

Effect of Pulsating Flow Characteristics on Performance and Surge Limit of Automotive Turbocharger Compressors

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ABSTRACT

The flow in turbocharger compressors and turbines for automotive engine application is highly unsteady in nature, as it responds to the intake and exhaust manifolds of the internal combustion engine. The optimization of the turbocharger system is therefore a very difficult task, since only steady flow maps are generally provided by turbocharger manufacturer.

For several years a specialized components test facility operates at the University of Genoa, particularly suitable to test turbochargers under steady and unsteady flow conditions. The test bench has been continuously upgraded in order to study components under pulsating flow condition by using different layout configurations. A recent set-up makes it possible to study turbocharger compressor under unsteady flow condition by using a rotating valve pulse generator system. Measurements of pressure signals downstream the compressor, instantaneous mass flow rate and turbocharger rotational speed are performed.

In the paper the effect of both pulse characteristics (frequency - i.e., engine rotational speed -, amplitude and mean value) on compressor performance is analyzed. In particular the attention is focused on the surge limit position under unsteady flow operation.

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INTRODUCTION

Downsizing and turbocharging are today widely used in both gasoline and diesel automotive engines to attain lower fuel consumption and exhaust emissions [1, 2]. The optimization of the turbocharging system is therefore a very difficult task. In this scenario, it's apparent that a better knowledge of turbine and compressor performance when coupled to the engine is required in order to properly carry out numerical simulation models.

The one-dimensional (1D) model, generally adopted to compute the engine-turbocharger matching calculation, requires several information on turbine and compressor behavior. Different obstacles have to be overcome in order to minimize the inaccuracy of the calculation [3, 4, 5].

The ordinary lack of information on turbocharger unsteady flow performance, typically occurring in the intake and exhaust automotive circuit, is a heavy limit. Only steady flow maps, defined in a restricted operating zone, are generally provided by the turbocharger manufacturer hence causing errors in the curve extrapolation. Besides, only few research facilities are able to experimentally reproduce the typical unsteady flow generated by the opening and closing engine valves [6, 7, 8, 9, 10], due to the unavailability of

adequate experimental equipment and to the difficulty in performing measurements of instantaneous parameters.

As regards turbocharger turbine, it's well-established that it's exposed to an unsteady flow which causes a deviation from the steady state operation [11, 12, 13]. Anyway, more aspects related to the turbine behaviour have to be analyzed in order to generalize a trend of unsteady flow performance with respect to steady state, taking into account the characteristics of the pulsating flow (i.e., pulse frequency, amplitude and mean value).

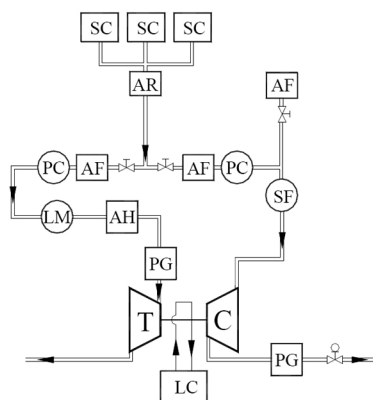
In addition, the reduction of engine displacement is leading the compressor to work under heavier unsteady flow condition, which causes a deviation from the steady state, even though the significant capacity of the circuit interposed between the compressor exit and the engine [14]. This aspect is emphasized by the adoption of different control strategies using advanced intake valve actuation systems [15].

As a consequence, deep experimental studies on the compressor behaviour under unsteady flow conditions are needed, also including the effect of flow unsteadiness on the location of the surge limit.

The aim of the paper is to analyze the effect of pulsating flow on compressor performance and the deviation from the

Measurements of pressure signal downstream the compressor, instantaneous mass flow rate and turbocharger rotational speed have been performed. In the paper a comparison between unsteady flow performance and the corresponding steady state is reported and analyzed. The influence of the pulsating flow intensity and frequency has been considered, also focusing on the surge line position.

The turbocharger test facility ([Fig. 1](#)) of the University of Genoa is a cold-air apparatus which allows to perform investigations on intake and exhaust automotive components. A more detailed description of the test bench is presented in [[13](#), [16](#)]. Thanks to the availability of different pulsating flow devices it is possible to study the I/E components behavior under the effect of an unsteady flow similar to that occurring in typical automotive applications. The pulsating flow can be generated by a motor driven cylinder head fitted with a Variable Valve Actuation system [[5](#), [14](#)] or alternatively a rotating valve device.



AF Air Filter	PC Pressure Control
AH Air Heater	PG Pulse Generator
AR Air Reservoir	SC Screw Compressor
C Compressor	SF Sensyflow Mass Flow Meter
LC Lubricating Circuit	T Turbine
LM Laminar Flow Meter	

The experimental activity reported in the paper has been developed by using a recent set-up which allowed to study turbocharger compressor under unsteady flow condition through a rotating valve pulse generator system.

Different measurements were performed along the circuit upstream and downstream the compressor. Both average and instantaneous pressure levels were measured through strain-gauge transducers, selecting an appropriate sample rate to properly record pressure oscillations. The temperature was measured by using a platinum resistance thermometer which allowed to detect only its average level. As regards compressor instantaneous mass flow rate, this was measured by using a hot wire fiber film probe, mounted downstream of the compressor. The sensor was calibrated against a viscous flow meter in steady state over the entire operating range experienced under unsteady flow conditions, also considering the temperature variation [16]. The turbocharger rotational speed was evaluated through an eddy current probe mounted close to the compressor wheel. Two high speed synchronized data acquisition cards were used to record instantaneous signals. All measured signals reported in the paper are an ensemble average of several complete cycles.

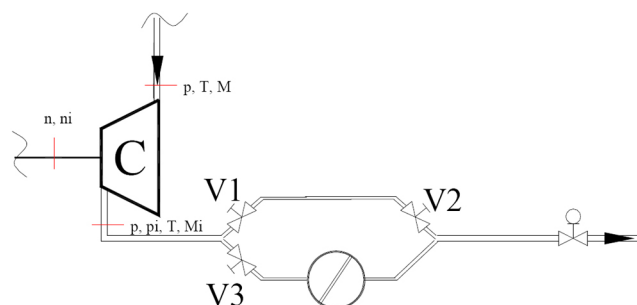


Figure 2. Compressor downstream circuit.

In a first step of the investigation, compressor steady flow performance was measured at different constant levels of corrected compressor rotational speed (80000 - 100000 - 1200000 - 140000 rpm) by using the same circuit and the