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Monitoring of the dilution of motor oil with Diesel using an advanced resonant sensor system

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Abstract

In modern light-duty Diesel vehicles the particulate filters in the exhaust system require periodic regeneration to prevent plugging. The regeneration procedure is a major cause of dilution of engine oil with diesel fuel. In order to investigate the effect of the operation conditions of the engine on the fuel content in the oil, a precise and fast in-line measurement system is required. In this contribution a resonant sensor system for determination of diesel content by measuring the viscosity of the oil is tested. A commercial off-the-shelf quartz tuning fork resonator is used as sensor element and evaluated using a universal analyzer for resonant sensors developed for fast and precise acquisition of resonant sensor responses. The experiments presented in this paper show that fuel concentration in the range of 0.2 % can be determined within seconds. The obtained results are compared to that obtained with an accurate lab bench viscosity and mass density meter.

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1. Introduction

The dilution of engine oil with fuel in diesel engines is not a new issue, but with lowering emission limits it gained more attention recently. Modern light-duty diesel vehicles are equipped with diesel particulate filters (DPF) in the exhaust system accumulating the soot emissions. To prevent plugging these filters need to be regenerated periodically by adding unburned fuel into the exhaust system to burn off the soot. Many manufacturers implement

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in-cylinder post-injection cycles, where fuel is injected into the cylinder after the regular combustion (at the end of the power stroke and during exhaust stroke).

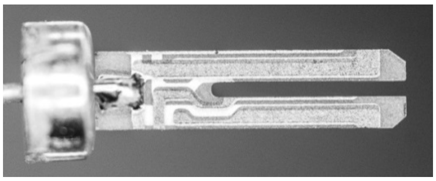
During these late injections, a thin film of fuel can build up on the cylinder walls and be wiped by the piston into the lubrication system of the engine where it dilutes the engine oil [1,2]. This effect is of particular interest in engines running on biodiesel because the boiling point of biodiesel is higher than of regular diesel and thus less of the post-injected fuel vaporizes and more is found on the cylinder walls. This effect has to be taken into account when running on blends of regular and biodiesel, the fraction of biodiesel will cause overproportional dilution of the engine oil [1-3]. Besides chemical effects (mainly due to interactions with additives in the oil) the most significant issue of the oil dilution is the reduction of viscosity [4, 5].

In order to investigate the dependence of fuel intake on operation conditions of the engines in more detail, an inline measurement system for oil dilution is required. It is intended to gain reliable information from correlating the settings and status of the engine with very small changes in oil properties, requiring a measurement system with a high measurement accuracy and minimal cross-sensitivities at high measurement rates.

2. Measurement System

There are various publications on the monitoring of different parameters of engine oil [6-11], and many of them make use of resonant sensors to determine physical fluid properties such as viscosity and mass density. In contrast to resonators with dominant shear oscillation where only the product of viscosity times mass density can be measured, tuning fork resonators allow a separation of mass density and viscosity [12-14]. For the experiments presented in this contribution, we used a commercial off-the-shelf 32.768 kHz clock crystal where the housing was removed manually (Fig. 1a).

Resonant sensors for the measurement of fluid properties are electromechanical resonators where the interaction with the surrounding fluid changes the resonant behavior. The mechanical resonance of such a resonator can be modeled as resonant circuit, which is often extended by additional elements representing parasitic properties of the system. For quartz crystal resonators (QCR) the most common model is the Butterworth - Van Dyke equivalent circuit (Fig. 1b).



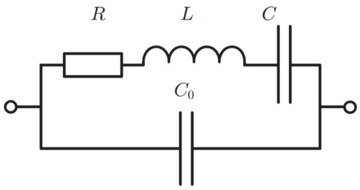


Fig. 1. (a) Commercial off-the-shelf 32.768 kHz clock crystal (~2 x 7 mm) with removed housing; (b) Butterworth - Van Dyke model for QCR. The simple damped resonant circuit is paralleled by the electrode capacitance C_0 of the QCR.

In order to achieve good measurement results, parasitic influences like the parallel capacitance have to be compensated [15, 16]. Moreover, depending on the physical parameters of the liquid (permittivity and conductivity) the parallel element has to be considered as a complex function of frequency and thus additional effort has to be made to separate the behavior of the desired mechanical resonance from parasitic effects. The only practicable solution in this case is to record the resonators behavior in vicinity of the resonance and to shift the extraction of desired mechanical parameters to a post processing step in the digital domain.

The resonator is excited and evaluated using a dedicated analyzer (MFA 200, first presented in [17]) for resonant sensors developed by Micro Resonant Technologies. Similar to an impedance analyzer, this instrument records the behavior of the resonator in vicinity of the resonance frequency. From this information, the parameters of the