Research on the fluid dynamics of diesel injection systems, design of innovative closed-loop control strategies, assessment of a new flowmeter for high-pressure fluids and 1D

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Research on the fluid dynamics in diesel injection systems, design of innovative closed-loop control strategies, assessment of a new flowmeter for high-pressure fluids and 1D modelling of liquid and gaseous flows

By

Oscar Vento

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Supervisors:
Prof. Alessandro Ferrari
Prof. Antonio Mittica

Doctoral Examination Committee:
Prof. Giancarlo Chiatti, Referee, Università di Roma Tre
Prof. Petter Dahlander, Chalmers University of Technology
Prof. Jingping Liu, Referee, Hunan University

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Abstract

The Common Rail (CR) injection system represents the most diversified fuel injection system for diesel engines. It allows high pressure injection levels and many injection events during an engine cycle. Due to its importance, it is still in-depth explored from different aspects and represents the main topic of numerous research works. The internal dynamics of the injector and modifications in the system layout are widely studied and injector manufacturers are focusing their work on different strategies to control the injected mass. In addition, the CR system presents many features still to be studied from the fluid dynamics point of view, leading also to the development of new measuring devices.

In this study, the fuel temperature effect on the CR hydraulic performance has been investigated. The measured temperature at the injector nozzle exit has been compared with the one obtained by means of a thermodynamic model in which the pump compression follows an isentropic process, while the process inside the injector is assumed as isenthalpic. This value is well correlated with the measured temperature, but it represents an overestimation. By means of a numerical model, the internal fluid dynamics process in an injector has been investigated with reference to the fuel temperature variations. For the considered temperature range, the main effect of the fuel temperature regards the needle lift trace and a higher needle lift peak value is reached when the fuel temperature augments.

The layout and the algorithm of an innovative flow-meter has been presented. It is able to measure the instantaneous flow-rate of a high-pressure flow with a superior dynamic response. A 3D model of an external gear pump, validated from the pressure point of view, has been used to further assess the accuracy of the presented flow-meter, by comparing the numerical flow ripple with the experimental one.

As far as the control strategies for the injected mass are concerned, an approach based on physical equations and one based on a TFA virtual sensor

are presented. In the former, the mass at the injector inlet is evaluated, which correlates well with the injected one. Hence, a closed-loop control has been set-up and tested by means of a rapid prototyping hardware. The ET provided to the injector solenoid is corrected, for each engine cycle, based on the predicted inaccuracy on the injected mass. Tests have been performed for both single and pilot-main injections. Pertaining to single injections, the error due to a different thermal regime experienced by the injector has been reduced below 1 mg, while for pilot-main injections, the oscillations amplitude of the overall injected mass with respect to the dwell-time has been reduced below 2 mg. The TFA-based technique consists in the estimation of the injection temporal length (ITL) by analysing the mean instantaneous frequency evaluated for the pressure trace at the injector inlet. This allows to control the injected mass by means of a correlation based on the ITL and the rail pressure, independent on the fuel temperature. For a wide range of working conditions (in terms of rail pressure and ET), the error in the injected mass estimation is below 1 mg.

Pertaining to the system layout, an innovative diesel injection system, the Common Feeding (CF), has been experimentally and numerically investigated. In this system the rail is substituted by an accumulation volume directly mounted on the pump, leading to a cost reduction and to an easier installation on the engine. The experimental campaign has been conducted by considering a CR system where the rail size has been varied, in order to understand which is its effect on the hydraulic performance, in terms of single and double injections. The performance of the CR system has been compared with the CF one. By means of a 1D numerical model, the effect of the different rail size has been investigated from the injector internal dynamics point of view.

Regarding to the 1D fluid dynamics simulations, the unsteady friction effect on simulations has been investigated. A 2 m long high-pressure pipe has been equipped with three piezoresistive transducers, the pressure time histories at the two extremities have been selected as boundary conditions of the pipe numerical model, while the one in the middle has been compared with the numerical outcomes. In addition, with a 1D numerical injector model the different unsteady friction techniques have been applied and compared. It has been observed that when two pressure signals are used as boundary conditions, no evident improvements are provided by the unsteady friction model, while when only one boundary condition is a pressure signal (as in the injector model)

the unsteady friction increases the accuracy of the results, but the improvement is not related to the selected method.

Finally, an analysis of the scopes to model compressible flows by means of the polytropic evolution has been performed. A new set of analytical equations has been proposed, which allows both the heat transfer and the wall friction. The steady-state flow properties obtained by means of the new equations have been compared with the ones of the Fanno flow. Limits of the polytropic assumption have been investigated by means of a numerical code, where a variable polytropic coefficient can be adopted. This method allows to reach the choking condition with a Mach number equals to 1. The proposed formulas are able to accurately predict the viscous diabatic flow properties distribution, if a local maximum in the temperature is not present. In addition, an analytical formula to obtain the Mach number corresponding to the maximum temperature featured by the flow has been deduced.

Keywords: Common Rail, fuel temperature, Common Feeding, closed-loop, flow-meter, polytropic, frequency dependent friction.