A Study on Structural Safety Evaluation of the In-pipe Turbine for a Micro-Hydropower System

Byung Chang Jung[1*], Young Cheol Huh[1], Jeong-Woo Han[1], Heung-Sub Kim[1], Jin-Woo Park[1], and Sang Hyuk Lee[1]

[1]Korea Institute of Machinery and Materials, Daejeon, South Korea

*Corresponding author: bcjung@kimm.re.kr

1. Introduction

Power generation using renewable energy sources such as solar, wind, hydroelectric, wave or biomass is increasingly required to reduce emission of carbon dioxide and global warming. Among renewable energy technologies, micro hydro-power using water flow in a pipe is beneficial due to high energy density, low construction cost and availability as distributed power sources in a city [1-3]. Since surface pressures of turbine blades rotating in a water pipe are relatively higher than those of wind turbines [4], structural safety of the turbine blades should be precisely analyzed and experimentally evaluated before installation on site. In this study, we devise a process of calculating equivalent one-point dynamic load for endurance test of a 50 kW in-pipe hydro turbine. In Section 2, specifications of the in-pipe hydro turbine and maximum blade pressure obtained from CFD analysis are briefly introduced. In addition, a process of calculating equivalent one-point dynamic load for endurance test is explained. In Section 3, setup, process and results of endurance test are summarized. It is concluded that the in-pipe hydro turbine satisfies the required durability performance.

2. Calculation process of equivalent loading condition

Fig. 1 and Table 1 show configuration and design condition of the in-pipe turbine. Fig. 2 shows maximum pressure distribution of the turbine while rotating one cycle in a pipe, and corresponding magnitude of blade nodal forces. To calculate one-point dynamic load, we assume that the blade is a both ends fully supported beam, and divide the beam (the blade) to 30 sections. Next, all the nodal forces at each section are summed. The 30 forces are applied at the designated location of sections, and calculated bending moments and shear forces are compared with those of the equivalent one-point dynamic load. Fig. 3 shows comparison results of bending moments and shear forces. It is confirmed that bending moments of both ends of the beam are similar. Finally, magnitude of one-point dynamic load is calculated as 5.244 kN. Location (h) and directions of the one-point dynamic load (α and β) is displayed in Fig. 4(b).

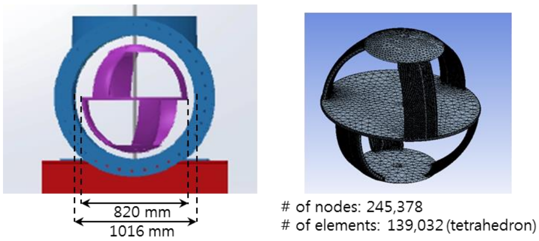


Fig.1 Configuration of the in-pipe turbine

Table 1 Design condition of the in-pipe turbine

Pipe diameter	Turbine diameter	Water velocity	RPM
		normal design condition	
1.016 m	0.82 m	6.81m/sec	102

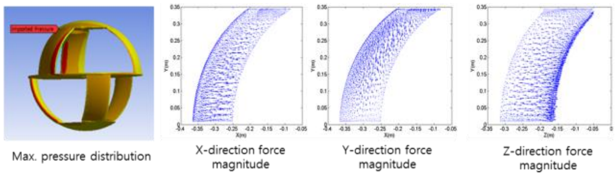


Fig.2 Pressure and force distribution on the turbine blade

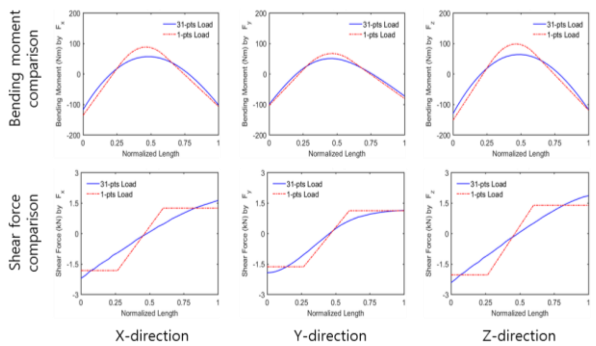
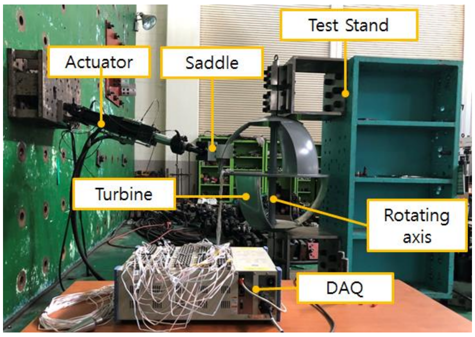


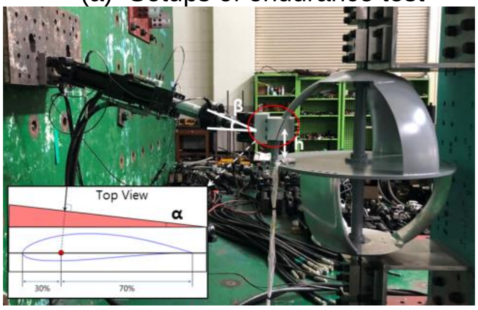
Fig.3 Comparison results of bending moments and shear forces

3. Experimental setup and test results

Fig. 4(a) shows setup of endurance test. One-point dynamic load is applied to the blade of the turbine using an actuator, and the saddle fixed on the blade guides the directions of the load. The rotating axis is fixed to the test stand. Seven strain rosettes (R1~R7) are positioned on the bottom of the blade as shown in Fig. 5(b). When the one-point dynamic load, 5.244 kN, is applied to the blade, stress is measured as 17.4 MPa. It is close to simulation result, 20.6 MPa, as shown in Fig. 5. The number of cycles and magnitude for the accelerated test are calculated based on the S-N curve in Ref.[5] as shown in Fig. 6 and Table 2. By the dye penetration test after 24 days endurance test, structural safety of the turbine blade at a normal operating condition is confirmed.

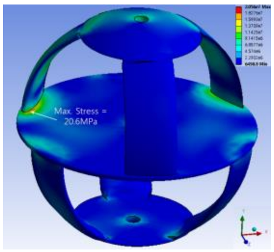


(a) Setups of endurance test



(b) Loading direction (α=17°, β=15°, h=0.153m)

Fig.4 Experimental Setups



(a) Predicted contour (pressure loading)

(b) Measured stress (equivalent one-point loading (5.244 kN))

Fig.5 Comparison of stress levels

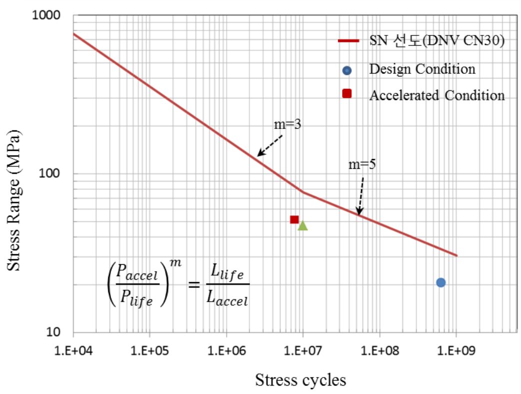


Fig.6 S-N curve [5] and test condition

Table 2 Design and test conditions

	Design condition	Accelerated test condition
Life cycles	$6.32\text{x}10^8$ cycles (102RPM×60min/hr ×5160hr/yr×20yr)	7,702,119 cycles
Dynamic load	0 ~ 5.244 kN	0 ~ 13.11 kN

4. Conclusion

In this study, structural safety of the in-pipe hydro turbine is experimentally evaluated. First, a blade pressure of the turbine while rotating one cycle in a pipe is obtained by CFD analysis. Next, one-point dynamic force which makes equivalent bending moments and shear forces to the blade is calculated for the endurance test. It is confirmed that measured stress at the turbine when applying one-point dynamic force is similar with predicted one. Using the DNV S-N curve of the material [6], dynamic load and the number of cycles for accelerated endurance test are calculated, and endurance test and dye penetration test are carried out. Finally, it is concluded that the in-pipe turbine for the micro-hydropower system satisfies the required durability performance.

Acknowledgment

This work was supported by the Technology Innovation Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (No. 20162010104420).

References

[1] M. Casini, Harvesting energy from in-pipe hydro systems at urban and building scale, *International Journal of Smart Grid and Clean Energy*, 4(4) (2015) 316-327

[2] D. Hoffmann, A. Willmann, R. Gopfert, P. Becker, B. Folkmer, and Y. Manoli, Energy Harvesting from Fluid Flow in Water Pipelines for Smart Metering Applications, *Journal of Physics: Conference Series*, 476 (2013) 012104

[3] I. Samora, P. Manso, M. J. Franca, A. J. Schleiss, and H. M. Ramos, Energy Recovery Using Micro-Hydropower Technology in Water Supply Systems: The Case Study of the City of Fribourg, *Water*, 8(344) (2016)

[4] H Kim, B. Kim, and H. Kang, Performance Prediction of a Helical Turbine for Micro-Hydropower in Water Pipe Line, *Journal of Korean Society of Mechanical Technology*, 17 (2) (2015) 349-354.

[5] DNV-RP-C203, Fatigue Design of Offshore Steel Structures, 2011