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Sensor Integration in BS VI Exhaust after Treatment System for Automobiles

Mylaudy Dr. S. Rajadurai[1], S. Shibu Anand[2], P. Matcharaja[3].

[1]*Head R&D, Sharda Motor, Chennai, Tamilnadu, India*
[2,3]*Sr. Engg R&D, Sharda Motor, Chennai, Tamilnadu, India*

***Abstract* - The demanding regulatory requirement mandates the need for new engine-management system and its integration with exhaust-treatment technologies strategy. Different types of sensors play vital role on the engine out and the efficient performance of the exhaust after treatment system. Location, geometry and the orientation of the sensor installation is discussed in detail. The sensitivity of the sensor with the HEGO index guidelines provide the required signal without the noise interference The impact of various particles such as conductive water particles and engine particulates are implemented during the design of exhaust after treatment system. This improves the life expectancy, accuracy level of sensing of the sensors. Advancement of gas sensor technology over the past few decades has led to significant progress in pollution control and thereby environmental protection.**

***Keywords* - Exhaust after treatment, Oxygen/Lambda, Temperature, pressure, Nox, PM, Emission Norms, HEGO Index, DOC, DPF, SCR, ASC, LNT, Hydro Carbon, Oxides of carbon and Oxides of Nitrogen.**

I. INTRODUCTION

Environmental awareness and emission legislation have made it necessary to achieve cleaner exhaust gases from gasoline and diesel engines. Additional systems are needed to reduce hazardous components from exhaust gas. The performance of these systems depends highly on sensors and controls. Reducing emissions like Hydrocarbons (HC), oxides of carbon (COx), oxides of nitrogen (NOx) and particulate maters (PM) in diesel and gasoline engines will become one of the greatest developmental challenges for the future. The primary goal of the future is to maintain the engines as a propulsion source with highest fuel economy.

To resolve this challenges EATS sensors are introduced in the exhaust system to measure those emissions, temperature, pressure from the exhaust stream and give it as a input for the ECU from those inputs we easy introduce the next successful step and resolve those emissions Either in the way of introducing catalyzes or the chemical injection to the exhaust stream.

To succeed those complexity sensors having some limitations, it needs to withstand high temperature and vibration without affecting its measuring efficiency because it's very sensitive so we have to know about the importance in the types of sensors used nowadays in field of exhaust and also handling, defects, design, packaging (1-4).

II. EMISSION REGULATIONS

According to our norms latest revision shown as in the table 1 emission must reduced and screened properly to protect our environment.

TABLE 1

Stage	***Year***	***CO***	***HC***	***HC + NOx***	***NOx***	***PM***	***PN***
		g/km					
Gasoline Vehicles (white)				**Diesel Vehicles** (shaded)			
	1991	14.3	2.0	-	-	-	-
		17.3	2.7	-	-	-	-
	1996	8.68	-	3.00	-	-	-
		5.0	-	2.0	-	-	-
	1998	4.34	-	1.50	-	-	-
		-	-	-	-	-	-
India 2000	2000	2.72	-	0.97	-	-	-
		2.72	-	0.97	-	0.14	-
BS II	2005	2.2	-	0.5	-	-	-
		1.0	-	0.7	-	0.08	-
BS III	2010	2.3	0.20	-	0.15	-	-
		0.64	-	0.56	0.50	0.05	-
BS IV	2010	1.0	0.10	-	0.08	-	-
		0.50	-	0.30	0.25	0.025	-
BS V	n/a[b]	1.0	0.10[d]	-	0.06	0.0045[e]	-
		0.50	-	0.23	0.180	0.0045	6.0×10^{11}
BS VI	2020	1.0	0.10[d]	-	0.06	0.0045[e]	6.0×10^{11}[e]
		0.50	-	0.17	0.080	0.0045	6.0×10^{11}

In view of the increasingly strict laws for emissions from motor vehicles and other sources of pollutants, the need for a new generation cost effective and reliable gas sensors has become a high priority in the survey list. Such sensors must be able to provide a stable and unambiguous signal in harsh environment.

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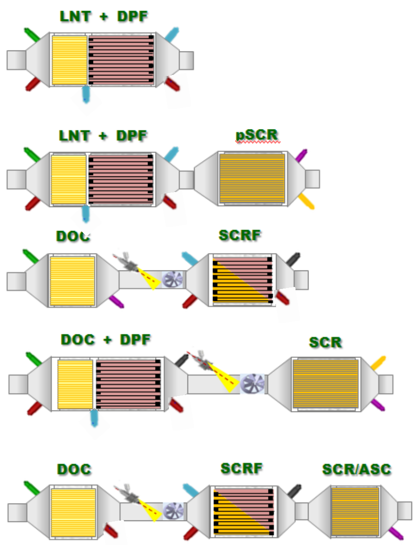
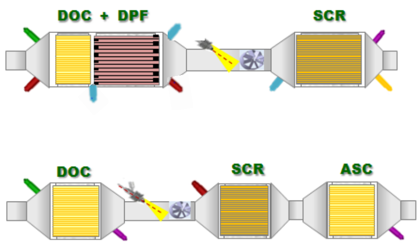
A. Passenger vehicles



B. Commercial vehicle



DOC - Diesel Oxidation Catalyst
DPF - Diesel Particulate Filter
CDPF - Catalysed Diesel Particulate Filter
SCR - Selective Catalytic Reduction
SCRF - Selective Catalytic Reduction Filter
LNT - Lean NOx Trap
ASC - Ammonia Slip Catalyst

III. Types Of Eats Sensor

- Oxygen Sensor or lambda sensor
- Temperature Sensor
- Pressure Sensor
- Oxides of nitrogen sensor (NOx)
- Particulate Matter(PM) or Soot Sensor
- Ammonia (NH_3) Sensor.

IV. Oxygen Sensor

Oxygen sensors or Lambda sensor are used measure the oxygen content in EATS. Oxygen sensors are working on the principle of electrochemical cell electrodes used are ceramic(Zirconium dioxide) membrane which is surrounded with the Platinum electrodes made of pores layer, Mid is vented with atmospheric air. When the exhaust stream exceeds the temperature of 750°C Zirconium dioxide(ZrO2) undergoes mechanism which is producing mobile oxygen ions and acting itself as a electrolyte bridge . Platinum(Pt) electrodes allows the oxygen ion from the exhaust stream to cross over the electrodes then the difference between the exhaust and ambient oxygen ion is recorded. where the higher ions passed high potential difference recorded whether lower ion moved lower potential difference recorded according to that potential differences we identify whether the mixture is rich or lean. Where we simply identified an output voltage of 0.2V recorded which is Lean mixture. In case the maximum of voltage of 0.9V recorded that is rich mixture. And the idle point is approximated at 0.45V the mid of stoichiometric point. These are given as inputs to ECU to control the system operations.

Oxygen sensors are mainly used to increase the fuel efficiency of the engine because the leading trend of selling the car with good mileage assistant and helps to avoid global warming by proper monitoring the level of mixture proportions by which oxides of carbon are screened. Incase High oxygen content in the exhaust gas indicates a lean mixture which leads to CO emission in higher. If it indicates Rich mixture we losses the fuel and results in mileage deficiency. In mountings Oxygen sensors are mounted on before DOC.

Sensors	Colour Codes
Lambda Sensor	
Soot Sensor	
Temperature Sensor	
NO_x Sensor	
Pressure Sensor	
NH_3 Sensor	

Oxygen Sensor

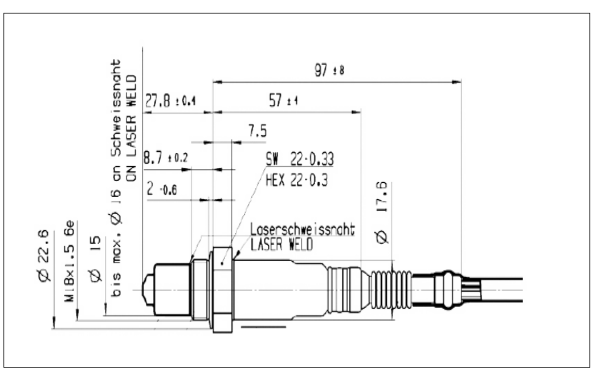
Commonly oxygen sensors are referred in several ways those are,

- *EGO* - Exhaust Gas Oxygen sensor(Single Wired)
- *HEGO* - Heated Exhaust Gas Oxygen sensor(Three Wire)
- *ISO HEGO* - Isolated Heated Exhaust Gas Sensor(Four Wire)
- *UEGO* - Universal Exhaust Gas sensor
- *ISO EGO* - Isolated Exhaust Gas sensor(Two Wire)
- Narrow Band Oxygen Sensors (Zirconium dioxide, Zirconium & Titanium Dioxide
- *Wide Band Oxygen Sensors* - Air Fuel Ratio (AFR) Sensor

A. Sensor Mounting Guidelines

- Sensors Dimensions
- HEGO index
- Acceptance criteria
- Sensors Mounting

B. Oxygen Sensor Dimensions



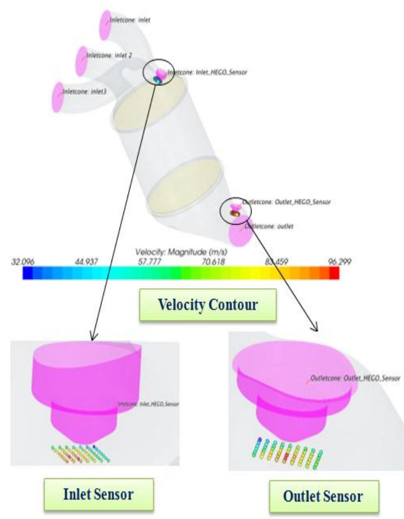
HEGO INDEX

HEGO Index is the parameter by which the exact location of the oxygen sensor is identified. The ratio of the difference between Vmax and Vmin to the Vmean is known as HEGO Index of the oxygen Sensor.

$$\text{HEGO Index (HI)}= \frac{(V_{maximum} - V_{minimum})}{V_{average}}$$

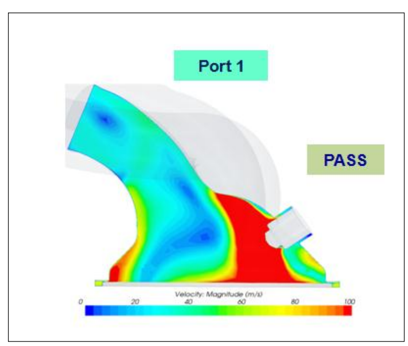
Calculation Targets

- HI < 1.4 m/s
- Average Velocity Flow > 100m/s



Oxygen sensor placed at before after DOC which is represented in the figure for the clarification.

C. Feasibility Study - HEGO Index



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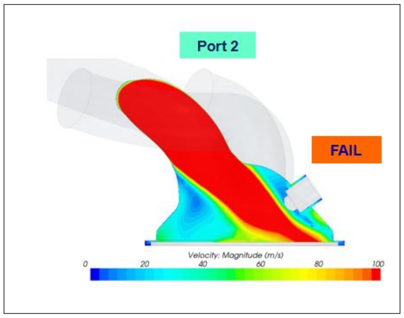
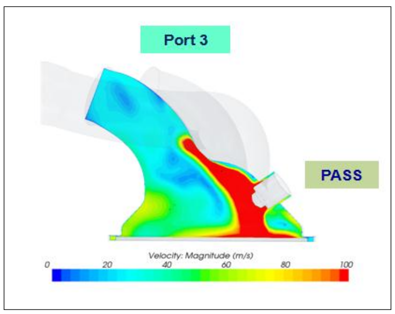


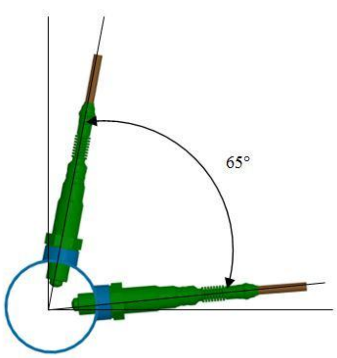


HEGO Index	Measured	Target
	0.742	< 1.5

From the HEGO analysis port 1&3 are passed our condition. While we looking port 2 velocity magnitude crossed our conditions which makes the sensor to improper functioning due to random and peak fluctuations.

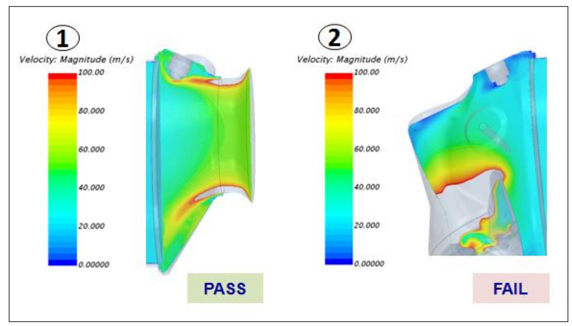
D. Sensor Placement

Locate a position for the oxygen sensor. The header collector makes a good location for mounting. It is recommended that you have at least 2 to 3 feet of pipe after the sensor or it may not read accurately at light loads. If your vehicle has catalytic converters, the oxygen sensor must be located between the engine and the catalytic converters.



The image shows the range of acceptable mounting positions. A vertical position can get too hot in confined spaces, so we recommend at least 15 degrees from the vertical. The horizontal position can cause condensation to drip onto the sensor, so at least 10 degrees from the horizontal axis.

E. Results



Oxygen Sensor Placed at the location and the results are shown below.

Oxygen Sensor	HEGO Index						
	Location	Vmax (m/s)	Vmin (m/s)	Vmean (m/s)	Measured	Target	Remarks
1	Before DOC	100	50	70	0.714	< 1.4	PASS
1	Before DOC	86	45	60	0.683	< 1.4	PASS
1	Before DOC	35	23	22	0.545	< 1.4	PASS
1	Before DOC	13.8	6	9	0.866	< 1.4	PASS
1	Before DOC	45	27	31	0.580	< 1.4	PASS
1	Before DOC	53	18	29	1.206	< 1.4	PASS
1	Before DOC	27	7	14	1.428	< 1.4	FAIL
1	Before DOC	42	21.3	26.5	0.781	< 1.4	PASS
1	Before DOC	39	17	20	1.100	< 1.4	PASS
1	Before DOC	23	8.9	14.6	0.965	< 1.4	PASS
2	After DOC	40	2	20	1.900	< 1.4	FAIL
2	After DOC	8.8	3.3	5	1.100	< 1.4	PASS
2	After DOC	26.3	14.7	19	0.610	< 1.4	PASS
2	After DOC	2.6	1.03	1.7	0.923	< 1.4	PASS
2	After DOC	23	11	12	1	< 1.4	PASS
2	After DOC	35	21	17	0.823	< 1.4	PASS
2	After DOC	12.7	6	7.4	0.905	< 1.4	PASS
2	After DOC	19.4	12	14	0.528	< 1.4	PASS
2	After DOC	6.2	4.2	1.4	1.428	< 1.4	FAIL
2	After DOC	9.1	3	3.6	1.694	< 1.4	FAIL

HEGO index of the oxygen sensor finalized the position of the sensor in case of the HI index doesn't meets the requirements then the sensor leads to misbehave in working functions.

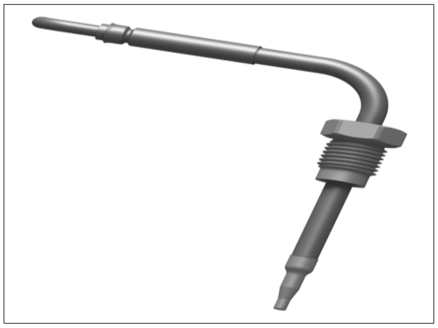
V. TEMPERATURE SENSOR

Temperature sensors are working on the principle of Positive Temperature Gradient or Negative Temperature Gradient. Temperature sensors are used as a warning system, to warn the catalytic converter temperature above the safe limit of 750oC (1380oF). Temperature sensors are also used to monitor catalyst functioning, usually two sensors will be fitted, with one before the catalyst and one after to monitor the temperature rise over the catalytic converter core. For every 1% of CO in the exhaust gas stream the exhaust gas temperature will rise by 100°C.

Mostly Electrical temperature Sensors are used on the field of exhaust systems and its types are

- Thermistor.
- Resistive Thermometer.
- Silicon bandgap temperature sensor.
- Thermocouple.

Temperature Sensor



A. Thermistor

Thermistor made of semiconductor , cheap, durable and reliable device. Its working is simple when the temperature change resistivity of the material changes from that we measure the recorded value of temperature. Where the Negative Temperature Co-efficient defines resistance decreases according to temperature rises. Where temperature increases resistance decreases means that is Positive Temperature Gradient.

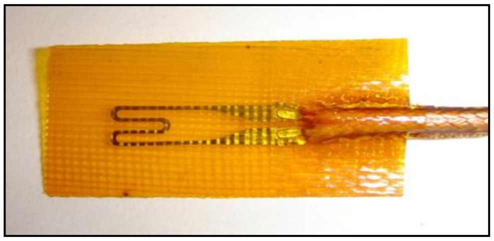
B. Resistance Thermometer

Resistance thermometers are higher accuracy device replaced the thermocouple in applications below 600°C. Made of fine wire wrapped with ceramic or glass wools.

Working as that temperature increases resistivity of the material changes according to value of resistivity temperature has been shown by the control unit. It's also known as Resistance Temperature Detectors.

C. Silicon Bandgap Temperature Sensors

Like as the Thermometers, Here when the temperature increases valence electrons try to cross the bandgap, diode can be used as the temperature measurement device to amplify the producing potential in the device. Here also amount of temperature rises migration rises too.



D. Resistance Temperature Detectors:

Resistance temperature detectors or RTDs are based on the natural change in a metals resistance with temperature. The resistance of most metals increases over a limited temperature range in a reasonably linear way with temperature. For such a linear relationship.

$$R_t = R_0 (1+\alpha t)$$

Where

Rt =Resistance at a temperature t (oC)
R0 =Resistance at 0oC
α =Temperature coefficient of resistance

E. Thermocouple

Two dissimilar metals joined together at their ends. One end is placed in the hot end and another one placed in the cold end ,a potential difference develops due to electromotive force which has been recorded. It’s known as seeback effect. And also works with Peltier and Thompson effect.Welded two dissimilar metals to form a bimetallic junction that produces voltage which varies with temperature. For a vehicle application, a type K (chrome/Nickel-Alumel) or type R or S (Platinum-Rhodium) would be used for the various range of temperatures.

Thermocouples can be made with very little mass which allows for a fast response with changing temperature. In order for the sensor to minimize drift and be durable in a vehicle exhaust environment however, the thermocouple must be protected by a sheath and made thicker.

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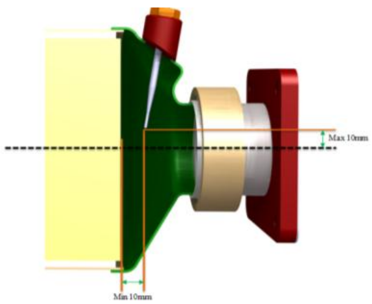
F. Sensor Positioning

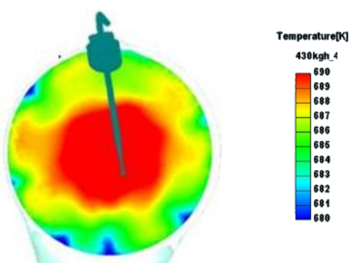
1. Protrusion of temperature sensor at T4 and T5 locations is to be considered minimum 30mm maximum 80mm from the sealing face of the boss.



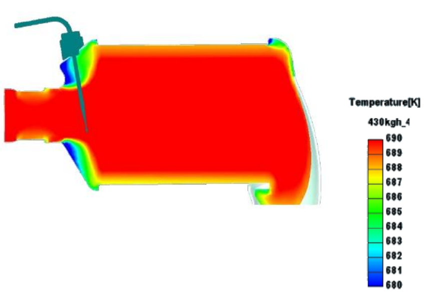
2. S1 & S2 Sensor axis should coincide with centre axis of substrate.

3. Distance between substrate and temperature sensor should minimum 10mm Radial and longitudinal cross sectional views are shown. In mountings temperature sensor are long and placed as per the requirements.

a) Radial Cross Sectional Plane S2



b) Longitudinal Cross Sectional Plane S1



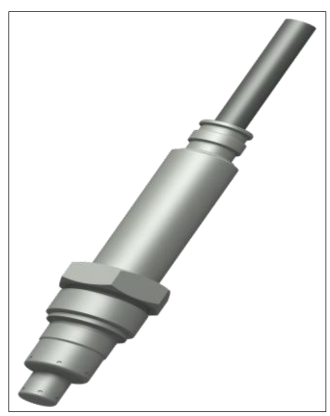
For the accurate readings sensors are placed mid of the requirement places. Analysis shown as, where the heat distributed along the surface. so that we have the sensor placement at the maximum temperature gradient areas.

VI. NOx Sensor

NOx sensors are extremely expensive and are generally only used when a compression ignition engine is fitted with a selective catalytic reduction converter (SCR), or a NOx trap / absorber in a feedback system. When fitted to an SCR system, there may be one or two sensors. When one sensor is fitted it will be pre-catalyst, when two are fitted the second one will be post catalyst. They are utilized for the same reasons and in the same manner as an oxygen sensor - the only difference is the substance being monitored. These kind of sensors also working on the same kind we discussed in the oxygen sensors using Nernst principle and ionization which acts as a electrochemical cell. It's used to measure NOx and Oxygen in the exhaust gas.

A. Ammonia (OR) NH3 (OR) NOX Sensors

It directly measure ammonia levels in the exhaust of diesel vehicles equipped with a selective catalytic reduction (SCR) after treatment system. The sensor output can be used to provide feedback to the SCR system helping provide optimal reduction of NOx emissions. In mountings NOx sensors are placed after the SCR units While development system having the sensors on before the DOC also.



NOx Sensor

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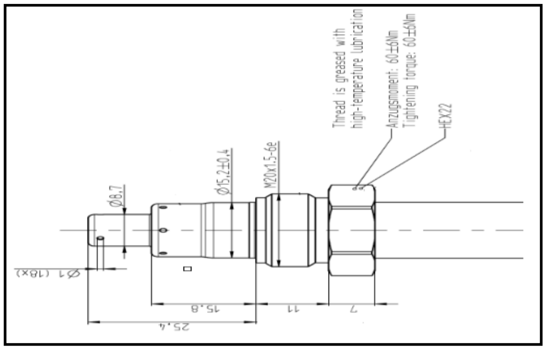
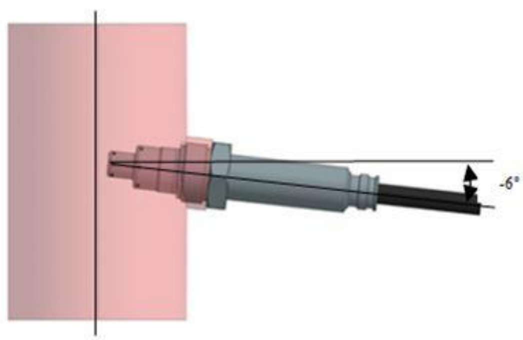
B. NOx Sensor Details



Ammonia sensor placed along and perpendicular to the exhaust stream as shown in the figure and also the maximum allowable values are defined.



VII. PM (OR) SOOT SENSORS

PM sensor can be inserted in the exhaust stream after the DPF. These sensors are working like we taking photo copies, exhaust stream PM is charged and recorded as a image, by image intensity we notice the amount of PM in the exhaust stream. In this position, the particulates that come through the filter can be measured by the sensor. IN mounting PM sensors are placed after the SCR units while testing sensor are placed after the DPF units.

The packaging under the vehicle can dictate where a PM sensor is best located, and since the DPF can be located before or after the selective catalytic reduction (SCR) catalyst, a PM sensor must be designed for robustness to urea exposure. . Internal to the exhaust pipe, a PM sensor located behind a DPF is exposed to water impingement from condensed water released by the DPF back face. During a DPF regeneration, exhaust temperatures at the DPF outlet can reach temperatures in the 650 to 700° C range. If the DPF is overloaded or the regeneration becomes uncontrolled, the temperatures can climb even higher.

Short durations of over temperature as high as 950°C are possible for a runaway situation. It is important that the sensor continues working after such an occurrence to diagnose a failed DPF, since the source of many DPF failures is high temperature gradient exposure by the DPF substrate. However, being located behind the DPF does offer poison and ash exposure advantages, since the DPF tends to filter them along with the particulate matter. Exhaust gas can also contain sulfates which can form corrosive acids, and if positioned behind a urea SCR catalyst, the sensor will be exposed to ammonia and urea.

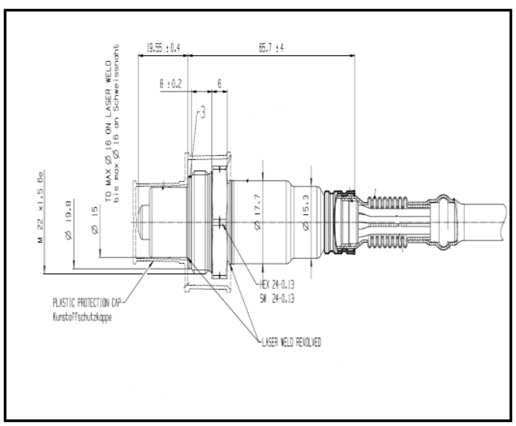
PM/Soot Sensor

The particulate matter sensor technology presented in this paper requires the sensor element to be above the dew point temperature in order to differentiate between conductive water particles and engine particulates. Since the DPF has a large thermal mass, it can take several minutes for the exhaust gas outlet temperature to rise above the dew point. During this time the sensor signal is depressed and not usable for detecting engine particulates. The farther back the PM sensor is located, the longer the delay for the dew point temperature to be reached. Thus, it is advantageous to be as close as possible to the DPF for achieving quicker time-to operation. Since the test cycle for evaluation of a DPF failure has limited time, the sooner the PM sensor is above dew point, the more time is available verification of DPF failure before setting a failure code. Unlike gas constituents, which tend to quickly diffuse in the exhaust, particulate matter is solid matter suspended in air that does not diffuse quickly. Thus, care must be taken in locating the sensor so that objects do not mask the particulate matter from the sensor.

This is important both upstream and downstream of the sensor so that the gas velocity vectors are not affected.

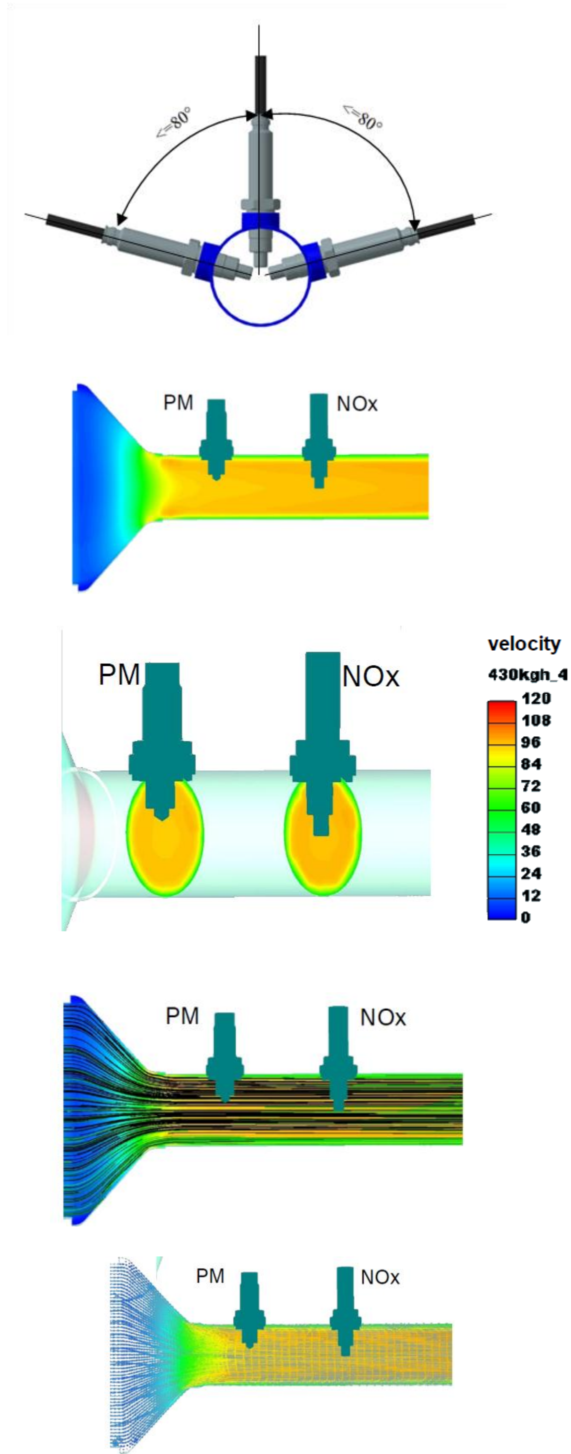
Since the sensor must receive solid particles onto the surface of its internal element, conventional contaminant protection coatings that require a torturous path to reach the element sensing surface are not feasible. Therefore, the PM sensor must rely in part on the DPF to prevent the contaminants from reaching the surface of the element. These contaminants typically consist of Calcium, Zinc, Phosphorous, and Sulfur primarily coming from the engine oil, but to some extent also from the fuel. Large amounts of acid can be produced in a diesel exhaust system, especially behind a DPF and SCR system. Since the PM sensor is not normally heated, this acid can reside on the internal sensor components for a significant amount of time. Further, the acid can enhance the oxidation of the iron found in the exhaust components with the oxidized material having the potential to find its way onto the sensing electrode. Iron oxide is a semiconductor which can become conductive in the measuring temperature range of the sensor. Since the PM sensor must be a fairly open design to flow particulate matter across the electrode face, it can be challenging to regenerate the sensor to a temperature that insures a complete oxidation of the particulate matter under the full range of temperature and flows. This is especially true for post DPF diesel locations which tend to run below 300°C and have relatively high velocities. In vehicles with 12 volt electrical systems, the amount of available power to heat the sensor is limited.

A. PM Sensor Details



Guidelines for the PM sensor is placement of sensor perpendicular direction to the exhaust stream and place the opening port as oppose the exhaust stream to collect the soot for its proper functioning maximum allowable values shown in figure.

B. NOx And PM Sensor Positioning



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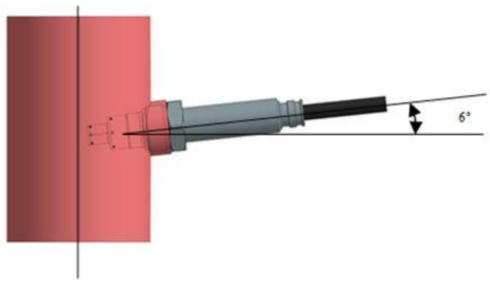
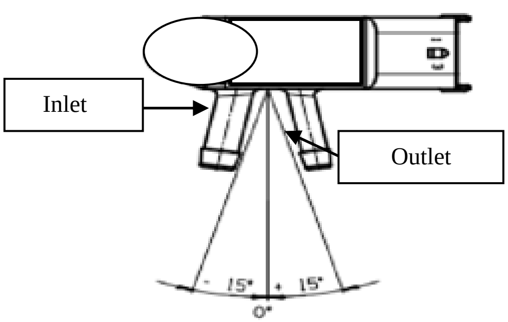


From the Analyse Sensor are placed in right positions. Soot sensor opening is placed in face of upstream for the proper functioning.

VIII. PRESSURE SENSOR

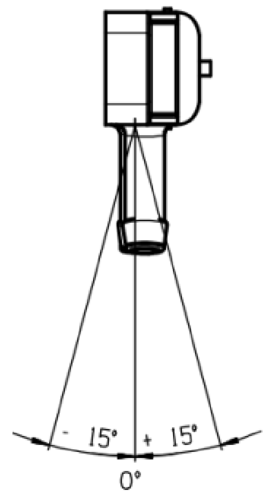
Pressure Sensor Working as a Transducer senses the fluid pressure by using the set of arrangements one is diaphragm made of silicon, stainless steel and etc... and another one is sensing material piezoelectric materials. When the diaphragm experience a deformation due to the fluidic influences due to piezoelectric effect voltage created which has been recorded and processed using the ECU. Placement and Direction it faces to exhaust stream is very noticeable. Straight profile pressure sensor better while taking measurements other than straight profile like tapered, bended are showing more deviations while testing.



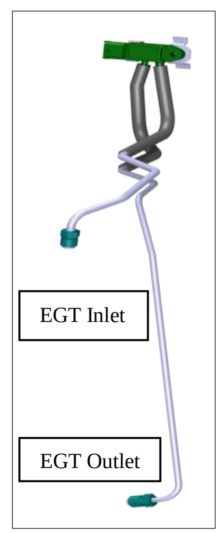
For EATS recommended pressure sensor specifications are Maximum Radial force on pressure port is 20N, allowable installation force is 40N. Maximum axial force at each pressure port is 280N.

A. Sensor Positioning

While installing the sensor on vehicle all the ports should be vertically downwards and above mentioned angle for the proper functioning.



Hoses secured on the pressure ports against sliding off to prevent escape of hot exhaust gas and to ensure safe operation inner diameter of the hoses 6.8mm and 4.6mm for the 8mm and 6mm pressure port respectively



Pressure Sensor And Tubes

Hoses put on pressure ports with a length of 20mm. Use washer Ø10mm minimum or adequate screw head diameter. Maximum permissible force for fixing screws while mounting tightening is 4.5kN. Installation location protected against the head wind blows. No constraints, length of the hoses and pipe must be at least 800mm hoses rising all the way to the sensor and protect against the cold wind blows to prevent the exhaust gas condensation and Maximum diameter of the screw in the interior of the mounting hole is 6mm.

B. Sensor Common Standards

PRESSURE SENSOR BOSS	M14 * 1.25P
TEMPERATURE SENSOR BOSS	M12 * 1.25P / M14 * 1.25P
NOx / PM SENSOR BOSS	M20* 1.5P
LAMDA SENSOR BOSS	M18 * 1.5P

IX. Conclusion

Installation of sensors with right positioning to provide accurate output was considered during the design process of the exhaust after treatment system. The performance of the sensor was improved with the required HEGO index. Sensors are mandatory for on board diagnostics for advanced emission control requirements. We clearly know the importance of the sensors, purpose and instrumentations. Introducing Sensor technology in the exhaust system provides efficient pollution abatement and thereby high engine performance and fuel efficiency and reliability.

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Biographies

Mylaudy Dr. S. Rajadurai, Ph. D.

Dr. S Rajadurai, born in Mylaudy, Kanyakumari Dt, Tamil Nadu, India, received his Ph.D. in Chemistry from IIT Chennai in 1979. He has devoted nearly 37 years to scientific innovation, pioneering theory and application through the 20th century, and expanding strides of advancement into the 21st century. By authoring hundreds of published papers and reports and creating several patents, his research on solid oxide solutions, free radicals, catalyst structure sensitivity, and catalytic converter and exhaust system design has revolutionized the field of chemistry and automobile industry.

As a corporate executive in the United States and India for over three decades, Dr. Rajadurai managed strategy on power train development and emission control for low, ultra low, super ultra low and partial zero-emission systems. From 1990-1996, he was the Director of Research at Cummins Engine Company. He was the Director of Advanced Development at Tenneco Automotive between 1996 and 2002 and subsequently Emission Strategist and Director of Emissions at ArvinMeritor until 2004. From 2004-2009, he was Vice-President of ACS Industries and since 2009 as Head of R&D Sharda Motor Industries Ltd.

He is a SAE Fellow, Life Member of the North American Catalysis Society, North American Photo Chemical Society, Catalysis Society of India, Instrumental Society of India, Bangladesh Chemical Society and Indian Chemical Society.

S. Shibu Anand B. E, PGDPMI.,

Mr. S. Shibu Anand, born in Mylaudy, Kanya kumari District, Tamil Nadu, India. He is a Project Manager working at Research and Development, Sharda Motor Industries Ltd., a global automotive component development and manufacturing Industry. Currently He is managing Force Motors, Tafe, Volkswagen, Simpson, Bosch, Ashok Leyland (BS IV, BS VI, Euro 6, Tier4f & Stage V) programs from RFQ till manufacturing hand -off. Indulged in the development of several other programs. He had strong work experience in TATA Teleservice Limited, Kochi. Currently Doing his post graduate diploma in project management in MIT, Pune & graduated in Electronics and Communication Engineering from Loyola Institute of technology, Chennai , Tamil Nadu, India (2015).

P. Matcharaja B.E.,

Mr. P. Matcharaja, born in Natham, Dindigul District, Tamil Nadu, India. He is product development engineer at Research and Development, Sharda Motor Industries Ltd., completed Bachelor of Engineering in the disciple of Mechanical Engineering from NPR College of Engineering and Technology, Natham in the year of 2016.