VISUALIZATION TECHNIQUES FOR SUPERSONIC BLADING DESIGN FOR ORGANIC RANKINE CYCLES

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ABSTRACT

The experimental results based on flow visualization techniques are presented in this paper in order to validate the computational outcomes regarding the real gas effects on the design of supersonic power production turbine for low enthalpy organic Rankine cycle (ORC). The “water table” test rig was built in the premises of the Laboratory of Fluid Mechanics and Turbomachinery of the Aristotle University of Thessaloniki to observe and verify the existence of the developed shock waves at the desirable location inside the blade passages as depicted from CFD results. For shock wave losses minimization, the “Method of Characteristics” is used. In particular, the stator design was performed by following the “Minimum Length Nozzle” concept for material and manufacturing cost reduction, as well for weight minimization, while the “Vortex Flow Method” was preferred instead of the “Corner Flow Method” for the rotor design because the maximization of the produced power is the key parameter for the current thesis.

INTRODUCTION

Over the last decades, a surge in consumption of fossil fuels has led to serious environmental problems such as global warning protection, destruction of ozone layer and atmospheric pollution. For these reasons, an increasing trend in exploitation of low-enthalpy heat sources in the field of power production from waste heat recovery, has gained a renewed interest. Towards to this direction, Organic Rankine Cycle systems have proven to be a very promising solution to avoid aggravation of this problem. ORC systems operate with heavy and molecular complex organic substances as the working fluid, which results to completely different design concept of the turbine compared to either standard gas or steam turbine designs. Also, during dry expansion, these fluids are close to dense gas region (on the right side of the saturation line) where the speed of sound is fairly low. This means that supersonic turbines with high-expansion-ratio must be used to ensure efficient performance (≥75%) of the power production turbine. On the other hand, the designers should be aware of the generated shock and expansion waves within blades passages, because of supersonic conditions, that enhance losses. For shock wave losses minimization, the “Method of Characteristics” is used. In particular, the stator design was performed by following the “Minimum Length Nozzle” concept for material and manufacturing cost reduction, as well for weight minimization, while the “Vortex Flow Method” was preferred instead of the “Corner Flow Method” for the rotor design because the maximization of the produced power is the key parameter for the present work.

The experimental test bed was designed and constructed in order to validate the compressibility phenomena that been developed throughout the supersonic passages inside the ORC turbine by means of flow visualization methods. The developed experimental rig [figure1] consists of a water table apparatus which can simulate compressible flows and the corresponding shock and expansion waves in combination with the generated vortices as depicted in CFD results. The concept of using a water table for the observation of the compressibility phenomena is based on the hydraulic analogy, which in fact is the analogy between the Mach number of a two-dimensional compressible flow and the hydraulic jump of a water flow with a free surface which is directly connected to Froude number.

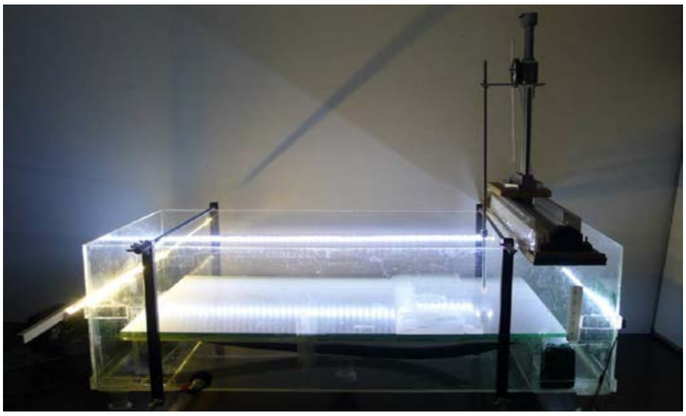

Figure 1. "Water table" Experimental setup

RESULTS AND DISCUSSION

The main outcome suggests that the working fluid choice must be done with utmost care as it has a significant influence on both ORC thermal efficiency and turbine performance while differentiated blade geometries will occur considering the dominant shock losses. Finally, although the outcomes from the flow visualization experiments shown that the proposed design method seems not to be robust enough to account for the operating variations (off-design), the generated shock waves were positioned as indicated by the theoretical analysis. More specifically, the last expansion wave appears to be only 4% further compared to computational outcomes [figure 2], while no reflection phenomena occurred inside the stator blade passage which means the applied design method is proven to be a dependable tool for the maximization of the produced power.

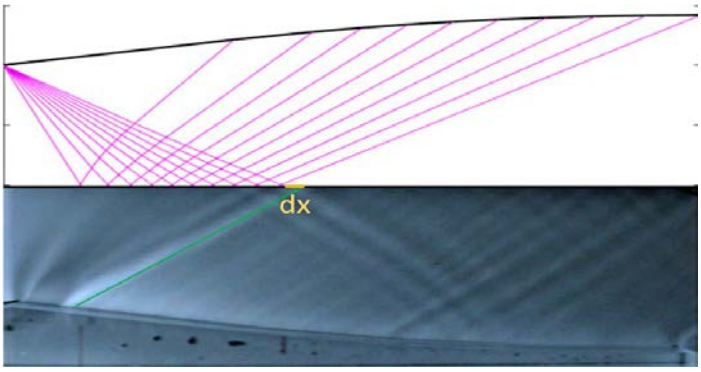

Figure 2. Experimental VS Analytical results

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