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Application of Low-Cost Transducers for Indirect In-Cylinder Pressure Measurements

Enrico Corti,[1] Lorenzo Raggini,[2] Alessandro Rossi,[3] Alessandro Brusa,[4] Luca Solieri,[5] Daire Corrigan,[6] Nicola Silvestri[7] and Matteo Cucchi[7]

[1]Universita degli Studi di Bologna Scuola di Ingegneria e Architettura, DIN, Italy
[2]Universita degli Studi di Bologna Scuola di Ingegneria e Architettura, Italy
[3]Università di Bologna Scuola di Ingegneria e Architettura, Italy
[4]University of Bologna, Italy
[5]Alma Automotive srl, Italy
[6]Ferrari Auto SpA, UK
[7]Ferrari Auto SpA, Italy

Abstract

The aim of this work is to present the results achieved in the evaluation of combustion metrics using low-cost sensors for the indirect measurement of cylinder pressure. The developed transducers are piezoelectric rings placed under the spark plugs. Tests were carried out on three different engines running in various speed and load conditions. The article shows the characteristics of the signals generated by the piezo-ring sensors, compared to those coming from laboratory-grade pressure transducers: focus is to assess the achievable accuracy in the determination of frequently used combustion metrics, such as those related to knock intensity (Maximum Amplitude of Pressure Oscillations, MAPO), combustion phasing (MFB_{10}, MFB_{50}, …), and peak pressure. Despite some issues related to the variation in sensitivity (temperature effect) to mechanical noise at high engine speeds and to signal deviation from the actual cylinder pressure trace in some portions of the engine cycle, the article shows that combustion metrics evaluated using low-cost sensors are meant to be used for combustion feedback control.

History

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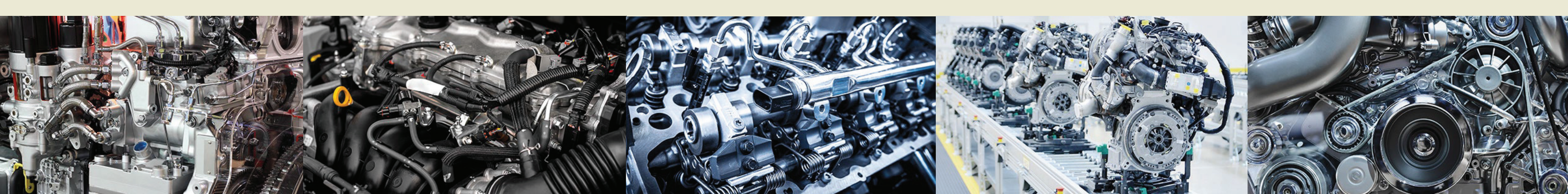

MFB_{90} - Crank angle at which the 90% of fuel mass inside the cylinder is burned

OEM - Original equipment manufacturer

P - Pressure inside the combustion chamber

PCB - Printed circuit boards

PFI - Port fuel injection

P_{max} - Maximum value assumed by the pressure inside the combustion chamber

R^2 - Bravais-Pearson correlation coefficient

RCCI - Reactivity controlled compression ignition

RDE - Real Driving Emission

RMSE - Root mean square error

ROHR - Rate of heat release

RPM - Revolutions per minute

SACI - Spark-assisted compression ignition

SOC - Start of combustion

TJI - Turbulent jet ignition

V - Volume inside the combustion chamber

dP - Derivative of the pressure inside the combustion chamber

dV - Derivative of the volume inside the combustion chamber

$d\theta$ - Derivative angle

k - Adiabatic index

rl - relative load evaluated by the engine control unit

ΔF_b - Bolt force variation

ΔF_c - Joint force variation

ΔL_b - Bolt deformation

Δt_j - Joint deformation

$\Delta\delta$ - Bolt and joint strain variation

θ - Crank angle

θ_{start} - Starting crank angle of the angular window for the evaluation of the CHR

θ_{end} - Final crank angle of the angular window for the evaluation of the CHR

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Appendix

This section shows the technical characteristics of the reference sensors and piezoelectric washer used for each engine.

TABLE A.1 Technical data of reference sensor used on Engines 1-3.

M12 × 1.25 measuring spark plug with integrated 3 mm cylinder pressure sensor Type 6115C		
Manufacturer	**Kistler**	
Measuring range	bar	0 ... 200
Overload	bar	250
Sensitivity at 200°C	pC/bar	≈−10
Sensor operating temperature range	°C	−20 ... 350
Thermal sensitivity shift		
200 ± 50°C	%	<±1

TABLE A.2 Technical data of reference sensor used on Engine 2.

Water-cooled pressure sensor for combustion engines Type 6061C		
Manufacturer	**Kistler**	
Measuring range	bar	0 ... 250
Overload	bar	300
Sensitivity at 200°C	pC/bar	≈−26
Sensor operating temperature range (uncooled)	°C	−40 ... 350
Thermal sensitivity shift		
RT ... 350°C (uncooled)	%	±3
50°C ... ± 30°C (cooled)	%	±0.2

TABLE A.3 Technical data of piezoelectric washer sensor used on Engines 1, 2, 3.

M12-M10 piezoelectric washer		
Sensor thickness	mm	1.9 ... 2
Measuring range	bar	0 ... >300
Overload	bar	NA
Sensitivity at 100°C	pC/bar	70 ... 120
Sensor operating temperature range	°C	<175
Thermal sensitivity shift		
−20°C ... 125°C	%	0 ... 4