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Research of NO_x Sensors Performance Test

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Abstract

NO_x sensors, as a core component of diesel engine exhaust treatment system, play an important role in exhaust emission control, which can accurately and quickly detect the NO_x and O_2 concentration. It has become a necessary option for the detection of existing exhaust emission standards. At present, there is limited and scattered information on knowledge and test methods of NO_x sensors, the research of NO_x sensors has become a challenging research topic at home and abroad. Based on these requirements, the article systematically integrates the knowledge of principle and testing methods. First of all, through introducing functional description of NO_x sensors and the basic principle of NO_x sensors, the relevant scholars can have an overall understanding of the product and master the operation mode of products. Secondly, the current status of performance test bench and methods of NO_x sensors were described, which can contribute to having a clear understanding of the development process. After that, a new structure of NO_x sensors test bench was purposed, which contains six major units including standard gas source, gas mixing unit, analyzer measurement unit, sensor measurement unit, data processing and display unit, exhaust gas treatment unit. And the test bench was validated. The experimental results show that the test bench has the advantages of high-repeatability, high reliability and low cost. And it can realize automatic detection of multiple target values, which is worthy further promotion. Thereby, the article can contribute to the development of its technology indirectly.

Keywords

NO_x Sensors, Function, Performance Test, Basic Principle

1. Introduction

With the rapid development of the economy, the production and sales volume of Chinese automobiles have become the first in the world. While people enjoy the convenience that automobiles bring to production and life, serious environmental pollution also follows, especially gas exhaust. New emission standard implemented in China on July 1, 2023, the vehicles do not meet the standard are prohibited sold, imported and produced. The standard placed higher rules on the exhaust emission of vehicles, thus tighter requirements have been put forward for automotive exhaust treatment devices. The main components of exhaust contain carbon monoxide (CO), nitrogen oxide (NO_x), hydrocarbon (HC), sulfur compounds (SO_x), particulate matter(PM), and so on [1] [2]. NO_x and PM have the high content and the widest harm among them, which can have the greatest impact on human health [3]. Therefore, strict control of NO_x and PM emissions from diesel engine exhaust is a key issue of concern in the diesel engine industry [4].

The NO_x sensor is an important part of exhaust treatment system, and the accuracy of NO_x and O_2 concentration is a major indicator of its performance. The quality of its performance is directly related to the level of exhaust emissions. At present, the production and test technologies of NO_x sensors are mostly designed by top for foreign manufacturers in the industry. There are technical confidentiality issues, which will result in domestic diesel engine and treatment system manufacturer being unable to test the accuracy performance of the NO_x sensors [5]. Based on this situation, this paper independently developed a NO_x sensor performance test bench, which solves relevant technical problems and implement automatic detection of NO_x accuracy performance.

2. Production Description

2.1. Basic Information

The NO_x sensor for diesel applications consists of a sensor probe and a non-detachable sensor control unit. The sensor probe itself contains a ceramic sensor element with an integrated heater. The overview of Sensor Control Unit (SCU) and NO_x sensor probe is shown in **Figure 1**. This kind of senor is an electrochemical sensor. Two functional parts build up the NO_x sensor. First, the sensor probe contains cable to the SCU with connector, sensor element and sensor housing with protection tube. Second, the SCU is a controller with hardware (HW) and software (SW). The housing is made of plastics to allow a sealed packaging inside to protect the co-fired ceramics (LTCC). The SCU has to be fixed with a bracket or cable tie.

Figure 1. The picture overview of Sensor Control Unit (SCU) and NO_x sensor probe.

In the Selective Catalytic Reduction (SCR) system, the NO_x sensor is located in the exhaust pipe, with its sensor element exposed to the exhaust gas [6]. The location is shown in **Figure 2**. A NO_x sensor is installed up- and down-stream SCR of the exhaust pipe. The upstream NO_x sensor mainly measures the concentration of NO_x in the diesel exhaust and determines the optimal injection amount of urea water solution (UWS). This calculation has to be done in the Electronic Control Unit (ECU). The downstream sensor mainly detects the catalytic performance of the catalyst. The up- and down-stream sensor is used for closed-loop control of SCR system, which precisely control reduction reaction. Ultimately, the diesel exhaust emission level is controlled.

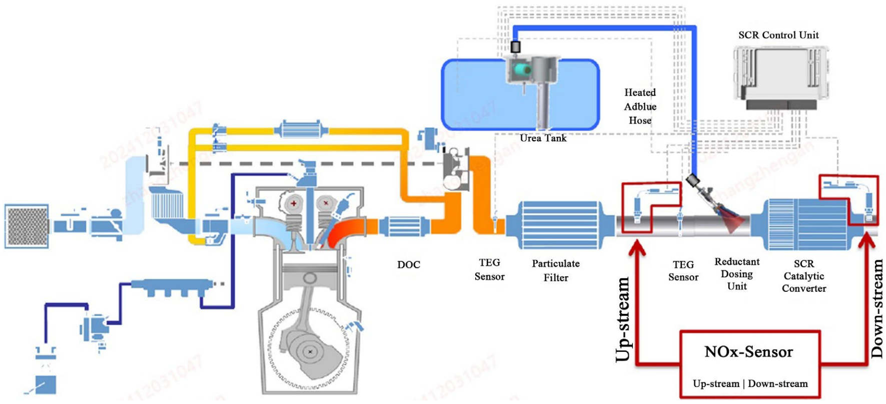

Figure 2. Location for reference of sensor in a diesel combustion engine system.

2.2. Function Description and Principle

The basic principle of the SCR system is to use Ammonia (NH_3) as a reducing agent to reduce NO_x into N_2 and H_2O under the action of a catalyst. Although NH_3 is non-toxic, it is a gas with a strong pungent smell and is not convenient to use directly in vehicles. Therefore, the NH_3 required for the reaction is provided by spraying urea aqueous solution into exhaust pipe. The reaction process is as follows.

$$(NH_2)_2CO + H_2O \rightarrow CO_2 + 2NH_3$$

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$$

$$2NO_2 + 2NO + 4NH_3 \rightarrow 4N_2 + 6H_2O$$

2.2.1. Function Introduction

The sensor is used to measure the O_2 and the NO_x concentration with the property of zirconium oxide (ZrO_2) that can conduct O^{2-} at 800˚C in exhaust gas of diesel engines. NH_3 is indirectly measured as an additional contribution to the NO_x signal.

The functional diagram is shown in **Figure 3**. The functional parts of the sensors elements are O_2 pumping cell, NO_x pumping cell Nernstian cell, two diffusion barrier and heater circuit [7]. And the main functional parts of the SCU are SBC module that include CAN transceiver and reverse protected voltage regulator, microtroller that accommodates the control logic of the system, O_2 cell control and NO_x cell control the include O_2/NO_x closed loop controller Application Specific Integrated Circuit (ASIC) and heater control with inverse polarity protection (IPP).

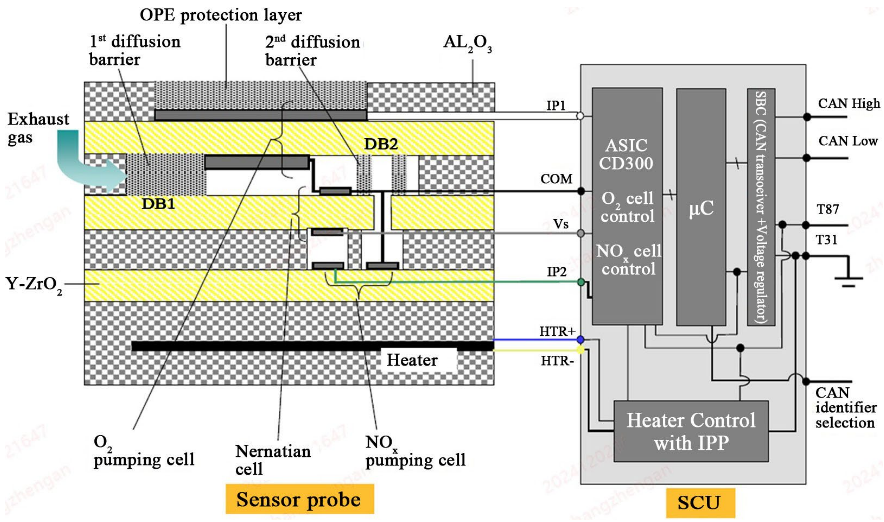

Figure 3. NO_x sensor operation diagram.

2.2.2. Operation Principle

When the sensor will start, it is set to "preheat" until the "dew point" bit is sent via CAN. The sensor will start heating up to its working temperature by sending the data "dew point reached". The message "dew point reached" can only be sent to the sensor if the gas flowing at the protection tube of the sensor does not contain any liquid components. Heating electrodes were heated to 800˚C. The exhaust gas enters the first cell of the sensor, and O_2 pumping electrode pumps O_2 in the out of the cell in form of O^{2-}. At this time, the current change that is generated is measured by inner pumping (IP1: control PIN of O_2 cell) and convert into O_2 concentration. The exhaust gas reached the second cell, then NO_x are catalytically reduced to N_2 and O_2 on the electrode. The generated O_2 is pumped out of the second cell in the form of O^{2-} through the second O_2 pumping electrode. The current change generated can be measured IP2 (control PIN of NO_x cell). the concentration of NO_x can be calculated eventually.

3. Experimental Research

3.1. Research Status and Progress of Test Methods

It is well known that the development of foreign NO_x sensor technology started relatively early. The mature sensor manufacturers include Bosch and Viteesco Technologies that products are expensive and have a monopoly in the industry. In addition, the technology mastered by well-known suppliers is not open to the public, resulting in slow development of NO_x sensor technology. The research and development of diesel engine treatment system in China started relatively late.

After the National IV standard clearly implemented, various diesel engine manufacturers, universities and research institutes began to pay attention to it, and then gradually entered the actual research and development progress of diesel engine treatment system technology.

Tan hong liang, et al, developed a NO_x sensor test bench. The main detection process includes the following steps. Firstly, the gas exhaust simulation needs to be configured. The mixed gas is preheated by the heating tube and then enter the probe of sensor. Secondly, computer control system collects data and analyzes it. By controlling the flower to achieve exhaust gas configuration of different concentrations, the test bench can detect the measurement accuracy of NO_x concentration of the sensor and record relevant data, but it also has the following disadvantages:

- Inaccurate results and large deviations. Due to objective factors such as the working characteristics of the nitrogen oxide sensor and the uneven composition of the measured mixed gas, the measurement results of the nitrogen oxide sensor will fluctuate. In this case, the value recorded at a certain moment will have a large deviation, resulting in large measurement uncertainty.
- No multi-point automatic detection and low detection efficiency. The measurement accuracy of NOx sensors is correlated with the detection points. Taking Bosch products as an example, there are $4O_2$ concentration detection points and 3NOx concentration detection points. Different detection points have different accuracy requirements, so multi-point detection must be performed. The existing technology uses manual adjustment, which causes the detection time to be too long.
- Unable to assess the accuracy of the gas source. When evaluating the test results, the actual concentration of the mixed gas is used as a standard value to evaluate the measurement accuracy of NOx sensor. If the actual concentration of the mixed gas is not detected online, the evaluation result of the sensor measurement accuracy is unreliable. In the prior art, the actual concentration of the mixed gas is calculated based on the flow rate of each standard gas, and the credibility of the test result is poor.
- Unable to detect O_2 concentration performance. Accurately measuring the O_2 concentration in exhaust gas is a prerequisite for reducing particulate matter emissions. The lack of detection capabilities will cause unqualified products to enter the market, posing a risk of particulate matter emissions violations.

Sun wen, et al, designed a NO_x sensor performance detection device, which contains control unit, power supply unit, heating unit, standard gas source unit, temperature control unit, exhaust gas treatment unit. The device used standard gas as the gas source, did not need to configure gas exhaust. It has the advantages of simple structure and convenient operation. There are also the following disadvantages: (1) Need to configure many gases with different concentration values and it is high-cost. (2) The test bench cannot realize automatic of different concentration points and can only be switched manually, resulting in low detection efficiency. According to previous research, significant progress has been made in sensor detection field. Therefore, a low-cost and high-reliability NO_x sensor performance test bench is urgently carried out.

3.2. Test Bench Design

In order to the needs of NO_x sensors accuracy detection in the field of diesel engines, the test bench designed in this paper can be configured with different concentrations of NO_x and N_2. The control range of NO_x is (0 - 2800.56) μmol/mol. The test bench is equipped with a high-concentration NO analyzer (model: CAI) with a range of (0 - 4688.22) μ mol/mol and an accuracy of ±1% FS (Full Scale), which has been calibrated a legal metrology agency to ensure the accuracy and stability of the mixed gas concentration. To achieve mass detection, the control program of the test bench has the characteristics of automatics gas distribution, automatic conversion, auto measurement and recording of various gas concentrations, which effectively improves the detection efficiency. The structural diagram of the test bench is shown in **Figure 4**. The test bench includes six major units, such as data processing and display unit, gas mixing unit, analyzer measurement unit, sensor measurement unit, exhaust treatment unit and standard gas source.

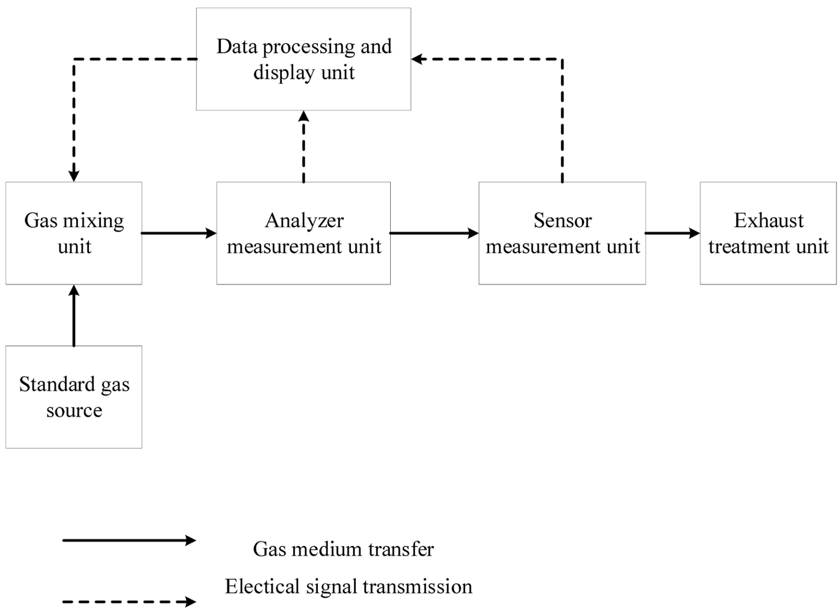

Figure 4. The structural diagram of the NO_x performance test bench.

The standard gas source consists of multiple gas tanks, which store high-purity N_2 and 95% N_2 + 5% NO mixed gas respectively, and are connected to the gas mixing unit through pipelines. The gas mixing unit includes a pressure regulating value, a gas mass flow meter, a mixer and related pipelines. And the gas mass flow meter receives the target flow signal output by the data processing and display unit, which can automatically adjust the flow of standard gas to achieve flow control of the above three gases. Then the three kinds of gases are mixed in a certain proportion in the mixer and introduced into the analyzer measurement unit. The analyzer measurement unit consist of a NO analyzer and an O_2 analyzer, which can respectively detect the NO_x and O_2 in the mixed gas in real time online and output the results to the next unit. According to the parameters of the three standard gases in the test bench, the calculation method of the flow rate of each standard gas corresponding to the sensor detection point is as follow.

$$Q_t/(Q_N + Q_t) = C_t/C_m \tag{1}$$

Q_t—set flow rate of test gas;

Q_N—N_2 flow rate for mixing;

C_t—set concentration of the test gas;

C_m—standard gas concentration.

The detection system allows manual minute adjustment of the flow rates of the three standard gases according to the gas concentration results of the NO_x analyzer and O_2 analyzer to meet the detection point concentration specified by the NO_x sensor. The sensor measurement unit includes measurement chambers and a controller. The data processing unit is used to set the target flow rate of each component gas at different concentrations and transmit to the gas mass flow meter in the gas mixing unit. The unit also includes receiving the detection data of the analyzer measurement unit and the sensor measurement unit. The exhaust gas treatment unit includes an exhaust gas processor to remove harmful gases from the mixed gas and prevent air pollution.

3.3. Result Analysis

Before the test, the NO analyzer was calibrated with 90.16 μmol/mol and 746.71 μmol/mol standard gas. According to the testing standards JB/T 11880.7-2014, the title is Diesel engines-Selective catalytic reduction (SCR) systems—Part 7 NO_x sensors, Then the detection device was used to test the NO_x accuracy performance of the sensor of Company A and B. The models are EGS-NX Gen2 CV and Generation 3.5a UNI-Volt respectively. And the test results are shown in **Table 1** and **Table 2**.

Table 1. Company A NO_x sensor test results.

test point/μmol/mol	Results/μmol/mol	Deviaton/%
0	0.52	/
90.16	92.58	2.7%
746.71	732.38	−1.9%

Table 2. Company B NO_x sensor test results.

test point/μmol/mol	Results/μmol/mol	Deviaton/%
0	0.14	/
90.16	88.58	−1.82%
746.71	731.32	−2.1%

By consulting the relevant technical specifications of the product, the test results meet the requirements of the drawings.

4. Conclusion

The paper described the basic working principle of the NO_x sensor and the current status of detection technology. By designing a self-developed performance test bench, an accuracy test of the sensor can be accomplished.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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