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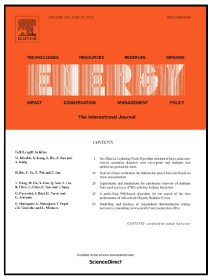

Boot injection dynamics and parametrical analysis of boot shaped injections in low-temperature combustion diesel engines for the optimization of pollutant emissions and combustion noise

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Boot injection dynamics and parametrical analysis of boot shaped injections in low-temperature combustion diesel engines for the optimization of pollutant emissions and combustion noise

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Abstract

Innovative direct-acting piezoelectric injectors that are capable of flexible injection rate shaping have been tested at a hydraulic test rig. The effect of boot injection dynamics on the injector performance was analyzed on the basis of the measured injected flow-rate time histories. The injectors were then installed on a Euro 5 low-compression ratio diesel engine, fueled with conventional diesel oil and managed with a late *PCCI* type combustion. The engine has been tested at a dynamometer cell, and a parametric analysis has been performed considering both the charging time and the holding time of the boot injection in order to assess the impact of their variations on engine-out emissions, combustion noise and brake specific fuel consumption. Explanations of the cause-and-effect relationships between the boot injection parameters and the engine performance have been provided: a three-zone combustion diagnostic tool has been applied to support the experimental investigation.
The tests at the engine dynamometer cell refer to the low-to-medium load and speed area of the engine *NEDC* zone, since the tests were focused on the exploitation of the boot injection in late *PCCI* combustion strategies.

Keywords: boot injection; direct-acting piezoelectric injectors; low-temperature combustion engine.

Highlights:

- Boot injection dynamics is analyzed on the basis of tests at the hydraulic rig.
- Continuous injection rate shaping schedules are implemented in a *PCCI* type engine.
- The effects of the boot injection parameters on emissions, combustion noise and fuel consumption are assessed.

1. Introduction

Injection rate shaping is an injection control strategy that is used in diesel engines. It consists of the modulation of the injected flow-rate time history, and it is aimed at obtaining reductions in engine-out emissions and combustion noise (*CN*) [1]. All fuel injection systems have a "natural" fuel injection rate pattern, which depends on the technical features of the specific fuel injection apparatus, and it makes the injected flow-rate vary over time during the injection event, according to a characteristic profile. The flexible management of the fuel injector, obtained by means of injection rate shaping, can be used to change the heat release rate (*HRR*) and control the radial stratification of the fuel within the cylinder [2], whereas circumferential stratification can be controlled by means of swirl and the number of nozzle holes [3].
The rate shaping of an injection event can be achieved by controlling either the injector needle lift (this occurs in dual spring injectors and in direct-acting Common Rail injectors) or the injection pressure (this is the case of hydraulically amplified Common Rail injectors and two-valve unit injectors) [4-7]. The rate shapes of single injection shots can be rectangular, ramp or boot shaped. In particular, boot injection is a low-rate profile that is usually introduced at the beginning of an injection event. Full exploitation of continuous injection rate shaping could be obtained through a suitable combination of all of these shaped profiles over the whole engine map [8], but this is a challenging task, even for advanced and flexible fuel injection systems.
Boot injection can offer many advantages [9], and can be efficiently implemented in modern Common Rail (*CR*) systems for passenger cars by means of direct-acting piezoelectric injectors [10]. These can modulate the rate shape by controlling the needle lift via the management of the level of the charge stored in the piezo-stack, and can guarantee great flexibility at different engine working conditions. Boot injection is basically performed in order to reduce the amount of fuel that is mixed with air during the early injection process. With this strategy, the autoignition delay of fuel premixed with air is greatly reduced [11] and, as a consequence, premixed burning, which occurs before the diffusive flames, diminishes. The decrease in the intensity of the premixed combustion portion limits the maximum heat release rates, thus determining a significant reduction in combustion noise. It has been estimated that a boot shaped main injection can decrease the combustion noise at high rail pressure levels by 3–4 dBA, compared to a pilot-main injection schedule [12, 13].
As far as the impact of boot injection on engine-out emissions is concerned, it is worth recalling that NO_x emissions in diesel engines are mainly produced because of high local temperatures, which depend to a great extent on the initial heat release rate [14], which in turn influences the subsequent temperature values in correspondence to the diffusion flames. In addition, soot production and oxidation both depend on the mixing rate and local flame temperatures [14]. Since in-cylinder peak temperatures and equivalence ratio values increase as the engine loads and speeds increase, the engine out NO_x and soot emissions in diesel engines can become critical, especially at high loads and speeds [15].