Renewable Energy 77 (2015) 32–42

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Unsteady simulation and analysis for hump characteristics of a pump turbine model

Li Deyou [a], Wang Hongjie [a,*], Xiang Gaoming [a], Gong Ruzhi [a], Wei Xianzhu [a,b], Liu Zhansheng [a]

[a] School of Energy Science and Engineering, Harbin Institute of Technology, No.92 West Dazhi Street, Harbin 150001, Heilongjiang, PR China
[b] State Key Laboratory of Hydro-Power Equipment, Harbin Institute of Large Electrical Machinery, No.51 Sandadongli Road, Harbin 150040, Heilongjiang, PR China

ARTICLE INFO

Article history:
Received 10 February 2014
Accepted 1 December 2014
Available online

Keywords:
Fluid machinery
Pump turbine
Hump characteristics
Swirling strength

ABSTRACT

Presently, hydropower is the world's largest source of renewable energy. Pump Storage Power Plant develops the rapidly because of its effective electricity storage and becomes the most part of hydropower. A pump turbine is the vital component of a Pump Storage Power Plant. To obtain efficient generation, safe and stable operation of a pump turbine is pretty important. However, the existence of the hump characteristics of a pump-turbine in pump mode usually leads to operating instability. Thus it is necessary to analyze regions of the hump characteristics. In this research experimental investigation and numerical simulation are employed in order to study the hump characteristics. Unsteady incompressible turbulent flow simulations for the full pump turbine model water domain are performed using the SST k–ω turbulence model. A refinement grid is generated, which allows the corresponding y-plus values of the runner blades, stay vanes and guide vanes less than 2 in average. Calculation results of torque in different discharges as well as head and efficiency in the small discharge regions are in solid agreement with the experimental data. The results show that there are three vortex groups which distribute in the tandem cascade passages when entering the hump region. They are equally located in the circumferential direction in the tandem cascade, and one vortex group is located in two passages of the special stay vane. The strength and range of the vortex group change with different discharges. It also shows certain instability during one runner revolution. This work can provide a basic understanding for the improvement of the stable operation of a pump turbine.

1. Introduction

Current trends in energy supply and use are unsustainable-economically, environmentally and socially. Renewable energy plays a critical role in mitigating the tension between the energy demands and public concerns on environmental pollution [1]. Moreover, a number of countries around the world is boosting the development of renewable energy technologies due to constant increase in fossil fuel energy prices together with a need to improve their energy security [2]. According to International Energy Agency, hydropower is the major renewable electricity generation technology worldwide. Since 2005, hydropower has generated electricity more than all other renewable energy combined [3,4]. Hydropower is a mature and cost-competitively renewable energy source. It plays an important role in today's electricity mix, contributing to more than 16% of electricity generation worldwide and about 85% of global renewable electricity [3]. Pumped Storage Power Plants develop rapidly and becomes the most important part of hydropower because of its effective electricity storage. To obtain efficient generation, safe and stable operation of a pump turbine is pretty important. The current development of modern pump storage plants aims towards a higher flexibility and reliability in operation as well as an extended operation range of the hydraulic machine especially in pump mode [5,6]. The hump characteristic is one of the special characteristics of a pump turbine in pump mode with low discharge. When it runs in the hump region, the discharge is very low. This may cause strong fluctuations. Strong noise could be heard during the starting period and the start time is prolonged. To ensure the safe and stable operation of a Pumped Storage Power Plant, the investigation for hump characteristics is significant.

Up to now, the internal flow pattern investigations for the hump region in pump mode are limited. Most research for the internal

* Corresponding author.
E-mail addresses: Lideyou@hit.edu.cn (L. Deyou), Wanghongjie@hit.edu.cn (W. Hongjie).

http://dx.doi.org/10.1016/j.renene.2014.12.004
0960-1481/

Nomenclature

H	head (m)
Q_m	discharge of the pump (kg s^{-1})
y+	dimensionless wall distance
T_m	runner torque (N m)
T	time period (s)
Q_{BEP}	the best operating condition at 18 mm guide vanes opening (kg s^{-1})
λ_{ci}	swirling strength
n_s	the specific rotational speed
P	the power output

flow patterns in the hump region are investigated through experimental facilities by different testing methods [7]. Danciocan [8] studied the steady velocity distribution between the guide vanes and transient velocity distribution in the tandem cascade in the positive slope region. Nowadays CFD analysis is considered as a powerful alternative tool to provide insight into flow characteristics in hydraulic machines. A great deal of research based on CFD methodology has been applied to predict performance of part load, cavitation, rotor–stator interaction and pressure fluctuation for hydraulic machine [9,10]. Choi et al. [11] studied the performance improvement of a 500 kW Francis turbine using CFD methodology, and validated the calculation results with experimental data. The same goes with the experimental results, some useful conclusions were obtained. However, only a few investigations for hump characteristic has been conducted using CFD methodology and a few useful results has been obtained. Liu et al. [12] investigated the hump characteristic of a pump turbine based on an improved cavitation model, and the calculation results are in solid agreement with the experimental data. Braun [13] conducted some calculations for the flow distribution in pump mode and an accurate head-discharge curve was obtained. The results showed that there was strong vortex between the guide vanes and flow became worse when entering the hump region. Yan [14] obtained the same fluctuation results as the testing in the vaneless region by using compressible model. Iino [15] considered that the hump characteristic was related to complex vortex structure in the runner inlet and center region of the tandem cascade through simulation and experimental investigation. Most studies were carried out on revealing the hump phenomena and how to get the accurate hump characteristics curves. The wave trough of hump characteristics curve is the most unstable point of a pump turbine. But the study of instability for hump characteristics is limited. The mechanism of hump characteristic is still unknown.

Fig. 1. Test rig of pump turbine.

Table 1
Test rig parameters.

Characteristic	Value
Maximum head [m]	80
Maximum discharge [m^3/s]	0.8
Impeller diameter range [mm]	300–500
Generating power [kW]	750
The test rig accuracy	0.20%

In this paper, 3D unsteady incompressible turbulent flow simulations are performed in whole pump turbine model 360° using the SST k–ω turbulence model. A refinement grid is generated which allows the corresponding y-plus values of the runner blade surfaces, guide vanes and stay vanes less than 2 in average. The mechanism of hump characteristics is analyzed based on unsteady simulations. The results obtained are in solid agreement with experimental data, especially for the torque–discharge curve. Finally four points are chosen to get the key factor of hump characteristics of a pump turbine.

2. Pump turbine specifications

The parameters of the model installed in the Harbin Institute of Large Electric Machinery test rig (see Fig. 1) are shown in Table 1. It has 9 runner blades and 20 stay and guide vanes. The inlet diameter of the runner is 0.524 m and the outlet diameter is 0.274 m respectively. The specific rotational speed is defined as follows:

$$n_s = \frac{n\sqrt{P}}{H^{5/4}} \tag{1}$$

According to the parameters of this pump turbine, the specific rotational speed is 112.9 (m, kW). The whole configuration including spiral casing, stay vanes, guide vanes and draft tube is considered in the physical model, as shown in Fig. 2.

3. Numerical model

3.1. Grid generation

The ANSYS ICEM 14.0 is employed to generate the mesh used for each part. A structure grid is used for the whole pump turbine model 360° which is divided into five parts: spiral casing, stay vanes, guide vanes, runner and draft tube (see Fig. 3). In numerical simulation, high grid quality can obtain more accurate results. The quality of the block structured grid is an aggregative indicator of the mesh orthogonal angle, expansion factor, aspect ratio and so on. The value of the grid quality ranges from 0 to 1. The higher value

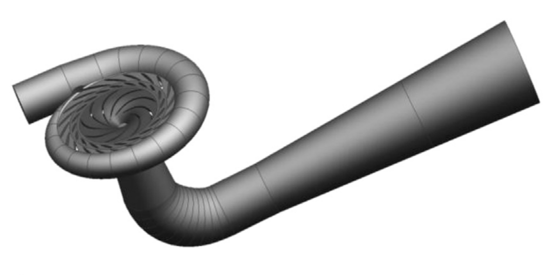

Fig. 2. The computational domain.