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Fault detection for modern Diesel engines using signal- and process model-based methods ☆

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Abstract

Modern Diesel engines with direct fuel injection and turbo charging have shown a significant progress in fuel consumption, emissions and driveability. Together with exhaust gas recirculation and variable geometry turbochargers they became complicated and complex processes. Therefore, fault detection and diagnosis is not easily done and need to be improved. This contribution shows a systematic development of fault detection and diagnosis methods for two system components of Diesel engines, the intake system and the injection system together with the combustion process. By applying semiphysical dynamic process models, identification with special neural networks, signal models and parity equations residuals are generated. Detectable deflections of these residuals lead to symptoms which are the basis for the detection of several faults. Experiments with a 2.0 l Diesel engine on a dynamic test bench as well as in the vehicle have demonstrated the detection and diagnosis of several implemented faults in real time with reasonable calculation effort.

Keywords: Diesel engine; Modelling, Fault detection; Fault diagnosis; Neural networks

1. Introduction

The increasing complexity of electronic controlled Diesel engines with a rising number of actuators and sensors requires an automated and improved fault detection and diagnosis on board the vehicle to secure reliability and availability. By an appropriate condition monitoring and an early fault detection maintenance intervals can be increased and troubleshooting in service stations can be supported leading to reduced down times. Moreover, there exist legal regulations to supervise all components in the vehicle which increase exhaust gas emissions.

Modern on-board diagnosis systems are mainly based on simple limit or plausibility checks of some measured signals and on simple signal-based methods like the frequency analysis of the engine speed signal. In future, these methods will probably no longer be able to match the rising requirements. Therefore, model-based fault detection methods developed in recent years are promising ways to enhance fault detection. Analytical process information in form of mathematical process models can be used to evaluate information of different sensors, whereby dependencies between different signals can be utilized. By measuring of at least one input and the corresponding output signal it becomes possible to deduce internal process quantities, for instance parameters or state variables. Thus, the origin of faults can be better detected and a separation and localization of faults can be achieved.

Fig. 1 shows the generation of fault detection features by an appropriate model-based signal processing. The comparison of the observed features with the nominal behaviour of the process leads to residuals. Detectable deflections of the residuals yield to symptoms. The symptoms are then processed in the subsequent fault diagnosis by means of fault–symptom–causalities. The faults are located and fault causes are determined. For model-based fault detection different methods can be

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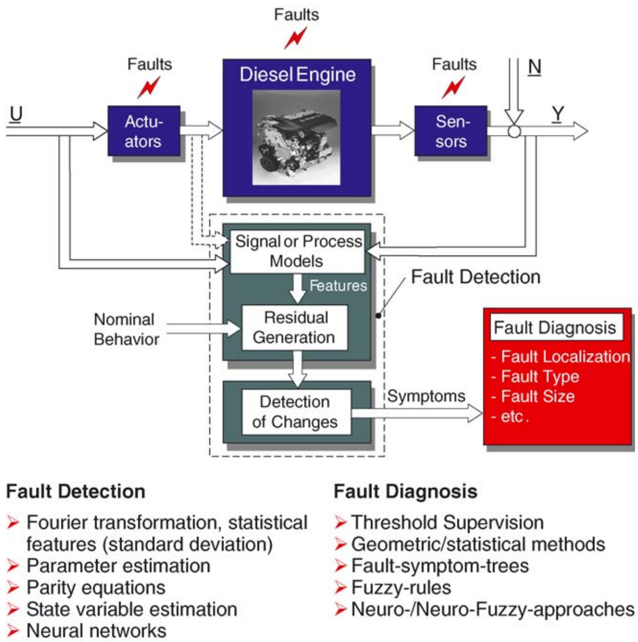

Fig. 1. General structure of model-based fault detection and diagnosis (Isermann, 1997).

applied, for instance parameter estimation, parity equations, state variable estimation or neural networks, (Isermann, 1984, 1997; Gertler, 1998; Chen & Patton, 2000). For the following fault diagnosis, classification or inference methods, including fault–symptom trees, fuzzy rules or neuro-/neuro-fuzzy approaches can be used. An overview can be found in Füssel (2002).

In the following contribution an overall fault diagnosis system for Diesel engines will be presented. The inlet system, the injection and combustion as well as the exhaust system will be under special consideration. The methods are based on an appropriate signal processing of measurable signals using signal- and process models to generate residuals and symptoms. The experimental investigations which are presented were performed at a Opel four-cylinder Diesel engine at the test stand and in the vehicle. Former publications on fault detection of gasoline engines are for example Rizzoni (1995), Isermann (2003a) or Isermann (2003b).

2. Concept for a modular model-based fault detection system of diesel engines

Fig. 2 shows the concept for the developed model-based fault detection and diagnosis of the complete engine, see also Kimmich, Schwarte, and Isermann (2001), Schwarte, Kimmich, and Isermann, (2001, 2002). The engine is partitioned in three major subsystems: Intake system, injection, combustion and crankshaft system as well the exhaust gas system. The actuators are commanded by the electronic control unit and act on different components of the combustion engine. In addition to the available mass production sensors only very few additional sensors are used. For each major subsystem, fault detection methods are developed to detect faults in the shown components and to generate symptoms. Then the symptoms are processed with diagnosis methods to decide on faults according to their type and location. The investigated engine is an Opel 2 l, 4 cylinder, 16 valve turbo charged DI Diesel engine with a power of 74 kW and a torque of 205 N m. The engine employs exhaust gas recirculation and a variable swirl of the inlet gas for emission reduction.

For automotive mass production applications suitable models have to be found, which permit a statement about the faultless or faulty system state with the restricted information of only a few sensors. Starting from a detailed physical model simplified substitution models can be derived. Their parameters then have to be obtained mostly by identification methods. However, physical models of combustion engines include sometimes complex non-linear fluid- and thermodynamic processes so that even simplified physical models are often too complex for implementation in engine control units. Then, for example, neural networks can be used to model the input–output behaviour of the strong non-linearities. By this way black box modelling with the special local linear neural network LOLIMOT comprises both automatic model structure generation and identification of its parameters. Another favourably usage of neural networks is the possibility to include models with partly known physical structure, resulting in semi-physical models (Töpfer, Wolfram, & Isermann, 2002). Then the combination of modelling the dominant characteristics physically and secondary effects with neural networks results in a good overall performance.

3. Model-based fault detection of the intake system

The fault detection of the intake system is based on neural network models, calculation of special features and parity equations. The considered intake system of the Opel DTI Engine is representative for a modern turbo charged passenger car Diesel engine. As shown in Fig. 3, the air flows through the air filter, air mass flow sensor, compressor, intercooler and inlet manifold. The blow-by of the crankshaft casing is led back between air mass flow sensor and compressor wheel. Recirculated exhaust gas is mixed to the air by the exhaust gas recirculation (EGR) valve. To reduce emissions, each cylinder is filled by a swirl port and a filling port. By throttling the filling port of each cylinder with the swirl flaps actuator (SFA) the swirl can be adjusted. Further components of the intake system are the pneumatic membrane actuator to manipulate the swirl flaps, the EGR valve and the electro-pneumatic converters which