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The exhaust emission online detection on the diesel engine

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ABSTRACT

Represented here is an exhaust nitric oxide emission online detection method on a single-cylinder diesel engine, which is based on the tunable diode laser absorption spectroscopy. Considering the effects of different particle matter concentration in exhaust gas on detection accuracy, the direct detection approach was adopted. The wave number chosen in the present study was 1900. 07059 cm^{-1}. The spectral parameters were calculated as a function of temperatures. And a thermo-couple was designed to detect the real-time temperature under different operating condition and modify the experimental results. All the experimental analysis demonstrated that the online detection system developed in the present study could realize the time resolution of 100 ms and effectively record the nitric oxide emission characteristics. With the high time resolution, the transient NO emission value under the transitional work condition was also obtained,which gives a new prospect to the future research on diesel engines.

1. Introduction

Diesel engines play a main role in the conventional power due to their high efficiency, high reliability, and high economy, which have been studied for around 200 years. Furthermore, diesel engine is definitely dominated in the marine power, and the proportion of diesel engine is up to 95% [1]. However, the exhaust emissions from diesel engines has been seen as a fatal matter which limits the applications of diesel engines. With the development of the modern society, the environment pollution has become one of the biggest problem, which is critical to human being. Especially in some developing countries, such as China [2]. So, the exhaust emission regulations become stricter and stricter. Several approach have been adopted to improve the emission performance of the diesel engines, such as SCR and EGR [3].

In order to understand the emission characteristics of the diesel engines better, the measurement technology is no doubt a main approach to obtain these information. There are many kinds of traditional ways, including the chemical reaction, the gas sensors, photochemical, the chromatographic and so on. These technologies usually belong a kind of sampling method, which has a low time resolution [4,5]. However, the diesel engine is a kind of rapid machine. So, there are a lot of valuable transient information in the exhaust emissions. Aiming to improve the emission performance of the diesel engines, we should grasp the transient emission information by employing a novel rapid measurement approach, which has a higher time resolution.

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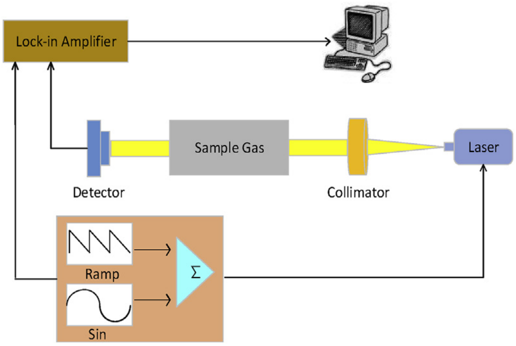

Fig. 1. The principle diagram of harmonic detection.

We describe here is a new approach based on tunable diode laser absorption spectroscopy (TDLAS), which is simple, and with high precision and high time resolution. TDLAS system can meet the requirements of exhaust emission detection, which has a good prospect in online measurement. TDLAS technique started from 1960s, which has been demonstrated to be an active method in gas detection in several application fields [6,7]. It is also employed by some researchers in the combustion diagnoses. With the development of the tunable diode laser, (such as the Quantum cascade laser (QCL), the Interband cascade laser (ICL), and the Distributed feedback laser (DFB)), it has become more and more popular in many research areas and some industrial areas [8,9].

In this work, we use the TDLAS system to measure the nitric oxide (NO) concentration in the exhaust. NO_x is the most harmful product in the exhaust of diesel engines, which is the cause of the acid rain [10]. The concentration of NO is dominated in the NO_x emissions, which may exceed 90%. It is quite different for testing on a running diesel engine comparing to some ambient environment [11]. The temperature and the pressure vary verse the different work conditions, which may affect the test result seriously [12]. In order to realize online detection on the running diesel engines, necessary modify must be adopted in the testing processing. We calculated the spectrum parameters of the NO molecule, and modified the test results by this calculation. The real-time temperature and pressure during different work conditions were obtain by using temperature and pressure sensors.

2. The mechanism and calculations

TDLAS is based on the law of Beer-Lambert, when a monochromatic laser get through the gas, the intensity change can be expressed as it:

$$I_t = I_0 \exp\left[-PS(T)\phi(\nu)XL\right] = \exp\left[-\alpha(\nu)\right] \tag{1}$$

I_0 is original laser intensity when there is no gas absorption. I_t is laser intensity after gas absorption. $S(T)$ is the absorption line strength of the gas, which expresses the absorption intensity of the spectral line, only related to the temperature. P is the pressure of the gas medium. L is the propagation distance that a laser through in the gas. X is the volume concentration of the gas. $\Phi(\nu)$ is the linear function, which expresses the shape of the measured absorption lines, relating to the temperature, pressure and each component content in the gas. There are two typical methods to realize the concentration measurement, direct method and harmonic method. For the direct method, the concentration is calculated directly using the integral value of spectral absorptivity, which is shown as followed:

$$X = \frac{\int_{-\infty}^{+\infty} -\ln\left(\frac{I_t}{I_0}\right) dv}{PS(T)L} = \frac{A}{PS(T)L} \tag{2}$$

The harmonic detection technology is a kind of wavelength modulation technique. In the actual measurement, a high frequency sine signal is always loaded on the low frequency triangle signal to realize a high frequency modulation for the target signal. With the process of signal demodulation, the low frequency noise in the measurement system can be reduced. and improve the sensitivity of measurement. In addition, the thermal noise of laser and detector is weak in the high frequency zone, which can avoid the influence of thermal noise on the detection results. System schematic diagram is shown in Fig. 1.

The NO concentration can be calculated by the intensity of the 2f signal which can be expressed by the Formula (3):

$$P_{2f} \propto \frac{I_0 S(T) PXL}{\pi \Delta\nu} \left\{ \frac{2}{m^2} \left[\frac{2+m^2}{(1+m^2)^{\frac{1}{2}}} - 2 \right] \right\} \tag{3}$$

I_0 is original laser intensity when there is no gas absorption. $S(T)$ is the absorption line strength of the gas, which expresses the absorption intensity of the spectral line, only related to the temperature. P is the pressure of the gas medium. L is the propagation distance that a laser through in the gas. X is the volume concentration of the gas. m is the modulation coefficient.