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Effects of rapid burning characteristics on the vibration of a common-rail diesel engine fueled with diesel–methanol dual-fuel

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HIGHLIGHTS

- A common rail engine of heavy-duty vehicles is fueled with diesel–methanol dual-fuel.
- Effects of rapid burning characteristics on the dual-fuel engine vibration are studied.
- The rapid burning characteristics greatly affect the dual-fuel engine vibration.
- By the optimum diesel injection timing and pressure, the vibration can be reduced.

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ABSTRACT

The diesel–methanol dual-fuel (DMDF) combustion mode is conducted on a six-cylinder, turbo-charged, inter-cooled diesel engine. In DMDF mode, methanol is injected into the intake pipe to premix methanol and air, and then ignited by the direct-injected diesel in cylinder. This study is aimed to investigate the effects of rapid burning characteristics on the vibration performance of the DMDF engine. The experimental results show that the combustion process of the DMDF engine can be divided into two phases. The rapid burning characteristics, the centroid angle of rapid burning (α) and the rapid burning fraction (β) have important influence on the vibration characteristics of the DMDF engine. The co-combustion rate (*CCR*) and engine load affect β greatly, and diesel injection timing also affects α and β greatly. However, the diesel injection pressure has little effect on rapid burning characteristics. By means of optimized diesel injection timing and pressure, the vibration can be reduced and the peak value of *CCR* can be increased.

1. Introduction

Diesel engines are widely used in transportation and construction machines owing to their high fuel efficiency and durability. However, the NOx and smoke are the main exhaust emissions and there is a trade-off relationship between them. Therefore, it is a hot-spot to research the simultaneous reduction of NOx and smoke emissions. The application of alternative fuel is one of the effective ways to reduce the emissions. At present, methanol has been studied intensively as a substitute fuel of diesel engines because it is easy to store, has a low cost and distributes broadly. At the same time, as the latent heat of vaporization and oxygen content of methanol are both high, methanol may be likely to have the ability of decreasing the emissions of NOx and smoke at the same time [1–3]. In the world, natural gas is the major source of methanol, whereas in China, the major source of methanol is coal, as China has abundant coal and less natural gas. In China, methanol is an important alternative fuel which can relieve oil shortage and improve clean coal utilization. Methanol can also be produced from biomass by syngas production method and fermentation method, which means that methanol is a kind of sustainable and environmental friendly alternative fuel [4,5]. The applications of methanol fuel on diesel engines are mainly methanol–diesel blends with additives and fumigation methanol. Compared with the methanol–diesel blends, the fumigation is more flexible in the proportion of methanol and diesel, and can also allow a higher percentage of methanol fuel. The fumigation method, also known as diesel–methanol dual fuel (DMDF) which is fueled with intake port

Abbreviations: CCR, co-combustion rate; DMDF, diesel–methanol dual-fuel.

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injected methanol and direct-injected diesel fuel, has been widely investigated recently [6–10]. Liu et al. [6] found that the smoke, CO and HC emissions decreased but NOx increased with the increase of diesel injection pressure in DMDF engines. Geng et al. [7] found that the emission of dry soot would experience a dramatic reduction if the load was low or medium, whereas a slight increase would be seen if the load was high. At the same time, when the load was low or medium, the particulate matters' mass and number concentrations would also experience a dramatic reduction. Wang et al. [8] found that at light loads, the efficiency was improved significantly with the increase of the intake temperature and the advance of the injection timing of diesel. Li et al. [9] found that fuel economy could be improved and knock could be avoided by increasing methanol fraction and advancing the start of ignition. Zhang et al. [10] found that the mass and number concentrations of particulates would be decreased dramatically from medium to high loads under the fumigation method.

It was also found that DMDF engines could operate more roughly than diesel engines through the experiments, and the knocking became an important bound which could restrict the operating range of dual-fuel engines. With the increase of loads, the features of the combustion changed from partial burn to roar combustion and then to knocking [11]. Some researchers [12] had to limit the amount of methanol to avoid engine knocking. Actually, the phenomenon that engine operated roughly was also found in other types of dual-fuel, such as natural gas–diesel dual-fuel, liquefied petroleum gas–diesel dual-fuel and alcohol–diesel dual-fuel. Many investigations were also conducted on knocking. Li et al. [13] indicated that the combustion phasing would exert a dominant influence on the ringing intensity, whereas the changes of EGR rate and initial temperature almost had no effects on it. Sahoo et al. [14] found that a greater ratio of pilot diesel would get involved in the premixed combustion. In consequence, the tendency of knocking would be increased in dual-fuel engines fueled with nature gas and diesel. Meanwhile, the tendency of early knocking would be increased when the load was medium or high if the injection timing was further advanced. Krishnan et al. [15] investigated the significant role played by the timing of pilot injection and the conditions of the inlet in the stability of nature gas–diesel dual-fuel engine operation and knock, the results of which indicated that the end-mixture auto-ignition would lead to the increase of knocking. Selim [16] measured the knock and ignition limits data, combustion noise of a dual-fuel engine fueled with diesel and liquefied petroleum gas, pure methane and compressed natural gas mixture separately. The combustion noise was evaluated by the maximum of pressure rise rate, while the knocking limits were considered as the torque output at the beginning of knocking. As a result, it was found that the combustion noise and knocking limits were connected with the gaseous fuel types, the design of engines and the running parameters. Zhou et al. [17] investigated knocking phenomena of a dual-fuel engine fueled with bio-diesel and methanol by the numerically method. The maximum peak-to-peak pressure data was used to quantify the knocking intensity. The conclusion was that cooled EGR, retarded SOI and lower premixed methanol mass fraction could suppress the engine knocking.

With the application of the numerical method, the knocking problem of a biodiesel–methanol dual-fuel engine was researched by Zhou et al. [17], in which maximum peak-to-peak pressure was applied to the quantification of the knocking intensity. According to the result, cooled EGR, retarded start of injection and lower premixed methanol mass fraction could suppress the engine knocking. Based on the viewpoints of Nwafor [18], more time would be provided for the heat transfer to the end gas if the combustion rate of nature gas was slower and thus the possibility of knocking would be increased in nature gas–diesel dual-fuel engines. By means of adding oxygen to the intake air, Abdelaal et al. [19] revealed the effect of the intake air oxygen concentration on the knock tendency in a dual-fuel engine fueled with nature gas and diesel. The result showed that the ignition delay was dramatically reduced, the burning duration was shortened and the tendency of knocking was decreased by adding oxygen to the intake air.

However, the previous studies were mainly focused on the combustion and emissions characteristics of DMDF engines. Although there were some studies on the knock tendency, the alternative fuel was nature gas and maximum pressure rise rate or torque output was used to judge the knocking tendency instead of direct vibration data of the test engine. In this study, maximum pressure rise rate and the vibration acceleration data are collected and analyzed for the vibration characteristics of the DMDF engine. Some operating conditions are adopted to study the change of vibration characteristics. In the meantime, combustion characteristics are analyzed to reveal the relationship between the rapid burning phase and the vibration.

2. Experimental setup and method

2.1. Test engine system

For the purpose of investigating how premixed combustion characteristics affect the vibration performance of DMDF engines, this research adopts a common rail diesel engine that is turbocharged, inter-cooled and in-line six-cylinder. This test engine's specifications can be seen from Table 1.

A methanol rail and three methanol injectors which are added at the head of the intake manifold are used to modify the engine for the purpose of inducing and mixing methanol with fresh air. Methanol is injected into the intake pipe at a pressure of 0.40 MPa so that the homogeneous mixture of methanol and air can be formed. The diesel supply system of the test engine is produced by BOSCH Company. An added electronic control unit is applied to controlling the injection of methanol, and the injection pressure and timing of diesel are controlled by the initial diesel electronic control unit. The test engine's schematic is shown in Fig. 1.

An eddy current dynamometer (CW260, CAMA) is responsible for the automatic control of the speed and torque of the engine. A pressure transducer which is piezo-electric type (6052A, Kistler) is installed at the head of the first cylinder to measure the in-cylinder pressure. Before transferring the pressure signal to the combustion analyzer (Kibox, Kistler), a charge amplifier (5019B, Kistler) is applied to the amplification of the pressure signal. An acceleration transducer (8702B50, Kistler) which is installed at the first cylinder's cylinder wall is adopted to measure the vibration performance of the test engine, while before transferring the signal to the combustion analyzer, a signal conditioner (YE3826A,

Table 1
Test engine specifications.

Items	Parameters
Model	YC6G270-30
Bore × stroke	112 mm × 132 mm
Displacement	7.8 L
Compression ratio	17.5:1
Intake valve opening	13.5 °CA before top dead center
Intake valve closing	38.5 °CA after bottom dead center
Exhaust valve opening	56.5 °CA before bottom dead center
Exhaust valve closing	11.5 °CA after top dead center
Rated power	199 kW @ 2200 r/min
Rated torque	1080 N m @ 1400–1600 r/min