Characterization of stressors at exhaust system components acquired on AgriPower equipment

Compiling a data base for robust exhaust gas aftertreatment systems

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Abstract

New exhaust emission standards for Non-Road-Mobile-Machinery (NRMM) are phasing in 2011. In a first stage, reduction of particulate matter (PM) is demanded and in a final stage further reduction of NO_x emissions required in 2013 and 2014. The development of exhaust reduction systems for AgriPower equipment is fundamentally similar to On-Road systems. Besides different certification test cycles such us ISO 8178 and Non-Road Transient Cycle (NRTC) significantly different duty cycles are expected. Therefore load conditions in such cycles need to be quantified to ensure robust development of emission control technologies.

In this study, for the fist time, duty cycles were investigated to develop a fundamental database under real life operation. The assessment was carried out on a modern production Fendt 930 Vario with 230 kW engine power. Temperature and vibration sensors were installed to acquire thermal and mechanical loads as function of duty cycle and engine speed and load. The acquired database is fundamental for the development of durable exhaust aftertreatment systems.

Based on the derived findings it is possible to validate exhaust systems with controlled burner and electro-dynamic shaker systems on component level reducing development time and cost. Thermal boundary conditions acquired support the engineering of compact exhaust aftertreatment systems with passive soot oxidation and NO_x reduction through SCR technology.

Introduction

Vehicle and engine manufactures of AgriPower machines developed successfully exhaust muffler systems focussing on noise reduction performance, heat rejection packaging and, of course, robustness. Future machines will require exhaust aftertreatment control technology to address European Stage III B / US Tier 4 interim and EU Stage IV, US Tier 4 final emission standards as shown in Fig. 1.

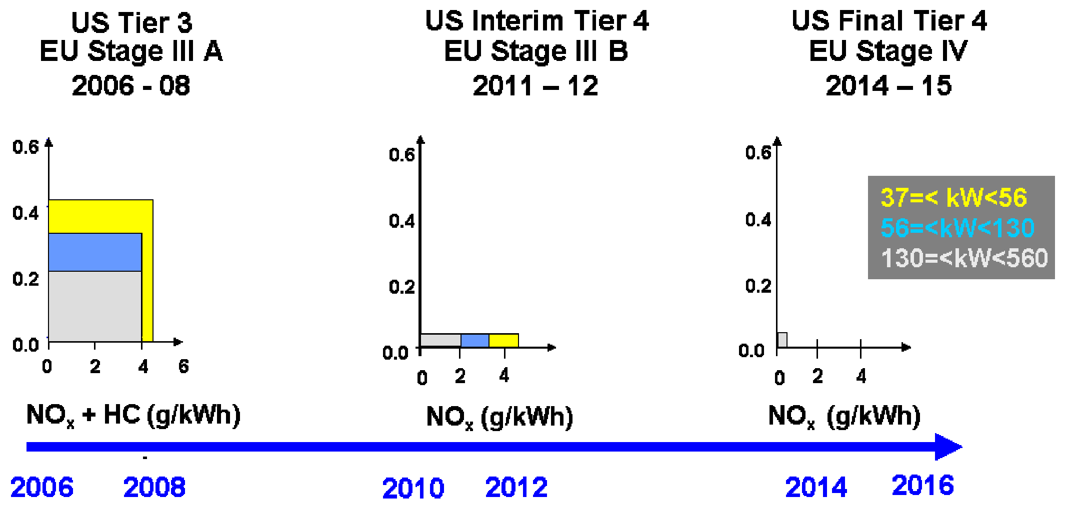

Figure 1 US and European Emission Regulations for Non-Road Mobile Machinery (NRMM) [1,2]

Exhaust aftertreatment system layout for upcoming EU Stage III B and Tier 4 I will depend on combustion control technology, e.g. using particulate-filter-only technology for low NO_x engines or SCR-only technology for in-cylinder particulate control.

Particulate reduction can be addressed in “passive” operation mode with nitrogen dioxide (NO_2) in continuous soot-oxidation mode [3] and “active” mode with additional fuel injection and soot combustion with oxygen where exhaust gas temperature above 600 °C are targeted [4]. In such cases heat rejection and of the exhaust system components during drop-to-idle situation, are more critical. Moreover, exhaust system surface temperatures, e.g in dusty environments, and also exhaust gas tail pipe temperatures can be extremely dangerous. Such high temperatures may present a safety and/or fire hazard during active regeneration events. The discussed aftertreatment control technologies are known in HD on-road vehicles and long term field experience is available. However, for AgriPower applications, severe engineering challenges regarding packaging due to visibility [5], cooling and heat rejection and exhaust gas tail pipe temperature level need to be addressed to minimize risk at all circumstances without compromise.

Figure 2 provides an overview of stressors applied on exhaust aftertreatment systems and components. Fatigue failures occur due to external loadings such as mechanical excitation and shock loads superimposed with thermal loadings due to temperature cycling and of course catalyst flow conditions which influence overall catalyst performance and catalyst degradation [6].

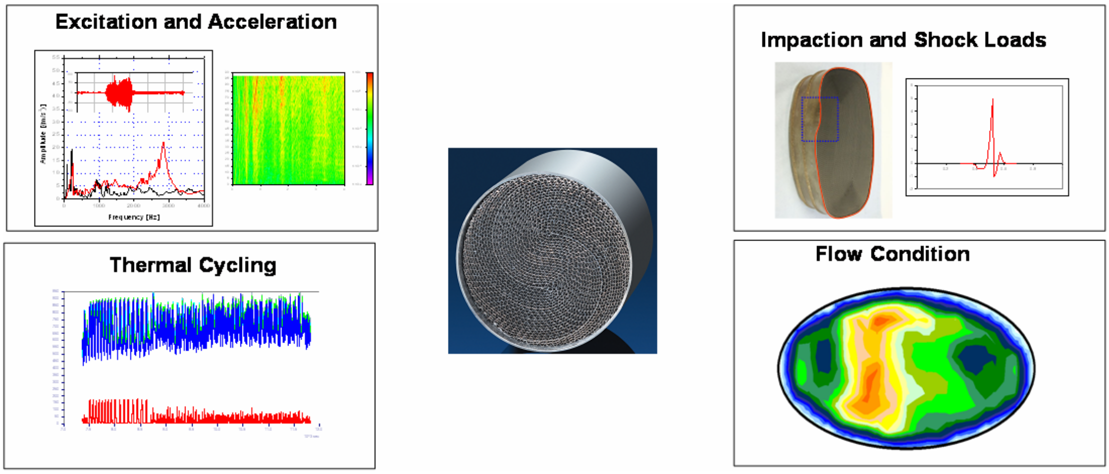

Figure 2 :Principle load factors on catalyst systems [5]

Because of the unique operation conditions and complex duty cycles, also during power-take-off operation, boundary conditions are different for particulate filter systems and catalysts compared to on-road applications. The assessment, in this paper described, was focused on acquiring thermal and mechanical load factors to ensure robust system development for future exhaust aftertreatment control technologies.

Setup and baseline measurement

A production Fendt Vario 930 was used for the assessment and tests have been carried out at GKN Walterscheid test lab. The exhaust system of the tractor was installed with thermocouples and acceleration-sensors. The accelerometers were mounted on cooled adapted plates to avoid sensor drifting and sensor overheating and damage. In a first stage load factors were recorded using an electrodynamic brake system attached at power-take-off system (PTO). Figure 3 shows the test vehicle and the setup for temperature and vibration sensors. Installation of catalyst systems at position 2 is expected to be beneficial due to higher exhaust gas temperatures compared to position 4.

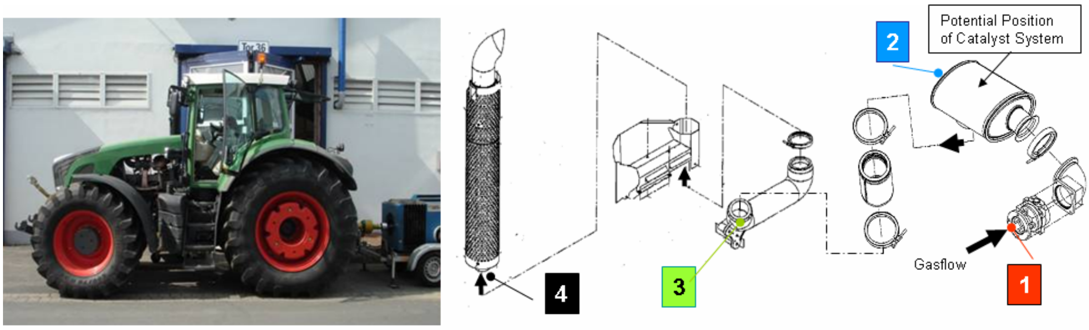

Figure 3 Test vehicle and with electrodynamics beak system and sensor setup thermocouples (Position 1, 2, 3, 4) and accelerometers (Position 1,2,4)

Vehicle measurement during engine ramp-up mode and in-use operation

Figure 4 shows acceleration data during engine full-load test cycle. The data were afterwards post-processed using Fast Fourier Transformation algorithm (FFT) to understand excitation level as function of frequency. Excitation levels are significantly higher at position 2 compared to the muffler system as a result of rigid mounting at position 4. Acceleration peaks were observed at 70 Hz, 164 Hz, 392 Hz, 531 Hz and 1527 Hz. Maximum acceleration levels are compared for position 1 and 4 in table 1. Exhaust gas temperature decreasing about 60 Kelvin from turbo to inlet muffler system which is beneficial for muffler surface temperatures.

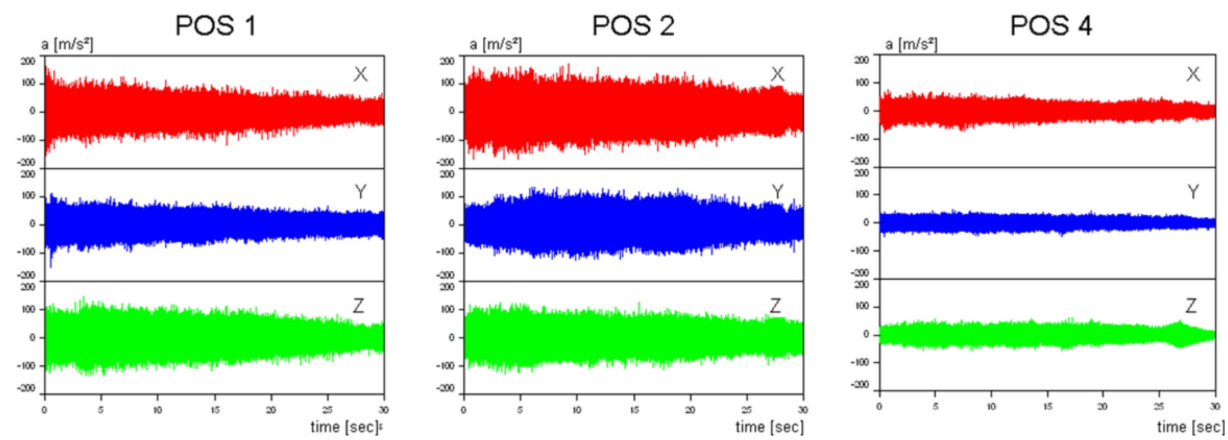

Figure 4 Acceleration at position 1, 2 and 4 during full load engine test (X-Axis: vehicle longitudinal axis; Y-Axis: vehicle transversal axis; Z-Axis: vehicle vertical axis)

Position	Temperature	Acc X	Acc Y	Acc Z
1	446 °C	159 m/s²	110 m /s²	143 m/s²
2	413 °C	168 m/s²	134 m/s²	123 m/s²
4	385 °C	73 m/s²	46 m/s²	61 m/s²

Table 1: Exhaust gas temperature and maximum vibration loads during ramp-up mode

The tractor was afterwards operated in various duty cycles to investigate exhaust gas temperature. Figure 5 shows the recording over two hour engine operation. The cycle can be subdivided in urban city interval with up- and down-hill periods and high load ploughing cycles' intervals. Ploughing setting was changed for the last 30 minutes. The evaluation of the temperature data are summarized in table 2. Engine load is calculated with 75 % and 56 % due to manoeuvre but significantly above 95 % during pure ploughing operation as shown in figure 5.

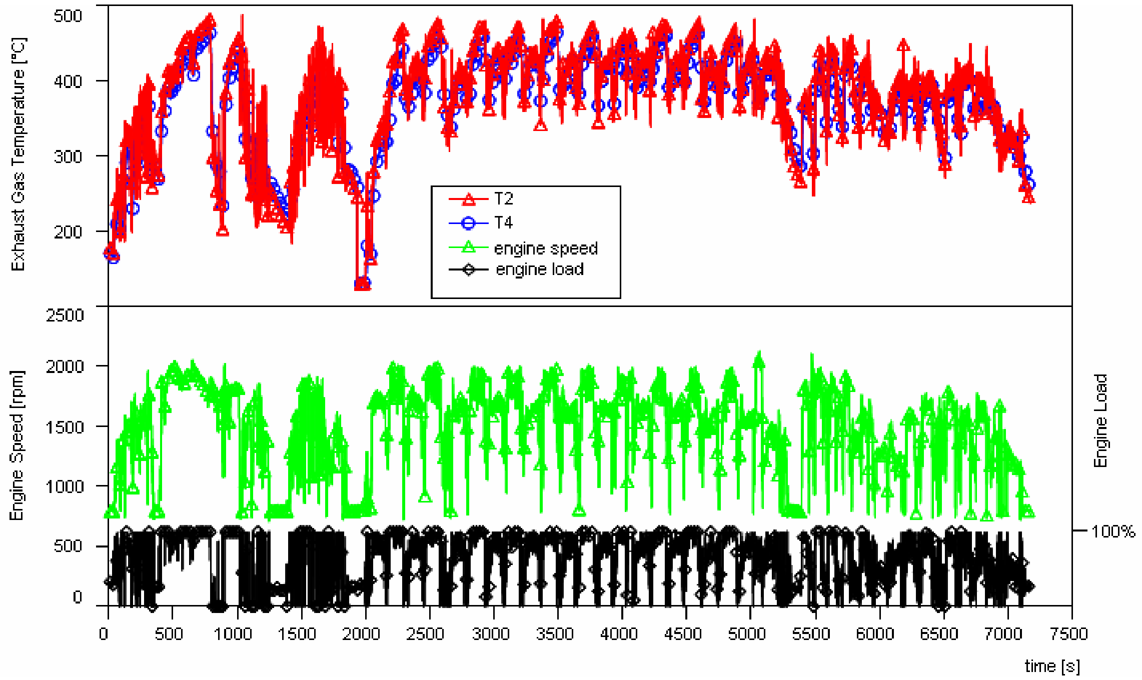

Figure 5 Temperature history during duty cycle

Interval	Profile	Time [sec]	Avg Load [%]	Avg engine speed [%]	Avg T2 [°C]	STDEV T2 [K]
1	Urban cycle	0 - 1800	60	1451	340	87
2 A	Ploughing operation	2000 - 5000	75	1614	416	49
2 B	Ploughing (mod)	5200 - 7000	56	1377	370	42

Table 2: Evaluation of thermal conditions during various duty cycles

Summary and discussion

Figure 6 shows simplified boundary conditions various applications as HD-truck, high performance cars and sport boats, motorcycles and chain saw compared to acquired AgriPower load conditions (shaded area) [7].

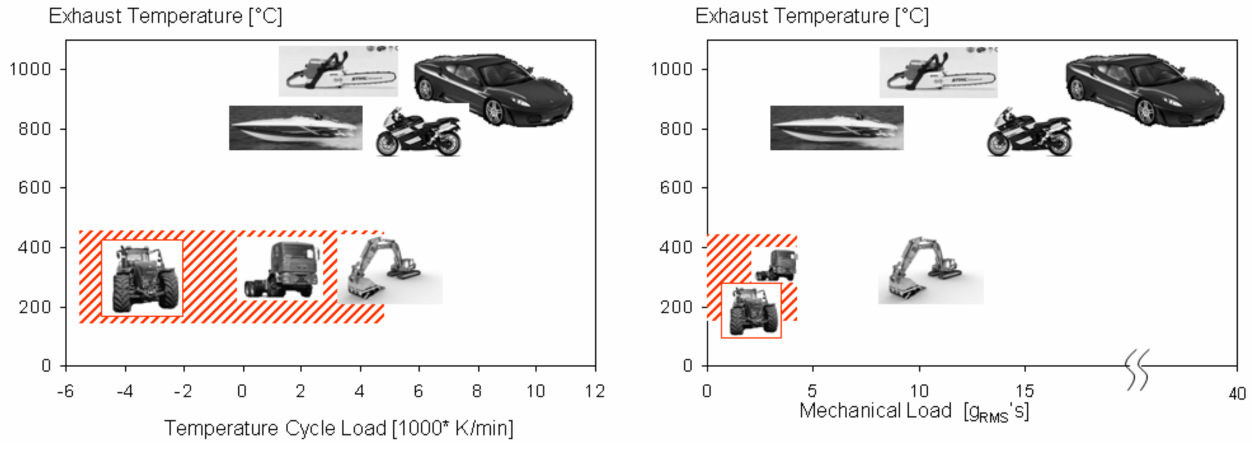

Figure 6 Thermal/ mechanical loads across various applications compared to acquired conditions

Given this, robust Metalit substrates are excellently engineered to withstand tractor load conditions. The acquired database is useful for the development of accelerated test protocols and simulation of load factors on component level as described in reference [8]. Future exhaust aftertreatment control technologies need to be designed to take advantage of given thermal conditions to maximize soot oxidation through NO_2 and fast SCR reaction. Sufficient soot oxidation with in closed coupled DOC and “passive” filter system combined with high performance SCR technology is known as most fuel efficient and cost effective technology to address the challenging EU Stage IV and US Tier 4 emission targets. Figure 7 presents the layout of such compact systems with integrated multi-functionality- the SCRi™ system [9,10]. The systems consist out of:

a) Substrates in a single canister with AdBlue®-Injection after DOC
b) System with reverse AdBlue®-Injection system and additional mixing length between Filter and SCR catalyst
c) Compact unit with DOC in donut-shape design, AdBlue® Injection upstream of PM-Metalit™ with hydrolysis coating and cascaded SCR substrate for minimized flow restriction.

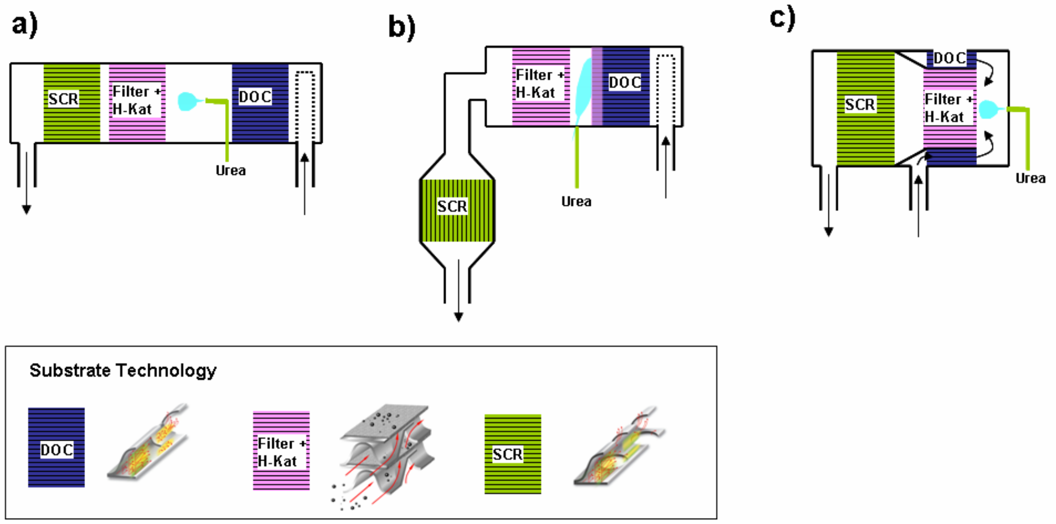

Figure 7 SCRi™ -System: Aftertreatment layout of combined PM / NO_x reduction technology

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