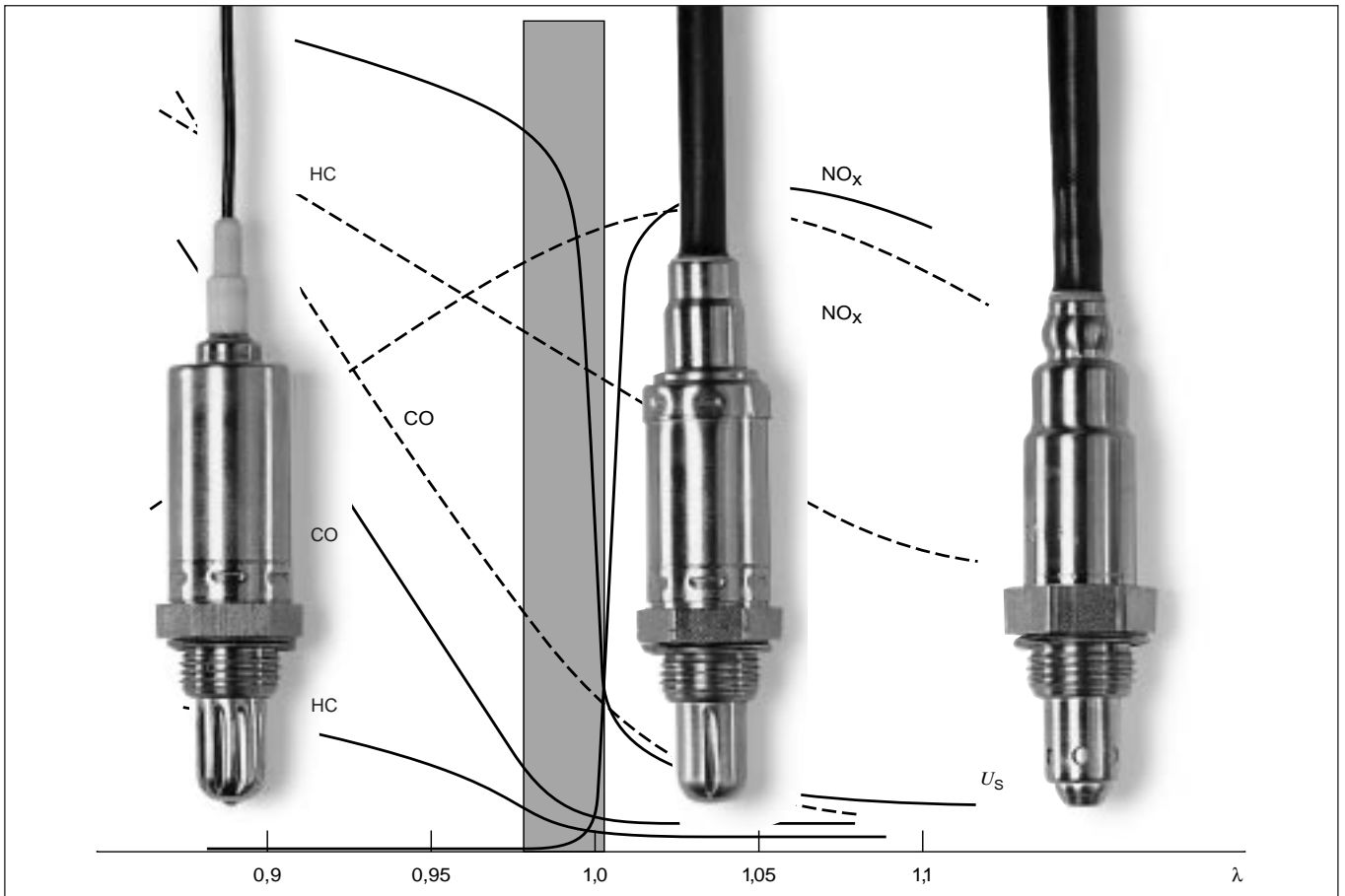


Lambda Sensor



Application

Together with the 3-way catalytic converter, the Lambda oxygen sensor and the Lambda closed-loop control represent today's most effective exhaust-emissions control system for the spark-ignition (SI) engine. At present, there is no alternative available which even approaches the low exhaust-emission figures obtained with this system.

Since 1976, Bosch has been producing the Lambda sensor for exhaust-emission control systems in the USA and Europe. The Bosch Lambda sensor was the world's first oxygen sensor to go into operation, and played a decisive role in the breakthrough of exhaust-emissions control using the closed-loop-controlled 3-way catalytic converter. In the meantime, this sensor has proved itself in millions of vehicles.

The Lambda sensor is screwed into the exhaust system. It is a detecting element for measuring the residual oxygen in the exhaust gas which, since it provides a precise indication of whether combustion is complete or not, is highly suitable as the measured quantity for closed-loop control of the A/F ratio.

The Lambda-sensor output signal not only provides an indication of instantaneous A/F mixture composition, but it also follows any A/F mixture changes. The mixture-formation system controls the supply of fuel to the engine in accordance with the signal from the Lambda sensor so that a stoichiometric A/F ratio "Lambda" of $\lambda = 1$ is maintained.

Lambda is the dimension used to define the mixture's A/F ratio.

$$\lambda = \frac{\text{instantaneous A/F ratio}}{\text{stoichiometric A/F ratio}}$$

Referred to the stoichiometric ratio $\lambda = 1$, a lean mixture ($\lambda > 1$) contains more air, and a rich mixture ($\lambda < 1$) contains less air.

Heated or unheated Lambda sensors are used depending upon exhaust-system design and operating conditions. The extensive Bosch Lambda sensor program covers a wide variety of variants.

The Lambda sensor is also used outside the automotive sector. For instance, for the closed-loop control of gas engines or of gas/oil burners.

Design (Fig. 1)

The Lambda sensor operates according to the principle of a galvanic oxygen concentration cell with solid electrolyte (Nernst principle). The solid-state electrolyte comprises a gas-impermeable ceramic element of zirconium dioxide which is stabilized with yttrium oxide and closed at one end.

The ceramic element's inside and outside surfaces are provided with electrodes composed of a thin, gas-permeable, porous layer of platinum which on the one side has an influence on the sensor characteristic due to its catalytic effects, and on the other serves for electrical contacting. On the outside surface of the sensor ceramic which protrudes into the exhaust-gas stream, the platinum layer is itself coated with a highly porous ceramic layer. This robust layer prevents the catalytic platinum layer being attacked by the corrosive and erosive effects of the deposits in the exhaust gas, and thus ensures long-term sensor stability.

Operation (Fig. 2)

The Lambda sensor is installed in the engine's exhaust-gas system at a point which throughout the engine's complete operating range provides the temperature which is necessary for efficient sensor functioning. The sensor protrudes into the exhaust gas, design being such that one electrode surface is surrounded by the exhaust gas and the other is connected to the atmosphere. Even under excess-fuel conditions, there is always residual oxygen in the SI engine's exhaust gas (at $\lambda = 0.95$, approx. 0.1 ... 0.3% by volume). The use of porous platinum electrodes means that at the electrode surface, catalytic conversion of this residual oxygen can take place with the carbon monoxide (CO), hydrocarbons (HC), and the hydrogen present in the exhaust gas. The residual oxygen remaining after complete conversion is a function of the exhaust-gas Lambda value, and is measured by the Lambda (oxygen) sensor. During transition from a lean mixture (high residual-oxygen content) to a rich mixture (very low residual-oxygen content), the residual-oxygen content reduces abruptly by several powers of 10 in the stoichiometric region $\lambda = 1$ of air-fuel mixture. This results in the sudden jump of sensor voltage output at $\lambda = 1$. The sensor voltage and its

Fig. 1: Arrangement of the Lambda sensor in the exhaust pipe (schematic)

1 Sensor ceramic, 2 Electrodes, 3 Contact, 4 Housing contact, 5 Exhaust pipe, 6 Ceramic protective layer (porous), 7 Exhaust gas, 8 Air.

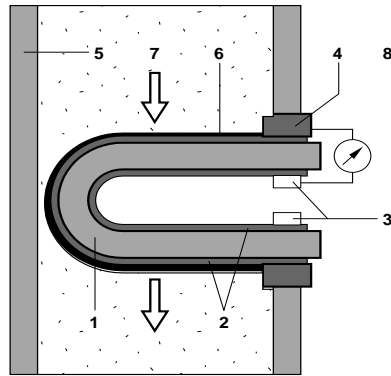


Fig. 2: Voltage characteristic of the Lambda sensor at 600°C working temperature

a Rich mixture (air deficiency)
b Lean mixture (air surplus)

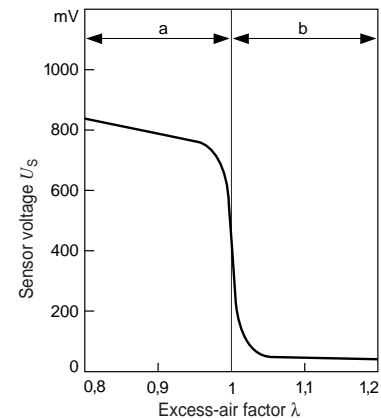
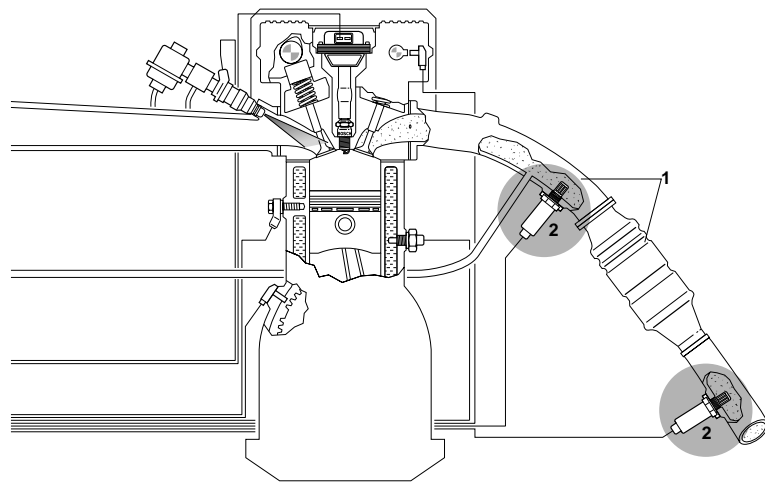


Fig. 3: Engine with exhaust-gas system

1 Exhaust-gas system with catalytic converter, 2 Lambda sensor(s)



internal resistance depend upon temperature. Reliable closed-loop control takes place at temperatures above 350°C (for the unheated sensor) and above 150°C (for the heated sensor).

Installation (Fig. 3)

The Lambda sensor is installed in the exhaust system at a point which, besides featuring exhaust-gas composition which is representative for all cylinders, must also be hot enough (at least 350°C for the unheated sensor and 150° for the heated sensor). A sensor life corresponding to more than 160,000 km as driven by the vehicle can be achieved if the specifications for sensor loading are complied with.

The Lambda closed-loop (feedback) control

The control loop comprises the engine (controlled system), the Lambda sensor (measuring element), the controller in the ECU, and the injectors (actuators).

The controlled variable is the residual oxygen in the exhaust gas. The object of the closed-loop control is to generate an optimal A/F mixture by adjusting the quantity of fuel (manipulated variable) injected by the injectors (actuators).

The Lambda closed-loop control automatically takes into account special modes such as start, acceleration, and full load.

Unheated Lambda sensor LS (Fig. 4)

The sensor's active ceramic body is held in position and sealed in the housing by means of a "finger-shaped" ceramic support tube and a disc spring.

A contact element between the support tube and the active ceramic body is used to provide contacting from the inner electrode to the connection cable.

The outer electrode is connected to the sensor housing by the metal seal ring. The sensor's internal elements are fastened and aligned by a protective metal sleeve which, apart from serving as a support for the disc spring, also protects the interior of the sensor against contamination. The cable is crimped to the end of the contact element which protrudes from the sensor, and is sealed off against dampness and mechanical damage by means of a temperature-resistant PTFE cap.

In order to keep the exhaust-gas combustion deposits away from the sensor ceramic, the end of the housing which protrudes into the exhaust-gas flow is protected by a specially shaped tube having slots designed to provide highly effective protection against the effects of excessive thermal and chemical stresses.

Heated Lambda sensor LSH (Fig.5)

Design

Basically, the heated Lambda sensor is identical to the unheated version.

The active sensor ceramic is heated from the inside by a ceramic heating element so that it remains above the 350°C function limit independent of the exhaust-gas temperature. The ceramic heating element has a PTC characteristic so that it heats up quickly and needs only very little power when the exhaust gas has heated up. The heating-element connections are fully decoupled from the sensor signal line ($R \geq 30 \text{ M}\Omega$).

In contrast to the unheated version, the heated sensor is equipped with a protective tube with small slots for exhaust-gas passage.

This increases the protection against contamination and prevents the sensor ceramic cooling down excessively when the exhaust gas is still "cold".

Fig. 4: Unheated Lambda sensor LS
1 Connection cable, 2 Disc spring, 3 Ceramic support tube, 4 Protective sleeve, 5 Contact element, 6 Sensor housing, 7 Active sensor ceramic, 8 Protective tube.

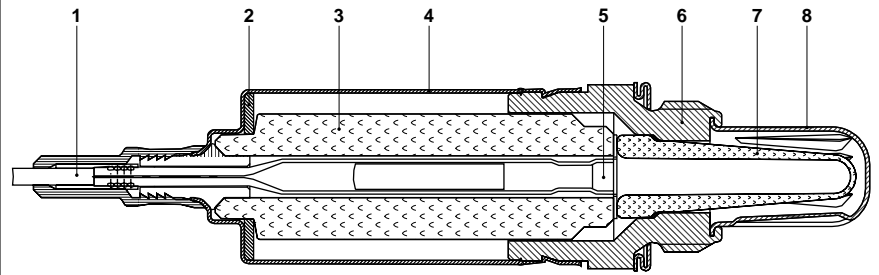
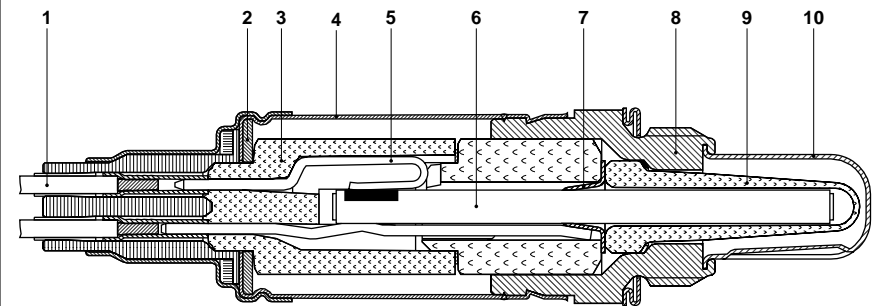


Fig. 5: Heated Lambda sensor LSH
1 Connection cable, 2 Disc spring, 3 Ceramic support tube, 4 Protective sleeve, 5 Clamp connection for the heating element, 6 Heating element, 7 Contact element, 8 Sensor housing, 9 Active sensor ceramic, 10 Protective tube.



Versions

Bosch has a number of versions of this heated Lambda sensor available:

- 3-pole version,
- 3-pole version with additional grounding by cable,
- 3-pole version with additional grounding by cable for lean-burn applications (LSM11), and
- 4-pole version, isolated ground.

Advantages

- Efficient closed-loop control even at low exhaust-gas temperatures (e.g. at idle),
- Flexibility of installation, considerable latitude regarding mounting method,
- Efficient functioning depends less on exhaust-gas temperature,
- Lambda control comes into effect more quickly after engine start,
- Improved exhaust-gas figures due to improved sensor dynamics,
- Reduced danger of contamination leads to longer service life.

Planar Lambda sensor (LSF) (Fig. 6)

The planar Lambda sensor has been developed from the proven tube-type ("finger-version") sensor. Functionally, with its voltage curve jump at $\lambda = 1$, it corresponds to the heated finger version, while at the same time providing the basic technology for further ceramic-type sensors. In contrast to the finger sensor though, the planar sensor uses ceramic foils as the solid-state electrolyte. Screen-printing techniques are employed for producing the individual functional layers (electrodes, protective layers, etc.). The printed foils are laminated one on top of the other, and this principle enables a heater to be integrated in the sensor element (Figs. 7 and 8).

From the construction viewpoint, the major differences between the LSF sensor and the LSH sensor are as follows:

- The LSF sensor element is fixed in the sensor housing by means of a ceramic seal packing.
- The double-wall protective tube was specially designed for the planar sensor and provides the sensor element with highly effective protection against excessive thermal and mechanical stresses.

Special characteristics:

- Short start-up times for the Lambda closed-loop control,
- Stable control characteristics,
- Lower heater rating,
- Small size,
- Low weight, and
- Isolated-ground design.

Planar broadband Lambda sensor LSU

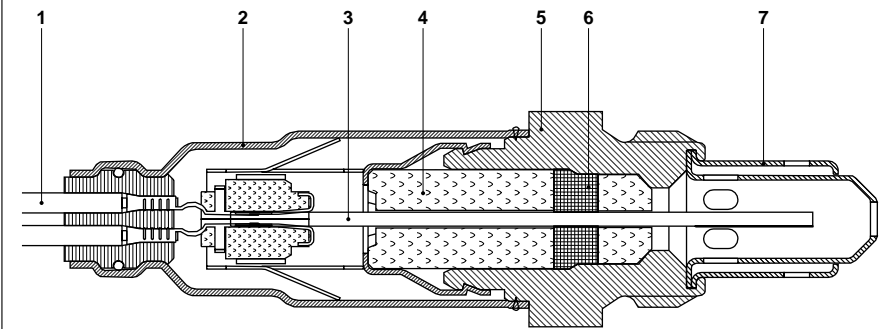
The broadband Lambda sensor is a planar dual-cell limit-current sensor. Its modular construction, combined with planar techniques, makes it possible to integrate a number of additional functions.

The fact that the LSU sensor is a combination of a Nernst concentration cell (sensor cell) and a pump cell for oxygenion transport, means that it can also measure accurately in lean and rich regions, not only at $\lambda = 1$ (Fig. 9). Each sensor is individually calibrated.

Special control electronics are required for the LSU sensor (evaluation circuit) This contains not only the internal con-

Fig. 6: Planar Lambda sensor LSF

1 Connection cable, 2 Protective sleeve, 3 Planar sensor element, 4 Ceramic support tube, 5 Sensor housing, 6 Ceramic seal packing, 7 Protective tube.



rol electronics for the pump and sensor cells as required for generation of the sensor signal, but also the control electronics for controlling the sensor's temperature.

As a result, novel applications become possible:

- Control also possible at $\lambda > 1$ and $\lambda < 1$,
- Continuous Lambda control at $\lambda = 1$,
- Diesel-engine control,
- Lean-burn concept for SI engines,
- Gas-engine control.

Fig. 7: Planar Lambda sensor LSF (functional layers)

1 Porous protective layer, 2 External electrode, 3 Sensor foil, 4 Inner electrode, 5 Reference-air passage foil, 6 Insulation layer, 7 Heater, 8 Heater foil, 9 Connection contact.

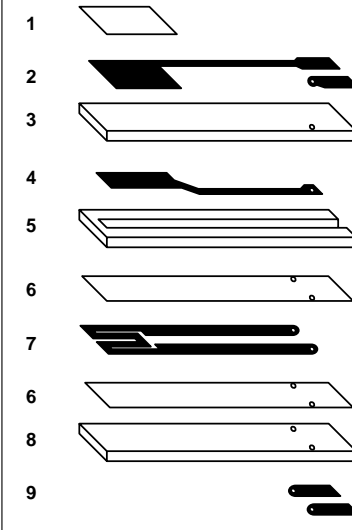


Fig. 8: Planar Lambda sensor LSF (layer build-up)

1 Exhaust gas, 2 Reference-air passage, 3 Heater. U_s Sensor voltage.

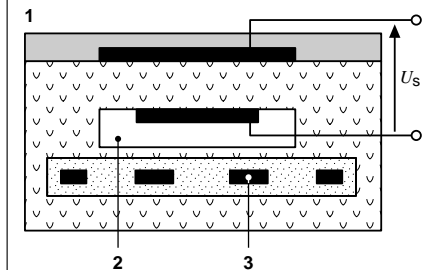


Fig. 9: Planar broadband Lambda sensor LSU (layer build-up and curve)

1 Exhaust gas, 2 Pump cell, 3 Diffusion gap, 4 Sensor cell, 5 Reference-air passage, 6 Heater, 7 Sensor signal, 8 Controller. I_p Pump current.

