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Exit-flow velocity survey of two single-tangential-inlet vaneless turbine volutes

Adam M. Fuller *, Keith V. Alexander

Department of Mechanical Engineering, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

A R T I C L E I N F O

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The most cited analytical technique for designing turbine volutes is to assume the throughflow is free from torque, although for this assumption to hold, the volute walls must lie near what would be streamlines in an unbounded free vortex-plus-sink flow. The single tangential inlet design, with inlet offset decreased and diameter increased to attain the weak exit swirl required by high specific speed turbines, deviates from such a shape, and the volute's internal geometry is no longer torque-free. It is desired to know the actual time-averaged flow leaving such a volute, so that a rotor can be designed to compliment it.

For two existing single tangential inlet volutes, time-averaged radial and tangential velocity and static pressure measurements of exit flow have been obtained on a cylindrical cut plane through the radial-inflow section using a three-port yawmeter in air. The Reynolds numbers based on inlet pipe mean conditions, around 10^5, are well into the fully-turbulent regime and on the order of comparable water turbines.

A comprehensive map of time-averaged exit flow of both volutes is presented. The integrated values of gross angular momentum flux change and total pressure loss coefficient are tabulated. Circumferential variation of flowrate and swirl strength highlight unexpected differences in outlet flow between the two volute designs. Results are presented alongside corresponding numerical results from the commercial package Fluent (Fluent, Inc., Lebanon, NH, USA) using Reynolds stress, k–ω, and inviscid flow models.

In both volutes, measured gross exit angular momentum flux was more than 1.7 times what the zero-torque assumption would predict when blindly applied to the volute as a whole. This discrepancy is attributed to significant turning near the volute's inlet region leading to an updated view of what an appropriate control volume is when applying the zero-torque assumption. Additionally, variation of both radial and tangential velocity in both the circumferential and axial directions on the order of 15% of the mean value reveal that volute swirl characterization by a single measurement would have a significant associated uncertainty.

1. Introduction

In turbomachinery design, matching flow angles to rotor blade angles is a common goal to minimize losses. While the through-velocity is typically easily deducible from flowrate and passage cross-sectional area, the swirl component may be sensitive to more subtle influences originating upstream. Furthermore, for fixed-geometry turbines which must operate at a fixed speed, e.g. micro-hydro turbines without guide vanes directly producing mains alternating current, the efficiency versus speed curve is relatively narrow, so matching the volute exit flow angle to the rotor leading edge blade angle is imperative to designing turbines which operate at maximum peak efficiency.

Here, the focus is on two existing single tangential inlet volutes for the N_S176 and N_S544 turbines described by Alexander et al. [1]. In the absence of guide vanes, the inlet's offset relative to the volute exit centerline, dimension '*F*' in Fig. 11 and mean inlet velocity are the two key parameters determining volute exit swirl. The simple assumption commonly applied to scroll casings is that there is no torque on the flow, meaning that the value of rV_t is unchanged through the volute. The two volutes examined here were designed based on this assumption, but are thought to perform off-design, although this has not been explored in detail until now. The parameter F_{AM} is introduced later as the ratio of volute outlet to inlet angular momentum flux, highlighting deviations from the torque-free assumption.

From the perspective of swirling flow requirements, turbines might be considered distinct from other applications of swirling flow such as cyclone separators [2,3], combustors [2,4,5], and chemical mixing chambers [6] which use very similar geometry, but have no spinning rotor and therefore less stringent demands on swirl strength to perform satisfactorily. In most turbine applications where precise flow angles are required, guide vanes are used to set the flow direction with more certainty. A notable exception to the guide-vane paradigm is the common turbocharger, whose rotor operates at a wide range of speeds and therefore would not

* Corresponding author.
E-mail addresses: adam.fuller@pg.canterbury.ac.nz (A.M. Fuller), keith.alexander@canterbury.ac.nz (K.V. Alexander).

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