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Effect of Circuit Geometry on Steady Flow Performance of an Automotive Turbocharger Compressor

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Abstract

Downsizing and turbocharging are today considered an effective way to reduce CO_2 emissions in automotive gasoline engines. To this aim, a deep knowledge of turbocharger behavior could be a key solution to improve the engine-turbocharger matching calculation. The influence of the intake system geometry on the surge line position is an important aspect to guide the project of the intake manifold, enlarging the compressor stable zone. This aspect has a considerable impact on engine performance, especially during transient operation. A wide experimental investigation was carried out at the turbocharger test facility of the University of Genoa on a small turbocharger compressor. Compressor characteristic curves measured considering an automotive intake circuit are compared with standard maps provided by turbocharger's manufacturer. This information allows the optimization of 1D model implementing more realistic maps of compressor. The influence of three different layouts has been investigated varying overall circuit volume and length, keeping values in a range compatible with passenger cars packaging constraints. In the paper, the main results of the experimental campaign are presented taking into account the influence of geometry variations on compressor map and surge line position.

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Keywords: Turbocharging; centrifugal compressor; internal combustion engine; surge; unstable zone; experimental.

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1. Introduction

The goal of CO_2 reduction imposed by the European Commission for new registered passenger cars leaded manufacturers to develop technological solutions to limit vehicles exhaust emissions and to reduce engine fuel consumption [1], especially considering vehicle real driving conditions and cold start [2]. Downsizing and turbocharging techniques seem to be a key technology to reach this target. Since 1D models are usually employed for matching calculations, an accurate definition of turbocharger (TC) performance when coupled to the engine is required to properly accomplish numerical simulation models [3-5]. Some typical drawbacks are linked to the performance maps typically provided by turbocharger manufacturer and implemented in 1D model:

- Only steady flow maps are available, while TC coupled to the engine operates under unsteady flow conditions
- Maps are usually defined over a limited range requiring strong extrapolation [6]
- Experimental characteristic curves are commonly measured in steady state using layout strongly different to the intake automotive circuit
- The methodology adopted to define the surge line position is usually not specified
- No information is provided about sensors location, thus increasing the uncertainty in the compressor efficiency calculation.

Therefore, the availability of detailed experimental information on turbocharger performance under both steady and unsteady flow conditions is an essential requirement to improve simulation models [7, 8].

The reduction of engine displacement with a reduced number of cylinders and the adoption of Variable Valve Actuation systems drives the compressor to work under unsteady flow conditions [9-11]. Compressor unsteady behavior also occurs near the surge line, thus reducing mass flow rate and inducing local unstable operation. The surge phenomenon, i.e. the periodic return of the compressed fluid through the compressor towards its inlet, can limit the pressure ratio capability, especially when the engine is working at low speed and high load. Car manufacturers limit boost pressure level to prevent surge condition in order to avoid a deterioration of rotor blades, a significant drop in the efficiency and a fluctuation of the supplied engine power. Compressor stability is a very complex issue and several studies are available in the open literature to deepen the dynamic of this phenomenon and the surge line definition properly controlling compressor instability [11-14]. In 1976, Greitzer [11] proposed a mathematical model to reproduce the dynamic response of compression system as a function of the circuit geometry [11] representing the starting point for many studies about compressor surge. In [15] Capon and Morris compared two compressor maps, one measured in standard steady-state operation [16], the other measured coupling the compressor inlet to an automotive intake circuit. These results highlighted the importance of dedicated experimental tests to reproduce the real compressor behavior, correctly defining the position of the surge line.

The strict packaging requirements for the engine and its accessories generally produce unfavorable flow at the compressor inlet. Different studies to investigate the influence on compressor performance of the flow conditions at its inlet have been developed, proposing solutions to improve the flow field through different diffuser shapes [17] or bleed channels [14] to obtain map improvements. In [18] and [19] the influence of the compressor inlet design on compressor map has been investigated, while pre-whirl flow at compressor inlet has been studied in [20, 21] in order to reduce negative effects of an inlet flow perpendicular to the compressor axis. Particularly, Galindo et al. [21] proposed an inlet swirl generator device (SGD) that can be used also to extend the surge margin by modifying its blades depending on the engine operative conditions.

Even if the influence of compressor intake circuit has been deeply investigated, a lack of information can be observed concerning the influence of the compressor downstream circuit.

In the paper, the results of a wide experimental campaign in steady state are presented. The investigation allowed to extend compressor maps definition considering the typical engine circuit geometries, thus reducing extrapolation errors in simulation models and guiding circuit design to achieve an optimization of turbocharger behavior. A comparison between compressor maps measured adopting an automotive intake circuit and turbocharger manufacturer's map is reported. Through a specific variable volume plenum integrated in the downstream compressor circuit, three different automotive intake circuit arrangements were tested, following specific requirements by a car manufacturer. The last stable point of the compressor was fixed monitoring the instantaneous