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Performance prediction of a nozzled and nozzleless mixed-flow turbine in steady conditions

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ABSTRACT

This paper presents a meanline model to predict the performance parameters of a turbocharger turbine under steady state conditions. The turbine was developed at Imperial College and the design was based on a commercial nozzleless unit that was modified into a variable geometry single-entry turbine.

The wide range of tests data from the Imperial College Turbocharger Group dynamometer enabled the evaluation of the model in the areas of the turbine map where currently no previous comparison had been made in the literature. This facility is designed to allow testing over a wide range of velocity ratios (0.3–1.1) previously unavailable with conventional test stands.

The nozzleless turbine model was validated against experimental results spanning an equivalent speed range of 27.9 and 53.8 rev/s $\sqrt{K}$ while for the nozzled case the model was validated against one single speed (43.0 rev/s $\sqrt{K}$) and three different vane angle settings (40°, 60° and 70°).

The results of the model simulation showed that the performance can be predicted with excellent accuracy for different turbine speeds and vane angles. Based on the model prediction, a breakdown aerodynamic loss was performed.

1. Introduction

Nowadays the more and more stringent limitations in emission regulations in the automotive sector have increased the demand for Exhaust Energy Recovery Systems (EERS). In particular the current trend of pushing towards heavily downsized engines make the EERS essential to the overall economy of a vehicle and its fuel consumption: heat recovery systems, organic rankine cycles and batteries seem to be in vogue as potential future EERS even though their implementation in mass production is still limited to a niche.

Despite being an established technology, turbochargers play a key-role amongst the EERS: costs and size together with improved engine performance make turbochargers the primary choice of car manufacturers. Significant improvements have been made in the design of turbochargers (aerodynamics, materials and bearings reliability have dramatically enhanced over the years) and therefore one of the main challenges in the current research is

(1) tackling issues related with turbocharger performance under pulsating flow conditions and
(2) understanding their impact on the overall engine performance. The implementation of fully unsteady turbocharger models is still far from being achieved due to (1) the complexity of the flow mechanisms occurring within the turbine and (2) the high demand of computational resources, which would be required.

Engine manufacturers commonly use commercial 1-D gas dynamic codes, which have already proven their effectiveness in many respects (combustion, acoustic and emissions) and compare well against experimental results [1]. Commercial turbocharger/engine matching software is developed around the assumption that turbochargers behave in a quasi-steady manner. This implies that the turbine and the compressor behave in a quasi-steady manner in which the enthalpy rise, the mass flow and the torque produced by the turbine are calculated by interpolating a steady state map. Although the quasi-steady assumption is far from being representative of the unsteadiness occurring within a turbocharger and despite there are still ongoing debates on the pertinence of such an approach (which go beyond the scope of this paper), the quasi-steady assumption gains its strength in that it only requires the knowledge of steady state maps, which are usually made available by turbocharger manufacturers since they do not have to disclose geometrical information of their product [1]. However the main drawback associated with these maps is that they are usually narrow in range (due to the limitation of

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