Fluid flow analysis of drooping phenomena in pump mode for a given guide vane setting of a pump-turbine model

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Key words: Pump-turbine, Flow analysis, Flow angle, Hydraulic loss, Drooping zone

Cite this as: De-you LI, Ru-zhi GONG, Hong-jie WANG, Wen-wen FU, Xian-zhu WEI, Zhan-sheng LIU, 2015. Fluid flow analysis of drooping phenomena in pump mode for a given guide vane setting of a pump-turbine model. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 16(11):851-863. [doi:10.1631/jzus.A1500087]

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Introduction

- Hydropower is the major renewable electricity generation technology worldwide. It has generated more electricity than all other renewable energies combined since 2005 (IEA, 2012).
- Pumped Storage Power Plants develop rapidly due to their effective electricity storage. A pump-turbine is the vital component
- The existence of drooping phenomena in the energy-discharge curve for a pump-turbine in pump mode will lead to operating instability.
- There are two reasons for drooping deriving from the technical definition. One is Euler (hydraulic rotational) momentum of the fluid ($\Delta c_u \cdot u$), which is an input parameter. The second is the frictional losses determined by both flow separation and boundary layers at different loads.

In this research, the reasons of the drooping behavior are built up.

1. Is it coming from incidence/deviation effects, due losses or both?
2. The losses in which part are more consequential to drooping.

Pump-Turbine Specification

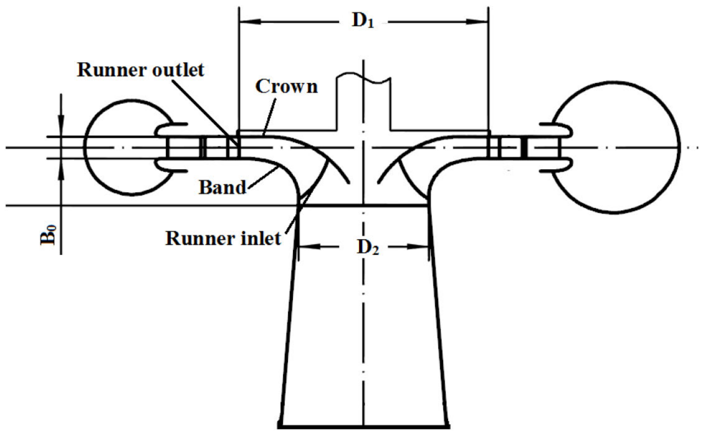

Fig.1 Sketch of the pump-turbine model

Table 1 Parameters of pump-turbine model

Parameters	Value
Runner outlet diameter D_1	524mm
Runner inlet diameter D_2	274mm
Number of blades Z	9
Number of guide vanes Z_G	20
Guide vane height B_0	45.77mm
Number of stay vanes Z_s	20

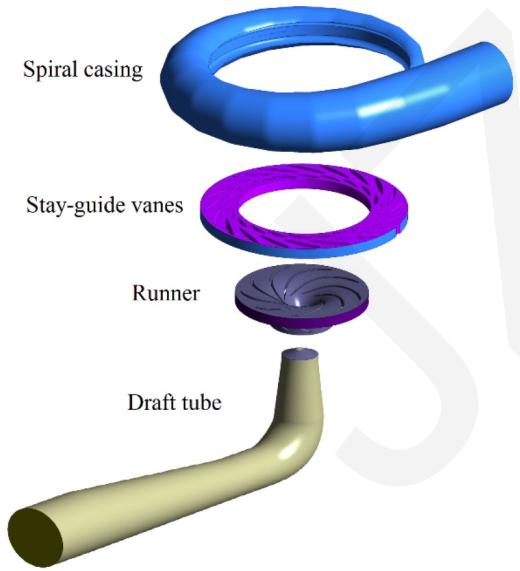

Fig.2 Computational domain

Fig.3 Test rig of a pump turbine model

Methods of analysis

Firstly, Based on validation of experimental benchmarks, five points-part-load (0.46φBEP), drooping zone load ($0.65\varphi_{BEP}$), near BEP ($0.90\varphi_{BEP}$), BEP ($1.00\varphi_{BEP}$) and overload ($1.24\varphi_{BEP}$) are chosen to analyze variation of flow angle at the leading edge (inlet) and trailing edge (exit).

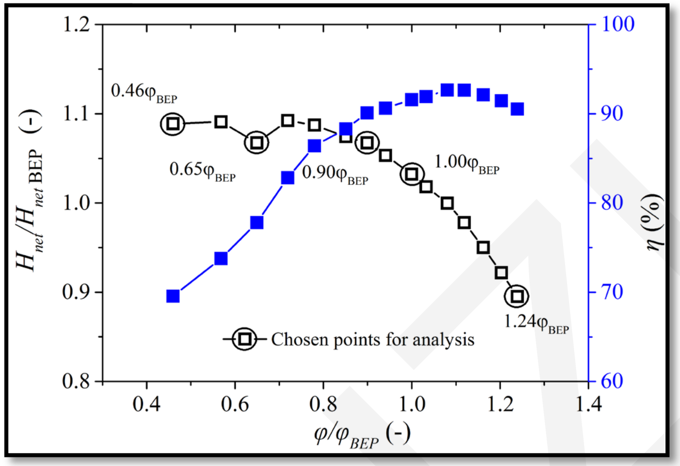

Fig.4 Information of the chosen analysis points

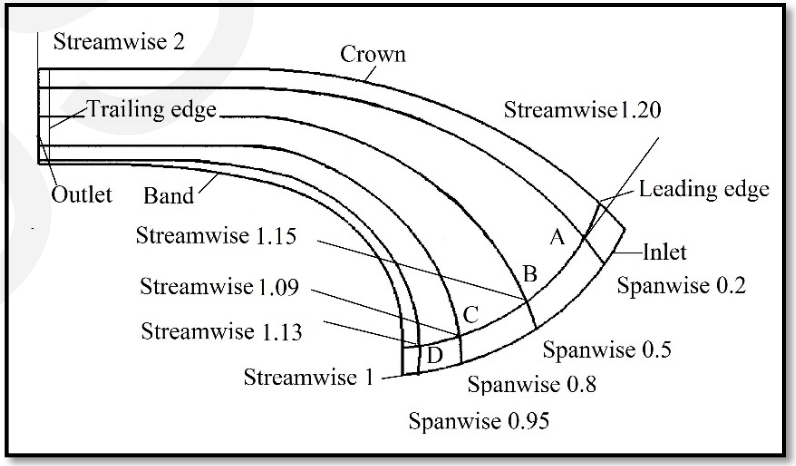

Fig.5 Schematic diagram of cross-sections studied

Secondly, through the Euler theory, Euler (hydraulic rotational) momentum of the fluid ($\Delta c_u \cdot u$) is obtained at different operating points based on the analysis of flow angle to find out its effects to drooping.

Methods of analysis

Thirdly, flow field analysis including velocity and pressure profiles, which is an extension of the flow angle studies, was carried out to show the separation zones at the different operating points.

Finally, frictional losses of the pump turbine are analyzed in the runner and tandem cascade at the different operating points to determine which part is more consequential to drooping.

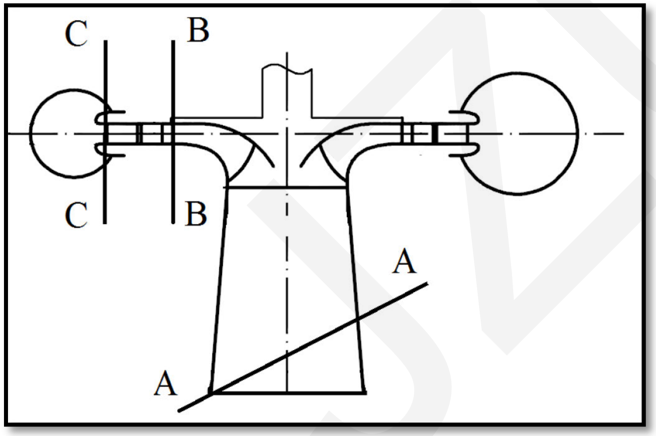

Fig. 6 Schematic diagram of cross plane outlet

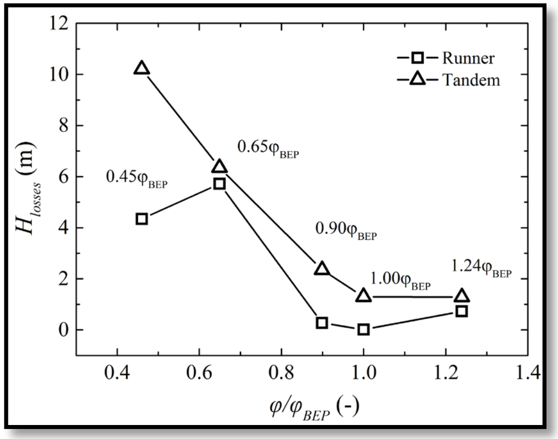

Fig. 7 Variation of hydraulic loss

Conclusions

1. Drooping phenomena in pump mode of a pump-turbine is investigated for a given guide vane setting (32mm) trough 3D numerical simulations using the SST *k-ω* turbulence model based on validation of experimental benchmarks

2. Drooping behavior is coming from both the incidence/deviation ($\Delta c_u \cdot u$) effect and frictional losses. Incidence and deviation effects are associated with the shape of the blade (inlet and exit). The losses are determined by both flow separation and boundary layers at different loads

3. Hydraulic losses in pump mode of pump turbines mainly focus on the runner and tandem cascade. Furthermore, the runner losses are more consequential to drooping.