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STABILITY ANALYSIS UPON HIGH-PRESSURE COMMON RAIL FUEL INJECTION SYSTEM UNDER MULTIPLE INJECTION MODES

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ABSTRACT–Fuel injection stability of high-pressure common rail fuel injection system (HPCRFIS) under multiple injection modes is a recognized technical problem. To explain it essentially, a numerical model based on bond graph method, which provides a standardized series of symbol system to describe various components in different physical fields as well as interactive effect analysis tool for different energy categories, was used to investigate the problem. As HPCRFIS is a typical nonlinear system with multi-physical coupling, it is very difficult to analyze system stability directly. Therefore, the system was linearized at typical moments. The system matrix for each typical moment was obtained thereby. To investigate the influential mechanism of system stability deeply, the variations of rank and eigenvalues distributions of state matrices were analyzed. The results show that the rank of state matrices changes abruptly when the needle or control valve moves. In terms of system stability, the oscillation characteristics are subject to the movement of needle or control valve. The ending of the former injection causes the system to show damping oscillation characteristics before the latter injection starts.The motion of control valve makes more contribution to system stability than that of needle, which could be concluded by Lyapunov stability criterion.

KEY WORDS : High-pressure common rail fuel injection system, Multiple injection, Stability analysis, Rank analysis, Lyapunov method

1. INTRODUCTION

Diesel engines have been widely used as the transport power and have been made great contributions to the prosperity and development of the world economy because of the advantages such as high thermal efficiency and good stability (Payri *et al*., 2018a, Jia *et al*., 2017, Geng *et al*., 2019). Fuel injection system (FIS) plays an important role in the operation of the diesel engine (Jo *et al*., 2015). Many parameters of FIS influence the combustion process and emission characteristics significantly of the diesel engine (Krogerus *et al*., 2018, Andreadis *et al*., 2010, Payri *et al*., 2016). In recent years, with the aggravation of energy crisis and environmental pollution (Song *et al*., 2017, Ferrari and Mittica, 2012, Ghadikolaei *et al*., 2019), the development of diesel engine is facing great pressure. Meanwhile, the advantages of dual-fuel engines and renewable energy like Ethanol have made a huge impact on traditional diesel engines (Yang *et al*., 2019). In order to comply with the increasingly stringent emission regulations, the multiple injection control strategy is preferred. Multiple injection means that more than one fuel injection should be completed in a working cycle (Soriano *et al*., 2018). Researches have shown that the emission and noise could be improved effectively with the application of multiple injection (Babu *et al*., 2018, Mohan *et al*., 2013, Plamondon and Seers, 2014).

The injection characteristics of the diesel engine under multiple injection mode are essential indicators to evaluate its performance. Many researchers have looked into it. Payri *et al*. (2018b) proposed a simulation model of a solenoid common-rail injector. The hydraulic characteristics of the injector were analyzed. And the results show that the injection mass of the second injection is influenced significantly by the dwell time. Meanwhile, the critical dwell time is determined by the calculation results under multiple working conditions. They found that the critical dwell time is related to the injection pressure and energizing time of the first injection. Herfatmanesh *et al*. (2016) found that the actual duration of main injection fluctuates periodically with the increase of dwell time between the pilot injection and main injection when their pulse widths are both fixed. And the frequency of the fluctuation is only related to structure parameters. Henein *et al*. (2002) investigated the injection quantity characteristics of HPCRFIS under different injection modes. They found that the actual injection durations of pilot injection, main injection and post injection are influenced by fuel pressure fluctuation. And the pressure

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