Cylinder Head Gasket

with Integrated Combustion Pressure Sensors

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Advanced Engine Controls
Enabled by Combustion Pressure Sensor (CPS)

• Balancing of large bore gas & diesel engines
• Closed loop control of light duty diesel engine: 50%MFB, IMEP-balancing, peak pressure, fuel quality correction
• Real time (in-cycle) fuel injection & ignition control
• Combustion control of diesel LTC/PCCI engines
• Control of gasoline, natural gas HCCI & lean burn engines
• Control of hybrid combustion engine & powertrain
• Knock & air-fuel control in aviation SI engines
• Advanced OBD, engine monitoring & diagnostics
• Virtual in-cylinder MAF, NOx, and EGR sensing
• High accuracy CPS could eliminate: knock, misfire, cam shaft, position, Mass Air Flow, & NOx sensors
Cylinder Head Gasket with Integrated CPS (CHGICPS)

- Multi Pin Connector
- Signal Conditioner
- Pressure Port
- Cover
Concept of Optrand Miniature CPS for CHGICPS

- Sensor front section diameter: 1.8mm
- Conical pressure seal 60 degrees
- Sensor back section diameter: 2.5mm

- Signal conditioner dimensions: W=10mm, H= 5mm, L= 20mm
- FO cable length: 30-60mm
CPS Auto-Referencing for Drift-Free Operation

- Closed-loop LED current control based on low pass filtered photodiode output
- Compensates for effects of under hood temperature changes on opto-electronics & light transmission
- Corrects for effects of sensor head & diaphragm temperature changes on sensor offset & gain
CPS Head Components & Assembly

- Inconel 718 diaphragm stainless steel housing
- Hermetic weld of diaphragm to housing & needle to housing
- Same CTE of fiber, glass seal & needle for hermetic & stress-free fiber seal
- 700°C fiber softening temperature & 520°C glass seal softening temperature2
Hat Shape CPS Inconel 718 Diaphragm for Long Sensor Life

Stress versus Pressure Cycles

Inconel 718

1.7 mm Diaphragm for 200 bar (2900 psi)

14.447 microns 116.8 ksi

131.6 ksi
Specifications of CHG-Integrated CPS

- **Pressure Range:** 0-150, 0-250(350) bar
- **Over Pressure:** > 1.5 range
- **Accuracy:** +/-1.2% of reading for p > 5 bar
  - +/-0.1 bar for p<5 bar, before SOC
  - +/- 0.2-0.4 bar for p<5 bar, after SOC
- **Temp. coeff. Sens.:** +/- 0.002 %/°C
- **Non-linearity:** +/-0.2% (@80% FS)
### CPS Specifications – Continued

- **Sensor tip temp.**: -40°C to 380°C or 450°C  
- **Conditioner temp.**: -40°C to 150°C  
- **Frequency range**: 0.1(1) Hz to 15(30) kHz  
- **SNR**: ~1500:1 @20kHz  
- **Power supply**: 3.0V-5.5V, 10mA max  
- **Output**: 0.05 V<sub>cc</sub> to 0.95 V<sub>cc</sub>; 0.25V to 4.75V @V<sub>cc</sub>=5V; ratio-metric  
- **Switch on delay**: < 20ms after V<sub>cc</sub> on  
- **Service life**: 0.5 -5 Billion cycles, 10k-30k h  
- **Diaphragm dia.**: 1.7mm, 1.0mm to be offered
Removable CPS Prototype

- Signal conditioner dimensions:
  Dia.=25mm, L= 75mm
- FO cable length: 1.5 m

- Sensor front section diameter: 1.8mm
- Sensor back section diameter: 2.5mm
CHGICPS Prototype with Removable CPS in Diesel Engine

Extended gasket
For sensor mounting

Replaceable Sensor
CHGICPS Performance @ 2000 RPM, Different Loads
CHGICPS Performance @ 2000 RPM, All Loads
CHGICPS Performance @ 2900 RPM, Full Load

Unfiltered Single Cycle Matched @ 8.5 ATDC Peak Pressure

- Fiber Optic CPS - PP 167.88 bar
- Reference Sensor - PP 168.19 bar
- Fiber Optic CPS - 11 Point Central Filter
- Reference Sensor - 11 Point Central Filter
- Delta
- Delta W/ 11 Point Central Filter
Summary & Conclusions

• Cylinder Head Gasket with integrated miniature cylinder pressure sensor has removable transducers having 1.8mm in diameter front section and 2.5mm diameter, 50mm long cylindrical body
• Prototype CHGICPS has 3.2mm thick distance layer and sensors having their signal conditioners outside CHG, connected to sensors by 1.5m-long fiber optic cables
• Increased CHG thickness compared to production version compensated by increased piston height
• Production intent CHGICPS to come with 2.5mm thick distance layer, sensors’ miniature signal conditioners attached to CHG flange, ~30mm long f.o. cables & single connector to connect all sensors to ECU
Summary & Conclusions

- Optrand Cylinder Pressure Sensor operates on principle of changing light intensity reflected from Inconel diaphragm deflecting under effect of pressure
- Sensor design is based on 2 optical fibers, one LED, one photodiode, & miniature signal conditioner electronics
- Current CGHICPS sensors use $\Phi$1.7mm diaphragms; $\Phi$1.0mm diaphragm to be offered in the future
- All welded fiber optic construction & metal to glass bonding allow sensor head temperatures up to 450°C
- Accuracy ranging from 1.0% to 3% & thermal shock error of 0.3 bar to 1 bar reported for prototype CHGICPS mounted in 6-cylinder diesel engine against water-cooled quartz reference at different load and RPM conditions
Future Work

• Long term endurance and soot tests
• CHGICPS prototype to be built based on 2.5mm thick distance layer for automotive diesel & gasoline HCCI and medium/heavy duty diesel & natural gas engines
• Prototype CHGICPS with 1.5mm thick distance layer to be developed based on 1mm dia. sensor
• Accuracy better than 1.5% to be met under all engine operating conditions
• B-level CHGICPS prototype to be developed with miniature signal conditioner attached to CHG flange
• B-level CHGICPS prototypes to be tested in vehicle and under automotive vibration, temperature, EMI/EMP, salt spray etc. conditions