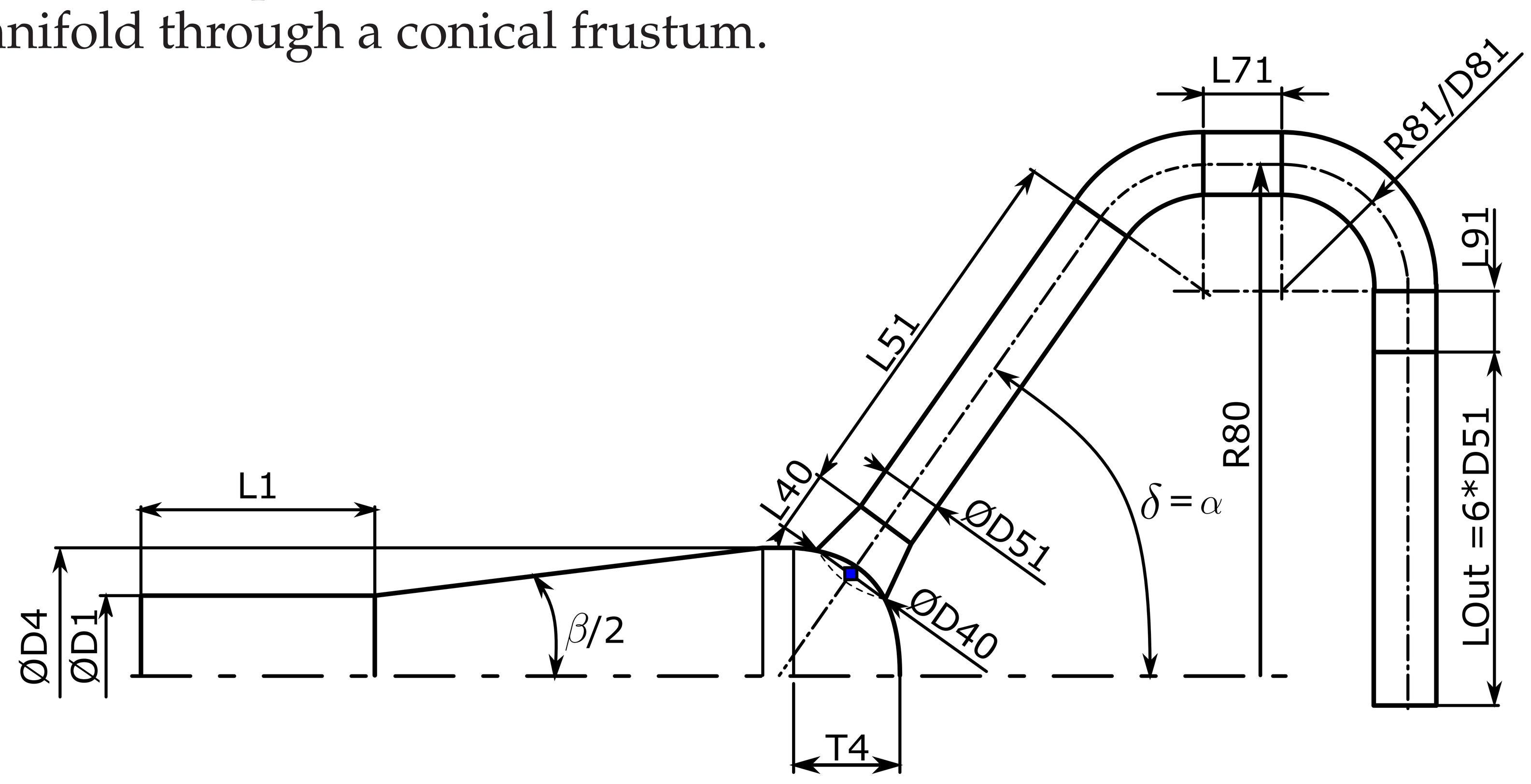

Figure 2. Sketch of the basic model with conical frustum, from [3].

The effects of variations of the base diameter D_{40} of the frustum and the deviation angle δ of the branch line on the power losses are displayed in Figure 3. While a change of the the deviation angle leads to a minor rise of the losses, an increase of the base diameter allows for greatly reducing the same quantity.

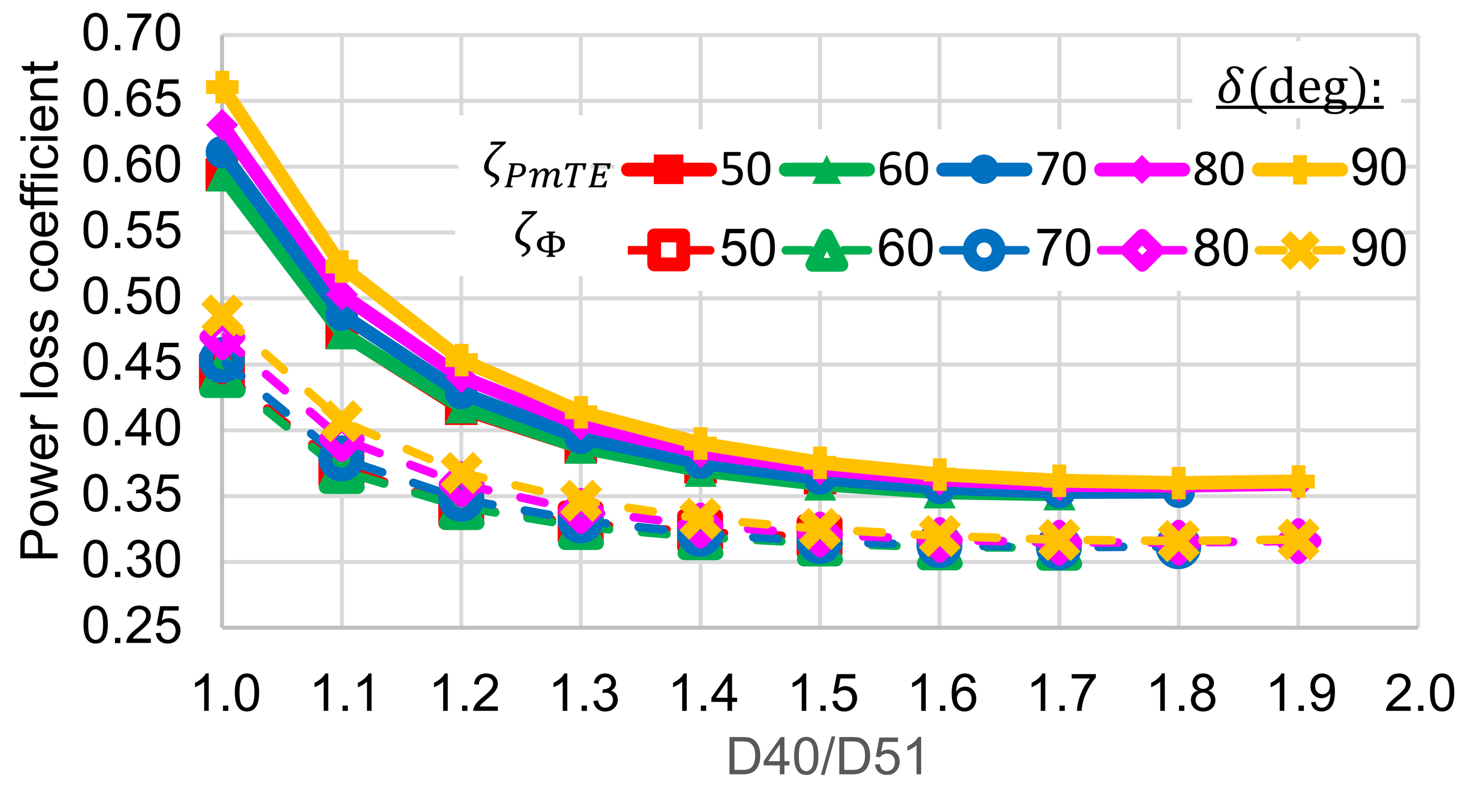

Figure 3. Power loss coefficients as a function of the diameter ratio D_{40}/D_{51} of the frustum for different deviation angles δ, from [3].

A change of the the deviation angle is much more significant on the secondary flow ratio, as Figure 4 proves, that an increase of δ lowers the magnitude of the secondary velocity ratio in the augmented station 101.

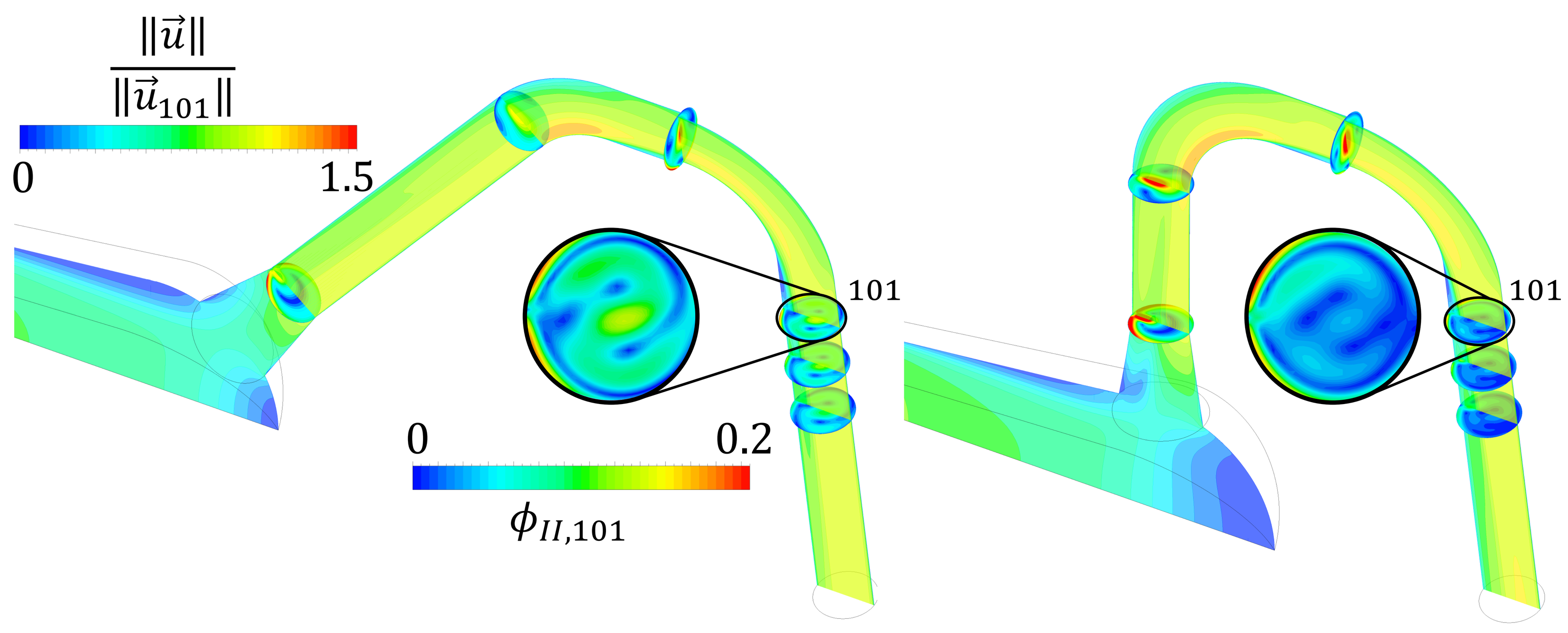

Figure 4. Flow velocity at midplane and secondary velocity ratio at several stations in the branch lines for the basic model with conical frustum, left: $\delta = 50°$, right: $\delta = 90°$, modified from [3].

Funding and Project Partners

FFG Österreichische Forschungsförderungsgesellschaft

gbd constructive thinking

References

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[2] J. Giesecke, S. Heimerl, and E. Mosonyi. *Wasserkraftanlagen: Planung, Bau und Betrieb*. Springer Berlin Heidelberg, 2014.

[3] F. J. J. Hahn, A. Maly, B. Semlitsch, and C. Bauer. Numerical Investigation of Pelton Turbine Distributor Systems with Axial Inflow. *Energies*, 16(6), 2023.