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External heat losses in small turbochargers: Model and experiments

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ABSTRACT

The behavior of small turbochargers is deeply affected by heat transfer phenomena. The external heat losses of these machines are studied and a simplified model that takes into account both radiation and convective mechanisms has been proposed. The model has been adjusted in a turbocharger test bench for two different turbochargers, later on it has been validated against experimental measurements on an engine test bench. Finally, the model has been used to estimate the most important external heat flows among the different elements of the turbocharger, showing the operative points in which external heat transfer in turbochargers cannot be neglected.

1. Introduction

Nowadays, ICE (internal combustion engines) face with two main challenges: the reduction of fuel consumption and pollutant emissions. With this purpose different techniques have appeared to better optimize the combustion process: high pressure fuel injection systems [1], multiple injections [2], high boost pressure [3], two stage turbocharging [4],EGR [5], variable valve timing [6], high swirl ratios [7], new clean fuels [8], etc. In this framework, the optimization of engine external systems can play an important role. One of the most used among these systems is turbocharging. In order to predict accurately engine behavior is necessary to predict the behavior of turbocharger [9]. This behavior must bear in mind at least two main factors: mechanical power transferred from the turbine to the compressor through the central axis [10] and the heat flows between these two elements due to the differences in the working fluids temperatures. This work falls in the second item trying to contribute to the knowledge of the external heat losses (convection and radiation) in small turbochargers.

Bohn [11] performed a parametric study for a passenger car turbocharger in order to analyze qualitatively the heat flux between turbine and compressor, finding that, in their measurements, and due to turbocharger geometry, radiation had a small influence on the total heat flux.

On the contrary, Baines [12] assured that the heat transfers of greatest magnitude and significance to turbocharger performance on-engine are external from the turbine to the environment, and internal from the turbine to the bearing housing and that radiation makes an appreciable contribution to the external heat transfer. They assumed that external heat transfer could be calculated as the energy unbalance in their measurements, but no model of radiation to ambient was presented.

In Ref. [13], authors suggest that the radiation and natural convection from the engine to the turbocharger are relevant but they do not quantify it, since they would need further investigation. In other work [14], the heat fluxes through the turbocharger were evaluated by means of well known correlations available in literature, but some of them were not described in the paper.

On other research works [15], authors simulated heat flows from the turbine and to the compressor artificially and assuming only external heat transfer from turbine to ambient.

In this work a simplified external heat transfer model taking into account all the possible heat fluxes in a turbocharger is developed. The simplicity of the model meets two main requirements. On the one hand, it must be computationally inexpensive in order to run coupled with whole-engine simulation software without additional computational cost. On the other hand, it must provide accurate results using measurable geometrical data of the turbocharger, since, in most cases, the detailed turbocharger geometry is not available for the user. The first part of the work concerns about the experimental methodology and the main parameters measured in order to characterize external

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Nomenclature

A	area, m^2
c	specific heat capacity, J kg^{-1} K^{-1}
h	convective coefficient, W m^{-2} K^{-1}
h	specific enthalpy, J kg^{-1}
K	conductance, W K^{-1}
L	length, m
$\dot{m}$	mass flow, kg·s^{-1}
r	radius, m
T	temperature, K
$\dot{Q}$	heat flow, W

Dimensionless numbers

F	view factor
Gr	Grashof number
Nu	Nusselt number
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number

Greeks symbols

α	percentage, –
ϵ	emissivity, –
ν	kinematic viscosity, m^2 s^{-1}
ϕ	diameter, m
σ	Stefan–Boltzmann constant, W m^{-2} K^{-4}

Subscripts

air	air
amb	refers to ambient
C	refers to compressor
CN	natural/free convection
CF	forced convection
ext	refers to external surface
gas	gas
H	refers to housing
H1	refers to housing node close to turbine
H2	refers to central housing node
H3	refers to housing node close to compressor
i,j,k,n	generic element
IC	compressor inlet
IO	oil inlet
IT	turbine inlet
lat	refers to lateral surface
oil	oil
OC	compressor outlet
OO	oil outlet
OT	turbine outlet
r	refers to radiation
s	shield
T	refers to turbine
unb	unbalance
w	refers to wall temperature
1,2	element number

heat transfer flow. Then, the proposed external heat transfer model of the turbocharger is presented. After that, results are presented. Later, an analysis of the different heat fluxes is performed by using the model and, finally, the main conclusions of the work are outlined.

2. Experimental tools

The experimental tools used in this work consist on two different test rigs (a turbocharger test rig, which is briefly described in Section 2.1, and an engine test rig, described in Section 2.2) and two different turbochargers units, whose main characteristics are mentioned on Section 2.3.

2.1. Turbocharger test rig

The measurement on turbocharger test rig has been used in order to adjust the proposed model. Fig. 1 shows the layout of a continuous air flow test bench [10]. It is composed by the following parts:

- A screw compressor with a maximum mass flow capacity of 0.2 kg s^{-1}, at a maximum discharging pressure of 3.5 bar (gauge), which provides the mass flow to the turbine. The mass flow rate is controlled by the screw compressor speed or an electronic discharge valve (placed after the screw compressor). The valve is used when a mass flow lower than the minimum supplied by the screw compressor is required. The extra flow is directly discharged to the atmosphere.
- The mass flow is heated in parallel by five tube-type electrical heaters. The flow through each of the heaters is regulated and balanced by means of valves placed on the heater's inlet ports. This system can reach up to 720 K at the maximum mass flow rate. This hot flow is collected in a plenum and conducted to the turbine inlet.
- After passing through the turbine, the air is cooled by means of a heat exchanger in order to allow the mass flow measurement by high accuracy hot film flow meters. All flow meters in the installation have been previously calibrated.
- The turbocompressor sucks air from the atmosphere. The air passes first through a filter and then its flow rate is measured. Downstream of the compressor, there is an electronically driven

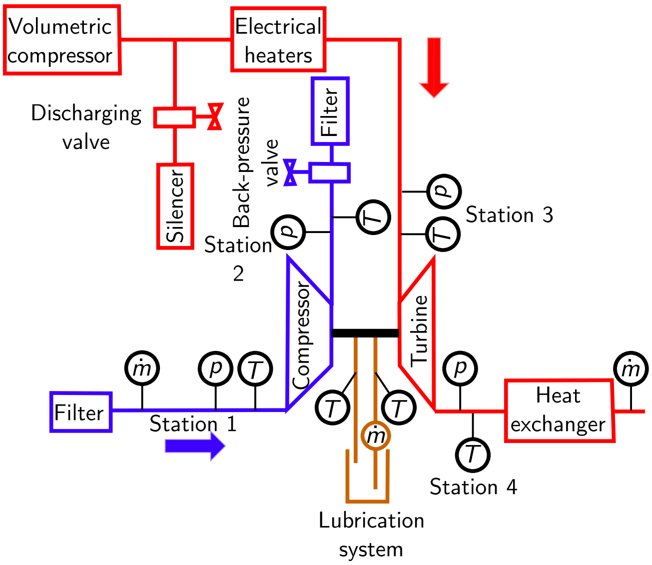

Fig. 1. Schematic test bench and location of main sensors.