Development of a 2.0-L Direct-Injection Diesel Engine Complying with Japan's Post New Long-Term Exhaust Emission Regulations


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1. Overview

Diesel engines provide a highly efficient combustion process with low fuel consumption owing to their lean-burn operation, low pumping loss and high compression ratio. However, because diesel engines constantly operate under a lean combustion condition, it is difficult to reduce nitrogen oxide (NOx) and hydrocarbon (HC) emissions simultaneously, as a three-way catalyst system only functions near a stoichiometric ratio. There has been a growing need to develop new diesel engine technologies for complying with increasingly tighter exhaust emission regulations. Therefore, we developed a lean-NOx trap catalyst (LNT) and an advanced engine control system for eliciting full LNT performance. These technologies have been added to the latest diesel combustion system and diesel particulate filter (DPF) technology in order to reduce NOx emissions substantially while retaining the traditional advantages of a diesel engine. Thanks to these new technologies, the Nissan X-Trail fitted with the clean M9R diesel engine became the first vehicle in the world to comply with Japan's stringent Post New Long-term Exhaust Emission Regulations that were enforced in October 2009.

2. Technical Features

Precise control of the air-fuel ratio and the catalyst temperature is necessary to elicit the full performance of the LNT system. For that purpose, the state transition diagram shown in Fig. 1 was developed to provide the desired state transition in each driving mode and to meet the operating requirements of the LNT system and DPF. This diagram consists of four operating modes: an ordinary driving mode, a DPF regeneration mode for cleaning accumulated particulate matter from the filter, a rich spike mode for reducing NOx adsorbed on the LNT by operating in a rich atmosphere for several seconds every few minutes, and a desulfation mode for removing stable adsorbed sulfur compounds on the LNT. In order to correctly detect when these different modes are required, the control unit incorporates a model for accurately predicting the state variables of the LNT, including the amount of NOx adsorbed, level of sulfur poisoning and catalyst temperature. Based on the engine operating state and predicted LNT state, the required exhaust aftertreatment process is judged and the fresh intake air quantity and fuel injection quantity are optimally controlled.

The amount of engine torque produced generally varies according to changes in engine combustion efficiency that occur when the air-fuel ratio and other parameters affecting combustion change substantially. The air-fuel ratio must be suitably controlled so that driveability does not seem unnatural to the driver and so that the operating requirements of the exhaust aftertreatment devices are met. That requires fine-tuned control of the intake air quantity and fuel injection quantity when switching between operating modes. To resolve these issues, a model reference control algorithm has been applied that takes into account the dynamic characteristics of the fresh air and recirculated exhaust gas (EGR). The specific control procedure is shown in Fig. 2. (A) The deterioration of the fuel consumption rate is corrected. (B) The response of the oxygen mass in the intake gas is estimated, taking into account the oxygen concentration in the EGR gas. (C) According to the result, a value is calculated for correcting the transient target air-fuel ratio, and (D) the target fuel injection quantity is calculated. As a result, the air-fuel ratio is controlled so as to avoid any unnatural driveability feeling even in the rich spike mode when the target air-fuel ratio changes suddenly.

The control algorithm has been combined with an improved combustion system for meeting the Euro 4 exhaust emission standards. This combination has made it possible to comply with Japan's Post New Long-term Exhaust Emission Regulations (Fig. 3).

3. Summary

The key technical points are to regenerate the LNT at an optimal timing by accurately estimating the amount of NOx adsorbed and to switch between the lean and rich operation modes without affecting driveability. That is accomplished by the newly developed control algorithm based on a model for estimating the engine's dynamic characteristics and the state of the exhaust aftertreatment system. We will continue our development efforts to make diesel engines a key environmental technology with the aim of further increasing their contribution to environmental improvement.

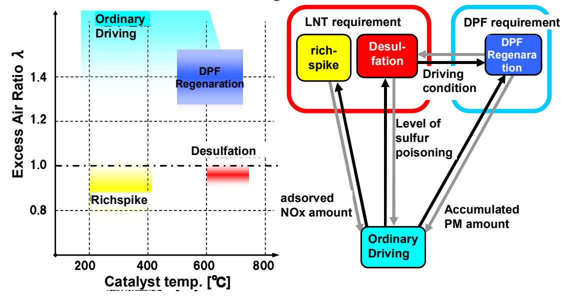

Fig.1 LNT control requirements and state transition diagram of exhaust aftertreatment system

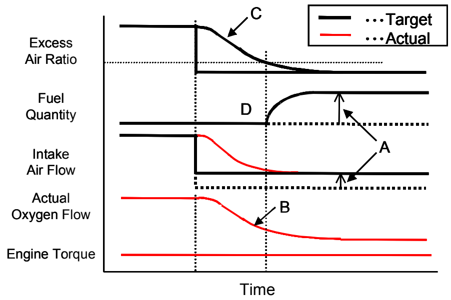

Fig.2 Air-fuel ratio control procedure

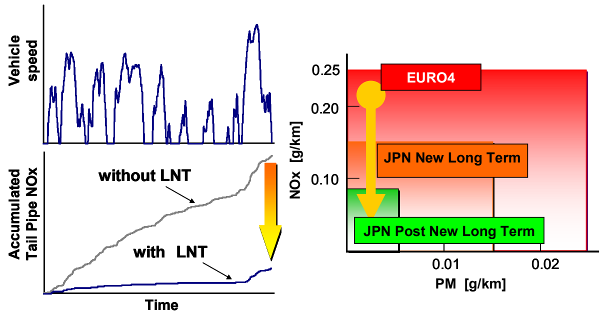

Fig.3 Effect of LNT system on reducing exhaust emissions

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