DESIGN GUIDELINES FOR AXIAL TURBINES OPERATING WITH NON-IDEAL COMPRESSIBLE FLOWS

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ABSTRACT

Preliminary design methods based on similarity theory. i.e. the Smith's chart, are a powerful and well-established tool to provide estimate of the size, the shape of the velocity triangles, and the fluid-dynamic performance of gas turbine stages. However, such criteria are arguably not suitable for the design of turbomachines operating with highly complex molecules that exhibit non-ideal fluid dynamic behaviour. In these machines, the departure of the flow from the ideal gas law can significantly alter the amount of dissipation induced by the various loss mechanisms, which may eventually result in shifts of the optimal design region.

Currently, physical comprehension of loss mechanisms in these turbines is mainly revealed through computational fluid-dynamic studies, which are indeed machine-specific and cannot be used to draw best design practices. On the other hand, the existing body of work [1] on design guidelines using meanline methods rely on semi-empirical loss correlations and lacks of thorough validation using higher-fidelity models.

This work aims to bridge this gap by proposing a meanline design procedure based on scaling analysis and coupled to a first principles loss model [2] extended to arbitrary fluid thermo-physical models. The developed model is used to investigate the performance trends of axial turbine stages operating with fluids of increasing molecular complexity (CO_2 and MM) and operating in the ideal and non-ideal thermodynamic region. The specific objectives are i) to draw improved design guidelines and performance maps valid for axial turbines, ii) to gain insight of the main loss mechanisms in these stages, and iii) to provide physical understanding behind such loss mechanisms.

The outcomes of the study suggest that the so-called Smith line, i.e. the locus of the optimal duty coefficients, is function of the fluid molecule and the turbine expansion ratio. An increase of the expansion ratio directly translates into stronger shocks-induced losses, associated with higher Mach numbers along the stage. Molecular complexity mainly affects dissipation due to mixing, e.g. trailing edge wake and leakage flow, shifting the region of optimal performance towards lower flow coefficients. 3D RANS CFD calculations are finally used to verify the predicted trends. The results corroborate the findings based on scaling analysis, paving the way to best design practices for single and multi-stage axial turbines operating with non-ideal compressible flows.

[1] L. Da Lio et al. "New efficiency charts for the optimum design of axial flow turbines for Organic Rankine Cycles". Energy, Vol. 77, 2014.

[2] Denton, J.D. "Loss Mechanisms in Turbomachines". The 1993 IGTI Scholar Lecture.