CERIS Civil Engineering Research and Innovation for Sustainability

Pumps running as turbines for energy recovery in water supply systems

Summary

Pressurised water supply systems are infrastructures that offer a potential for energy recovery in locations where these systems operate with an excessive pressure. The integration of micro hydropower plants for energy recovery is a challenge, as these systems feature a significant daily discharge variation, which limits the domain of operation of these power plants. Pumps running as turbines (PATs) are hydraulic machines suitable for this application, despite facing two major issues. Firstly, PATs are characterised by a sharp efficiency decrease when operating far from the best operating point. Secondly, the characteristic curves of the turbine mode are not provided by pump manufacturers, which hinders the implementation of PAT power plants. The present thesis is based on the experimental investigation of the variable speed operation of centrifugal pumps used as turbines aiming at optimising the energy recovered. A new methodology is developed, firstly, to estimate the performance of the turbine mode (flow rate, specific energy, power and efficiency) and, secondly, to model the variable speed hill chart performance of PATs. The research procedure includes the experimental investigation of the characteristic curves of the PATs, the experimental investigation of the unstable phenomena experienced by the PATs and, finally, the development of an empirical model for predicting the PATs performance. Firstly, the variable speed operation of PATs is experimentally investigated. Data are collected for three single-stage end-suction centrifugal pumps with different unit specific speed values to characterise the characteristic curves of the turbine mode and of the extended operation in the generating mode. Measurements of the water temperature, the discharge, the pressure, the torque and the rotational speed are performed to determine the hydraulic and the mechanical performance of these PATs. Secondly, the pressure fluctuations developed during the part load and the full load operation of PATs are investigated. Data collected include the pressure measurements in the high and in the low pressure sections of the PAT and the high speed flow visualisation in the PAT draft tube. The spectral analysis of the pressure measurements and the image processing of the flow visualisation highlight the dynamics of a cavitation precessing vortex rope that develops in the PAT draft tube. Thirdly, a new empirical model is developed to estimate the hydraulic and mechanical characteristic curve of PATs and to model the variable speed hill chart performance of the PAT. The methodology is based on the Hermite polynomial chaos expansion (PCE), which propagates the known characteristic curves obtained during the experimental tests, providing a continuous surrogate function for predicting the characteristic curves of a given PAT, inside the range of unit specific speed values tested. The PCE is, afterwards, applied for modelling the variable speed hill chart performance of the PAT. Obtained results provide an insight on the variable speed operation of PATs with respect to the turbine mode, the extended operation in the generating mode, the possibility of the development of pressure fluctuation instabilities and, finally, the modelling of the variable speed hill chart performance for a given PAT. The hill chart model is described by a continuous polynomial function, which can be used to optimise the design and the operation of PAT micro hydropower plants, aiming at maximising the energy recovered and at avoiding potential instabilities caused by the part load and the full load operation.

Keywords

Pumps running as turbines, variable speed operation, water supply systems, hydropower, performance prediction, hill chart modelling.

Test-Hydro pipe-rig for testing small-power reaction turbomachines in both transient and steady state conditions, assembled at the Hydraulics and Water Resources Laboratory of IST.

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