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Technical OBD description for VW /Audi with ME(D)17 ECMs

This description applies for the following OBD groups/ test groups:

OBD Group Name	Test group	Engine	Models	Standard	Controller / OBD II strategy
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	Bosch ME(D)17 BE-V

General statements:

- In case of monitors which are applicable only for specific OBD group(s) or test group(s) the specific OBD group(s) or test group(s) are mentioned to the description part.
- ME(D)17 means MED17 for FSI concepts and ME17 for MPI concepts.
- The sections “enable conditions” describe typical enable condition for the monitoring functions. All specific enable conditions for each monitor are described in the summary table, which is submitted separately.
- Disabling symptoms are described in the disabling matrix, which is submitted separately.

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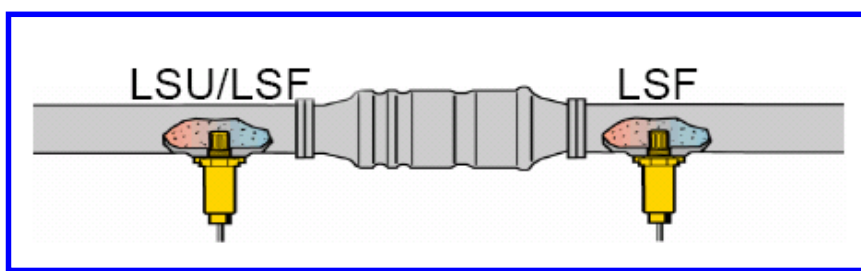
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1 CATALYST MONITORING

There is one diagnostic function which is used for the monitoring of the catalyst efficiency. This is based on measuring the oxygen within the catalyst determined by at least two oxygen sensors. The oxygen storage capacity correlates with the NMHC or NOx emissions. Depending on which one of these two emission components reaches its OBD threshold first, the relevant threshold corresponds to either the NMHC or the NOx emissions.

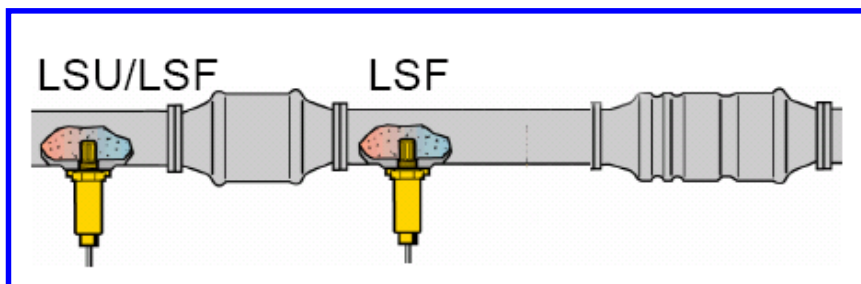
This diagnostic function is used for various catalyst systems:

System with total volume catalyst monitoring:



The catalyst system may consist of one or two separated catalyst bricks, with the oxygen sensors mounted before and after the catalyst(s).

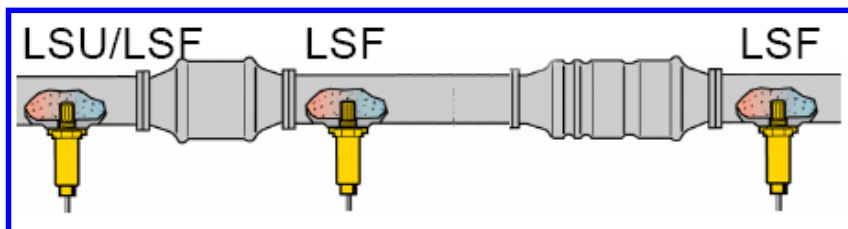
System with partial volume catalyst monitoring:



This system is applied in different designs:

- With two separate catalysts and the oxygen sensors mounted before and after the primary catalyst
- As a multi-stage catalyst system with the oxygen sensor in the intermediate pipe
- As an oxygen sensor catalyst (future)

System comprising three oxygen sensors (only SULEV concepts):



This system initially monitors only the primary catalyst until it has reached a certain aging state, before the overall catalyst monitor is activated.

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Note: In the I5 SULEV only the primary catalyst is monitored despite the use of three oxygen sensors.

OBD Group Name	Test group	Engine	Models	Standard	Monitoring concept
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	Partial volume catalyst monitoring with EWMA

The catalyst diagnostic is implemented with or without EWMA filtering.
The diagnostic routine is executed once per driving cycle.

1.1 Active measurement of OSC

1.1.1 General description

The catalyst monitor is based on the determination of the oxygen storage capacity (OSC). The correlation between the conversion efficiency and the OSC has been investigated on catalysts with various characteristics specifically concerning stages of aging correlated to exhaust emissions (HC/NO_x). Therefore, the catalyst is diagnosed by comparing its storage capability against the storage capability of a borderline catalyst. The oxygen storage capacity (OSC) can be determined by the following method:

1. Determination of the Oxygen storage state (active test)

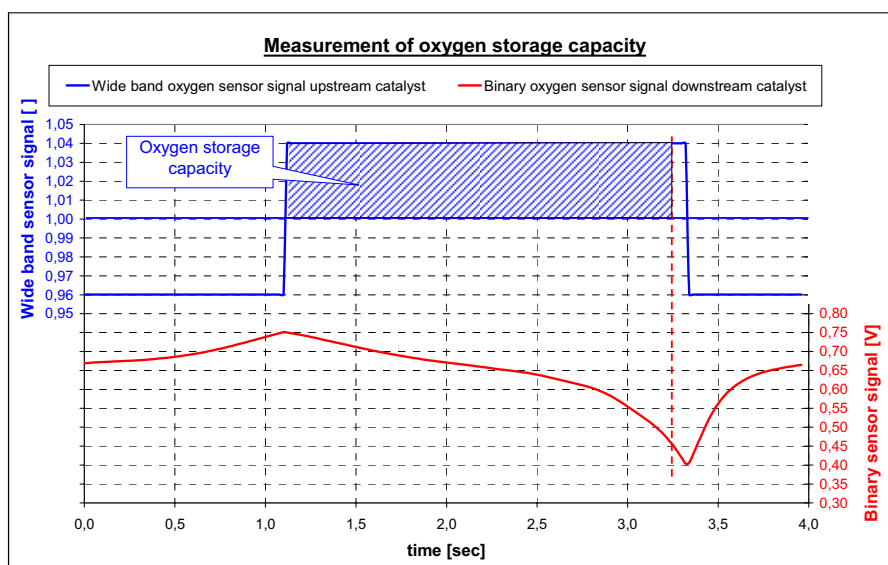
For the purpose of monitoring, the ECM cycles the A/F ratio by commanding a rich and a lean fuel mixture as follows.

- First, a rich A/F ratio is commanded by the ECM until a minimum of oxygen has been removed (cumulated rich gas > threshold - This threshold is derived from the Oxygen Storage Capacity of the borderline catalyst for the current operating point taken from the corresponding look-up table and typically multiplied with a factor between 1.3 and 2.5).
- Then, the catalyst is operated with a lean A/F ratio commanded by the ECM and the Oxygen Storage Capacity is calculated from the oxygen mass stored in the catalyst as follows:
- $OSC = \int \text{air mass flow} * \text{lean mixture} (\lambda - 1) * dt$
- The catalyst is operated in this mode until the oxygen stored in the catalyst exceeds a calibrated limit or the downstream oxygen sensor indicates that the catalyst is completely saturated with oxygen (typically 450-550mV), or when the measured OSC value is higher than the x-fold ($x = 1.5-2.5$) Oxygen Storage Capacity of the borderline catalyst for the current operating point.

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- The catalyst is then diagnosed by comparing its oxygen storage capacity to the calibrated threshold of a borderline catalyst. A normalized OSC value is calculated from the quotient of the actual OSC value and borderline OSC value.
- After each completion of a measuring cycle a cycle counter is incremented
- Measuring cycles are run until the cycle counter reaches a certain number (typically 3 to 5 without EWMA and 1 with EWMA), then the diagnostic is finished.
- Calculation of the normalized mean value from the single measurements
- Comparison of the filtered normalized value with the fault threshold

The following picture shows an example of an OSC measurement:



1.1.2 Monitoring function description

According to the operating principle described above the following main parts of the monitor can be distinguished:

- Check of monitoring conditions for active test
- Lambda request (interface to lambda controller)
- Mixture enrichment in order to remove any stored oxygen
- Measurement of oxygen storage capacity (OSC) by lean A/F ratio operation
- Processing
- Fault detection

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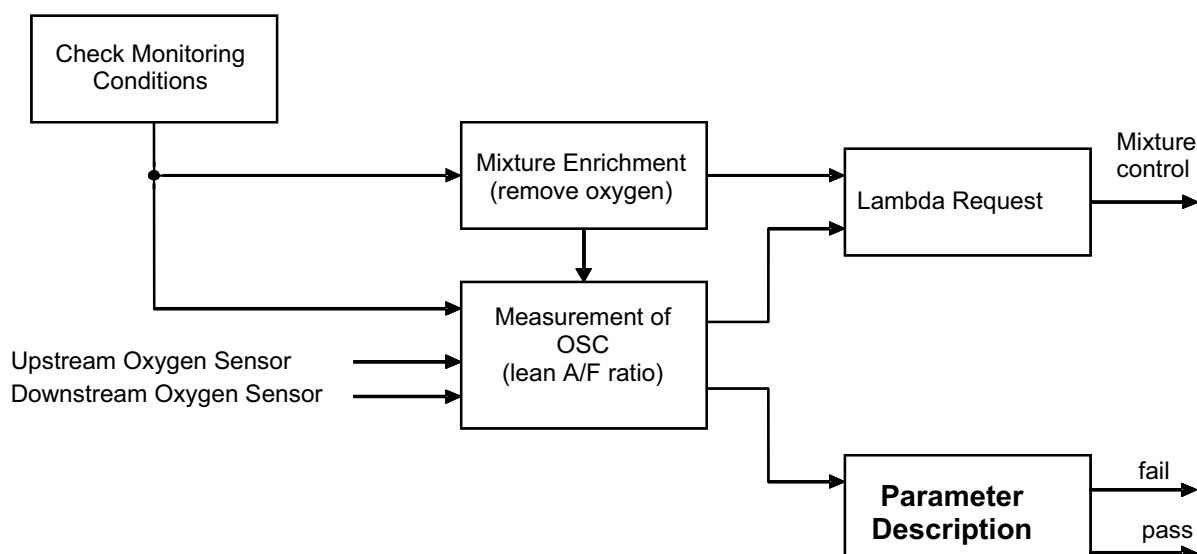


Figure 1: Active measurement of OSC – monitoring structure

Processing:

After the measurement of the OSC, the OSC value is normalized to the OSC value of the borderline catalyst, which is taken from a map, depending on the exhaust gas mass flow and catalyst temperature.

The final diagnostic result is calculated by averaging several, normalized OSC values and compared to the threshold. The measurement of the OSC can be carried out consecutively or stepwise.

For a catalyst system with 3 Oxygen sensors this measuring procedure can be applied to different portions. The different alternatives are shown in the table below.

secondary parameters	primary catalyst	main- catalyst	catalyst- system
- first λ-sensor is active - second λ-sensor is active - modeled primary catalyst exhaust gas temp. in range - exhaust gas mass flow in range - exhaust gas mass dynamic in range	measurement of OSC calculation		
- first λ-sensor is active - third λ-sensor is active - modeled primary catalyst exhaust gas temp. in range - modeled main catalyst exhaust gas temp. in range - exhaust gas mass flow in range - exhaust gas mass dynamic in range			measurement of OSC calculation

Figure 2: Necessary conditions to check the different catalyst volumes

If the secondary parameters for the different catalyst portions are met at the same time, the diagnostic functions can run simultaneously.

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Flow chart catalyst monitoring

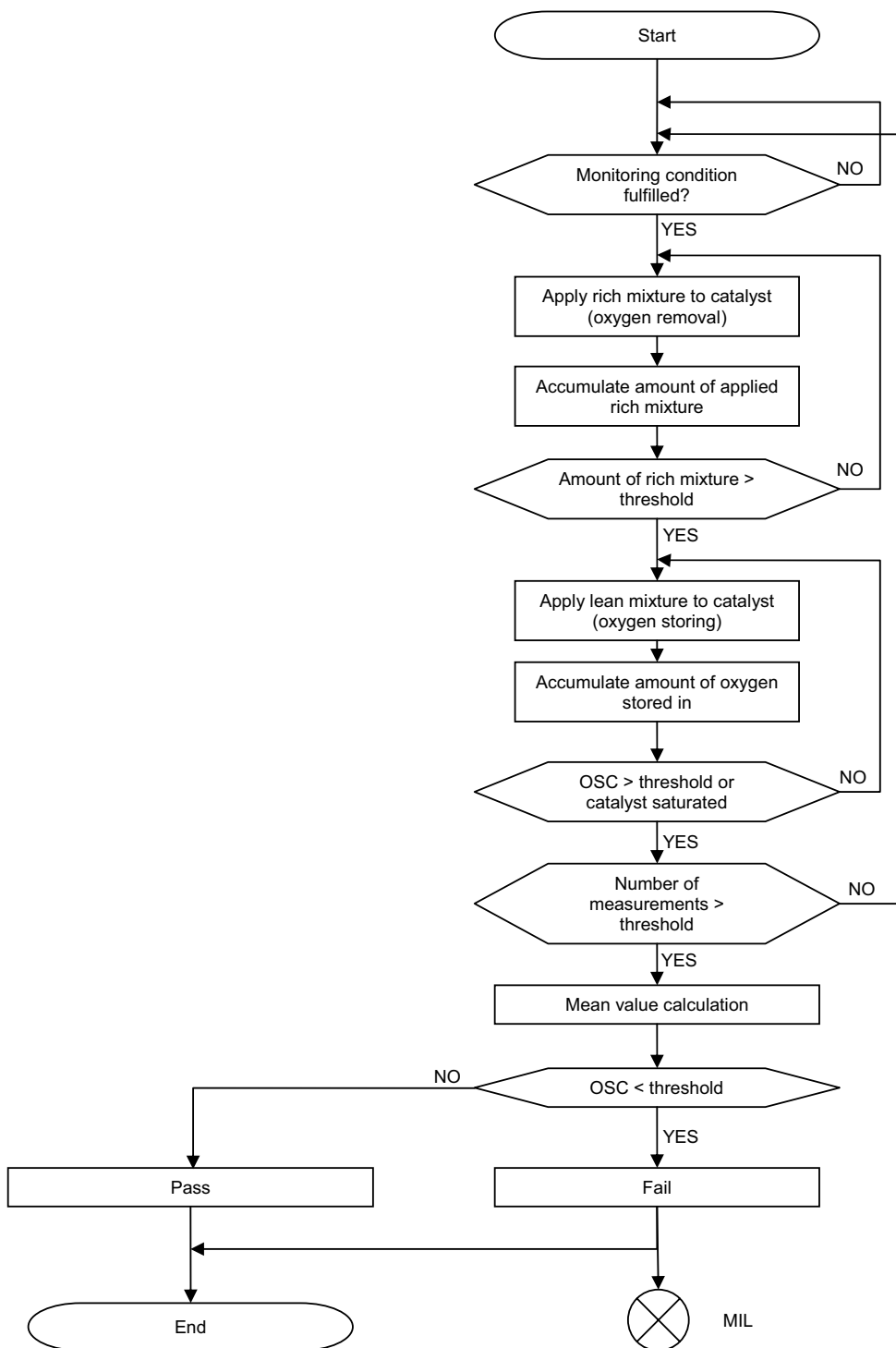


Figure 3: Flow chart catalyst monitoring

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1.2 Monitoring of front catalyst and catalyst system

1.2.1 General description

The catalyst monitor is based on the determination of the oxygen storage capacity (OSC). The correlation between the conversion efficiency and the OSC has been investigated on catalysts with various characteristics, specifically concerning stages of aging correlated to exhaust emissions (HC/NOx). Therefore, the catalyst is monitored by comparing its storage capability against the storage capability of a borderline catalyst.

In this special application, the exhaust gas system consists of a close coupled catalyst (primary catalyst) and an underfloor catalyst (main catalyst).

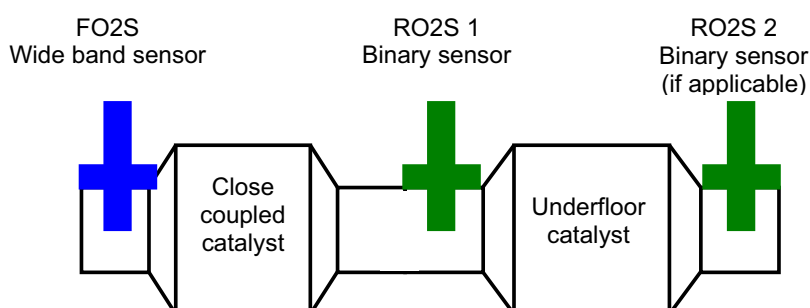


Figure 4: Overview front and main catalyst, one spare part only

This diagnostic function determines the OSC of the primary catalyst and the OSC of the catalyst system, (close coupled and underfloor catalyst), and depending on the results, a malfunction of the cat system is detected.

The diagnosis only depends on the measured OSC of the close coupled catalyst, if the oxygen storage capacity of the close coupled catalyst is greater than a first threshold. In this case the OSC of the catalyst system will not be measured.

If the oxygen storage capacity of the close couple catalyst is smaller than a first threshold, the OSC of the catalyst system will also be measured.

Malfunction criteria:

The exhaust gas aftertreatment system is recorded defective, if the OSC of the complete catalyst system is smaller than a second threshold.

Based on the following hardware configurations and the corresponding diagnostic concepts the following methods are applied to receive a diagnostic result:

1. System with total volume catalyst monitoring (ULEV II/Bin5, 1 brick or 2 bricks):

- Determination of a normalized mean overall catalyst diagnostic value, system without EWMA
- Determination of a normalized, EWMA filtered overall catalyst diagnostic value, system with EWMA

2. System with partial volume catalyst monitoring (PZEV BVWXV02.5259):

- Determination of a normalized mean primary catalyst diagnostic value, system without EWMA

3. System with three oxygen sensors and partial and total volume catalyst monitoring (SULEV/PZEV):

- Determination of a normalized mean primary catalyst diagnostic value and comparison of the diagnostic value with a maximum threshold. If the result exceeds this threshold the diagnostic is finished with a PASS result.

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- If the result is lower than the maximum threshold, the routine switches over to the total volume catalyst monitoring
- Determination of a normalized mean total volume catalyst diagnostic value,
- Generation of the product from the primary catalyst diagnostic value and the total volume diagnostic value and comparison of the result with a fault threshold

 In the case of the above described switching of the diagnostic routine, two calibrated look-up tables will be referenced to alter the values of the individual partial and total volume catalyst values and export them as factors, which allows the quantified assessment of the individual catalysts within the complete system

Depending on the calibration of the look-up tables the following methods are applied:

In case the measurement of the primary cat delivers a very positive result (value exceeds a threshold), the main cat is not measured, which means that in this case only the primary cat factor is compared with a fault threshold.

Primary cat factor > threshold → Pass Result

However, measuring of the main cat is simulated for the IUMPR creation.

In case the result of the primary cat measurement remains below the threshold, the additional measurement of the total volume catalyst monitoring is activated.

3.1. Calibration variant 1 (BADXV02.03PA)

Calibration example

Partial volume catalyst monitoring look-up table:

Partial volume OSC	Partial volume factor
<0.3	0
>0.3 & <1	0.5
>1	2

Total volume catalyst monitoring look-up table:

Total volume OSC	Total volume factor
<0.8	0
>0.8 & <1.38	1.3
1.38 – 1.6	1.3 – 2.4

- After completion of the total volume catalyst diagnostic the product of the partial and the total volume catalyst values is created and compared with a fault threshold.
This calibration variant results indirectly in individual fault thresholds for the primary and the overall catalyst.

Partial volume cat factor x total volume cat factor < Fault threshold → Fail Result

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3.2. Calibration variant 2 (BVWXV02.03SA / BVWXV02.03PA)

Partial volume catalyst look-up table:

Partial volume OSC	Partial volume factor
0	0
1	1
5	5

Total volume catalyst look-up table:

Total volume OSC	Total volume factor
0	0
1	1
5	5

The look-up tables are calibrated such that the incoming normalized mean OSC values remain unchanged; after switching over to the total volume catalyst monitoring, the product from the unchanged factors is created.

Partial volume OSC = partial volume factor
Total volume OSC = total volume factor

Partial volume cat factor x total volume cat factor < Fault threshold → Fail Result

This logic is shown in the following flow chart

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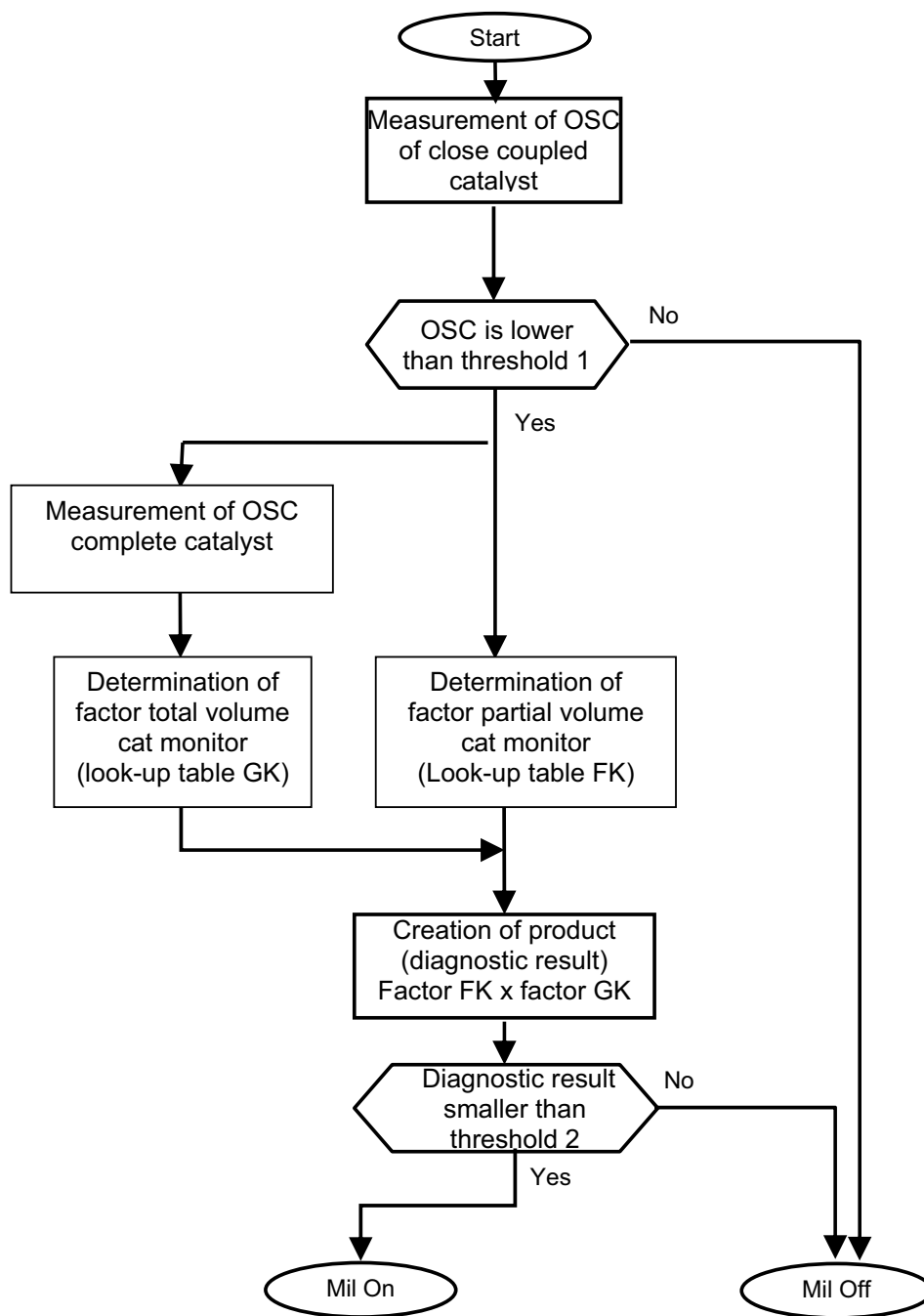


Figure 5: Flow chart front and main catalyst monitoring

Processing:

After the measurement of the OSC, the OSC value is normalized to the OSC value of the borderline catalyst, which is taken from a map, depending on the exhaust gas mass flow and catalyst temperature.

The final diagnostic result is calculated by averaging several normalized OSC values and comparing the result to the threshold. The measurement of OSC can be carried out consecutively or stepwise.

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1.2.2 Secondary parameters

All secondary parameters listed below have to be fulfilled for a calibrated duration:

- O2 Sensors ready for operation
- Catalyst temperature in calibrated range
- Maximum permissible catalyst temperature change < threshold
- Axial temperature distribution of catalyst within range (the catalyst temperatures are modeled in several layers)
- In case the lowest temperature of all the layers falls below a threshold for a certain time (cool down time), this temperature must be exceeded for another time period (re-heatup time) before the diagnostic is re-enabled (radial warming after cooling-down must be ensured)
- The low-pass filtered minimum temperature > threshold (ensures thorough radial warming in warm-up phases even after cooling down caused by overrun fuel cut-off phases)
- Delta exhaust mass flow < threshold
- Exhaust gas mass flow in calibrated range
- Deviation of actual lambda from setpoint lambda < threshold
- Lambda controller not at minimum or maximum
- Requested lambda value for diagnostic routine is achieved
- Engine speed in calibrated range
- Engine load in calibrated range
- SAS not active
- Canister purge flow is low

1.2.3 In-Use Monitor Performance Ratio

The incrementing of the numerator, the denominator and the ratio calculation for the catalyst monitoring is executed by the IUMPR kernel function. Like all monitors, for which a standardized track and report of the in-use performance is required, the catalyst monitor reports to the IUMPR kernel function via status flags - see the description of the IUMPR kernel function.

Incrementing the numerator

In determining the numerator we must differentiate between the exhaust systems and the diagnostic strategies.

For the system with the total volume catalyst monitoring as well as for the system with partial volume catalyst monitoring with only two oxygen sensors available for the diagnostic concept (one before the overall catalyst volume and one after the overall catalyst volume), only the OSC of the overall catalyst system can be measured.

This is why the PASS result is not faster than a FAIL result for the catalyst diagnostic. Hence, this is a symmetric diagnostic and the numerator can be incremented after the required number of diagnostic cycles.

The SULEV applications, which monitor both catalysts (only 2.0l T I-4 FSI) use either the measurement of the primary catalyst, or the measurement of the overall catalyst volume, depending on the aging state of the primary catalyst.

For the PASS result, the measured primary catalyst OSC only needs to exceed a first threshold.

For the FAIL result, additionally to the primary catalyst OSC measurement the OSC measurement of the overall catalyst volume is activated. Hence the time required for the FAIL result is longer than the time required for the PASS result and is actually prolonged by the time necessary for the overall catalyst volume measurement.

Therefore, in case a PASS result for the primary catalyst is achieved, the numerator is not incremented before the time, that would have been necessary for the FAIL result of the total volume catalyst monitor has passed after the primary catalyst PASS result.

This time period is calculated such that the 3-fold rich mixture charge of the borderline catalyst and the 1.65-fold lean mixture charge of the borderline catalyst into the actual catalyst would have occurred with a lambda adjustment of a fictive conditioning phase and an oxygen charge phase, based on the subsequent exhaust gas mass flow.

Hence, the numerator for the measurement of the primary catalyst cannot be incremented before the above described time period has passed.

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When measuring both the primary and the overall catalyst volumes the numerator is incremented immediately after the diagnostic has finished.

Incrementing the denominator

The denominator is incremented when the monitor is not inhibited due to stored faults and the general denominator conditions have been fulfilled for the current driving cycle.

1.3 EWMA for catalyst diagnosis

Applicable only for test groups

OBD Group Name	Test group	Engine	Models	Standard	Controller / OBD II strategy
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	Bosch ME(D)17 BE-V

In order to improve the robustness of the catalyst diagnosis an alternate statistical MIL illumination approach using an EWMA (Exponentially Weighted Moving Average) filter is introduced.

1.3.1 General description

When enabling conditions for catalyst monitoring are met, enrichment is commanded to remove oxygen from the catalyst, then the mixture is commanded lean to measure Oxygen Storage Capacity (OSC) of the catalyst. This OSC value is normalized to the OSC of the threshold converter and is used as input to exponential filter (EWMA).

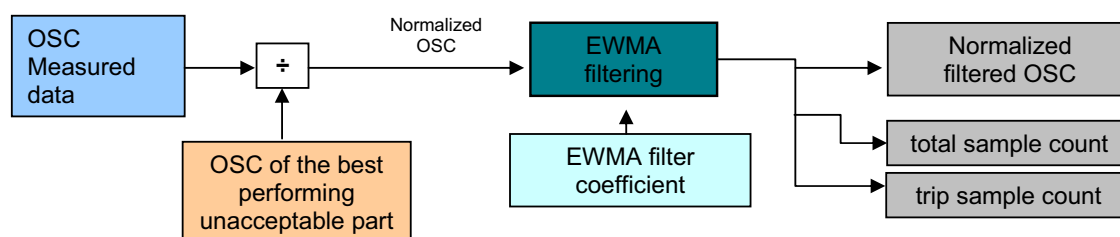


Figure 6: EWMA for catalyst diagnosis

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1.3.2 EWMA system description

The EWMA filter is being calculated / updated with each OSC measurement.

After reaching a stabilized condition only one OSC sample is collected for each driving cycle.

If the current OSC raw value deviates by a certain amount from the EWMA filter value, a malfunction is suspected (step change suspicion). The criteria of the step change suspicion are not dependent on the MIL ON threshold. Typically an error decision (MIL ON) is achieved at the 2nd (1st)* driving cycle.

* blue values are application values for Test Group ADXV02.03UA

Three different states are possible:

1. Stabilized state

- Standard behavior during normal aging of the catalyst.
- Calculation of one OSC sample during each driving cycle.
- Numerator increment after each OSC sample.
- Test failed (malfunctioning catalytic converter) and MIL ON is set immediately after the EWMA filter value falls below the malfunction threshold.

EWMA: Stabilized State

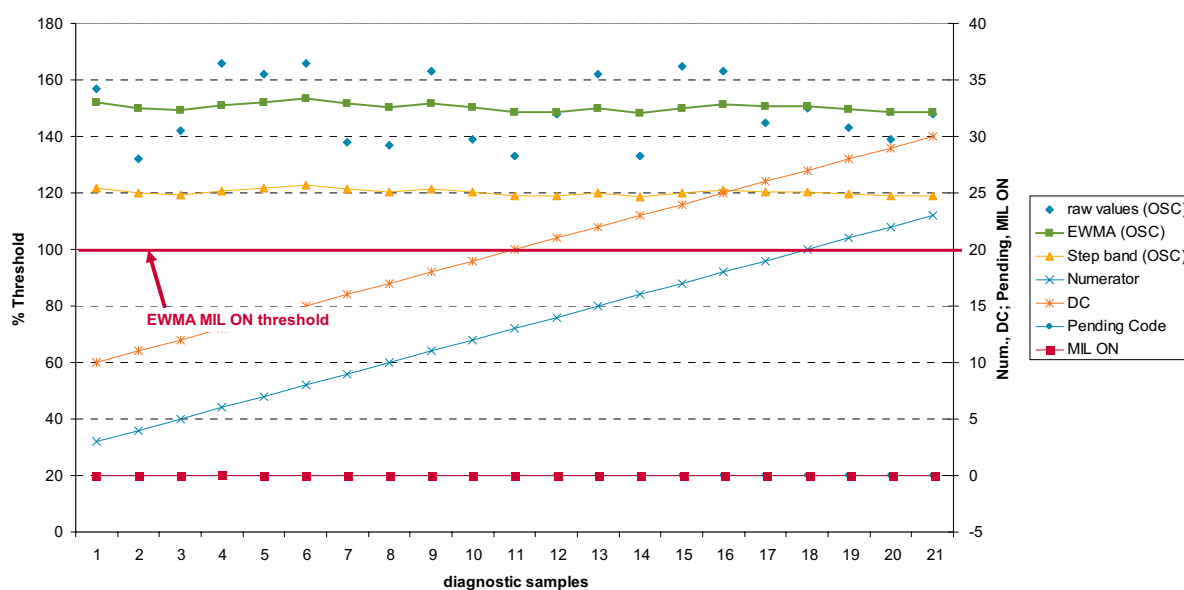


Figure 7: EWMA stabilized state

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2. Step change

- If the current OSC raw value falls below the step band a „step change“ is suspected.
- Step change suspicion triggers up to 4 (2)* diagnostic samples per driving cycle. Calculation of an arithmetical mean value for a total of 8 (2)* diagnostic samples.
- Numerator increments after the 4th (2nd)* OSC sample within a driving cycle.
- If the difference between the EWMA filter value and mean value is bigger than a certain amount (typically 20% (30%)*), the EWMA value is set to the mean value, step change is detected.
- Test failed (malfunctioning catalytic converter) and MIL ON is set immediately after the EWMA filter value falls below the malfunction threshold – typically at the 2nd (1st)* driving cycle.

* blue values are application values for Test Group BADXV02.03UA

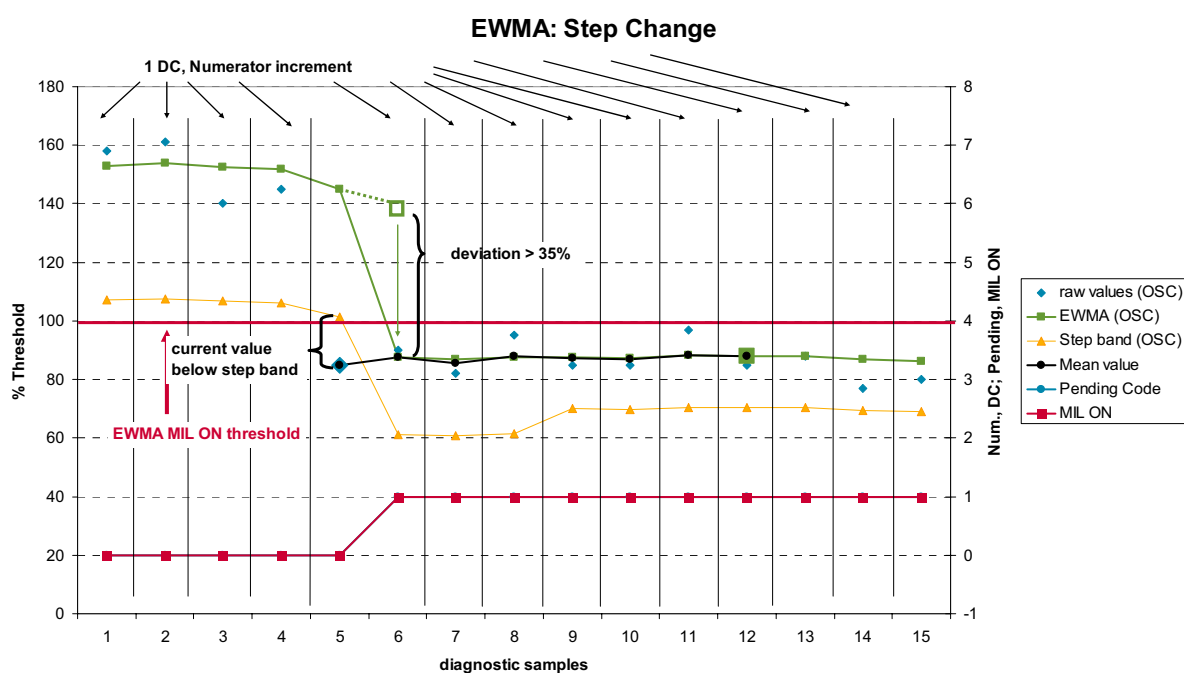


Figure 8: EWMA step change

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3. Fast initialization

- EWMA filter value is being initialized with the calibration value.
- During state “fast initialization” up to 4 (2)* diagnostic samples per driving cycle are collected. Calculation of an arithmetical mean value for a total of 8 (2)* diagnostic samples.
- The In Use Monitor Numerator starts incrementing after the 8th (2nd)* OSC sample.
- If the difference between EWMA filter value and mean value is bigger than a certain amount (typically 20% (30%)*), the EWMA value is set to the mean value.
- Test failed (malfunctioning catalytic converter) and MIL ON is set immediately after the EWMA filter value falls below the malfunction threshold – typically at the 2nd (1st)* driving cycle.

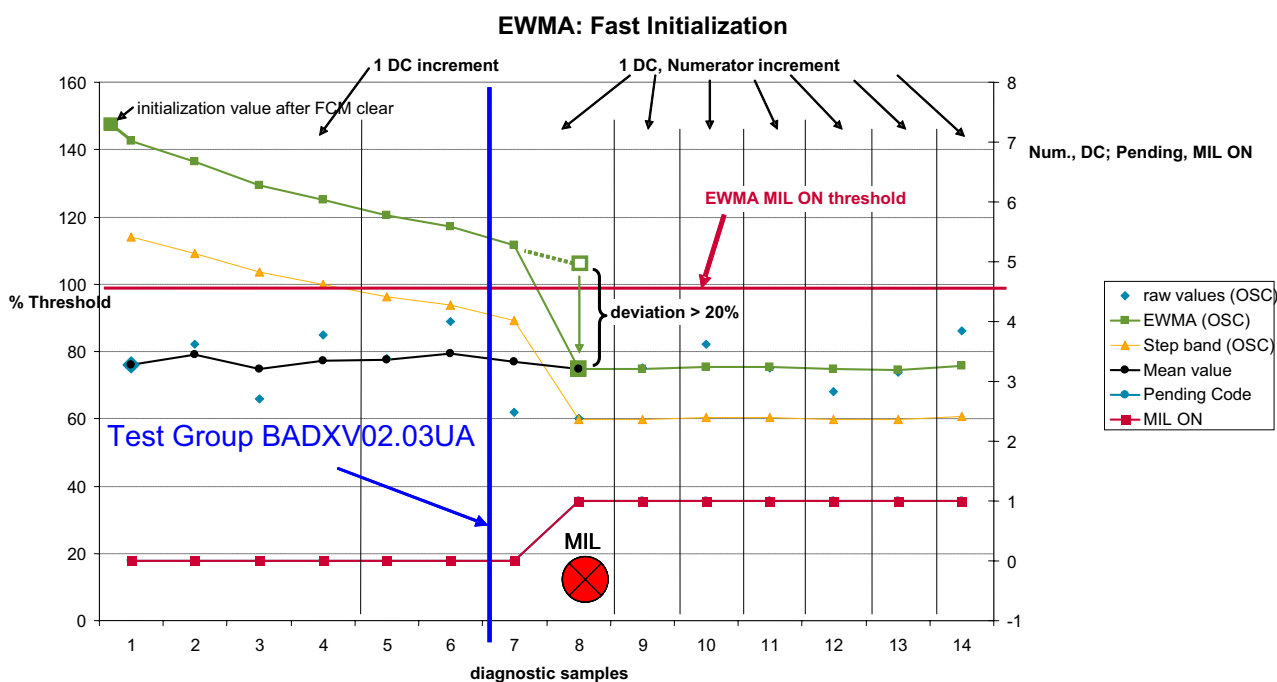


Figure 9: EWMA fast initialization

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2 HEATED CATALYST MONITORING

not applicable

3 MISFIRE MONITORING

3.1 General description

The method of engine misfire detection is based on evaluating the engine speed fluctuations.

One crankshaft segment can be assigned to the combustion event of one cylinder. A combustion event that has not occurred or has not occurred completely leads to a drop in engine speed and engine torque compared to normal operation. As a result, the segment times of the crankshaft increase. The segment times are measured using a sensor at the crankshaft and the engine speed fluctuations are determined. The following figure illustrates the example of misfire due to missing spark.

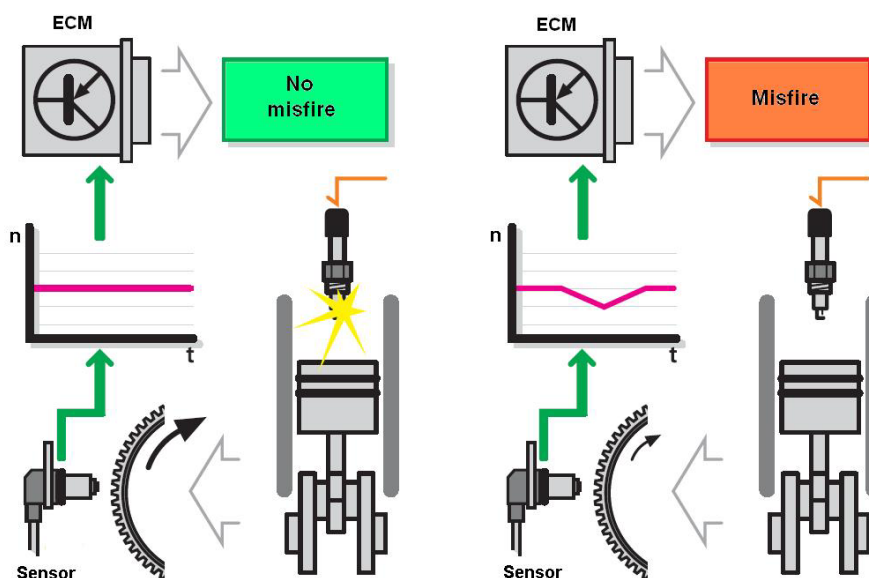


Figure 10: principle of misfire detection

3.2 Monitoring strategy

To detect a misfire, the engine speed fluctuations are assessed. The number of misfire events is counted and compared against a defined threshold value.

3.3 Enable conditions

- After engine start: the number of combustion events exceeds a defined threshold (2 crankshaft revolutions)
- For hybrid additionally, after engine restart: the number of combustion events exceeds a defined threshold (2 crankshaft revolutions)

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- Engine speed within a defined range
- Engine torque $\geq$ threshold value (taking the positive torque condition according to the regulations into account)
- Intake air temperature $>$ threshold value (this enable condition is disabled)
- Engine temperature at engine start $>$ threshold value (this enable condition is disabled)
- Deceleration fuel cut-off not active
- Rough road condition not detected

3.4 Malfunction criteria

The crankshaft segment times are measured and these measurements are used to calculate the engine roughness values. If the engine roughness value is greater than a calculated threshold value, a misfire fault is detected. The threshold value for the engine roughness consists of a base value determined by means of gear-dependent characteristic engine-speed and load maps. According to the currently selected gear, the corresponding characteristic map is used (this applies to manual and automatic transmissions). During the engine warm-up a correction value, which depends on the engine temperature, is added to the base value.

If misfiring is present in more than one cylinder (e. g. a combustion and a misfire alternately), due to the respective engine roughness criterion, the detection capability based on the engine roughness value can decrease compared to single misfiring cylinders. For this reason the periodicity of the engine roughness values is used as additional information. The engine roughness values are filtered and a new multiple filter value is generated. In this way, multiple misfire events can be detected reliably.

The adaptation of the sensor wheel tolerances and the characteristic engine behavior are interpreted for defined engine-speed and load ranges, if no misfire has been detected. The robustness of the misfire monitor increases with the adaptation progress. The adaptation values are stored in a non-volatile memory and are included in the calculation of the engine roughness.

If the enable conditions are fulfilled, two counters are incremented when misfiring has been detected. This serves to distinguish between emission relevant misfiring and catalyst-damaging misfiring.

During intervals of 1,000 crankshaft revolutions the detected misfire events are counted for each cylinder. If the total sum of the detected misfire events is greater than a defined threshold, the fault "emission relevant misfire" is detected.

During intervals of 200 crankshaft revolutions the detected misfire events are counted and weighted for each cylinder. The weighting factor is determined by a characteristic map which is dependent on engine load and speed. If the total sum of the detected misfire events is greater than a defined threshold, the fault "catalyst-damaging misfire" is detected.

After each interval, the misfire counters are reset.

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3.5 Flow chart

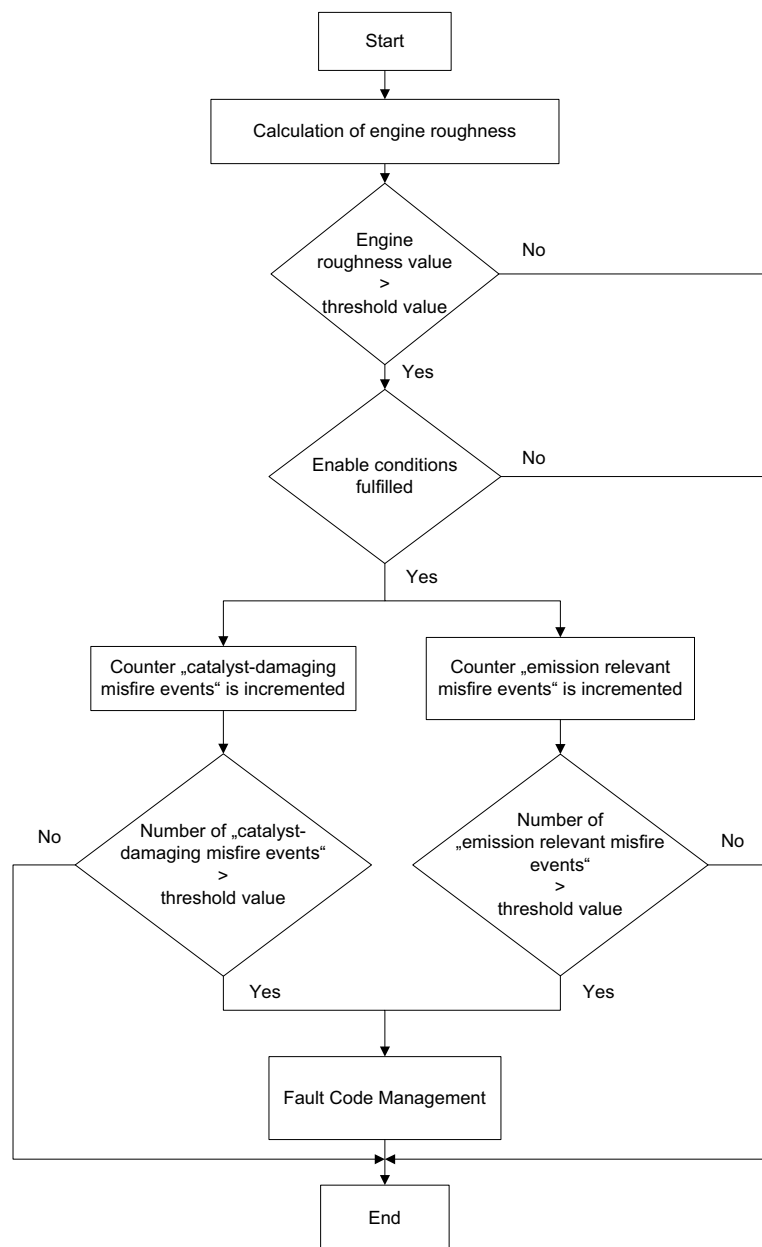


Figure 11: Flowchart Misfire detection

The flowchart represents one combustion event.

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3.6 Additional misfire detection description with Cylinder Deactivation system

Applicable only for test group

OBD Group Name	Test group	Engine	Models	Standard	Controller / OBD II strategy
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	Bosch ME(D)17 BE-V

3.6.1 General description

In general, misfire detection is unaffected by the presence or operation of the Cylinder Deactivation (CD) system. However, if a cylinder is deactivated, then a misfire determination is not done.

3.6.2 Enable Conditions

Enable conditions are unaffected by the presence or operation of the Cylinder Deactivation, with the following exception (applicable 2011 and 2012 model years):

- After CD system switch (into or out of CD) misfire monitoring is disabled for 10 crankshaft revolutions

3.6.3 Malfunction Criteria

On an engine equipped with CD system, a different method of counting misfires is used for fault determination.

Emission relevant misfires:

Fault if:
$$\frac{\# \text{ misfires}}{\# \text{ commanded combustions}} > \% \text{ threshold}$$

Multiplying both sides of the equation by the number of compressions in a misfire interval (1000 revolutions):

Fault if:
$$\# \text{ misfires} * \frac{\# \text{ combustions}}{\# \text{ compressions}} > \text{threshold}$$

Thus, the misfire count is weighted according to the number of commanded combustion events occurring in the interval (number of compressions is fixed; for a V8 engine it is 4000). If CD is never active, this is equal to the number of compressions; if CD is active for the whole interval, there will be half as many combustions as compressions. In this way, misfire faults are reliably detected irrespective of CD activity.

3.6.4 Catalyst Damaging Misfires

When Cylinder Deactivation system is active, the heat up effect on the catalyst of a single misfire is greater, as each misfire contains one fourth of the engine's fuel requirement, rather than one eighth (V8 engine), and a separate look up table for misfire weighting factors is used. Cylinder Deactivation weighting factors are greater (except at very low speed & light load) and so Catalyst Damaging Misfire faults are always detected at the same catalyst temperature, irrespective of Cylinder Deactivation activity.

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3.6.5 Flow chart

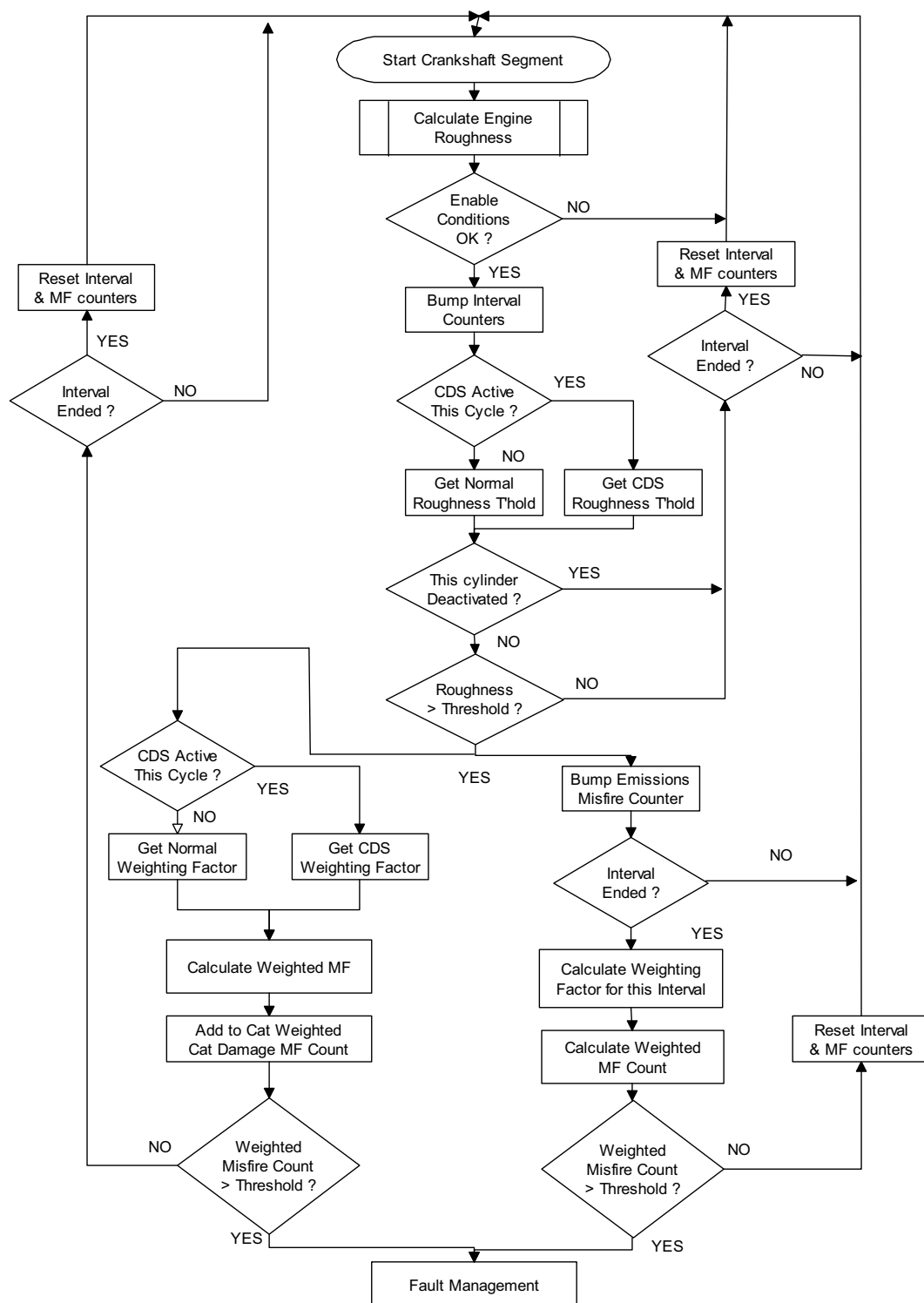


Figure 12: Flowchart Misfire Detection with Cylinder Deactivation

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4 EVAPORATIVE SYSTEM DIAGNOSIS

4.1 Leakage check

4.1.1 General description

The leakage diagnosis procedure is a pressure check of the EVAP system. In order to perform the check, the EVAP system will be sealed and pressure applied by the leakage diagnosis pump (LDP). The pressure variation time is analyzed by the ECM.

4.1.2 Monitoring function description

The diagnosis procedure consists of the following steps:

1. Tank pressure check

The first step of leakage diagnostics is the pressure check of fuel tank system by testing the reed switch. In case of an open reed switch, the fuel tank system has sufficient pressure for the sealed check and no further pressure has to be supplied to the fuel tank system by the LDP.

The diagnosis is waiting until the EVAP purge valve is opened in order to purge the carbon canister. In case the reed switch remains open or the reed switch stuck open, the reed switch is defective.

In the case the reed switch is closed, the LDP is switched on in order to supply pressure to the fuel tank system and the diagnostic is continued with the step 2 to 3 (as described below).

2. LDP Self-check procedure

Closed check

LDP control is disabled and the reed switch has to be closed otherwise the reed switch is defective.

Close to open check

LDP control is switched on once and the diaphragm has to move to the upper position. The time is measured between closed and open position of diaphragm detected by the reed switch. When the final upper position of diaphragm is reached in a certain time, then the check will be passed.

3. Leak check of EVAP system

Fast pulse

After the self check procedure, the LDP control supplies pressure to the fuel tank system with a pressure dependent number of compression strokes in a certain time. In order to supply pressure to the fuel tank system, the LDP can perform compression strokes in several attempts.

EVAP system sealed check, measure stroke and measure phase

The decrease of fuel tank pressure is measured via time of diaphragm movement followed by a compression stroke. Within a certain time, the LDP control is determined within at least four measurement strokes. The averaged time is a measure for the tightness of fuel tank system.

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4.1.3 Flow chart leakage check

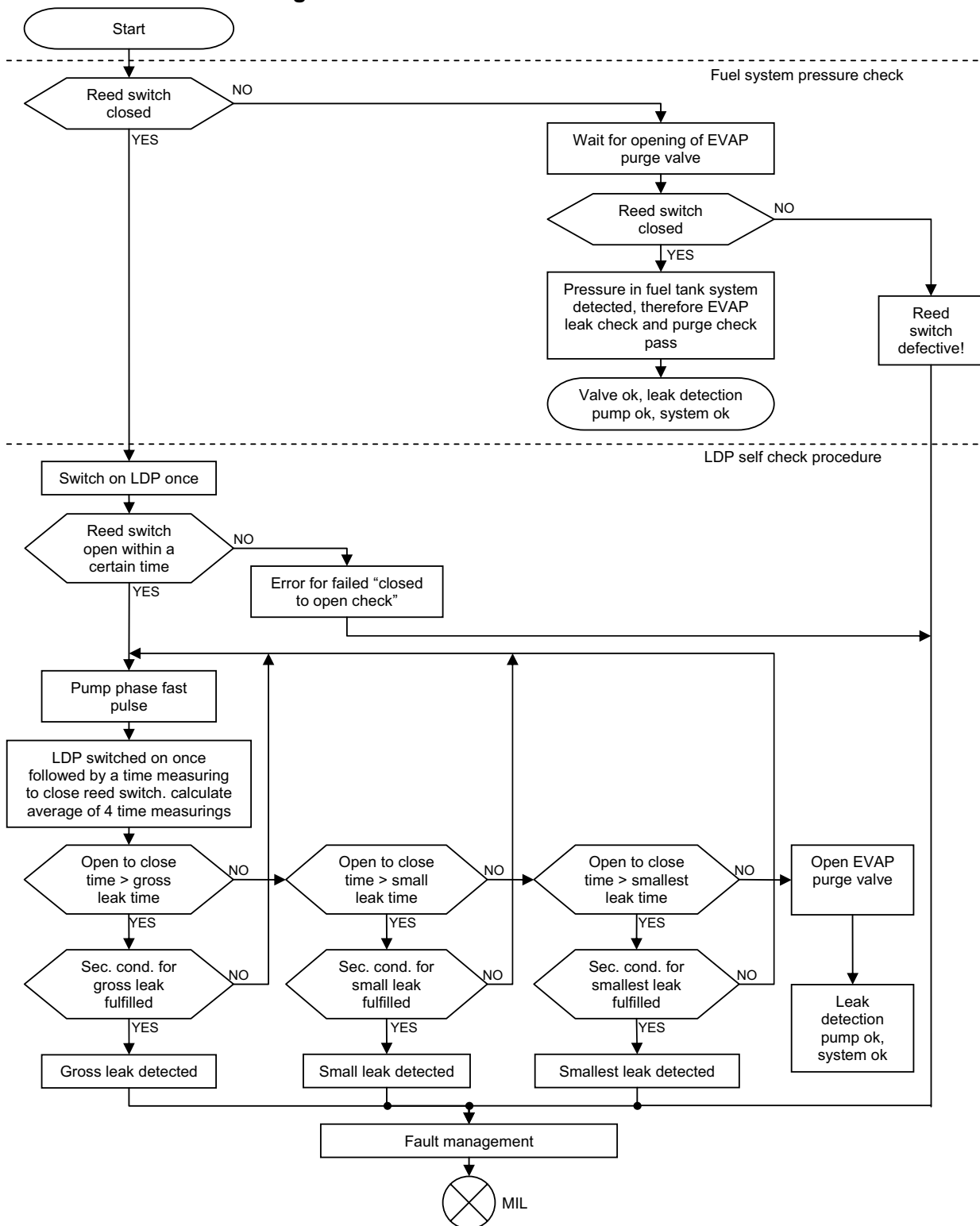


Figure 13: Flow chart leakage check

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4.2 Purge Check

4.2.1 General description

The fuel tank has an integrated ventilation system in order to enable a pressure equalization between the tank and the environment when temperature variations occur or when fuel is added to or extracted from the tank. To prevent fuel evaporation to the atmosphere, a charcoal canister is installed between the tank and the atmosphere, which absorbs discharged hydrocarbons contained in the fuel vapor. As the charcoal canister has a limited storage capacity, it has to be discharged after defined time intervals. This is realized by temporarily opening a connection between the charcoal canister and the intake manifold for a short period of time. After the canister purge valve is opened, ambient air is drawn in through the charcoal canister due to the vacuum in the intake manifold. The stored hydrocarbons are discharged and enter the combustion chamber together with the ambient air. The additional air and fuel charges during the canister purge phases lead to a mixture deviation, which is compensated by the ECM.

The evaporative system monitor is carried out once per driving cycle. During part load conditions, the purge valve is commanded open and the response of the lambda control is monitored. If no clear mixture response can be detected after the majority of a defined number of checks has been run, a fault is suspected and an air check is carried out in the next idle speed situation. If no clear response of the idle speed control on the additional air charge occurs after the switch-open command of the canister purge valve at idle speed, a faulty flow rate in the evaporative system is detected and the corresponding entry in the fault memory is set.

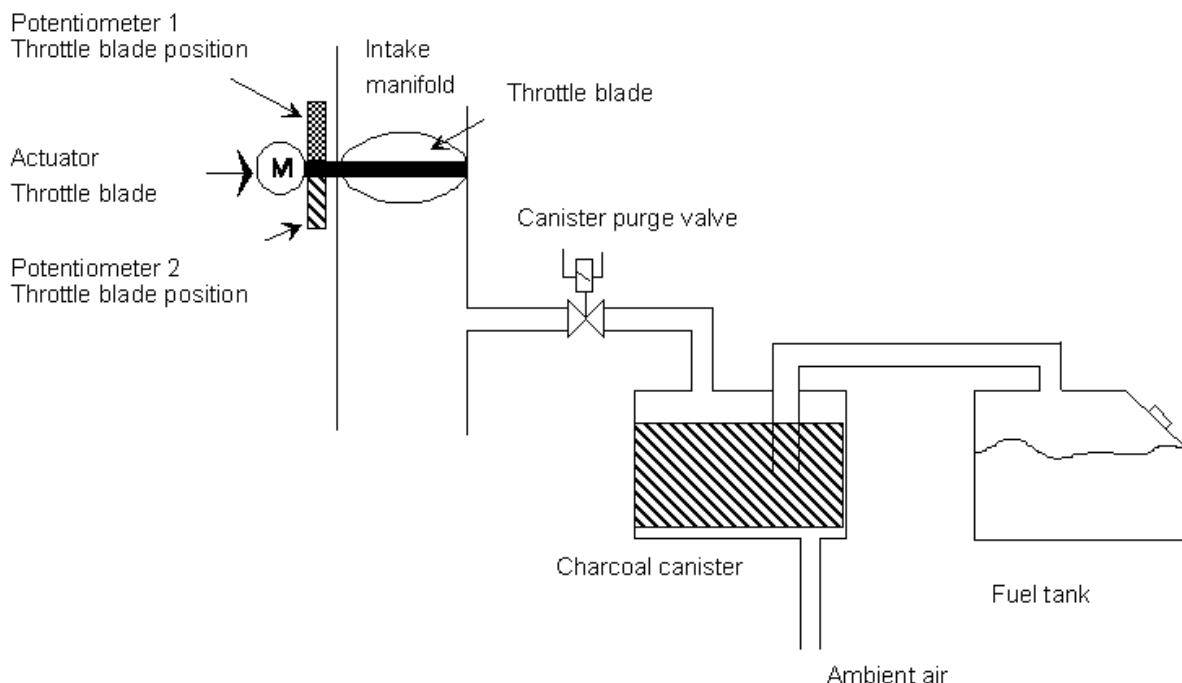


Figure 14: Operating principle of the Evaporative system

4.2.2 Monitoring Strategy

The part load check is the comparison between the mixture deviation that is present during the opening process of the canister purge valve and a threshold value. The idle speed check is the comparison between the ratio of expected mass air flow/actual mass air flow and a threshold value, performed while the purge valve is open.

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4.2.3 Enable Conditions

- Canister purge integral greater than threshold value (depending on engine start temperature)
- Integrated air mass greater than threshold value (depending on engine start temperature)
- Engine coolant temperature and limp-home mode temperature greater than threshold value
- Altitude less than 2700 m above sea level
- Ambient temperature greater than threshold value
- Lambda control in a closed control loop condition
- Engine speed deviation less than threshold value

4.2.4 Malfunction Criteria

Depending on the load condition of the engine and the charge state of the charcoal canister, opening the canister purge valve leads to a mixture deviation (lean or rich), which is detected and compensated by the ECM.

If all enable conditions are fulfilled at part load, the current mixture value is stored as a reference value and the canister purge valve is commanded open according to a given characteristic curve. During the opening process, the current mixture value of the lambda control system is continuously compared with the reference value. If the absolute value of the mixture deviation does not reach a defined threshold value, the canister purge valve may be defective, or the mixture composition currently coming from the charcoal canister does not lead to response in the lambda control. Thus, initially a fault suspicion is generated and an air check is requested for the next idle speed situation. To avoid unnecessary idle speed phases in vehicles with a start/stop system, a fault suspicion is generated not before a defined number of mixture checks without a PASS result have been carried out.

At idle speed, the additional air charge caused by the open canister purge valve leads to an increase in engine speed, which is compensated by the idle speed control by means of closing the throttle valve.

At idle speed, the canister purge valve is commanded open according to a given characteristic curve. When a sufficient opening percentage of the purge valve is reached, a relative mass air flow value is generated from the expected mass air flow values without any canister purge valve activity and the actual mass air flow value. If the relative mass air flow value does not reach a defined threshold value, a faulty flow rate in the evaporative system is detected.

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4.2.5 Flow charts

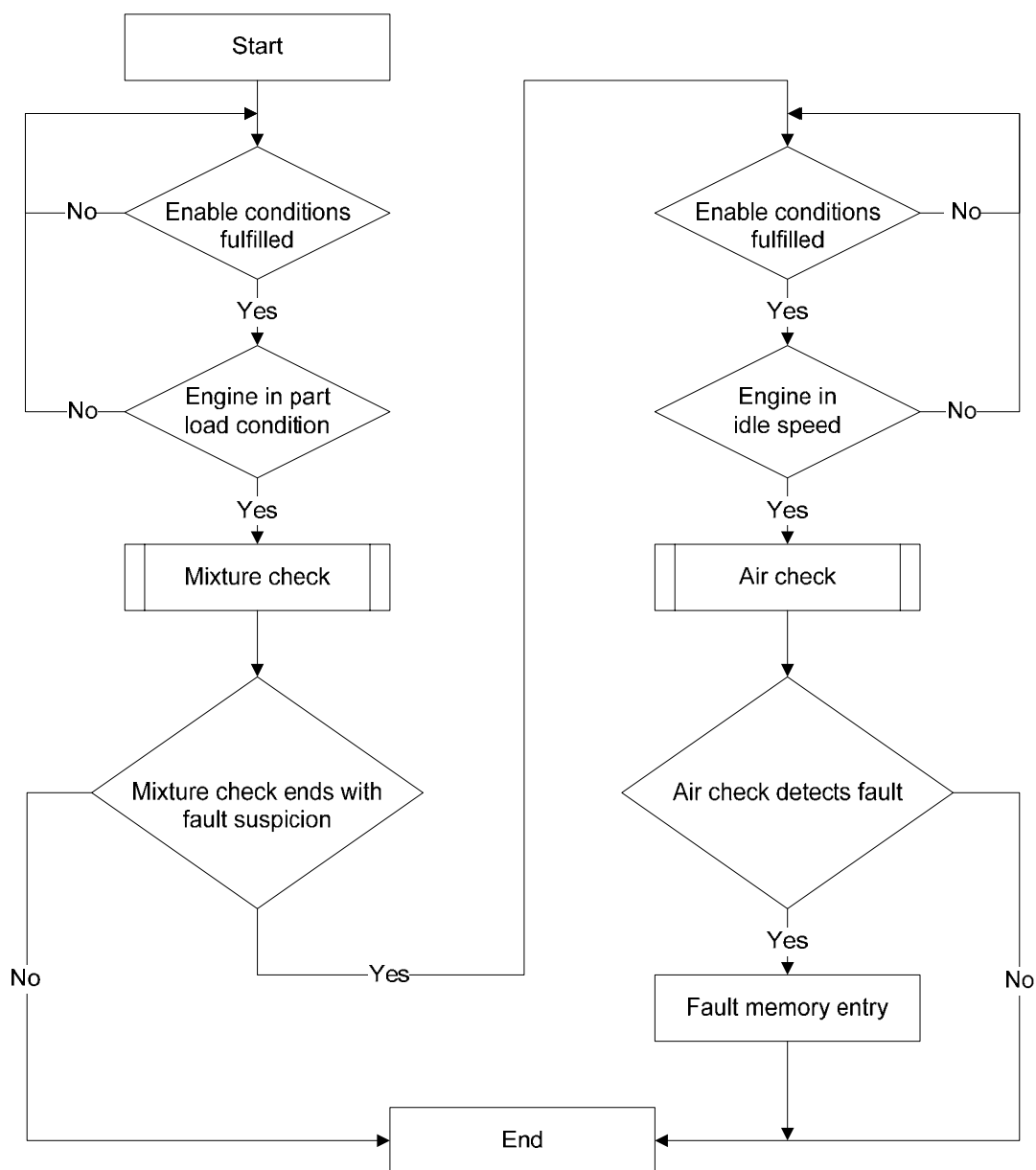


Figure 15: Overview of the Evaporative System Monitoring

For details of the Mixture check and the Air check see the following two flowcharts.

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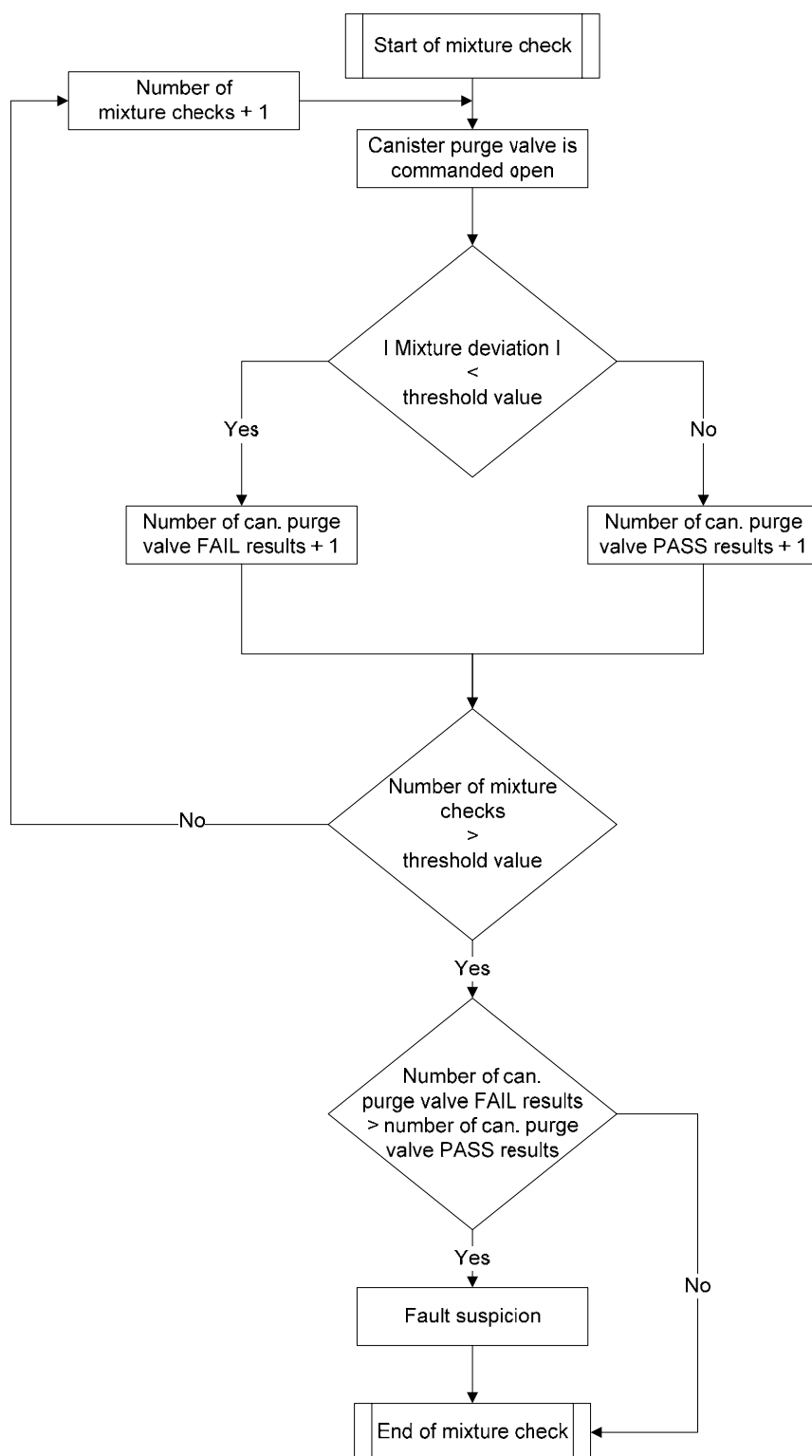


Figure 16: Mixture check (Part load check)

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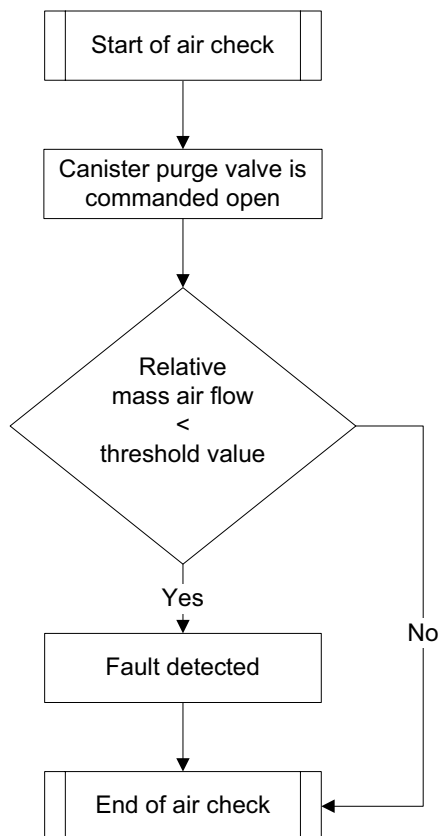


Figure 17: Air check (Idle speed check)

4.2.6 In-Use Monitor Performance Ratio

Incrementing the numerator:

The numerator is incremented by one when the diagnostic has ended and a fault could have been detected. The enable conditions are monitored by a shadow counter, which causes the numerator to increment whenever the diagnostic could have run.

Incrementing the denominator:

The denominator is incremented by one when the conditions for incrementing the denominator according to CCR (d) (4.3.2) (D) „Evaporative System Denominator“ are fulfilled

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5 SECONDARY AIR SYSTEM MONITORING

5.1 System monitoring based on pressure sensor – 2 bank independent secondary air circuits

Applicable only for test group

OBd Group Name	Test group	Engine	Models	Standard	SAIR system configuration
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	2 banks, 2 pumps, 2 pressure sensors, 2 one-way valves

5.1.1 General Description

After a cold start condition (e.g. 5 - 40°C) the air system blows for a certain time air into the exhaust manifold. The exhaust gases will be enriched with oxygen and a post-combustion of HC and CO occurs. By this exothermic reaction the exhaust system will be heated and the time to reach the light-off temperature of the catalyst will be accelerated.

The system comprises two airflow-independent secondary air injection circuits; one for each bank of the V8 engine. Refer to Figure 18.

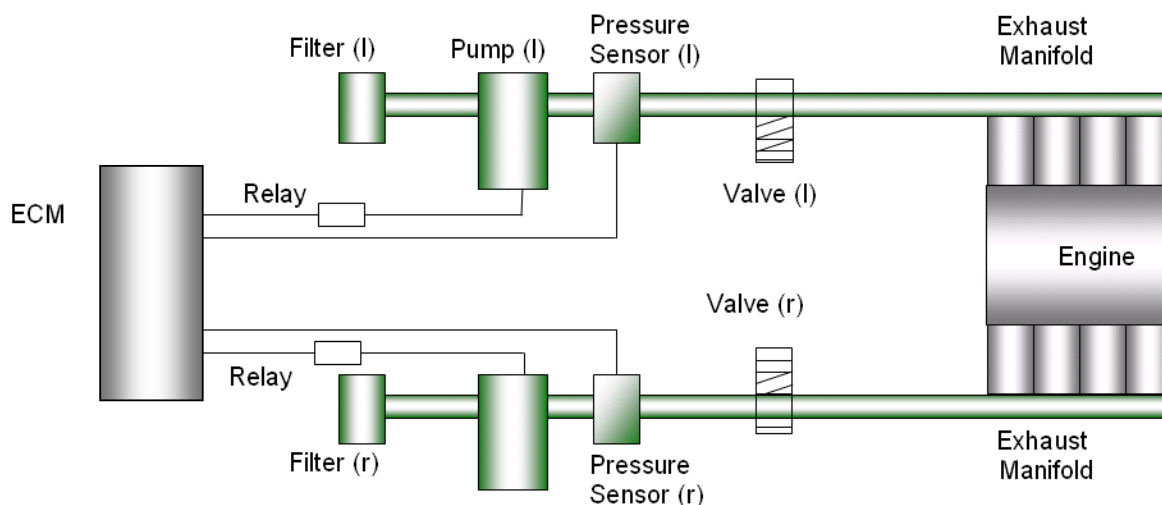


Figure 18: V8 Engine Secondary Air System components

5.1.2 Monitoring Structure

The monitor of the secondary air system comprises a passive function that is carried out during normal secondary air injection while the engine is cold started.

At idle state or under part load engine condition, the secondary air pumps are switched on and the valves open under the pressure of the pumps. The pressure sensors evaluate the pressure of each bank between the air pump and air valve.

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5.1.3 Monitoring Conditions

To start the monitoring function the following conditions have to be satisfied:

- Pressure sensor readiness
- Engine coolant temperature below threshold (e.g. 60°C)
- No output stage error from secondary air pump relay

Monitoring Function Description (refer to Figure 19 and Figure 20)

Phase 0

During ECM initialization the measured atmospheric pressure is measured and stored. An initial rationality check is conducted through comparison of the pressure readings on the air pressure sensor to the atmospheric pressure. If the variance between these sensors is outside a diagnostic threshold then a fault code will be stored indicating a defective pressure sensor.

Phase 1

During catalyst heat up the secondary air pump is switched, the air valve opens and the absolute pressure reading from the secondary air pressure sensor is taken. This is compared with the ambient pressure to generate a pressure bias measure. If this value is greater than a given maximum threshold a fault code will be generated to record an emission related block within the system. If the value is below a diagnostic threshold, a leak fault code will be generated.

Phase 2

Following air pump switch off (air valve closed) the air pressure value at the pressure sensor is taken again and again compared to the atmospheric measure. If the calculation returns a result showing this value to be lower than a minimum threshold then a defective air pressure sensor reading will be recorded, whilst if the value is above a maximum threshold then a pump fault code will be stored.

In addition, a secondary air valve check is performed during Phase 2. If the mean secondary air pressure value exceeds a threshold and fluctuation of the pressure outside minimum and maximum thresholds is present, then a leakage of the valve is indicated.

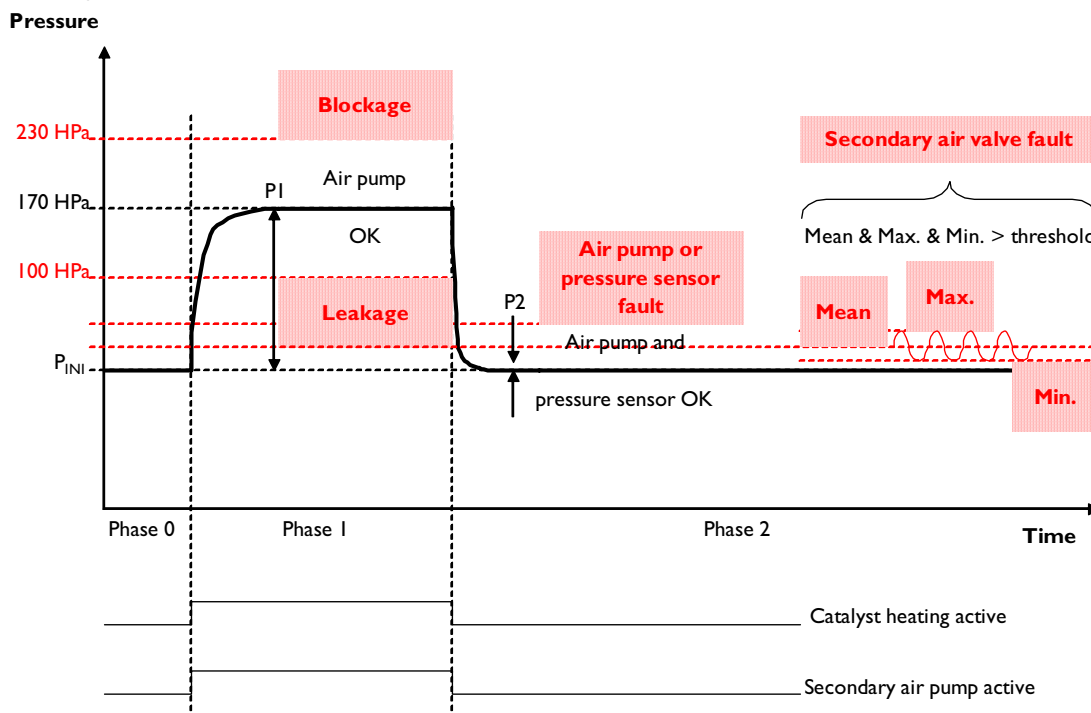


Figure 19: Phases of AIR system Monitoring

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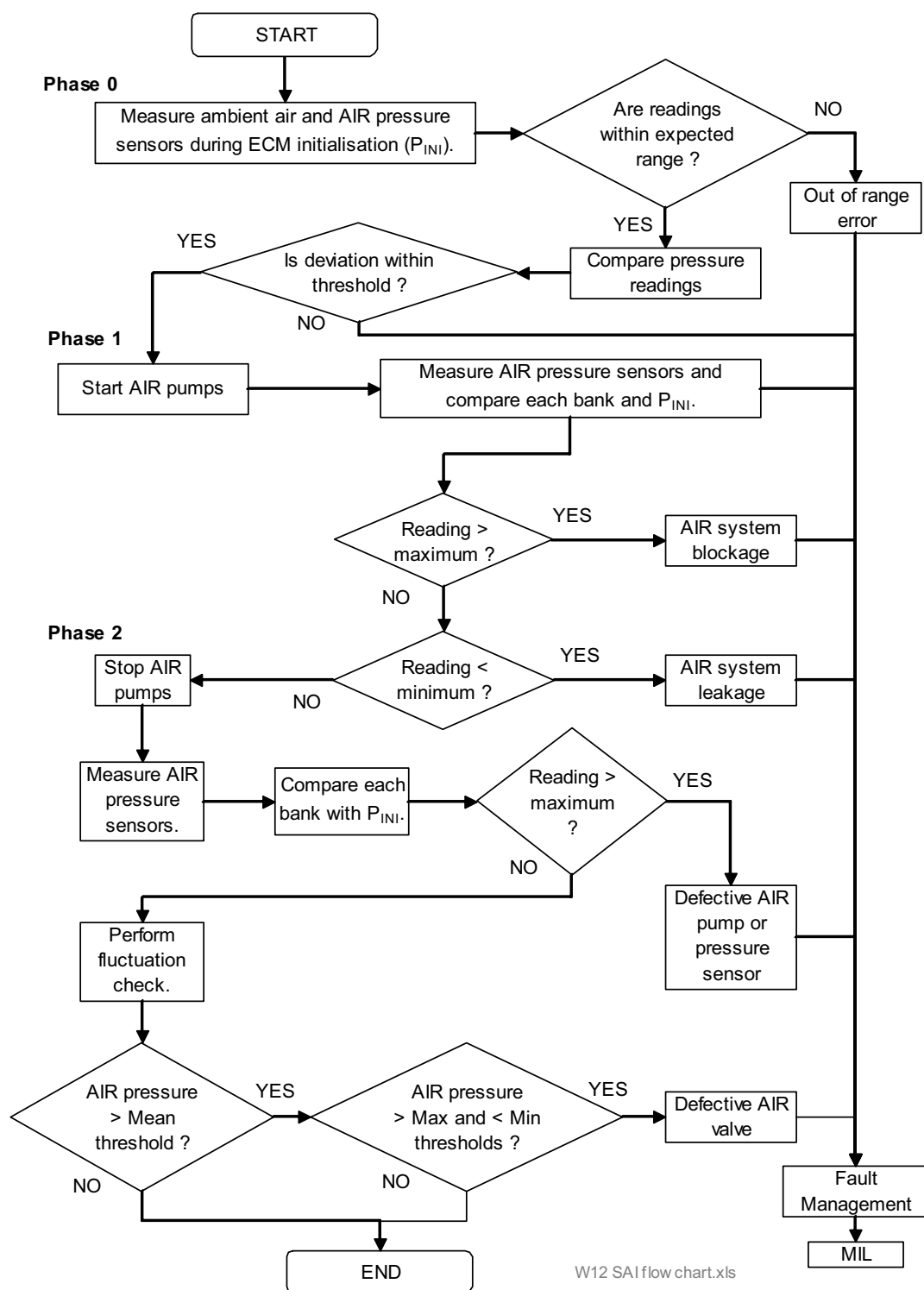


Figure 20: Flow chart Secondary Air System monitoring

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6 FUEL SYSTEM MONITORING

6.1 General description of lambda control strategies

To minimize the emissions of motor vehicles, an exhaust gas aftertreatment system is installed after the combustion engine.

This system consists primarily of the following components: oxygen sensors, which measure the exhaust gas composition in the gas phase, and the catalytic converters, which ensure the active conversion of the combustion residues emitted by the engine.

Additionally to these hardware components, a control system is required.

The purpose of this control system is to ensure an exhaust gas composition that enables a maximum conversion rate of the released emissions by the exhaust gas aftertreatment system that is installed after the combustion engine.

As shown in the illustration below, the signals from the oxygen sensors are transmitted to the engine control module (ECM) and serve for further engine management calculation.

As an example, the following figure shows a system with one catalyst near the engine and one underfloor catalyst, and three oxygen sensors. A system with only one catalyst and/or only two oxygen sensors would look similar.

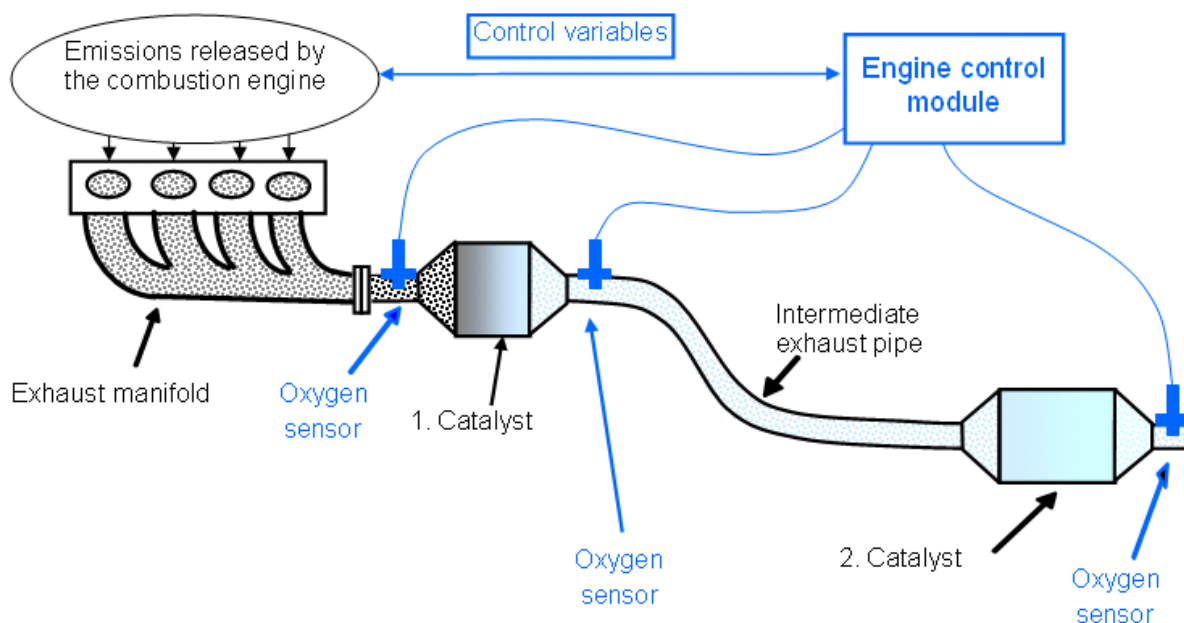


Figure 21: Exhaust gas aftertreatment components

As mentioned before, the purpose of the lambda control system is to adjust the fuel injected to the engine. This produces an exhaust gas composition that enables an optimum conversion rate to be achieved by the hardware configuration of the exhaust gas aftertreatment system.

The adjustment of the exhaust gas composition is achieved by slightly varying the amount of fuel injected into the combustion chambers of the engine.

Due to the chemical reactions, the achievable conversion rate of the catalyst is subject to several limitations.

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Considering the functional principle of the lambda control system, the restrictions that must be considered for a catalyst with operational temperature, must be taken into account.

One of the main influencing criteria that must be considered is that a catalytic converter (catalyst) can only enable the chemical conversion of the exhaust gas components contained in the exhaust gas flow. The chemical reactions are the OXIDATION of carbon monoxide (CO) and hydrocarbons (HC) and the REDUCTION of nitrogen oxides (NO_x).

Due to the reaction process, oxygen is used during the oxidation, and it is released during the reduction. Hence, the effect of the carbon monoxide (CO) and the hydrocarbon (HC) conversion rate will be reduced drastically when the exhaust gas composition lacks oxygen ($\lambda < 1$).

With a surplus of oxygen in the exhaust gas ($\lambda > 1$), the conversion rate of nitrogen oxides (NO_x) reduces, accordingly.

See this behavior in the following figure.

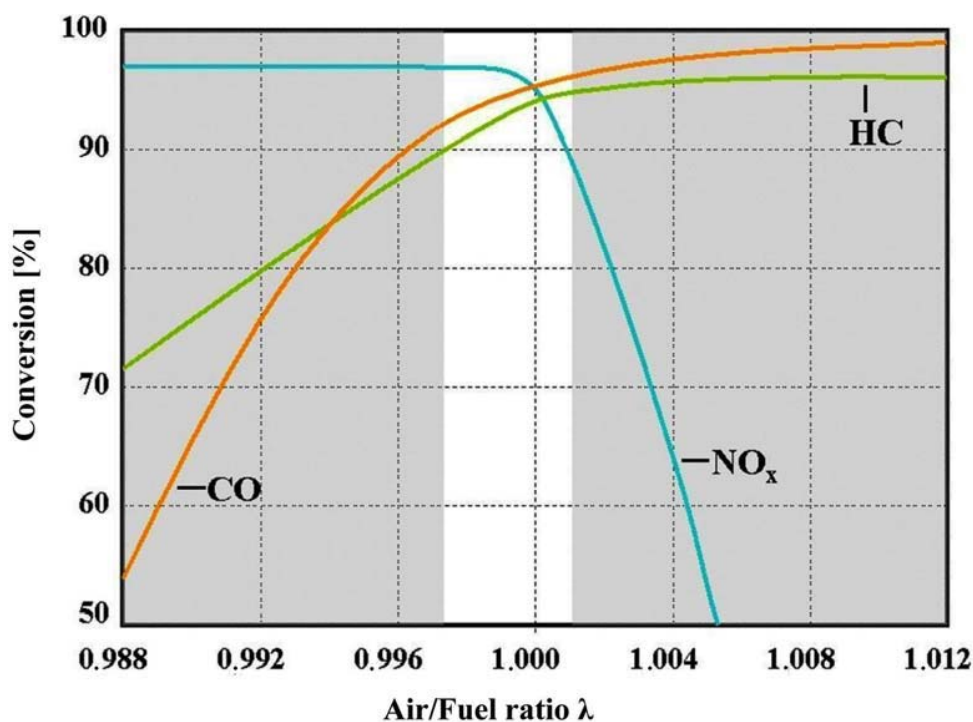


Figure 22: Conversion rate with respect to air/fuel ratio

Additionally, insufficient or excessive oxygen resulting from temporary deviations of the optimum exhaust gas composition can be compensated by taking oxygen from the oxygen stored within the catalyst or storing it there, correspondingly.

This process, however, is only feasible within the maximum Oxygen Storage Capacity (OSC) of the catalyst. The corresponding correlation is shown on the next page.

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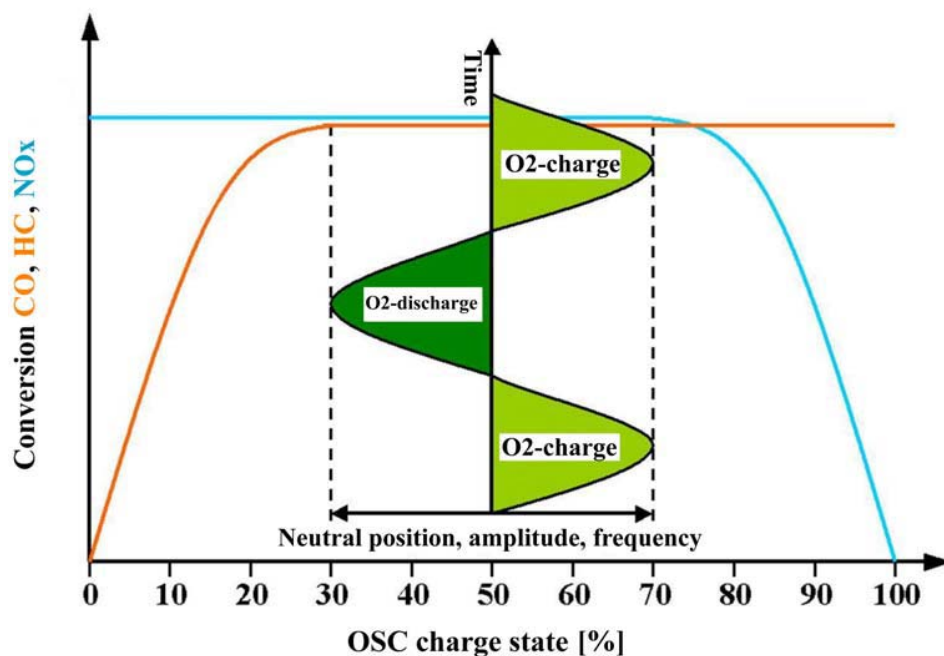


Figure 23: Conversion rate with respect to OSC oxygen storage state

To summarize, the task of the lambda control, which leads to a mixture control eventually, can be described as the provision of the catalyst with a mixture composition that ensures the maximum conversion of the exhaust gas components even with varying engine conditions (varying loads and speeds).

The exhaust gas composition post the catalyst is measured by a binary oxygen sensor. See the following corresponding characteristic sensor curve.

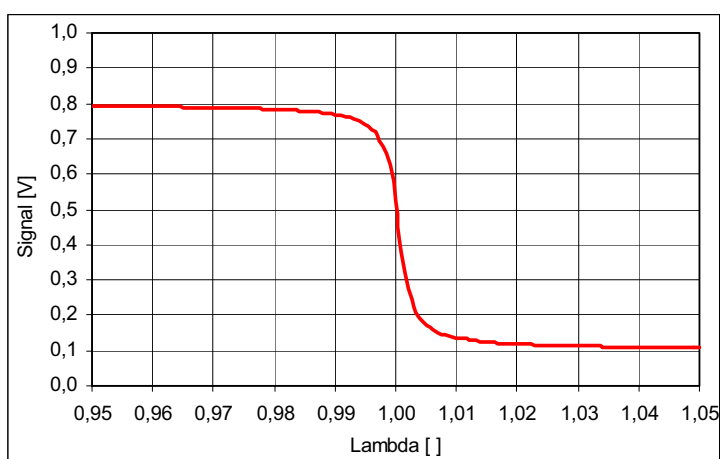


Figure 24: Signal of the binary oxygen sensor with respect to lambda

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The next figure illustrates the response of the oxygen storage, by showing the lambda signal downstream of the catalyst with respect to the charge state of the oxygen storage.

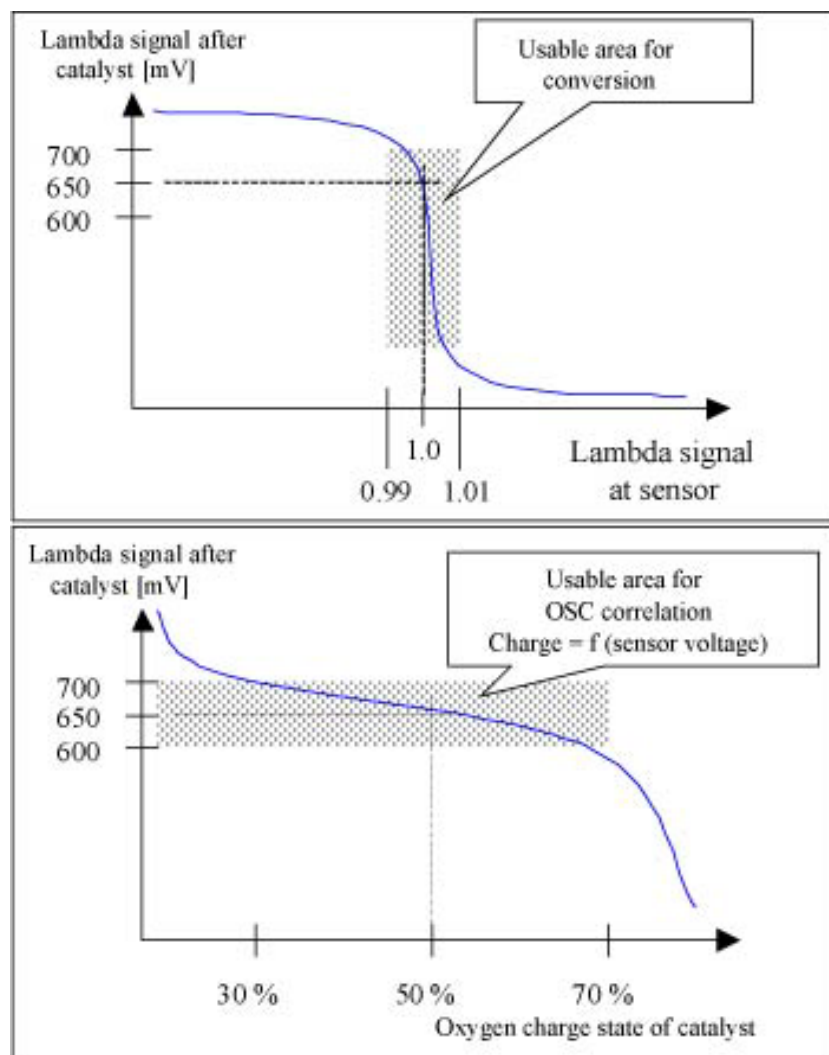


Figure 25: Signal of the binary oxygen sensor with respect to lambda and with respect to the oxygen storage state of the catalyst

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6.1.2 Principle of Operation of a Fixed frequency Control

The following explanation relates to the following configuration example: A wide range oxygen sensor is installed upstream of the catalyst, and a binary Nernst sensor is installed downstream of the catalyst. In the figure the oxygen storage in the catalyst is also shown. It has become obvious, that either the exhaust gas composition, the lambda signal upstream of the catalyst, or the oxygen storage state in the catalyst may be used as the contr

the provision of the catalyst with a mixture composition that ensures the maximum conversion of the exhaust gas components even with varying engine conditions (varying loads and speeds).

The exhaust gas composition post the catalyst is measured by a binary oxygen sensor. See the following corresponding characteristic sensor curve.

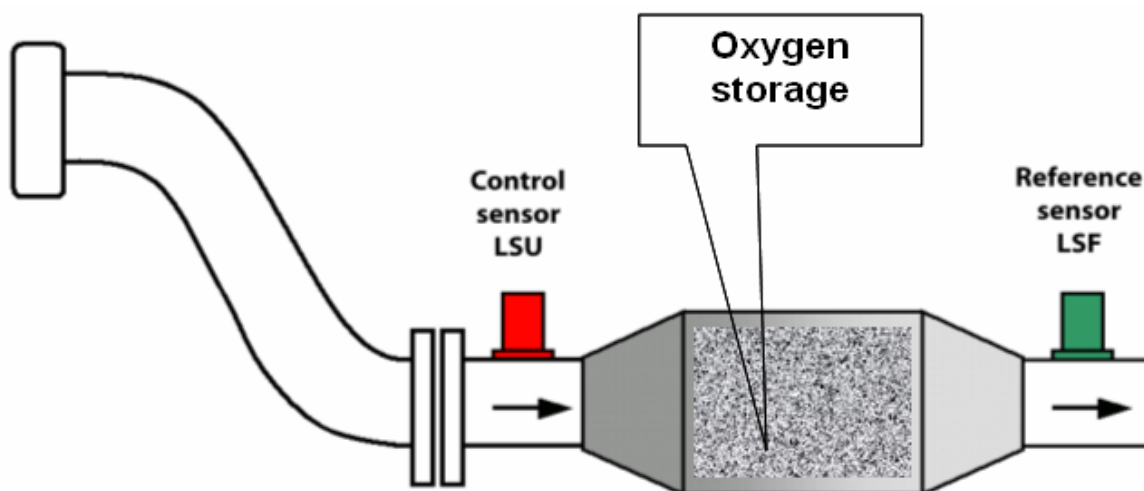


Figure 26: Layout of a catalyst with an oxygen storage

The following discussion explains the principal results of the two control strategies.

The principle of the control strategy "lambda" is shown in Figure 66Figure 56. It can be seen from the illustration that a deviation from the setpoint lambda value is responded to in such a way that the measured lambda value is adjusted in order to achieve the setpoint value.

When observing the charge state of the oxygen storage, a short disturbance leads to a lean exhaust gas composition and thus to the additional charging of the oxygen storage, if the current condition is the same as shown in following figure.

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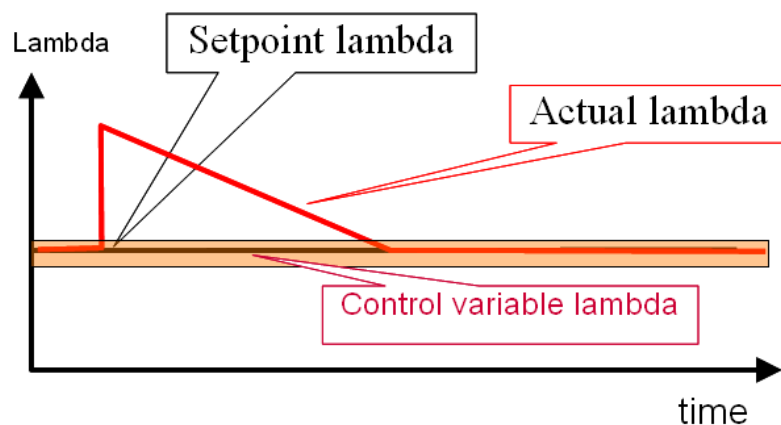


Figure 27: Control parameters in case of control variable "lambda"

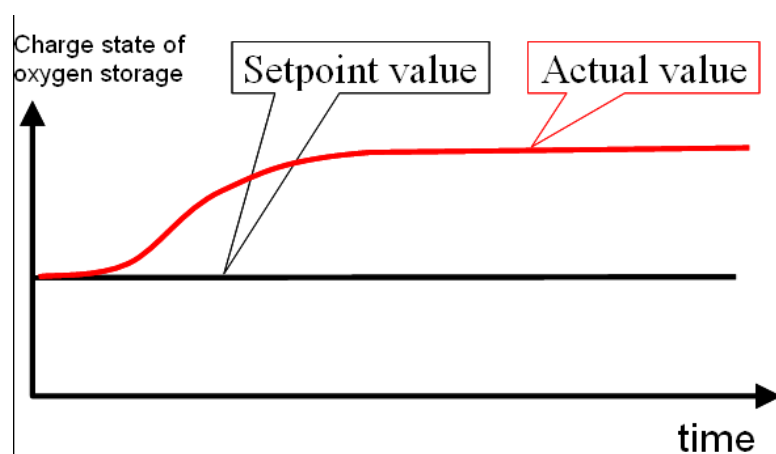


Figure 28: Influence on the charge state of the oxygen storage in case of control variable "lambda"

The additional charging of the oxygen storage results in a decrease of the NO_x conversion.

The following figure shows the principle for 6.1.2 Principle of Operation of a Fixed frequency Control the NO_x conversion decreases

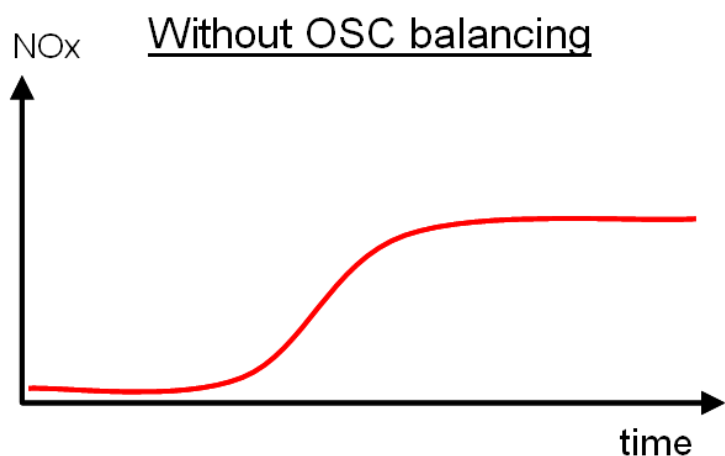


Figure 29: Influence of the change of the oxygen storage's charge state on the NO_x emissions

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The increased oxygen charge of the catalyst leads to a decreased voltage of the binary oxygen sensor downstream of the catalyst.

Secondary
sensor
signal

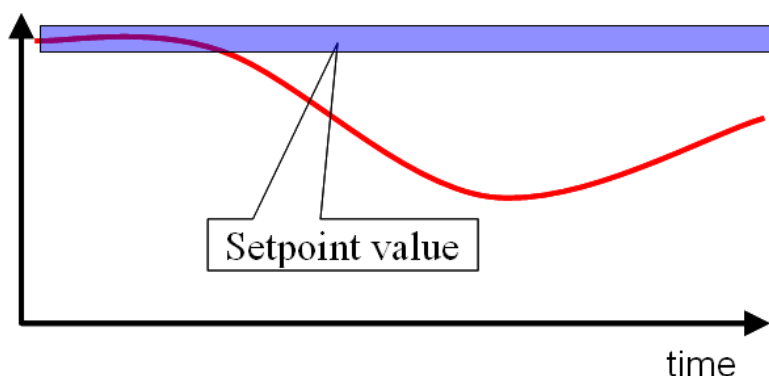


Figure 30: Deviation of the sensor voltage downstream of the catalyst by reason of changing the catalyst oxygen charge state

The trim control, which is the control system after the catalyst, detects the deviation of the actual voltage from the setpoint voltage and compensates it.

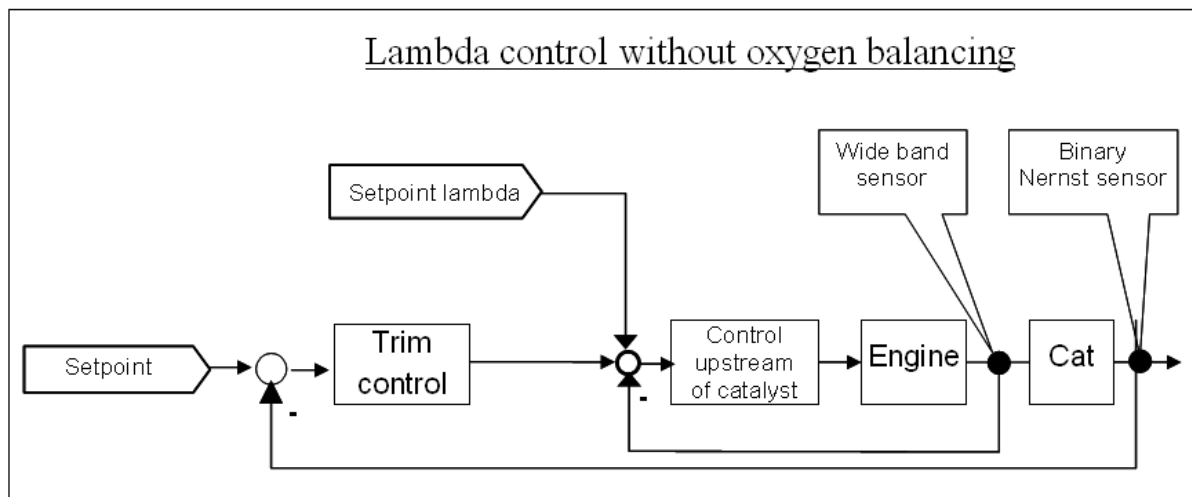


Figure 31: Control without balancing

This method of correcting a disturbance of the charge state of the oxygen storage by means of the trim controller has a disadvantage, which is that the correction is effected relatively slowly, and a response to a disturbance of the control variable is not possible before a decrease of the exhaust gas conversion is already present.

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6.2 Air / fuel system monitoring

6.2.1 General description

Fuel Injection System

In comparison to conventional systems the gasoline is not injected into the intake manifold but directly into the combustion chamber.

Due to the higher pressure level in the combustion chamber, e.g. during the compression stroke, a high pressure fuel injection system is used.

Mixture Pilot Control

The air flow sucked in by the engine the engine speed and fuel pressure are measured. These signals are used to calculate an injection signal. This mixture pilot control follows fast load and speed changes.

Lambda-controller

The ECM compares the oxygen sensor signal upstream the catalyst with a reference value and calculates a correction factor for the pilot control.

6.2.2 Monitoring function description

Adaptive pilot control

Drifts and faults in sensors and actuators of the fuel delivery system as well as unmeasured air leakage influence the pilot control. The controller corrects amplitudes increases. If there are different correction values needed in different load speed ranges, a certain time passes until the correction is complete. The correction values will be determined in three different ranges.

Fuel trim

The basic air/fuel ratio control using the signal from the front O₂ sensors(s) is corrected by an adaptation calculation. This adaptation results in a factor which is applicable for the whole working range. (e.g. 20%) A further trim control based on the signal(s) from the rear O₂ sensor(s) is correcting the adaptation factor. Therefore this trim control is working in the same way in the whole range.

If the trim control reaches the allowed limit (e.g. 2%) the fault code for fuel delivery trim control is set.

Any deviation from the characteristic curve of oxygen sensor upstream catalyst due to poison will be detected by the control loop downstream catalyst.

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6.2.3 Chart and flow charts air / fuel system monitoring

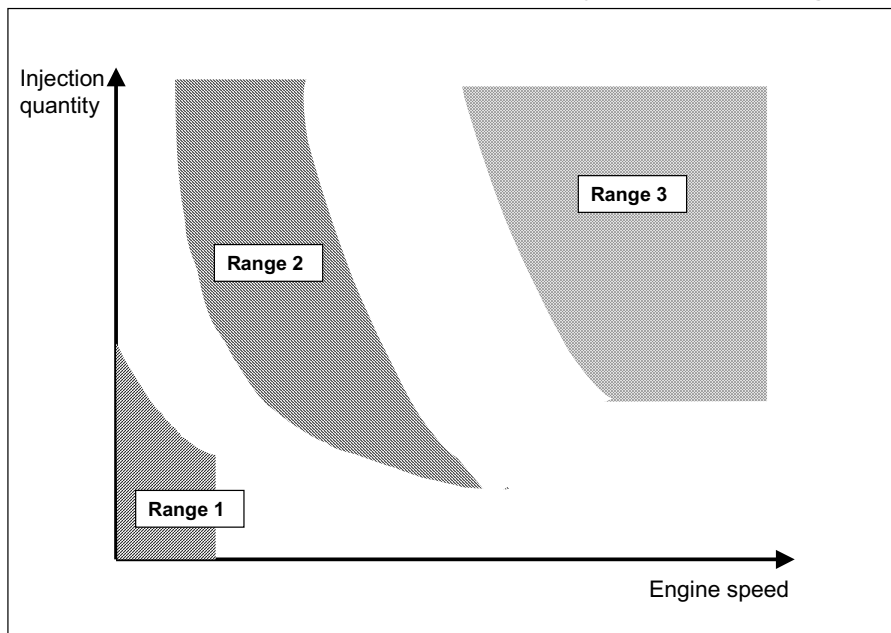


Figure 32: Fuel trim – injection quantity / engine speed

Lambda deviations in **range 1** are compensated by an additive correction value multiplied by an engine speed term. This creates an additive correction per time unit.

Lambda deviations in **range 2** are compensated by multiplication of a factor.

Lambda deviations in **range 3** are compensated by multiplication of a factor (optional depending on individual calibration).

A combination of all two (three) ranges will be correctly separated and compensated.

Each value is adapted in its corresponding range only. But each adaptive value corrects the pilot control within the whole load/speed range by using a linear interpolation formula. The stored adaptive values are included in the calculation of the pilot control just before the closed loop control is active.

Diagnosis of the fuel delivery system

Faults in the fuel delivery system can occur which cannot be compensated for by the adaptive pilot control.

In this case, the adaptive values exceed a predetermined range.

If the adaptive values exceed their plausible ranges, then the MIL is illuminated and the fault is stored.

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Flow chart: fuel trim

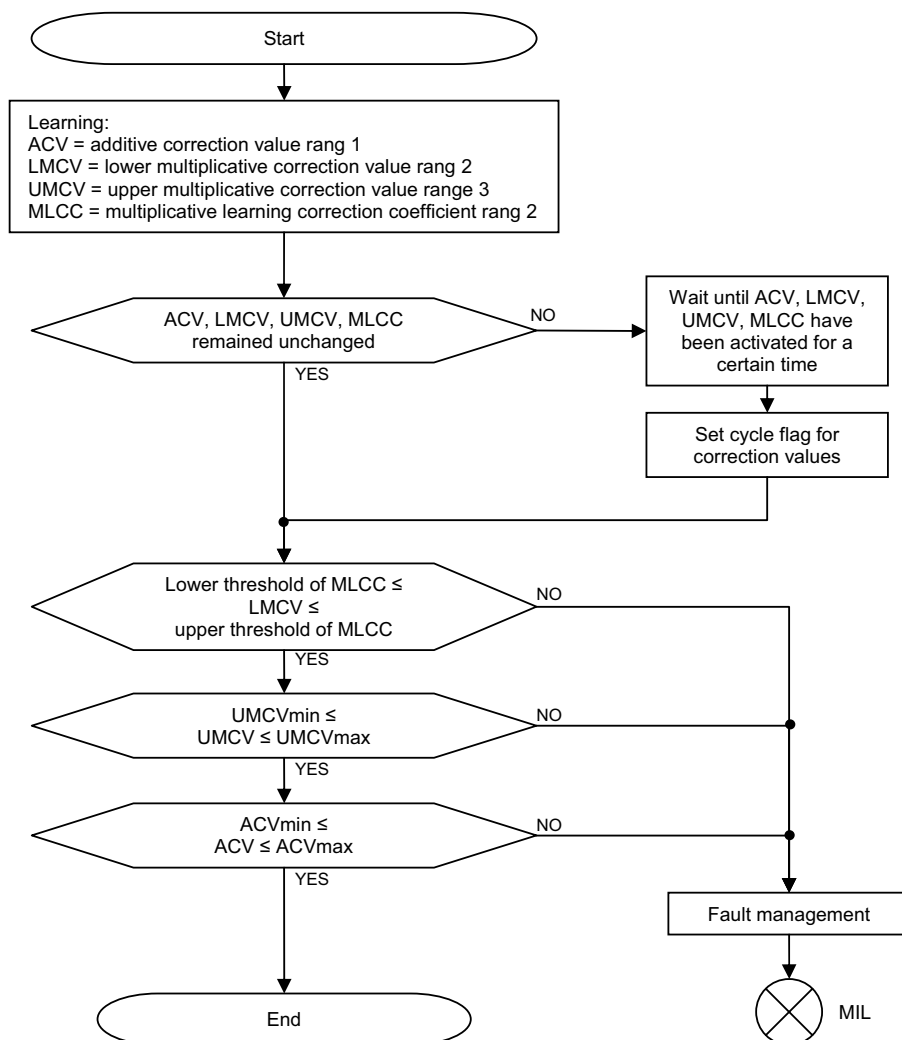


Figure 33: Flow chart fuel trim (part 1)

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Flow chart: fuel trim (part 2)

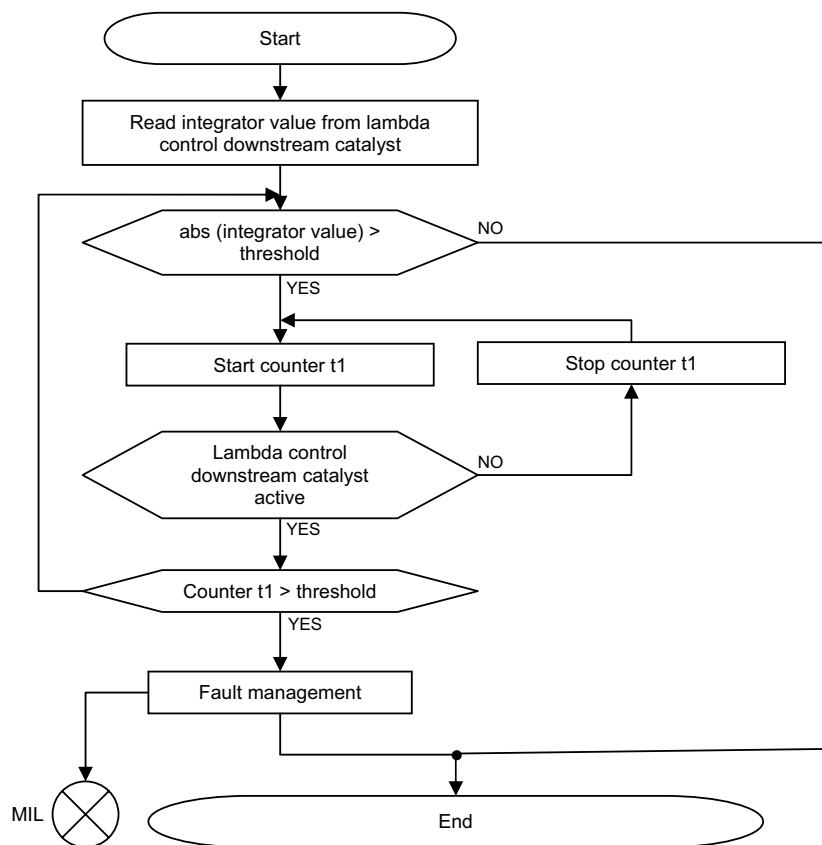


Figure 34: Flow chart fuel trim (part 2)

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6.2.4 Similar conditions for fuel system

The fuel system monitor runs in different ranges of the engine map. Faults at idle are detected in the Range 1, faults off idle in the Range 2 and if applicable faults at higher load in a Range 3. It depends on the engine type whether it is necessary to use a third range.

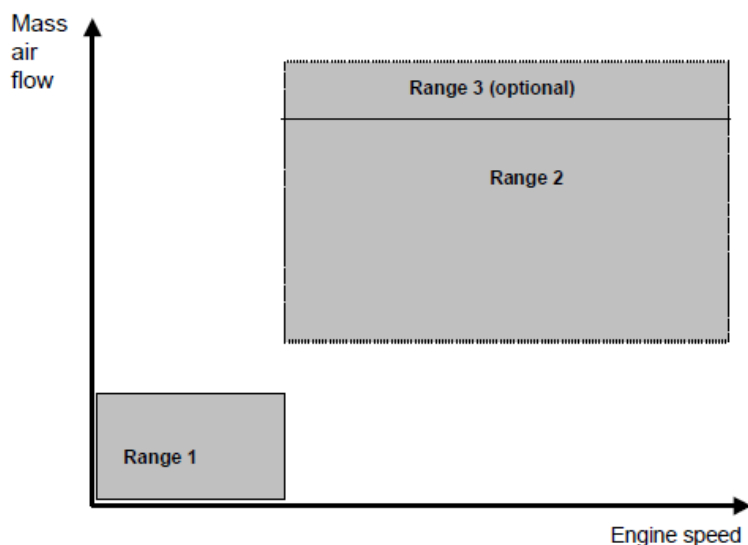


Figure 35: Similar conditions – mass air flow / engine speed ranges

The OBD system uses two ranges, Range 1 and Range 2. Although monitoring runs only within the two ranges the results are not independent from each other.

A pending code found in one of the ranges would be confirmed in either of the ranges. Healing of a pending or confirmed code needs pass results in both ranges.

Consequently any decision leads to the same P-code, valid in the whole working range:

- P0171 System too lean
- P0172 System too rich

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Extended monitoring range for fuel delivery system trim control DTC

The basic air / fuel ratio control using the signal from the front oxygen sensor is corrected by an adaptation calculation. This adaptation results in a facto that is applicable for the whole working range of the fuel adaptation, e.g. 24% - 65% load and 1500 – 4000rpm engine speed.

A further trim control based on the signal from the rear oxygen sensor is correcting the adaptation factor. Therefore, this trim control is working in the same way in the whole range. If the trim control reaches the allowed limit the fault code for fuel delivery trim control is set.

Applying the whole range would allow to confirm or erase a fault code under different conditions than first detected and thus come to a faster decision. Using this whole range for monitoring this function rather than the limits given in sect (c)(33), as seen in the following graph:

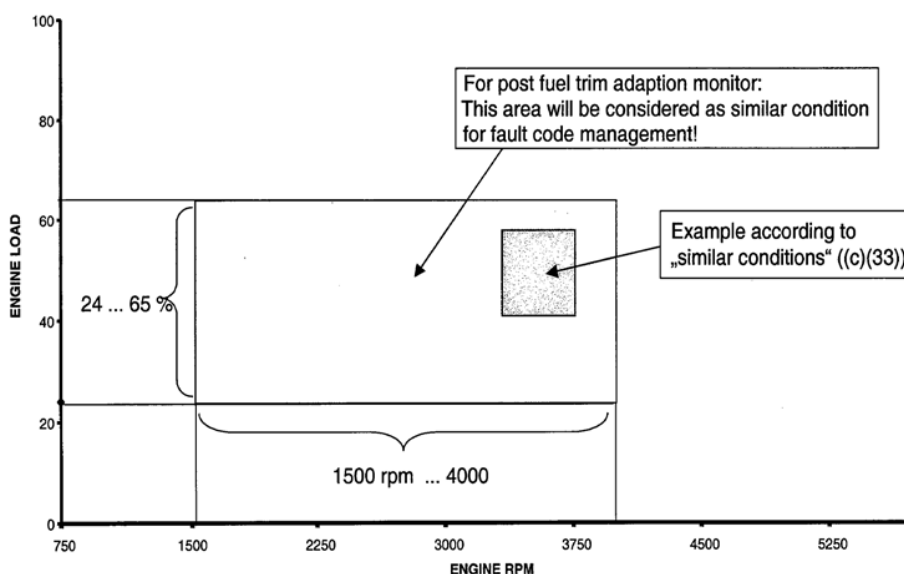


Figure 36: Monitor window – post fuel trim adaptation

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7 EXHAUST GAS SENSOR MONITORING

General description

The Lambda control loop consists of a linear oxygen sensor upstream catalyst and one or two binary oxygen sensors downstream front catalyst (and post main catalyst). The secondary control loop (downstream of the catalysts) corrects deviations of the upstream oxygen sensor.

Upstream oxygen sensor (wide band sensor)

The wide band oxygen sensor (other commonly used names are LSU or UEGO) measures the oxygen content and the lambda value of the exhaust gas. Because of its continuous characteristic line the wide band sensor is applicable for the upstream catalyst position. This kind of sensor is able to measure a wide range of lambda (e.g. 0.65 ... λ ... air).

The wide band oxygen sensor has an integrated sensor heater. The heater performance is controlled by the ECM in order to maintain a certain sensor temperature. The sensor temperature is measured indirectly by the internal resistance.

The relevant output signal of a wide band sensor is the pump current (I_p). It is proportional to the lambda value.

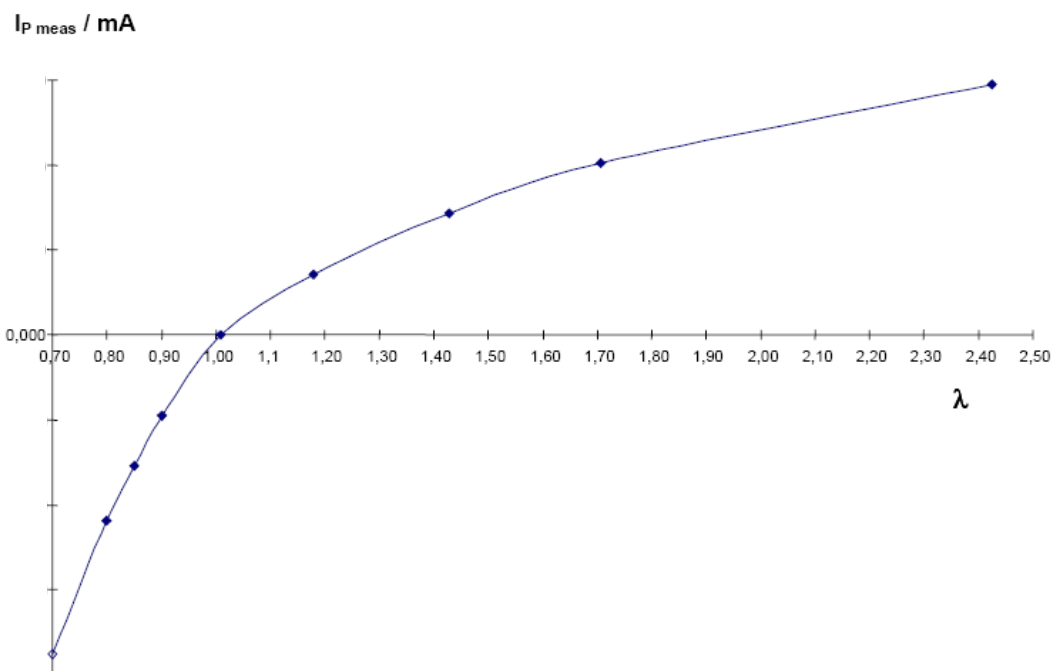


Figure 37: characteristic line of wide band sensors

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Downstream oxygen sensor (binary sensor)

The binary oxygen sensor (other commonly used names are LSF or HEGO) measures also the oxygen content of the exhaust gas. The output voltage of this sensor is reading a level of > 0.45 V for a rich exhaust gas constitution. In case of a lean exhaust gas constitution, the sensor reads voltages < 0.45 V. For stoichiometric mixture ($\text{Lambda} = 1$) the characteristic line of the binary sensor has a steep gradient.

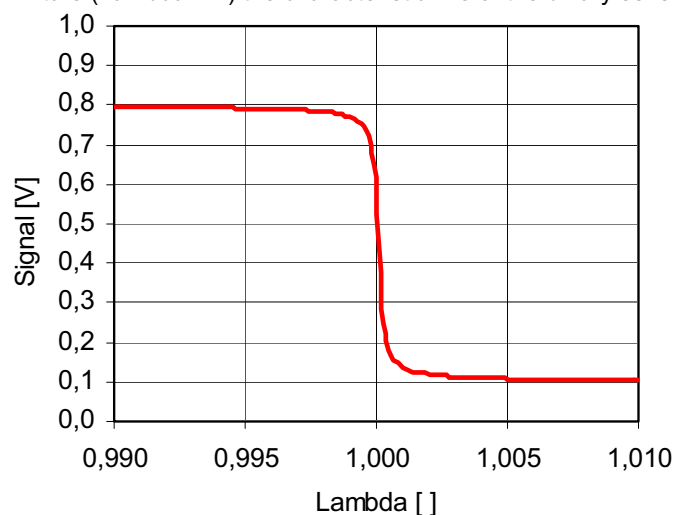


Figure 38: characteristic line of binary sensors

The binary sensor is located downstream the catalyst and is used for catalyst monitoring, monitoring of the upstream oxygen sensor and secondary fuel trim. There is also a sensor heater integrated to ensure a sufficiently high operating temperature.

All sensors are monitored by several single monitoring procedures as follows.

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7.1 FO2 Sensor dynamic

Different failure types of wideband oxygen sensors may affect the sensor characteristics:

- **Clogged protection tube:**
diffusion of exhaust gas into measurement chamber is being slowed down
→ slower sensor signal transition, being detected by front O2 Sensor dynamic
- **Crack in pumping cell:**
typically results in rich shift of the signal
→ being detected during fuel cut-off
- **Crack in reference cell:**
typically results in lean shift of the signal
→ being detected by rear fuel trim monitoring
- **Poisoning of sensor ceramic surface:**
diffusion of exhaust gas into ceramic element is being slowed down
→ slower sensor signal transition, being detected by front O2 Sensor dynamic check

Overview of FO2 Sensor monitoring strategies:

OBD Group Name	Test group	Engine	Models	FO2S Response Rate Strategy
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	Area

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7.1.1 Oxygen sensor, signal too slow, P0133, P0153, P3209, P3239

Master: bank 1: P0133, bank 2: P0153; Slave: bank 3: P3209, bank 4: P3239

This function monitors the dynamic behavior (responding properties) of a continuous wideband LSU oxygen sensor, which is located upstream of the catalyst (primary oxygen sensor). Slow dynamic sensor behavior may lead to a rise of exhaust gas emissions, and, on the other hand, the results of other monitoring functions that use the signal of the primary sensor (such as the catalyst monitor or the secondary air monitor) may be falsified, or the corresponding monitoring function disabled.

7.1.1.1 Monitoring Strategy

The monitoring function detects symmetrical and asymmetrical faults in the primary oxygen sensor that may be caused by either slow transition or delayed response. The area ratios for each direction and the ratios of the maximum gradients of the actual signal and the setpoint signal for each direction are used as evaluation criteria.

7.1.1.2 Enable Conditions

- Oxygen sensor has reached operating temperature (typically 720 °C)
 - A calibratable waiting period is exceeded after the operational readiness was set
 - Secondary air injection is inactive
 - Flex-Fuel engine with no ethanol sensor: Ethanol concentration adaptation is inactive (only Flex-Fuel concepts)
 - Relative fuel quantity from transition compensation < threshold value
 - Volume flow rate of carbon canister purge < threshold value
 - Canister purge diagnostic is inactive
 - Tank leakage diagnostic is inactive
 - Catalyst temperature > threshold value
 - No fuel cut-off to any cylinder, all injection valves are activated
 - Engine coolant temperature > threshold value
 - Engine speed, load, and exhaust gas delay time constant in defined range
 - Evaporative system not active, or time of activation > threshold value
 - Currently no gear change in process
- This enable condition is optionally calibratable, i. e. it is only active when it is required. For details, see the Summary Table
- Gradient of the engine load $\leq$ threshold value
 - "Open circuit in the pump current circuit" monitoring function is completed
 - Second lambda control loop not active
 - Forced lambda modulation not active

7.1.1.3 Malfunction Criteria

The monitoring function utilizes surges in the amount of fuel injected, and compares the actual oxygen sensor signal with the expected oxygen sensor signal. For this purpose, two corresponding, comparable areas and maximum gradients are calculated. One of the areas and the respective maximum gradient are determined on the basis of the actual sensor signal, the other area and the respective maximum gradient are determined on the basis of the expected sensor signal.

Starting with the response to a fuel surge, the area between the inverted signal and a horizontal line, which begins at the point of the start value, is calculated during a defined time period. Within the same time frame the maximum gradient of the signal is calculated.

Then a quotient from the actual area and the expected area and a quotient from the maximum gradients are calculated. The slower the oxygen sensor responds, the lower the absolute value of the quotient value calculated from these values and/or the two gradients will be. While the area ratio and the gradient ratio are reduced in the case of a slowly rising signal, only the area ratio is reduced in the case of a delayed signal rise. The gradient ratio remains largely unaffected as long as the response of the actual signal occurs within the measurement window. If no response within the measurement window occurs, as in the case of very large faults, both ratios equal zero.

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Typically, the monitoring function utilizes an active modification of the setpoint lambda value. There are two kinds of surges, R2L surges and L2R surges. Single uni-directional surges with a calibratable waiting period between two surges, are applied.

Several options are generally possible when using the fuel surges as a means of activation:

- The monitoring function executes its own lambda modification. This enables double surges with R2L and L2R modifications or single uni-directional surges with a calibratable waiting period between two surges (this strategy is applied starting with MY 2010).
- Measuring the two flanks during the lambda modification of the active catalyst monitoring function (this strategy is planned for future model years)
- Measuring the R2L flank during overrun fuel cut-off and measuring the L2R flank during catalyst purge (rich operation) after overrun fuel cut-off (currently not taken into account)

The options listed above may be applied individually by coding.

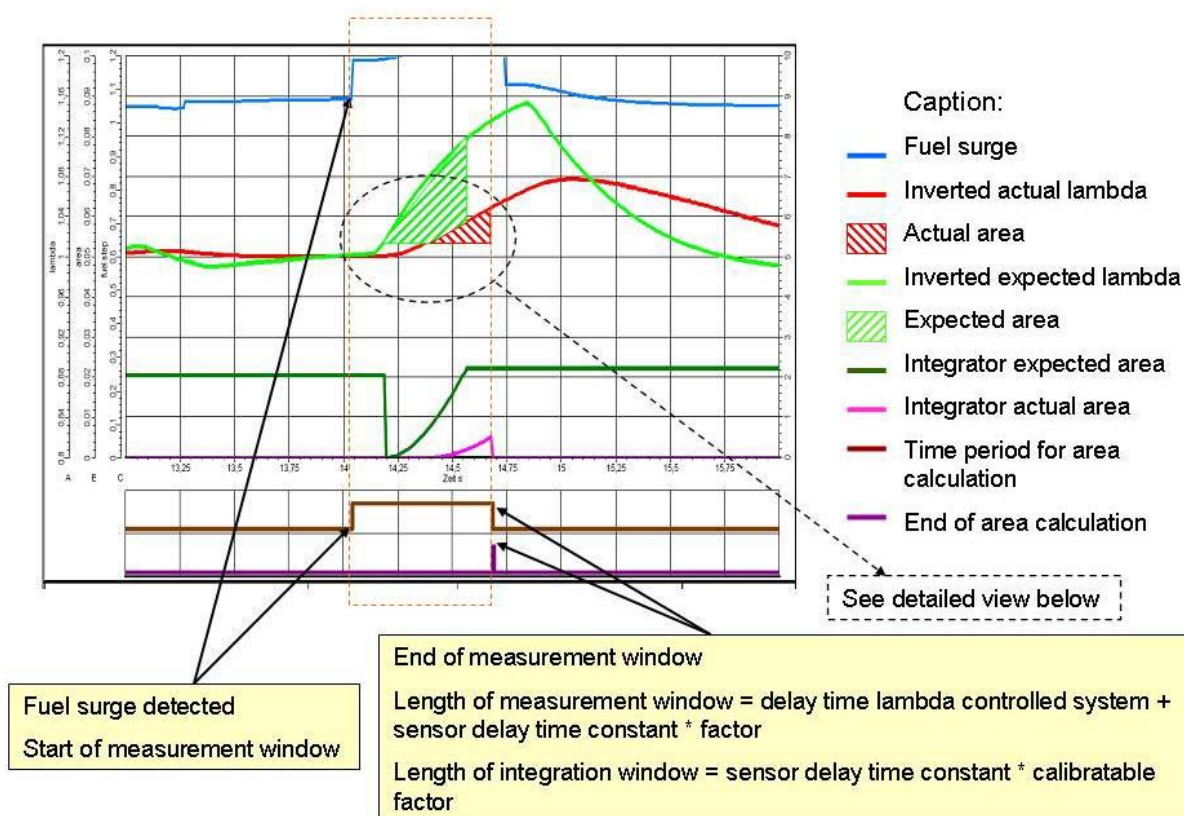


Figure 39: Principle of the response rate integral calculation

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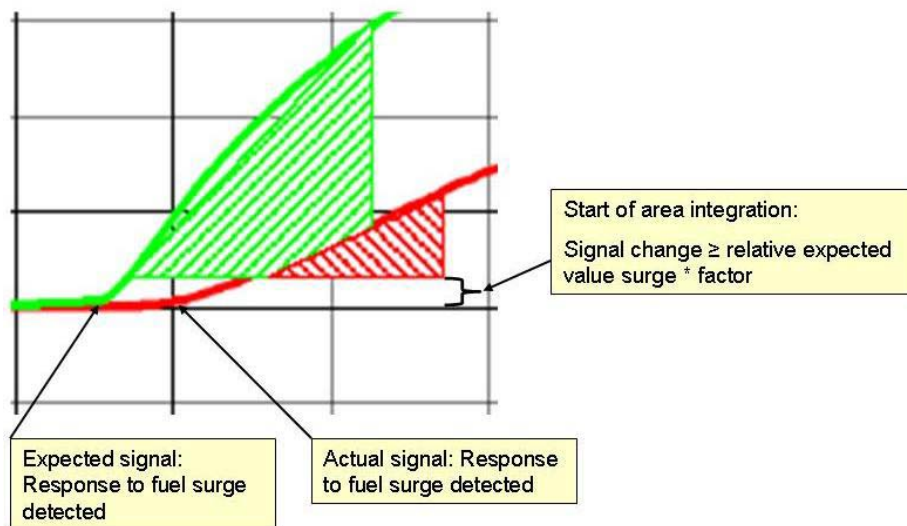


Figure 40: Detailed view

The figure shows a fault case where the length of the integration window of the setpoint signal is calculated according to the formula above. The length of the integration window of the actual signal, however, is defined by the end of the common measurement window for both areas as seen in Figure 39: Principle of the response rate integral calculation(brown line).

The Active Modification of the Setpoint Lambda Value and its Marginal Conditions

When the enable conditions are fulfilled, the monitoring function requests a modification of the setpoint lambda value. First, a negative $\Delta\lambda$ value is requested (enrichment). When the areas and the gradients are calculated, a positive $\Delta\lambda$ value is requested (enleanment). The lambda value is conditioned prior to each surge of the setpoint lambda value. Prior to a L2R surge, a lambda value of approximately 1 is applied. Prior to a R2L surge, a rich pre-conditioning is carried out, i. e. the mixture is set to slightly rich ($\lambda = 0.98$ to 0.99). This reduces the NOx exhaust emissions caused by the R2L modification.

Important Marginal Conditions for a Surge of the Setpoint Value

A slow oxygen sensor may cause the lambda controller to oscillate. When this occurs, the L2R modification is done when the slope moves towards "rich", anyway. When an R2L modification is done, the slope of the control action also has to move in the same direction, i. e. towards "lean" (synchronization).

Explanation

Due to the enleanment caused by the control action, the requested enrichment may not achieve the injection of the desired fuel quantity, when the modification of the setpoint lambda value is not synchronized with the control action. As a result, the necessary modification to measure the dynamic response of the sensor cannot be achieved. In case a slow oxygen sensor causes the lambda controller to oscillate, the falling slope of the control action line shows that the delayed sensor signal is responding to a preceding enrichment, i. e. the signal is moving towards "rich". The sensor signal is moving in the right direction, but not as a result of the previously initiated surge. Therefore a dynamic measurement may lead to a false result (e. g. an unjustified pass result).

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Further Marginal Conditions for a Surge of the Setpoint Value

- The forced modulation of the continuous lambda control and the second control loop are disabled.
- The current control difference does not exceed a threshold value.
- The intensity of control action has increased several times in succession
or
The intensity of control action has not exceeded a threshold value for longer than a time threshold.
- The total effect of the setpoint lambda value modification and/plus the operational control action must not exceed the maximum permissible enrichment or enleanment for the corresponding control action
- When the L2R modification starts, the difference between the current lambda value and the minimum permissible lambda value must be $1.5 \times \Delta\lambda$ of the setpoint value surge L2R. When the R2L modification starts, the difference between the current lambda value and the maximum permissible lambda value must be $1.5 \times \Delta\lambda$ of the setpoint value surge R2L.

Calculating the Setpoint Value and the Actual Value of the Inverted Lambda Signal

The area integrals and the maximum gradients are calculated by inverting the setpoint and the actual values of the sensor signal. A low pass filter, which uses a calibratable time constant, is applied to the inverted measured oxygen sensor signal. The filter protects against high-frequency disturbances, which might distort the area integral triggering and the gradient calculation triggering. The setpoint value signal is initially delayed by an exhaust gas delay time element. Subsequently, a low pass filter, which uses the sensor delay time constant, is applied to the setpoint signal. As with the actual signal, a low pass filter, which uses a filter constant, is applied to the setpoint signal again, in order to guarantee its comparability with the actual signal.

Calculating the Area Integrals and the Area Ratio (Dynamic Raw Values)

This describes the calculation of the R2L surge. The L2R surge is calculated in the same manner. For a single measurement, the extent of the surge has to be large enough to measure and thereby to initiate the integration of the setpoint and the actual area.

Detecting a Fuel Surge

To initiate the calculation of the area integrals and the gradients, a relative fuel surge has to be detected. This fuel surge is detected when the difference between the current value and the previous fuel factor value exceeds a calibratable threshold value. Once a fuel surge is detected, both the setpoint and the actual value must respond within a certain time frame.

The time frame for the area integration is calculated when the fuel surge starts. This time frame is calculated from the exhaust gas delay time (gas travel time to the location of the oxygen sensor). The delay time is multiplied with a factor that depends on the sensor delay time constant, which depends on the operating point (engine speed and load / exhaust gas mass flow). The time constant corresponds to the signal increase of an error-free sensor.

The oxygen sensor signal can be expected to react shortly after the end of the exhaust gas delay time. Integration is subsequently started and it continues for the duration of the time constant. This process occurs in both the setpoint and the actual signal. When the actual signal does not respond at the expected time, the integration cannot be executed throughout the entire time frame of the time constant. The area and consequently the dynamic value, decrease.

Due to tolerances in the exhaust gas delay time parameters of the lambda control, the measurement window does not start after the end of the total delay time, but when 80 percent of the current delay time has passed. Tolerances in the sensor delay time constant have to be compensated for by varying the length of the measurement window, using the multiplication factor.

Area Integration of the Expected Inverted Oxygen Sensor Signal (Setpoint Value)

The area integration of the expected inverted signal is initiated when the first response to a fuel surge is detected. For this purpose, the maximum and the minimum values (depending on the direction of the flank change) of the inverted setpoint lambda signal are continuously calculated. These calculations are made after a fuel surge is detected from the lambda controller's response, as described above. An initial response is detected

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when the signal has changed from the expected signal excursion by a certain factor (typically 0.05 to 0.2). When this condition is satisfied, the area integration and a time counter, which determines the integration period, start. The integration period is calculated from the product of the current time constant and a constant, calibratable factor. When the time counter value is greater than or equal to this integration time, the area calculation is stopped.

Calculating the Maximum Gradient of the Expected Inverted Oxygen Sensor Signal (setpoint value)

The gradient of the expected inverted signal is calculated only after a response to the fuel surge can be detected. For this purpose, the maximum and the minimum values (depending on the direction of the flank change) of the inverted setpoint lambda signal are continuously calculated. These calculations are made after a fuel surge is detected from the lambda controller's response, as described above. An initial response is detected when the signal has changed from the expected signal excursion by a certain factor (typically 0.05 to 0.2). Once this condition is fulfilled, the calculation of the gradient is started, beginning with continuously calculating the difference between the current value and the previous value in 10 ms calculation steps, and calculating the maximum value from the individual gradients of the calculation steps.

Area Integration of the Measured Inverted Oxygen Sensor Signal (Actual Value)

The inverted actual lambda signal is calculated mostly analogously to the integration of the setpoint area. In this case also, the maximum or the minimum value of the inverted setpoint lambda signal is continuously calculated when a fuel surge is detected. Then, the time frame for the integration and the time counter are started when the signal has changed by a calibratable factor, compared to the expected signal excursion. The time frame for the integration is also stopped when the time counter reaches a value calculated from the product of the current time constant and the same calibratable factor, as it is used for calculating the setpoint area.

If there is an excessive delay in the oxygen sensor's response, no response to the fuel surge will be detected in the actual signal. As a result, no area integration can be done, and the area value for the actual signal is set to zero. Thus, the current area ratio also equals zero.

Calculating the Maximum Gradient of the Measured Inverted Oxygen Sensor Signal (actual value)

The maximum gradient of the measured inverted lambda signal is calculated in the same way as the maximum gradient of the setpoint value.

Generating the Diagnostic Values for each Direction

The diagnostic values are calculated for both the falling and the rising flank, respectively. The calculation incorporates the quotient of the actual value integral area (numerator) and the setpoint value integral area (denominator), as well as the quotient of the maximum gradient of the actual value (numerator) and the maximum gradient of the setpoint value (denominator).

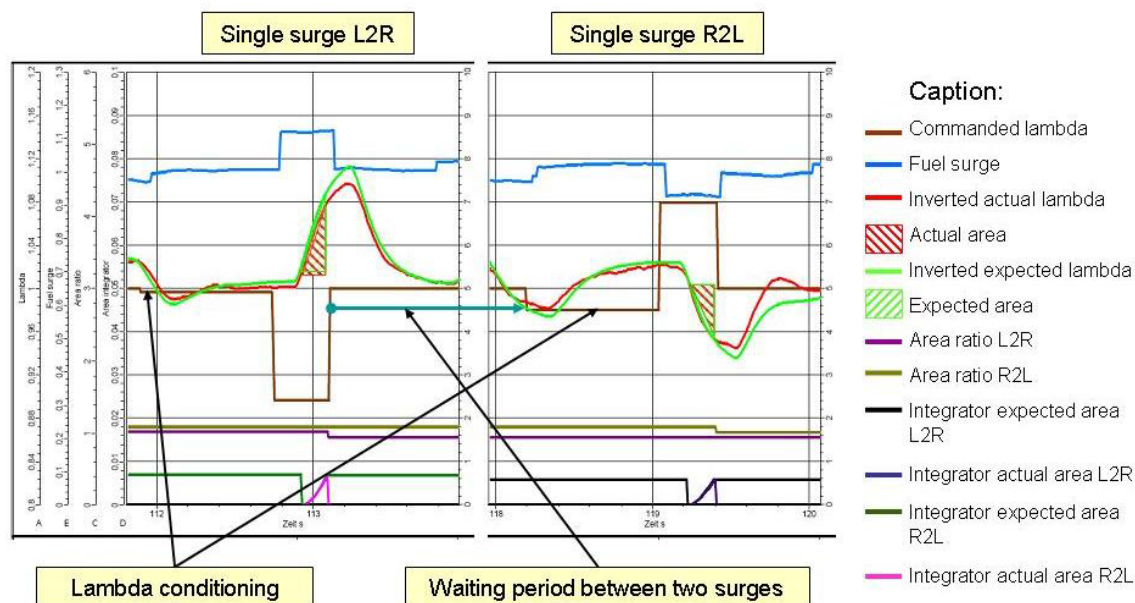
Subsequently, the individual area ratios for each direction can be corrected using a factor from a characteristic curve which is a function of the engine temperature (typical factor: 50 °C = 1.5; 90 °C = 1.0).

Explanation: When the engine has not yet completely warmed up, the applied fuel mixture surge reaches the location of the sensor only partially as a result of the fuel being adsorbed to the intake manifold and/or the combustion chamber (surface film). These effects are not considered when modeling the system to be controlled, which is used for generating the target signal. Hence, they have to be taken into account in the diagnostic procedure in order to avoid diagnostic errors with faultless sensors.

From these values, which are calculated as described above, filtered values are generated. The filtered values are the diagnostic values that are used to make fault decisions.

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Measurement with faultless oxygen sensor



Measurement with 250 ms symmetrical delayed response (lag time)

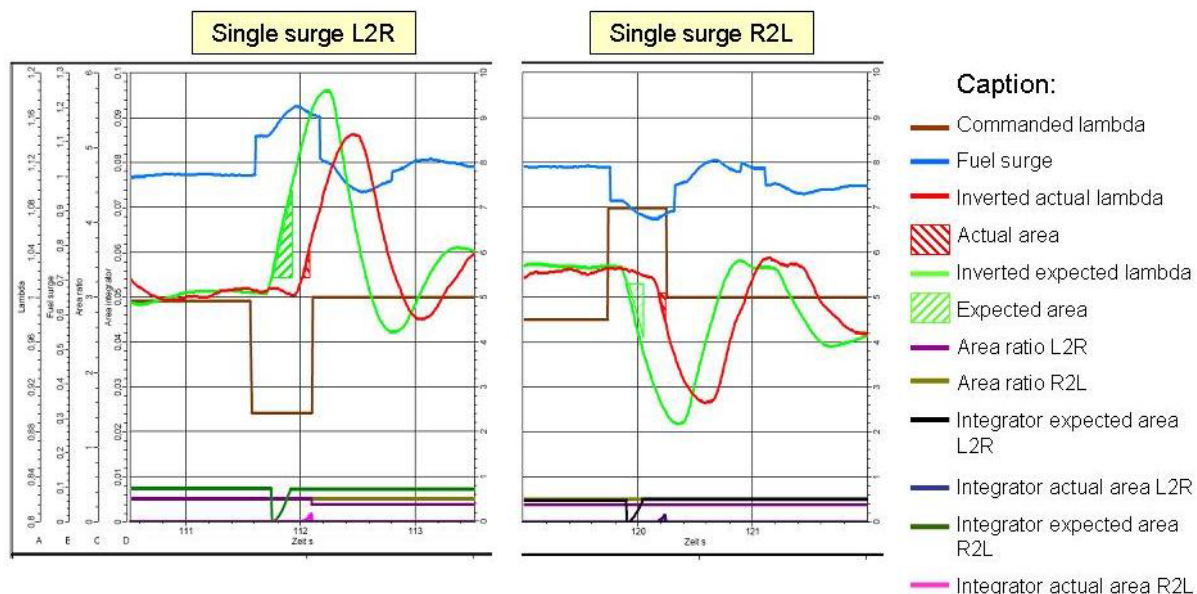


Figure 41: Primary, heated oxygen sensor - Examples for determining the area in an error-free system and in a system with a 250 ms delay

The areas in the examples are determined by successive single R2L and L2R surges.

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Calculating the Filtered Dynamic Values

From the values that are calculated for the falling and the rising flanks filtered values are generated. These filtered values are the diagnostic values which are used to make fault decisions.

The event filter constant for the first measurement is 1, which means that the filter is actually initialized with the first measurement value. With each further single result, this filter value decreases by the reciprocal value of the number of measurements. Thus, in each step an average is generated for the individual results that are present up to this point. The reason for this approach is the expectation that the oxygen sensor dynamic does not change substantially between two individual measurement steps (assuming continuous ageing) and therefore all results should be weighted equally.

Potential Results

As a diagnostic value for each direction is calculated for both the area ratio and the gradient ratio, within certain limits it is possible to calibrate different fault thresholds for the different fault types, according to their impact on emissions.

Case 1: Pass Result

In order not to have to carry out unnecessary monitoring cycles with active lambda modification in the case of a good sensor dynamic and thus, to provide monitoring time for other monitors more quickly, the number of measuring samples to attain does not have to be as high as in the fault case.

After each individual measuring sample, verification is made to determine whether it is still possible for the dynamic value to drop below the highest fault threshold with further measurements being taken. If this is no longer possible, the monitor is ended with a pass result.

The sensor is dynamically OK,

if the value of the R2L area ratio multiplied by the quotient of the current counter value for the R2L area ratio and the number of measurements necessary for a fault result (Z1) is greater than the threshold value for the asymmetrical delay fault

and

if the value of the L2R area ratio multiplied by the quotient of the current counter value for the L2R area ratio and the number of measurements necessary for a fault result (Z1) is greater than the threshold value for the asymmetrical delay fault.

and

if the value of the R2L gradient ratio multiplied by the quotient of the current counter value for the R2L gradient ratio and the number of measurements necessary for a fault result (Z1) is greater than the threshold value for the gradient ratio

and

if the value of the L2R gradient ratio multiplied by the quotient of the current counter value for the L2R gradient ratio and the number of measurements necessary for a fault result (Z1) is greater than the threshold value for the gradient ratio.

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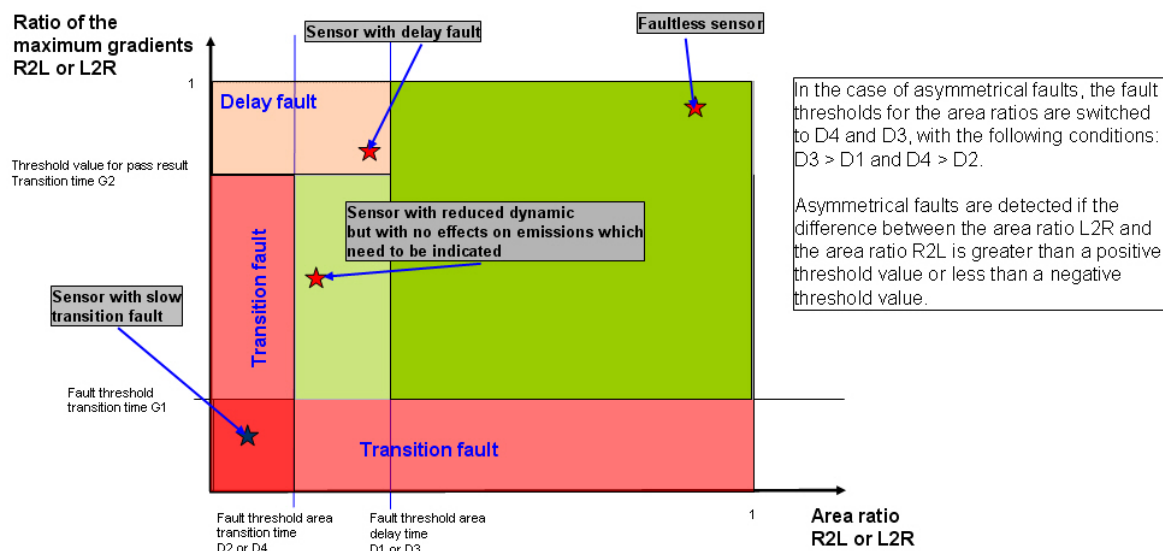


Figure 42: Overview Fault threshold values

Case 2: Fail result due to a symmetrical delay fault

If the difference between the dynamic values of the area ratios for the R2L flank and the L2R flank is greater than a minimum threshold value or less than a maximum threshold value, a symmetrical fault is detected.

- If the higher one of the two counters (for the R2L flank and the L2R flank) exceeds a threshold value Z1 (typically 4 to 6)

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) exceeds an upper threshold value G2

and

- the corresponding area ratio (for the R2L flank or the L2R flank) falls below the fault threshold value for the symmetrical delay fault D1,

the sensor is dynamically defective, the monitor is ended and a dynamic fault is stored.

Case 3: Fail result due to a symmetrical slow transition fault

If the difference between the dynamic values of the area ratios for the R2L flank and the L2R flank is greater than a minimum threshold value or less than a maximum threshold value, a symmetrical fault is detected.

- If the higher one of the two counters (for the R2L flank and the L2R flank) exceeds a threshold value Z1 (typically 4 to 6)

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) exceeds a lower threshold value G1

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) falls below a second, higher threshold value G2,

and

- the corresponding area ratio (for the R2L flank or the L2R flank) falls below the fault threshold value for the symmetrical transition fault D2,

or

- the corresponding dynamic value for the gradient ratio (for the R2L flank or the L2R flank) falls below the threshold value G1,

the sensor is dynamically defective, the monitor is ended and a dynamic fault is stored.

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Case 4: Fail result due to an asymmetrical delay fault

If the difference between the dynamic values for the R2L flank and the L2R flank is less than a minimum threshold value or greater than a maximum threshold value, an asymmetrical fault is detected.

- If the higher one of the two counters (for the R2L flank and the L2R flank) exceeds a threshold value Z1 (typically 4 to 6)

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) exceeds an upper threshold value G2

and

- the corresponding area ratio (for the R2L flank or the L2R flank) falls below the fault threshold value for the asymmetrical delay fault D3,

the sensor is dynamically defective, the monitor is ended and a dynamic fault is stored.

Case 5: Fail result due to an asymmetrical slow transition fault

If the difference between the dynamic values for the R2L flank and the L2R flank is less than a minimum threshold value or greater than a maximum threshold value, an asymmetrical fault is detected.

- If the higher one of the two counters (for the R2L flank and the L2R flank) exceeds a threshold value Z1 (typically 4 to 6)

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) exceeds a lower threshold value G1

and

- the corresponding gradient ratio (for the R2L flank or the L2R flank) falls below a second, higher threshold value G2

and

- the corresponding area ratio (for the R2L flank and the L2R flank) falls below the threshold value for the asymmetrical transition fault D4

or

- the corresponding dynamic value for the gradient ratio falls below the threshold value G1,

the sensor is dynamically defective, the monitor is ended and a dynamic fault is stored.

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7.1.1.4 Flowchart

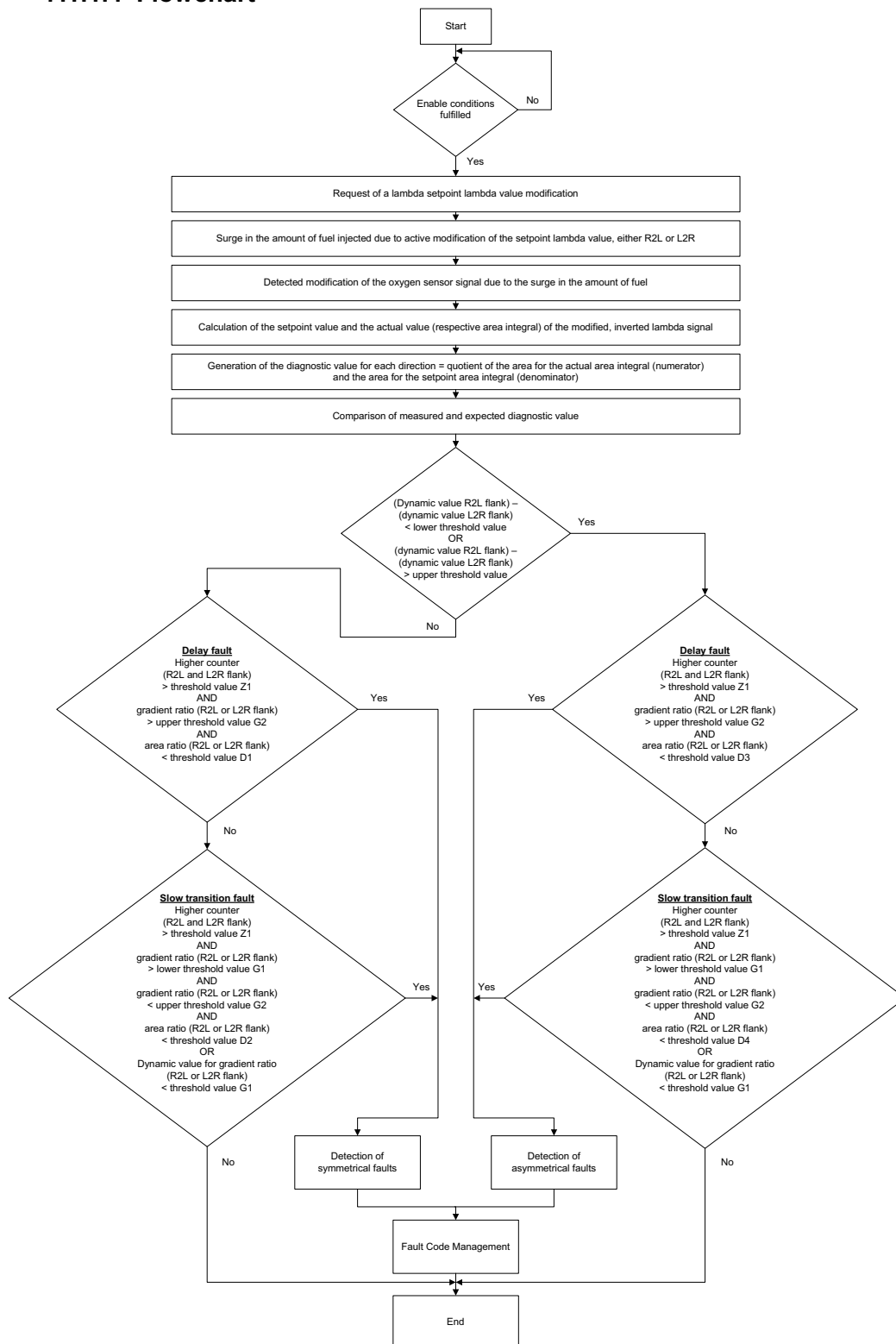


Figure 43: Flowchart Oxygen sensor, signal too slow, P0133, P0153, P3209, P3239

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7.1.1.5 In-Use Monitor Performance Ratio

The incrementing of the numerator and the denominator, and the ratio calculation for the response rate monitor of the primary heated oxygen sensor are executed by the IUMPR kernel function. In accordance with all monitors requiring a standardized track and report of the in-use performance, the rate response monitor of the oxygen sensor reports to the IUMPR kernel function via status flags – see the description of the IUMPR kernel function.

Incrementing the numerator

Measurements with a properly working oxygen sensor can usually be taken quickly and without any disturbances. A slow oxygen sensor increases the measuring time only insignificantly. The measurements, however, are interrupted more frequently. Therefore, the time required for fault detection and hence for incrementing the numerator has to be simulated by a shadow counter.

A time counter is started, whenever the enable conditions and the conditions for the signal evaluation/validation are fulfilled, and when the waiting period between two fuel surges has elapsed. This time counter is repeatedly increased each 100 ms, until a calibratable threshold value is exceeded. This fault-case measuring time must be adapted to the worst case fault. When this time period for one event has elapsed, an event counter is incremented. When the event counter exceeds a threshold value in an error-free system, the condition "numerator complete" is set.

The numerator for the sensor dynamic diagnostic is also incremented, when an actual fault is detected.

Incrementing the denominator

The denominator is incremented, when the standardized conditions during a current driving cycle, in accordance with CCR (d) (4.3.2.) (E) (ii), are fulfilled, and when the monitoring function is not affected or inhibited by already stored faults or faults of sensors that are necessary to determine the denominator.

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Flowchart

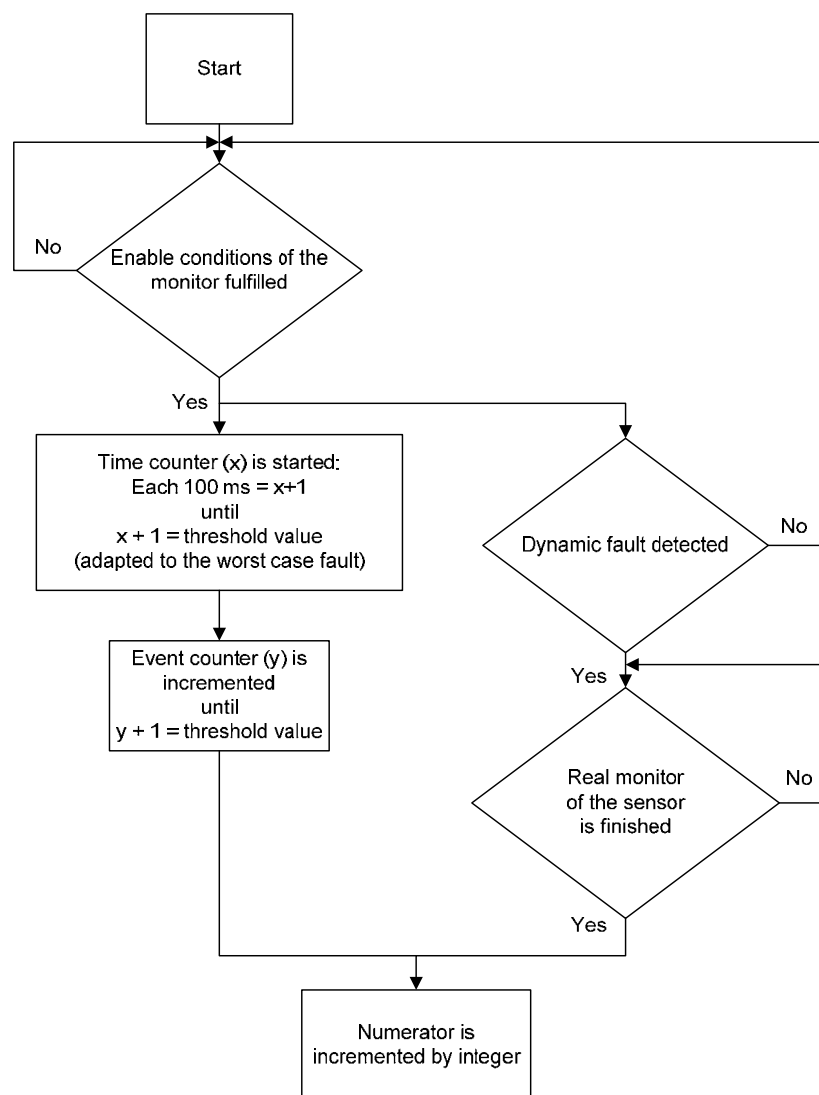


Figure 44: Flowchart IUMPR numerator Oxygen sensor, signal too slow

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7.2 FO2 Sensor circuit continuity check

7.2.1 Diagnosis of electrical faults at the FO2 Sensor

Lambda control can be disabled only when at least a pending fault code (service \$07) has been entered in the fault code memory. Several operating conditions exist, under which faulty components can be pinpointed only after a time delay. Lambda control must however be disabled when fault symptoms are detected.

This diagnostic function detects and sets a general electrical fault. The actual fault which is accompanied by a second entry into the fault code memory is then pinpointed afterwards by the appropriate diagnostic function. This second fault entry could either be a sensor line error or a heater fault of the upstream O2 sensor. In order to ensure timely MIL illumination (two-in-a-row principle) the general electrical fault is also set when a sensor line error or a heater fault of the upstream O2 sensor is set.

A general electrical fault of the upstream heated oxygen sensor will be set either

- when the internal resistance of the O2 sensor's Nernst cell is implausibly high or the ceramic temperature of the FO2 sensor is implausibly low. All of the following monitoring conditions must be fulfilled in both cases:
 - the exhaust gas temperature model is valid
 - the modeled exhaust gas temperature at the upstream O2 sensor's location lies above a calibrated minimum
 - the FO2 sensor's heater is enabled/switched on and throttle fuel cut-off condition doesn't exist
 - the FO2 sensor's heater diagnostic has not been inhibited (battery voltage supply)
 - no errors from the FO2 sensor's heater power stage
 - no faults of the FO2 sensor's evaluation IC
 - no short circuits of the FO2 sensor
- or when the FO2 sensor's IC Nernst voltage line diagnostic is performed via its IC diagnostic and an interruption of this line is detected.
- or when the FO2 sensor's virtual ground line diagnostic has been performed via its IC diagnostic and an interruption of this line is detected
- or when the FO2 sensor's heater circuit diagnostic is performed and a heater fault is detected.

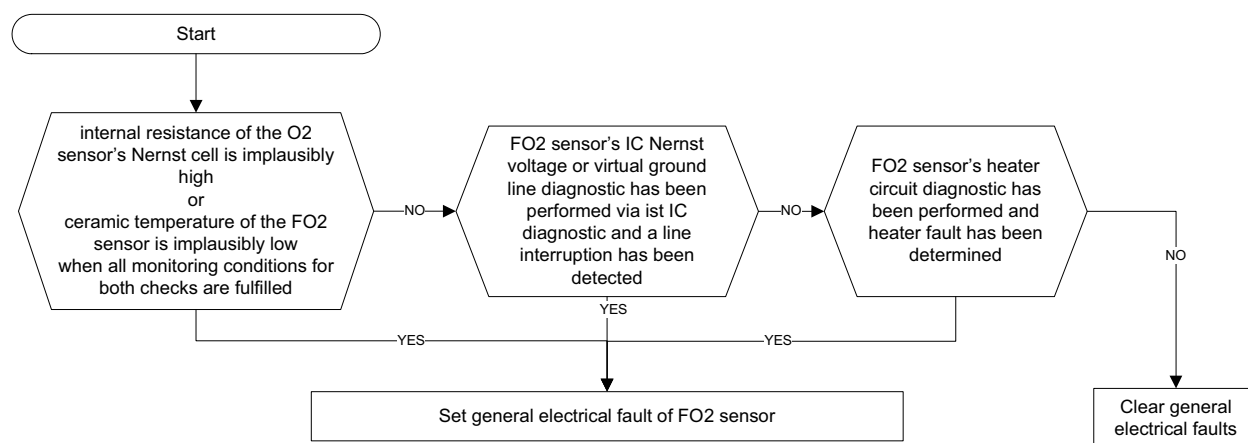


Figure 45: Flow chart diagnosis of electrical faults at the FO2S

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7.2.2 Diagnosis of evaluation IC of the FO2 Sensor

This chapter describes the sum of all possible evaluation IC checks of the FO2 sensor. The hardware of the Oxygen sensor consists of an IC (CJ 125) with the capability of self-diagnostics. The diagnosis of the evaluation IC of the heated upstream oxygen sensor (HO2S) detects electrical faults of the UN (Nernst voltage), VM (virtual ground), IA (compensation) and IP (pump) signal lines. The picture below shows the signal lines between the IC (CJ125) and the HO2 sensor. These electrical faults could result from short circuits to battery, or ground and signal interruptions. Short circuits are detected by a self-diagnosis of the CJ125. Line interruptions are identified by observing the system. The diagnosis monitors communication between the CJ125 IC and the electronic control unit and also performs a rationality check of the supply voltage as well as the adaptation values of the IC's electrical compensations. The CJ125 communicates with the ECU via a serial port interface (SPI). The evaluation IC's diagnosis runs continuously.

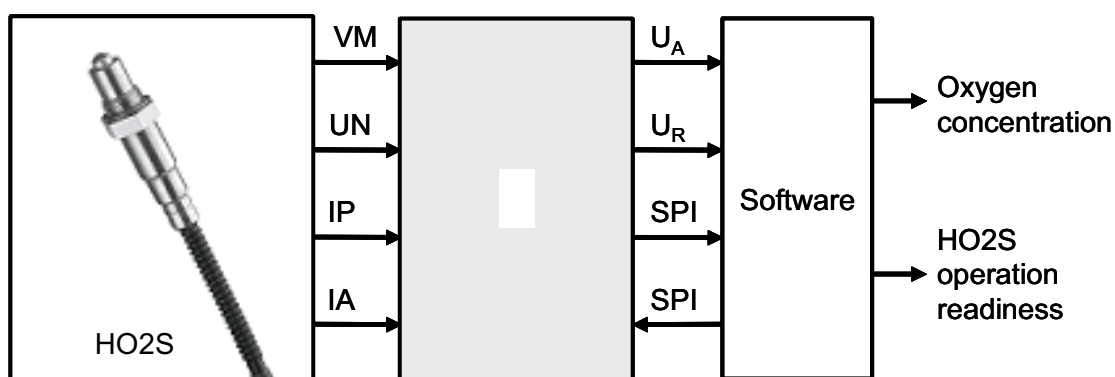


Figure 46: Overview signal lines of heated O2 Sensor

General Monitoring conditions

- engine start has finished
- battery voltage is within diagnostic range
- engine speed has exceeded the calibrated minimum threshold

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1. Open circuit - VM line interruption (LSUVM)

Monitoring conditions - VM line interruption

- all general monitoring conditions are fulfilled
- offset corrected voltage of the FO2 sensor respectively lies above and below the lower and upper plausible output voltage U_a of the CJ125 IC required for detecting a VM line interruption
- internal resistance of the galvanic (or Nernst) cell of the HO2S lies above a calibrated threshold after a calibrated period of time
- the exhaust gas temperature at the FO2 sensor's vicinity lies below the calibrated permissible maximum for detecting a VM line interruption
- the FO2 sensor's heater power stage toggles on and off
- the FO2 sensor's pump voltage has not been switched-off
- heater control active for a calibrated period of time
- no FO2 sensor power stage error
- the following conditions have to be fulfilled altogether for a calibrated period of time
 - heater enabled
 - engine is running
 - heater control is switched-on
 - no fuel cut-off lasting longer than a calibrated period of time
 - battery voltage exceeds calibration

1.1 VM line interruption due to heater coupling check (LSU 4.2)

This check is performed for the HO2S type LSU 4.2.

The pump- or limit-current of the Nernst cell no longer flows when there is a VM line interruption. This results in an extremely high resistance, which remains even when the O2 sensor is sufficiently hot. The O2 sensor's ceramic temperature doesn't rise although the system reacts by increasing the heating power. A further effect is the coupling of the duty cycle signal of the heater into the O2 signal. Heater couplings resulting from switching are counted. The counter is incremented each time the voltage signal rises or falls with an artificial gradient which doesn't represent exhaust gas flow. A signal fault is set when the counter exceeds the calibrated threshold.

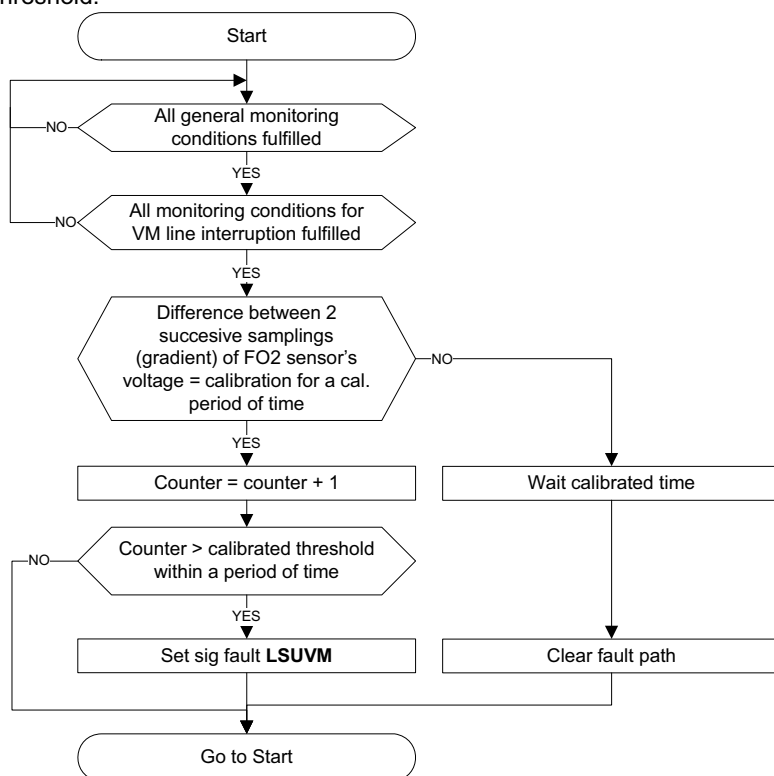


Figure 47: Flow chart VM line interruption (heater coupling check)

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1.2 VM line interruption due to internal resistance of Nernst cell check (LSU 4.9)

This check is performed for the HO2S type LSU 4.9.

The pump- or limit-current of the Nernst cell no longer flows when there is a VM line interruption. This results in an extremely high resistance which remains even when the O2 sensor is sufficiently hot. The O2 sensor's ceramic temperature doesn't rise although the system reacts by increasing the heating power. A malfunction is detected and a signal fault is set when the internal resistance of the galvanic (or Nernst) cell exceeds a calibrated threshold after a calibrated period of time.

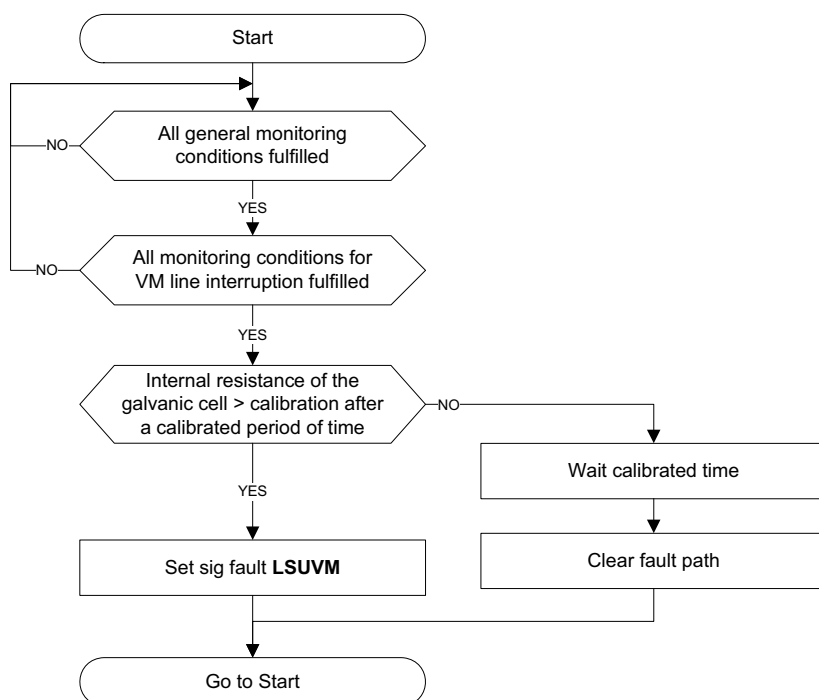


Figure 48: Flow chart VM line interruption (internal resistance of Nernst cell check)

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2. Open Circuit - UN line interruption LSUUN

A UN line interruption leads to an irrationally high UR signal as well as an undefined output voltage UA - see fig.1. A signal fault LSUUN is set when the offset corrected voltage of the upstream HO2S lies above the upper (or below the lower) plausible output voltage UA of the CJ125 IC required for detecting a UM line interruption.

Monitoring conditions - UN line interruption

- all general monitoring conditions are fulfilled
- no power stage error of the FO2 sensor's heater
- FO2 sensor's pump voltage has not been switched-off
- internal resistance of the FO2 sensor's Nernst cell exceeds calibrated threshold (after enough time has been allowed for all transient events, induced during the determination of the FO2 sensor's internal resistance, to settle down)
- heater control active for a calibrated period of time

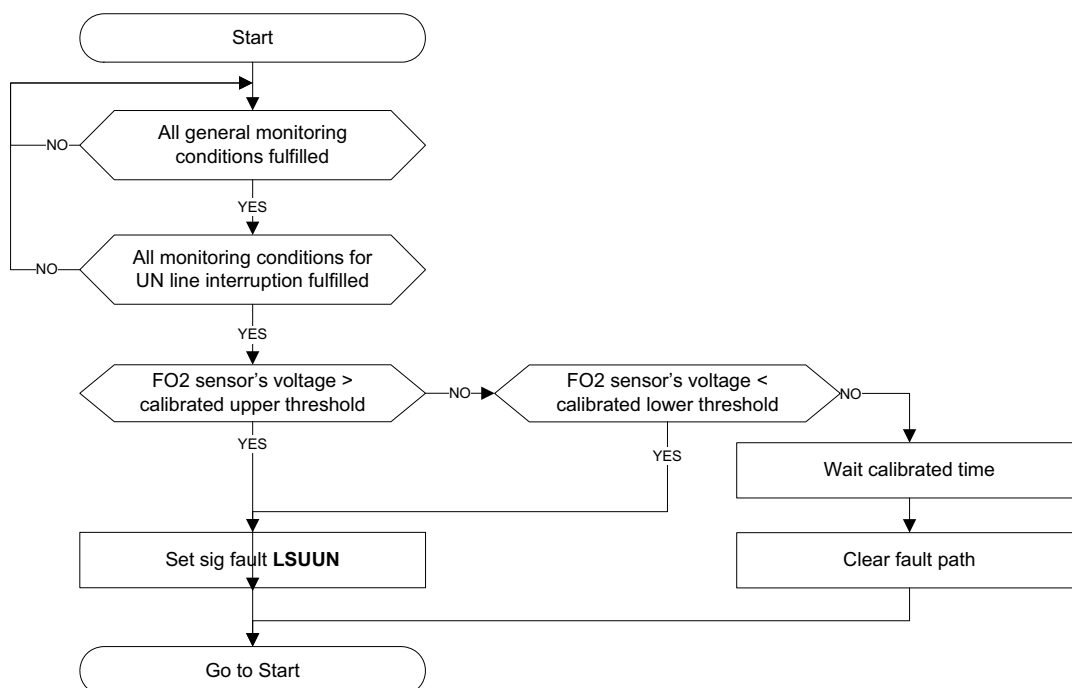


Figure 49: Flow chart UN line interruption

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3. Open Circuit - IA line interruption LSU1A

An IA line interruption leads to a non-plausible large oxygen sensor voltage signal in a fuel cut off condition. A signal fault LSU1A is set after a calibrated delay time, if the oxygen sensor's voltage is greater than or equal to a calibrated threshold. The fault is set after an additional calibrated time if the fuel tank is empty or in an unknown state.

Monitoring conditions - IA line interruption

- all general monitoring conditions are fulfilled
- fuel cut off condition exists
- modeled exhaust gas temperature at the upstream side of the main catalyst is less than a calibrated value
- FO2 sensor's pump voltage has not been switched-off
- oxygen sensor has reached its operating temperature

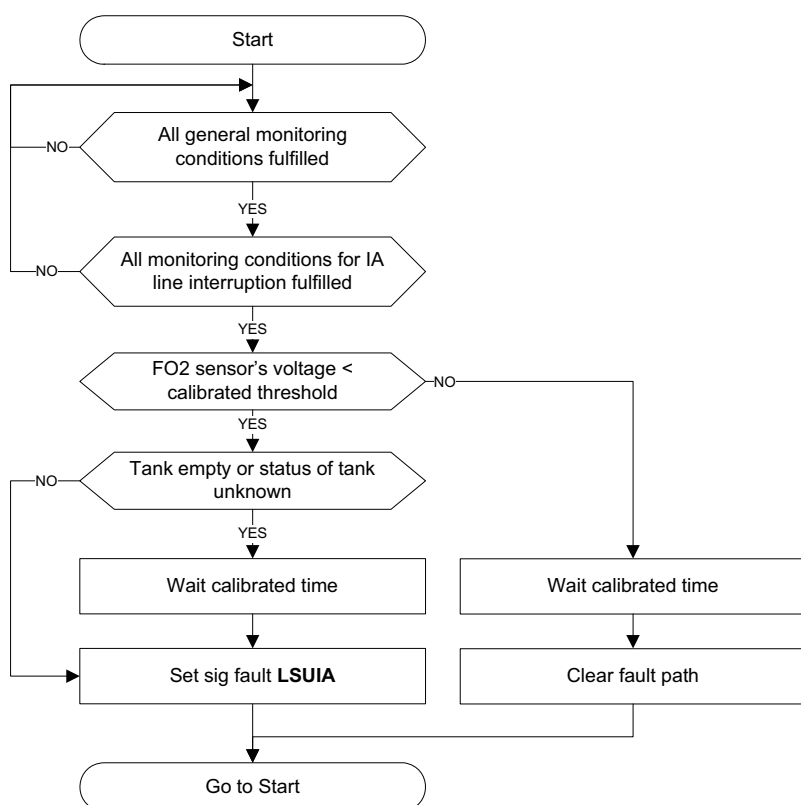


Figure 50: Flow chart IA line interruption

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4. Open Circuit - IP line interruption LSUIP

The pump current of the FO2 sensor, which flows through the IP line, is equivalent to the oxygen concentration in the exhaust gas. An IP line interruption means the pump current will be permanently equal to zero. The output voltage UA of the CJ125 IC will remain constant and corresponds to the normalized A/F ratio of one ($\lambda=1$). UA no longer varies with the oxygen concentration in the exhaust gas. An IP line interruption is detectable via three methods:

- Detection during fuel cut off condition
- Detection by mixture enrichment or lean-off
- Detection by closed-loop control to a nom. A/F value that differs from one

4.1 Detection during fuel cut off condition

The fuel cut off condition is an operating mode with a nominal A/F ratio > 1 . A plausibility fault is set when during fuel cut-off condition, the value of the oxygen sensor's voltage is less than a calibrated threshold for a calibrated period of time.

Monitoring conditions for detection during fuel cut-off

- all general monitoring conditions are fulfilled
- FO2 sensor has reached its operating temperature
- fuel cut-off condition exists for at least 3 seconds
- FO2 sensor's pump voltage has not been switched-off
- canister purge system diagnosis has been performed and no faults were detected
- all monitoring conditions have been fulfilled for a period of time.

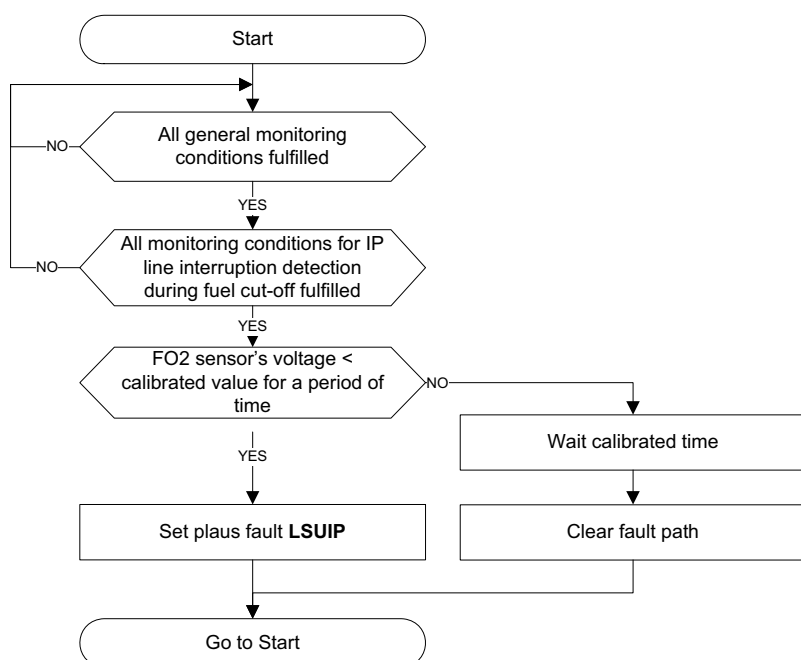


Figure 51: Flow chart IP line interruption (during fuel cut off condition)

4.2 Detection by mixture enrichment or lean-off

A maximum fault is set when the absolute difference between the A/F controller's output value at the moment the FO2 sensor's voltage springs into the calibrated range (i.e within 1.5V) and the A/F controller's output value thereafter, exceeds the calibrated maximum allowable excursion in that calibrated range.

Monitoring conditions for detection via mixture enrichment or lean-off

- all general monitoring conditions are fulfilled
- FO2 sensor has reached its operating temperature
- A/F ratio closed loop control is activated

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- oxygen sensor's voltage is within the calibrated range
- electrical trimming of the FO2 sensor is inactive
- end of start control in the heater control function
- artificial fuel system modulation is active
- the artificial fuel system's modulation amplitude is greater than or equal to a calibrated threshold for a calibrated period of time
- no initialization of A/F ratio closed loop control factor
- no lean-off protection set
- proportional portion of the A/F closed loop control on the downstream side of the catalyst has not been activated
- catalyst heating not activated
- FO2 sensor's pump voltage has not been switched-off

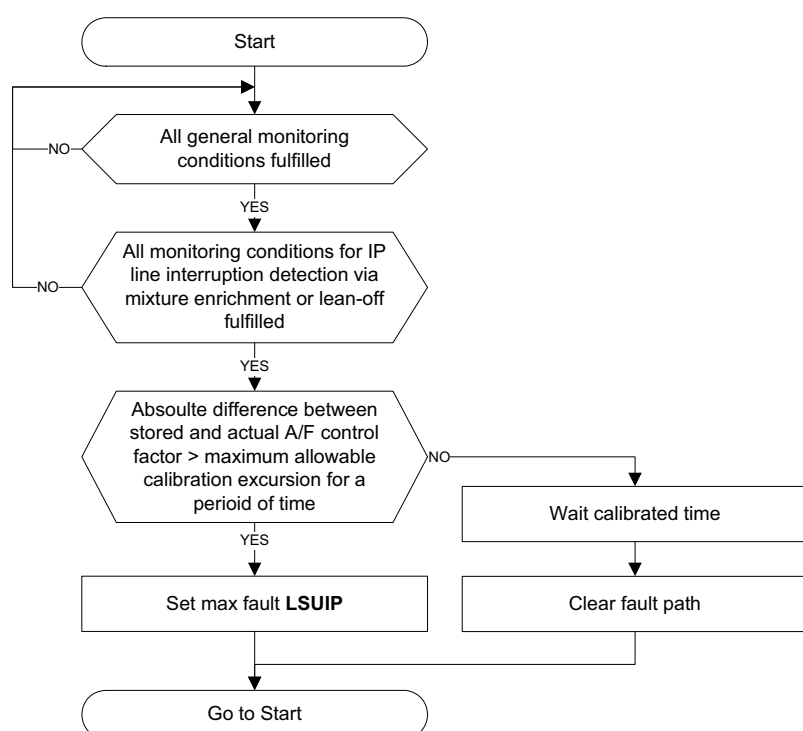


Figure 52: Flow chart IP line interruption (by mixture enrichment or lean-off)

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4.3 Detection by closed-loop control to a nom. A/F value that differs from one

A IP signal fault is set when the normalized nominal A/F ratio (lambda) differs from one (lies beyond a calibrated range) and the oxygen sensor's voltage lies within a calibrated range during the time required for the integrated exhaust gas mass flow to exceed a calibrated threshold.

Monitoring conditions for detection by closed-loop control to a nom. A/F value that differs from one

- all general monitoring conditions are fulfilled
- Lambda (A/F ratio) closed-loop control is activated
- oxygen sensor has reached its operating temperature
- the heater of the FO2 sensor has no faults
- FO2S response rate diagnosis didn't detected a fault
- FO2S pump voltage has not been switched-off
- electrical trimming of the FO2S is inactive

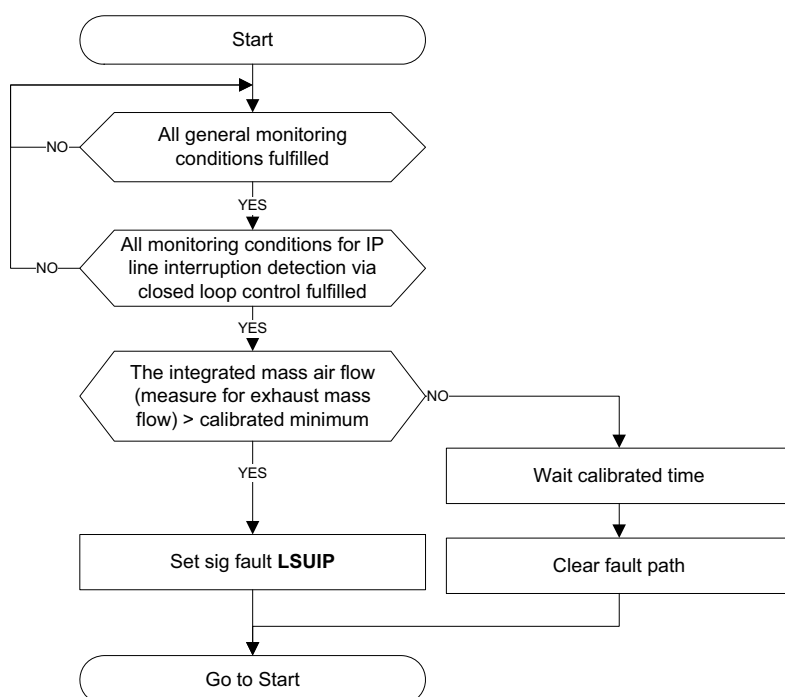


Figure 53: Flow chart IP line interruption (by closed-loop control to a nom. A/F value)

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5 Short circuits to ground or to battery voltage LSUKS

Short circuits are detected by a self diagnosis of the CJ125 IC. An integrated voltage comparator at each and every pin of the HO2 sensor's CJ125 IC, detects and sets a maximum or a minimum fault if the voltage at that pin respectively lies above a calibrated maximum or below a calibrated minimum for a calibrated period of time.

Explicitly, a maximum fault is set either when

- the HO2 sensor's voltage at the VM pin exceeds a calibrated plausible maximum or
- the HO2 sensor's voltage at the UN pin exceeds a calibrated plausible maximum or
- the HO2 sensor's voltage at the IA or IP pin exceeds a calibrated plausible maximum.

Likewise, a minimum fault is set either when

- the HO2 sensor's voltage at the VM pin lies below a calibrated plausible minimum or
- the HO2 sensor's voltage at the UN pin lies below a calibrated plausible minimum or
- the HO2 sensor's voltage at the IA or IP pin lies below a calibrated plausible minimum.

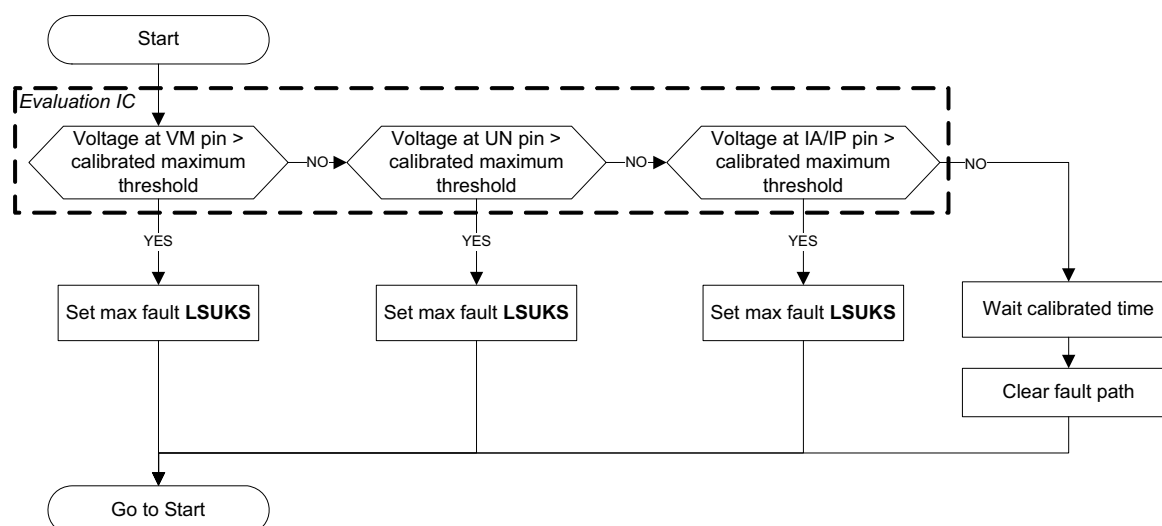


Figure 54: Flow chart Evaluation IC short circuit to battery

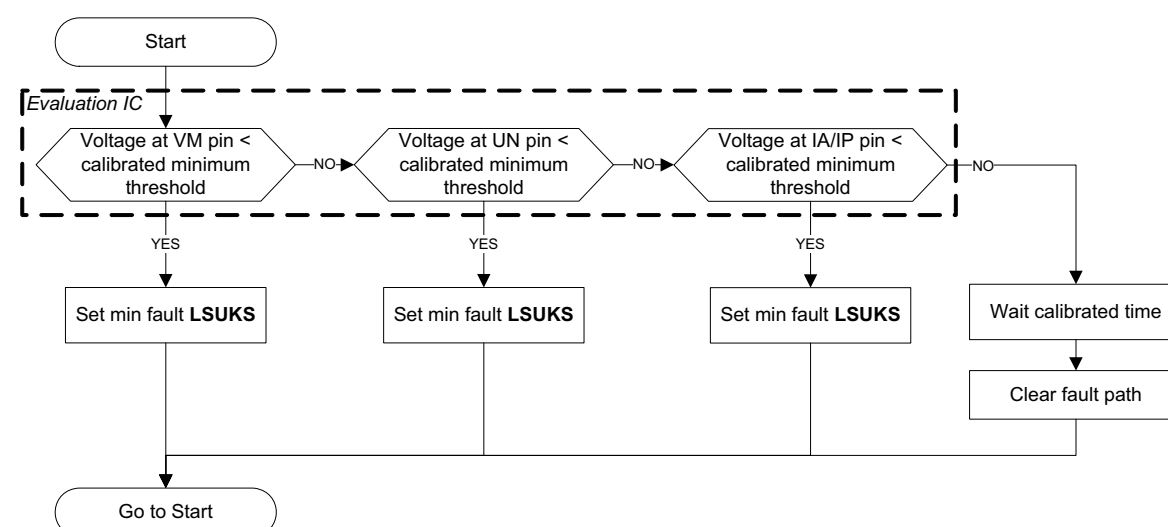


Figure 55: Flow chart Evaluation IC short circuit to ground

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6. Monitoring of communication between the Evaluation-IC CJ125 and the Micro-controller of the ECM ICLSU

6.1 Non-plausible commands counter

The CJ125 evaluation IC communicates with the main processor of the ECM via a serial port interface. They both send data to each other. Interference on the SPI bus leads to non-plausible signals. These non-plausible signals, which persist even when the data is re-transmitted, are tracked by incrementing an internal error counter. A signal fault is set when the counter exceeds a calibrated threshold.

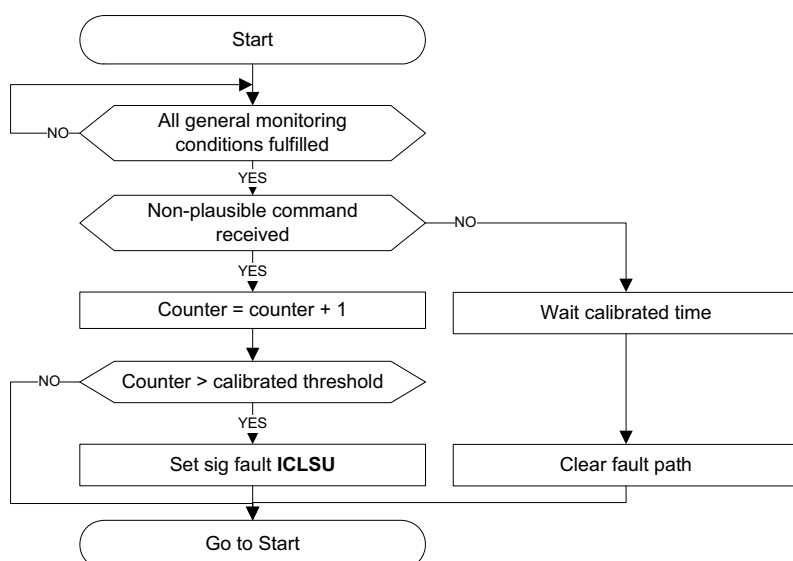


Figure 56: Flow chart communication Evaluation IC (non-plausible commands counter)

6.2 Comparison of initialization and mirror register

A further communication monitor compares the old value of the initialization register, which is backed up in a mirror register, with its current value after a rewrite. A plausibility fault is set after a calibrated period of time, if the current value of the initialization register isn't equal to that of its mirror register.

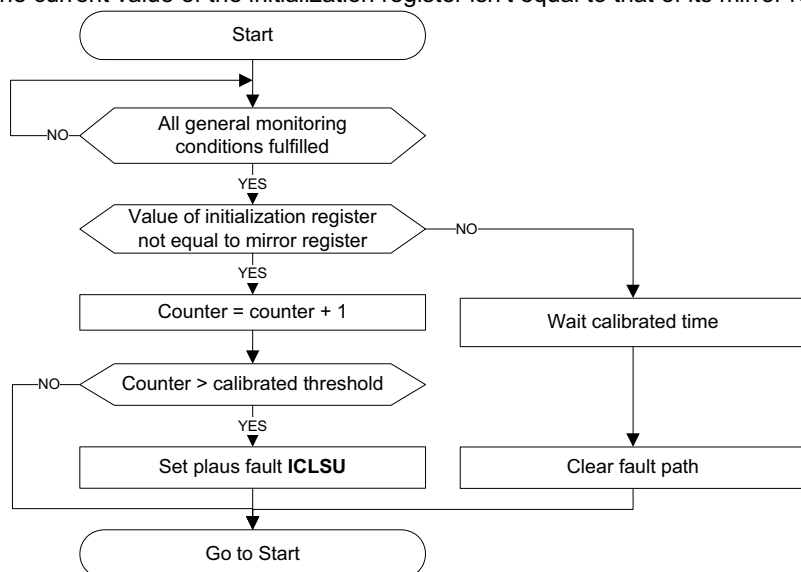


Figure 57: Flow chart communication Evaluation IC (Comparison of the registers)

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7. Low supply voltage of the CJ125 IC ICLSU

The CJ125 IC is specified for supply voltages > 9V. It possesses a supply voltage detection module. Low supply voltages lead to faulty diagnosis at the voltage comparators. A minimum fault is set when the supply voltage drops below 9V. The supply voltage monitor is aborted if the monitoring conditions are not fulfilled.

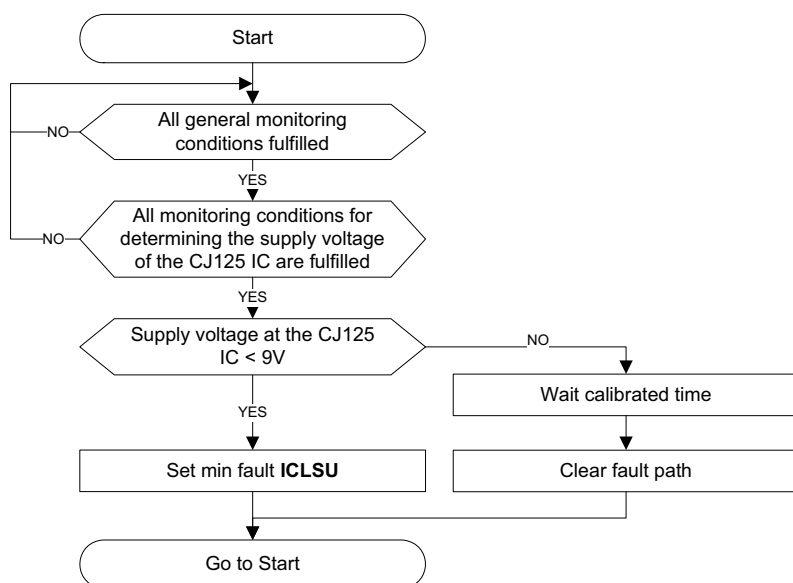


Figure 58: Flow chart Low supply voltage of the CJ125 IC

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8. Electrical trimming ICLSU

Electrical trimming of the oxygen sensor is performed in order to determine and store the difference between the expected and the actual pump-current-proportional output voltage. This difference stems from hardware tolerances. Electrical trimming is carried out once after engine start and once in the idle mode during a calibrated period of time. A maximum fault is set when after electrical trimming the adaptation value for the corresponding curve (normal and rich) exceeds a calibrated maximum.

Monitoring conditions for electrical trimming

- engine start has finished
- engine is in idle mode.

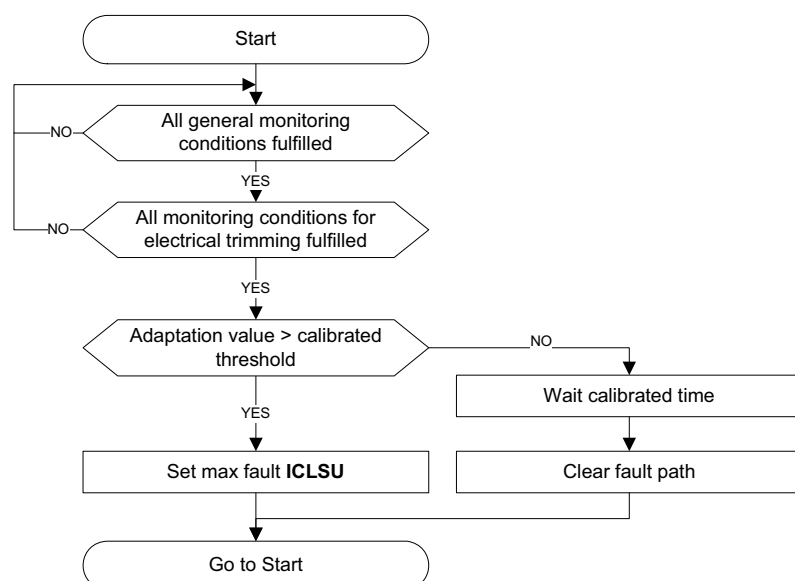


Figure 59: Flow chart electrical trimming of FO2 sensor

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7.3 FO2 Sensor rationality check

This chapter describes the sum of all possible rationality checks of the upstream HO2S.

7.3.1 Offset check

This diagnostic function continuously checks the heated upstream oxygen sensor's (HO2S) response signal by comparing it with that of the downstream oxygen sensor or by utilizing technical parameters of the engine control system. A faulty sensor signal is implied when the characteristic lambda curve derived from the upstream HO2S's response signal (see figure below) indicates an air-fuel mixture that is leaner or richer than that expected from the nominal curve.

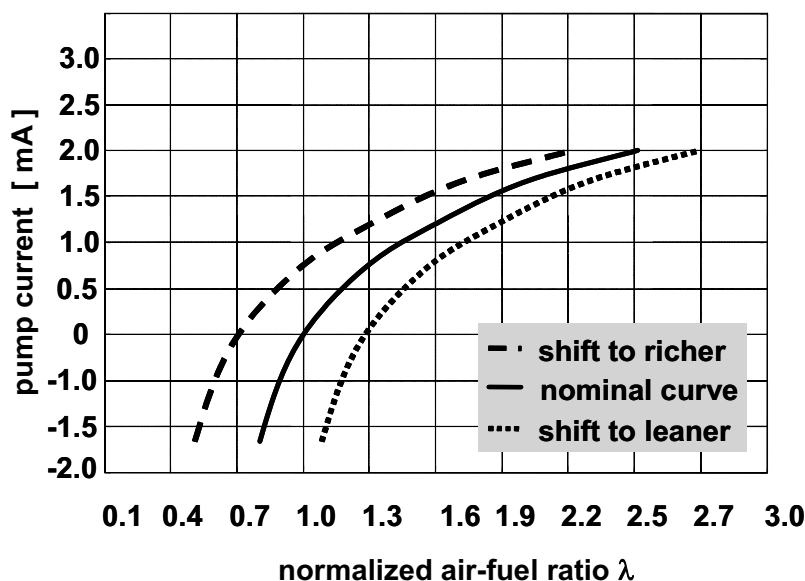


Figure 60: Shift in the characteristic lambda curve of FO2 sensor response signal

The integral component of the downstream lambda controller is interpreted as a sensor/fueltrim system fault. A shift is acceptable (because of tolerances) only when it lies between a calibrated minimum and maximum threshold value.

If the integral component of the downstream lambda controller exceeds the calibrated maximum 'sensor' threshold value for a calibrated debouncing delay, an unacceptable 'shift to lean' is detected and a maximum fault (**PLLSU**) is set.

If the integral component of the downstream lambda controller exceeds the calibrated maximum 'fueltrim' threshold value for a calibrated debouncing delay, an unacceptable 'shift to lean' is detected and a maximum fault (**FTDLA**) is set.

If the integral component of the downstream lambda controller lies below the calibrated minimum 'sensor' threshold value for a calibrated debouncing delay, an unacceptable 'shift to rich' is detected and a minimum fault (**PLLSU**) is set.

If the integral component of the downstream lambda controller lies below the calibrated minimum 'fueltrim' threshold value for a calibrated debouncing delay, an unacceptable 'shift to rich' is detected and a minimum fault (**FTDLA**) is set.

Note:

Normally the rationality check monitors aging effects of the HO2S or other effects in the exhaust system. This aging effects develop very slow. Due to this reason the integral component of the downstream lambda controller will change slow too. Emissions are quite well during this behavior. If the integral component exceeds an irrational threshold a 'fueltrim' fault is set. Such a malfunction can not be found in one FTP test cycle.

To detect suddenly occurring faults a step function is implemented. On basis of the control difference of the rear sensor voltage and the control value of the downstream lambda controller a predicted magnitude of failure is made which results in a strongly reduced diagnosis time. Such 'sensor' malfunctions can be.

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Monitoring conditions for offset check

- engine start has finished
- no critical misfire rate
- lambda control active for calibrated period of time
 - after critical misfire rate **or**
 - in case of second driving cycle to confirm P-code
- diagnoses of downstream HO2S performed without any fault
- diagnosis of upstream HO2S' voltage performed without faults
- diagnosis of 'exchanged upstream HO2S' performed without faults
- no fault of 'heater influence on upstream HO2S' diagnostic
- no fault of 'upstream HO2S' response rate' diagnostic
- no fault of 'CJ125 evaluation IC of the upstream HO2S' diagnostic (i.e. no electrical faults and no communication errors)
- no fault of 'upstream HO2S heater' diagnostic
- no fault of 'upstream HO2S heater power stage' diagnostic
- no lean shift fault in last driving cycle without cooled off sensor
- no fault debouncing active
- downstream HO2S switches from lean to rich or vice versa during debouncing
- enabled by diagnostic scheduler

7.3.2 Plausibility check with help of upstream and downstream O2S signals

The following checks determine, in selected operating points, if the deviation of the upstream HO2S signal is out of certain limits using upstream and downstream oxygen sensor signals and closed loop controller condition as main parameters.

Plausibility check - shift to lean

A shift of the upstream HO2S characteristic lambda curve towards lean will cause a rich A/F ratio at the downstream HO2S. Because of an airtight exhaust system the mixture at position of upstream HO2S and the mixture at position of downstream HO2S has to be equal. So lean mixture at upstream and rich mixture at downstream HO2S is not rational and shows a malfunction.

The following methods are performed.

Method A1 - shift to lean

If the upstream HO2S measures a lean mixture and the downstream HO2S measures a rich mixture and the monitoring conditions are simultaneously fulfilled, a malfunction is detected and a plausibility fault PLLSU is set after debouncing.

Method A1 - shift to lean - monitoring conditions

- both the upstream and downstream oxygen sensors are ready for operation
- one of the following 2 conditions is fulfilled
 - A the following conditions are fulfilled
 - the lambda controller has reached its limit in the rich direction
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
 - B the following conditions are fulfilled
 - diagnoses of downstream HO2S performed without any fault
 - the proportional component of the downstream lambda controller is active
 - the absolute value of the proportional component of the rear controller is greater than calibration and the integral component and the proportional component both have the same sign, or the absolute value of the proportional component is greater than (Integral component + calibration)
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold

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Method B1 - shift to lean

If the normalized A/F-ratio setpoint value of the upstream HO2S lies in a desired region (see monitoring conditions) and the downstream HO2S measures a rich mixture and the monitoring conditions are simultaneously fulfilled for a calibrated period of time a malfunction is detected and a plausibility fault PLLSU is set after debouncing.

Method B1 - shift to lean - monitoring conditions

- both the upstream and downstream oxygen sensors are ready for operation
 - the lambda controller has not reached its limit in the lean direction
 - diagnoses of downstream HO2S performed without any fault
 - one of the following 2 conditions is fulfilled
- A the following conditions are fulfilled
- desired normalized A/F-ratio setpoint value equals one
 - the absolute value of the proportional component of the rear controller is greater than calibration and the integral component and the proportional component both have the same sign, or the absolute value of the proportional component is greater than (Integral component + calibration).
 - the proportional component of the downstream lambda controller is active
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
 - downstream HO2S switches from lean to rich or vice versa
- B the following conditions are fulfilled
- desired normalized A/F-ratio setpoint value exceeds calibrated threshold (lean region)
 - closed loop lambda control is active
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
 - downstream HO2S switches from lean to rich or vice versa

Plausibility check - shift to rich

A shift of the upstream HO2S characteristic lambda curve towards rich will cause a lean A/F ratio at the downstream HO2S. Because of an airtight exhaust system the mixture at position of upstream HO2S and the mixture at position of downstream HO2S has to be equal. So rich mixture at upstream and lean mixture at downstream HO2S is not rational and shows a malfunction.

The following methods are performed.

Method A2 - shift to rich

If the upstream HO2S measures a rich mixture and the downstream HO2S measures a lean mixture and the monitoring conditions are simultaneously fulfilled, a malfunction is detected and a signal fault PLLSU is set after debouncing.

Method A2 - shift to rich - monitoring conditions

- both the upstream and downstream oxygen sensors are ready for operation
 - one of the following 2 conditions is fulfilled
- A the following conditions are fulfilled
- the lambda controller has reached its limit in the lean direction
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
- B the following conditions are fulfilled
- diagnoses of downstream HO2S performed without any fault
 - the proportional component of the downstream lambda controller is active
 - the absolute value of the proportional component of the rear controller is greater than calibration and the integral component and the proportional component both have the same sign, or the absolute value of the proportional component is greater than (Integral component + calibration)
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold

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Method B2 - shift to rich

If the normalized A/F-ratio setpoint value of the upstream HO2S lies in a desired region (see monitoring conditions) and the downstream HO2S measures a lean mixture and the monitoring conditions are simultaneously fulfilled for a calibrated period of time, a malfunction is detected and a plausibility fault PLLSU is set after debouncing.

Method B2 - shift to rich - monitoring conditions

- both the upstream and downstream oxygen sensors are ready for operation
- the lambda controller has not reached its limit in the rich direction
- diagnoses of downstream HO2S performed without any fault
- one of the following 2 conditions is fulfilled
 - A the following conditions are fulfilled
 - desired normalized A/F-ratio setpoint value equals one
 - the absolute value of the proportional component of the rear controller is greater than calibration and the integral component and the proportional component both have the same sign, or the absolute value of the proportional component is greater than (Integral component + calibration).
 - the proportional component of the downstream lambda controller is active
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
 - downstream HO2S switches from lean to rich or vice versa
 - B the following conditions are fulfilled
 - desired normalized A/F-ratio setpoint value lies below calibrated threshold (rich region)
 - closed loop lambda control is active
 - debouncing is finished (see the following conditions):
 - integrated mass airflow exceeds calibrated threshold
 - downstream HO2S switches from lean to rich or vice versa

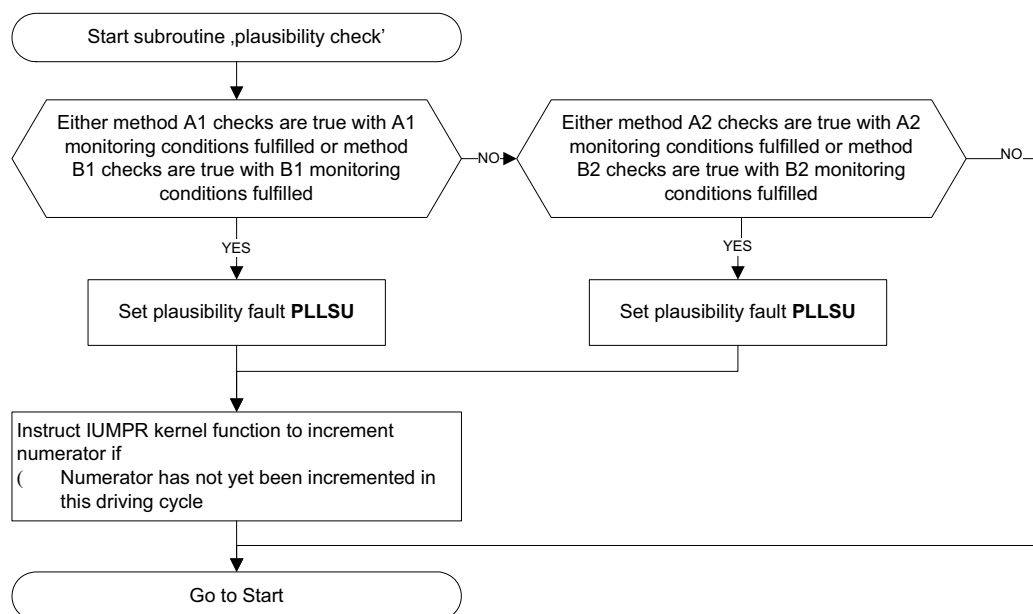


Figure 61: Flow Chart subroutine plausibility check FO2 Sensor

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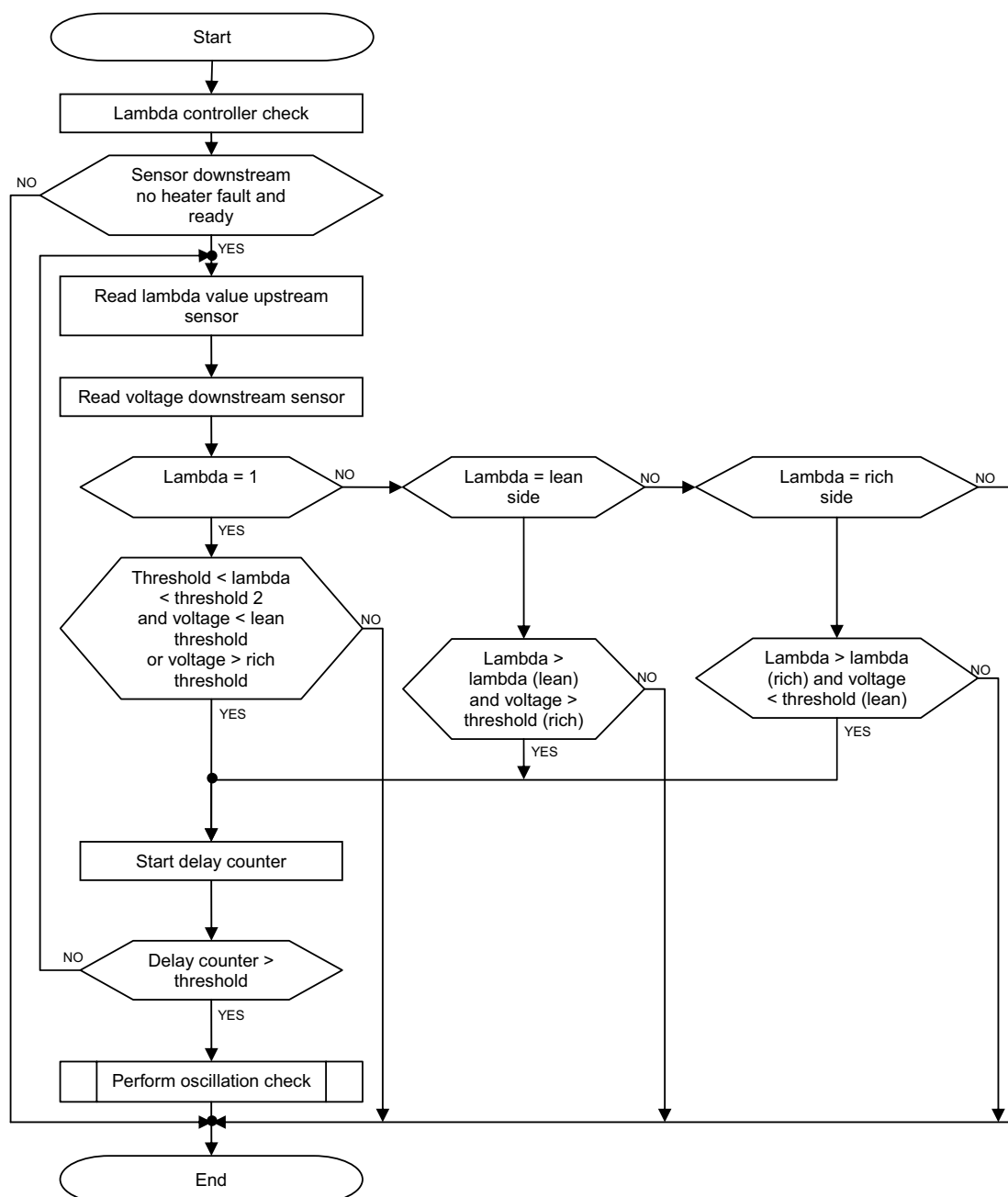


Figure 62: Flow Chart rationality monitor FO2 Sensor

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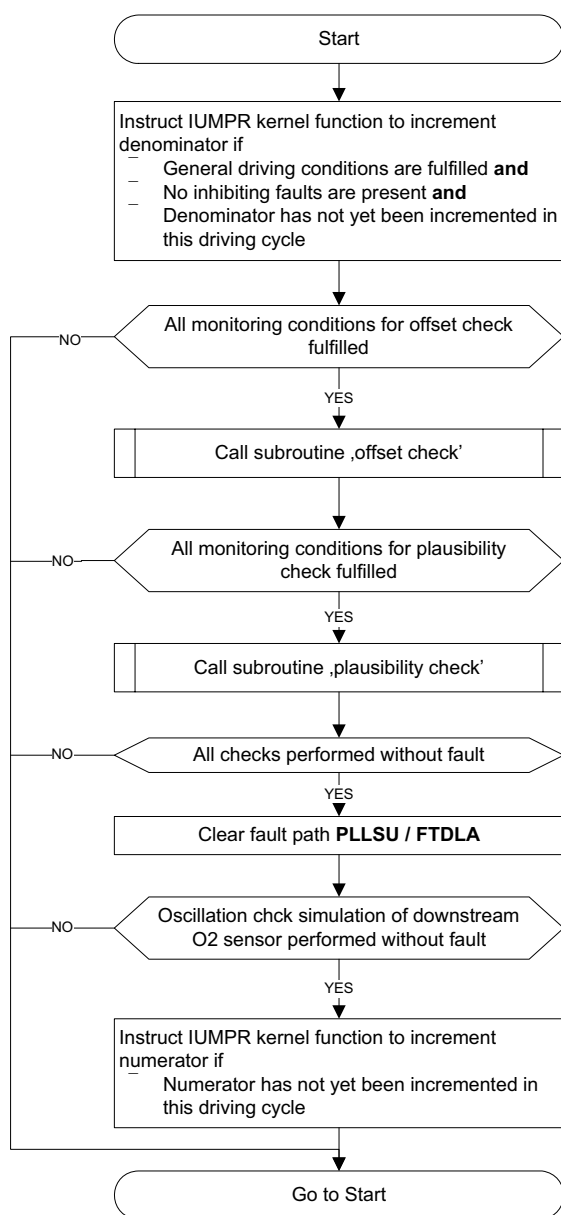


Figure 63: Flow Chart IUMPR offset check FO2 sensor

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7.3.3 Diagnosis of O2 sensor voltage (FO2S not in exhaust system)

This chapter describes the sum of all possible LSU voltage checks of the upstream HO2S.

The diagnosis performs a range check of the voltage V_A of the output signal of the heated wide band upstream oxygen sensor (HO2S) after amplification by the CJ125 integrated circuit. V_A depends on the characteristics of the oxygen sensor itself and those of the peripheral circuitry of CJ125.

Generally, in homogenous or homogenous-lean engine operation the measured output voltage V_A lies clearly below the voltage read when the oxygen sensor lies in ambient air. If the measured Voltage V_A exceeds the calibrated ambient air voltage but lies below a calibrated maximum voltage, all for a calibrated period of time, a malfunction is detected and a plausibility fault (**ULSU**) is set. .

A fault could be triggered if an electrically connected oxygen sensor is not properly mounted in the exhaust system.

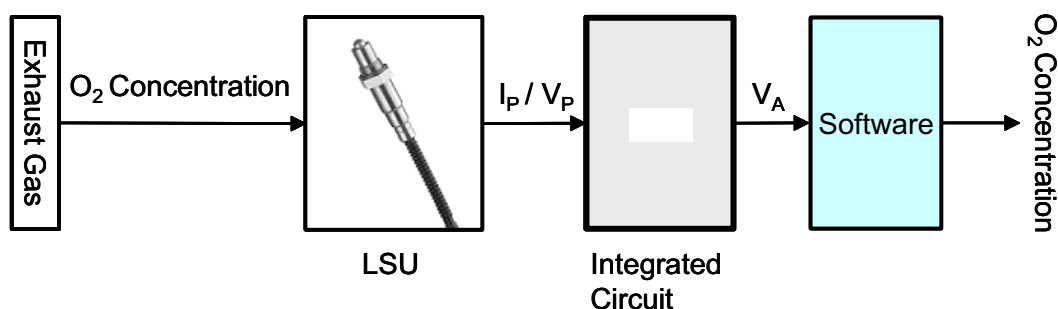


Figure 64: Overview voltage diagnosis of the FO2 sensor

Monitoring conditions

- all injection valves are active
- engine start is finished
- upstream oxygen sensor has reached operating temperature
- upstream oxygen sensor is ready for operation
- set point value of normalized air-fuel ratio lies below threshold value
- no lean shift fault in last driving cycle without cooled off sensor
- fuel tank level has been validated
- AIR injection not active
- no fault of crankshaft ventilation diagnosis
- diagnosis of 'evaluation IC of the upstream HO2S' performed without faults
- enabled by the diagnostic scheduler

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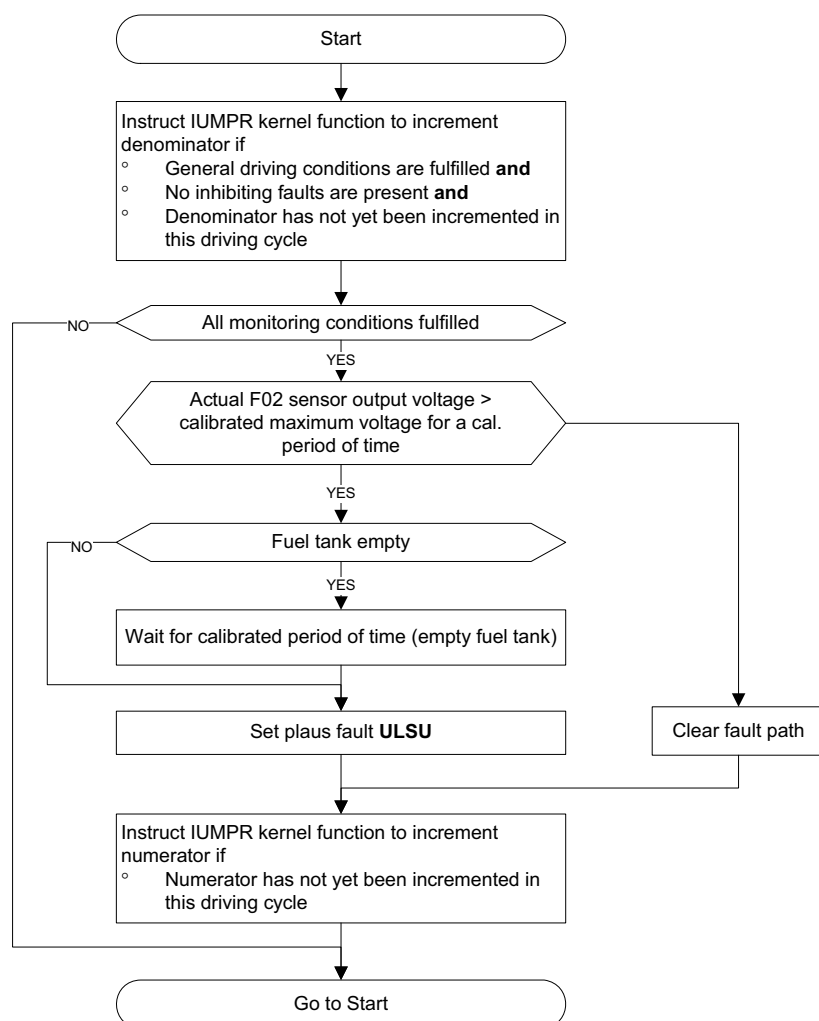


Figure 65: Flow chart diagnosis of O2 sensor voltage

7.3.4 Heater Coupling Check

This monitoring function will detect any short circuits between sensor heater and the Nernst cell of the Oxygen sensor by watching the Lambda signal. The Lambda value variation is checked by the ECM. The heater is operated by a pulsating signal with a frequency of two Herz. The sensor signal characteristic is checked for noises with a significant level and a frequency of the heater operation. If the level of noises is greater than a threshold, a low resistance short-cut between heater and pump current or the current of the Nernst cell is detected.

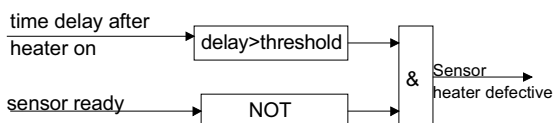
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7.4 FO2 Sensor heater

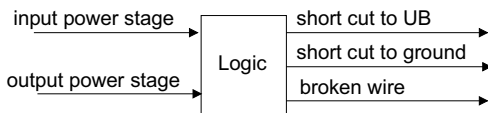
For proper function of the Oxygen sensors, their ceramic elements must be heated. A non-functioning heater delays or prevents the sensor readiness (LSU) for closed loop control and thus influences emissions. The heating up is controlled by the heater control. The heater control loop is integrated within the oxygen sensor hardware and has to achieve a target temperature of about 750 °C of the ceramic element.

Heater Monitoring of Linear Oxygen Sensor Upstream Catalyst

Operating readiness



Power stage (final stage)



Heater Control Loop

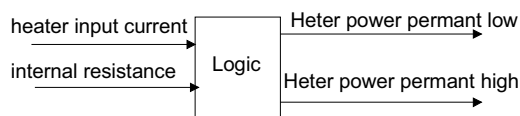


Figure 66: Characteristics -Switch on of sensor heater is ECM controlled

This chapter describes the sum of all possible heater checks of the upstream HO2S. The operating temperature of the HO2S depends on the type used. Internal heating is required when the heat dissipated from the exhaust gas isn't sufficient to maintain the HO2S at its operating temperature. The extra power required for heating depends on the deviation from the operating temperature. It can be controlled by varying the duty cycle factor of the heater.

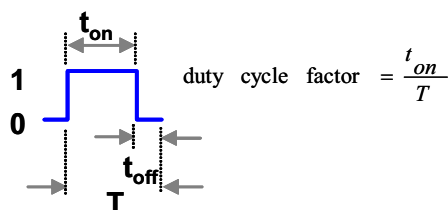


Figure 67: Duty cycle factor of the heater

7.4.1 Calibration resistor check

A reliable Nernst cell temperature determination is ascertained by referencing a calibration resistor. The resistance of this calibration resistor mounted in the ECM is constant.

If the difference between its nominal and measured value exceeds a calibrated threshold for a calibrated period of time, a malfunction is detected and a signal fault **HSV** (heater sensor voltage) is set.

If the signal fault is present, a proper Nernst cell temperature determination will be impossible.

Monitoring conditions for calibration resistor check

- battery's voltage lies within calibrated range
- engine start has finished
- engine is running

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- temperature upstream catalyst exceeds dew-point
- heater of upstream oxygen sensor is ready for operation
- no faults of diagnosis of 'Evaluation IC of the upstream HO2S'

7.4.2 Temperature check of Nernst cell after engine start

The oxygen sensor's ceramic temperature is determined by measuring the internal resistance of its Nernst cell. If the ceramic temperature of the sensor lies below a calibrated minimum after a calibrated period of time, a malfunction is detected and a plausibility fault is set.

Monitoring conditions for temperature check after engine start

- the heater control is active
- all injection valves are activated
- internal resistance calculation (with respect to heater control) is possible
- no faults of diagnosis of 'Evaluation IC of the upstream HO2S'
- no HO2S power stage faults
- battery's voltage lies within calibrated range
- engine start has finished
- engine is running
- temperature upstream catalyst exceeds dew-point
- no fault of calibration resistor check
- engine soak time exceeds calibrated threshold
- engine start temperature exceeds calibrated threshold
- enabled by the diagnostic scheduler
- diagnosis enabled time for 'temperatur check of Nernst cell after engine start' not elapsed

7.4.3 Maximum heater output check

If the target temperature of the oxygen sensor's ceramic isn't reached during controlled operation, the duty cycle factor of the output function will converge towards one. A duty-cycle factor equal to one for a long period of time is implausible and prohibited.

If, with maximum heater output, the temperature of the oxygen sensor's ceramic lies below a calibrated threshold for a calibrated period of time, a malfunction is detected and a maximum fault **HSV** is set

Monitoring conditions for maximum heater output check

- battery's voltage lies within calibrated range
- diagnosis of 'Evaluation IC of the upstream HO2S' performed without faults
- the heater control is active
- calculated model of exhaust gas temperature is valid
- modeled exhaust gas temperature exceeds calibrated threshold
- no fuel cut-off
- engine start has finished
- engine is running
- temperature upstream catalyst exceeds dew-point
- no reduced heating power active
- no fault of power stage of upstream oxygen sensor heater
- enabled by the diagnostic scheduler

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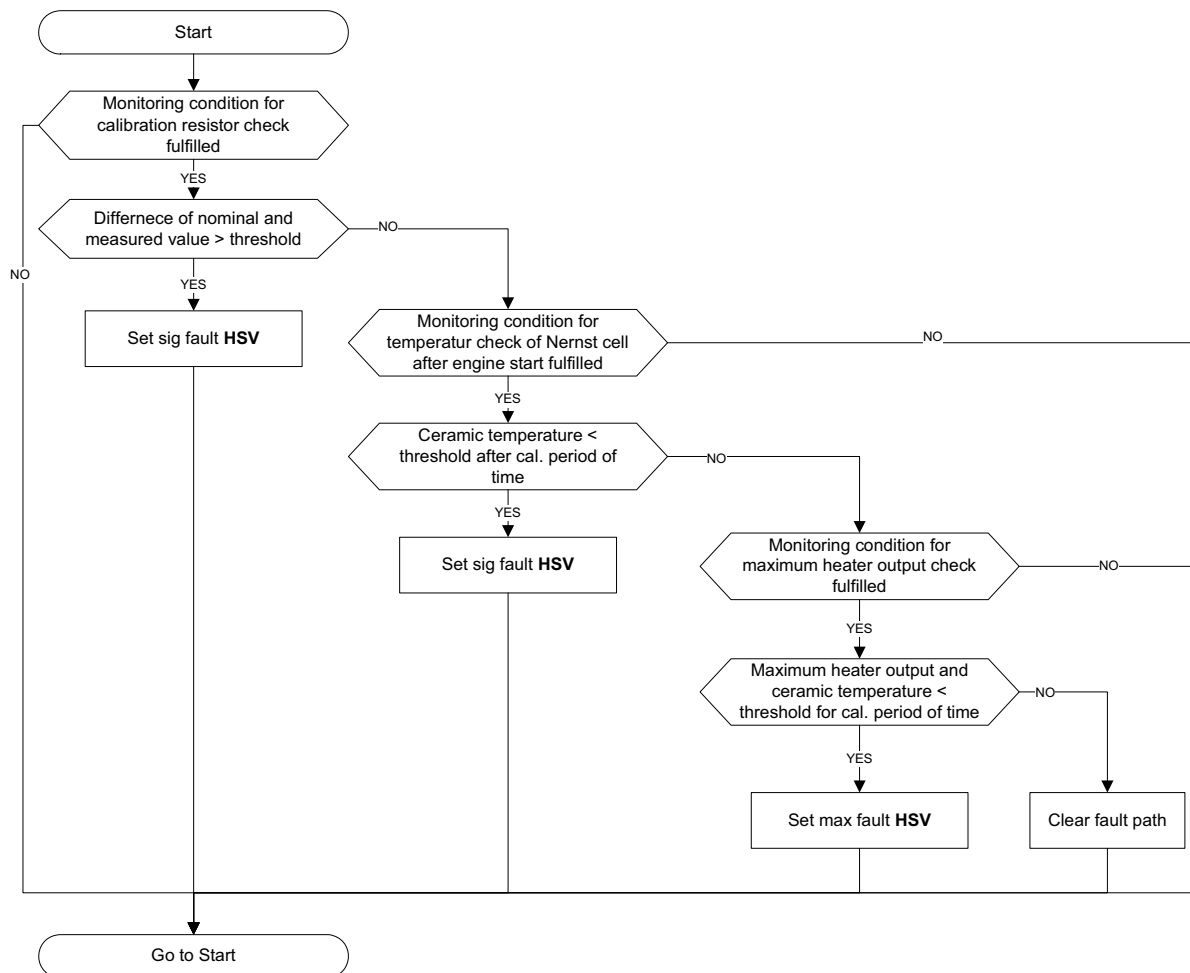


Figure 68: Flow chart FO2 sensor heater monitoring

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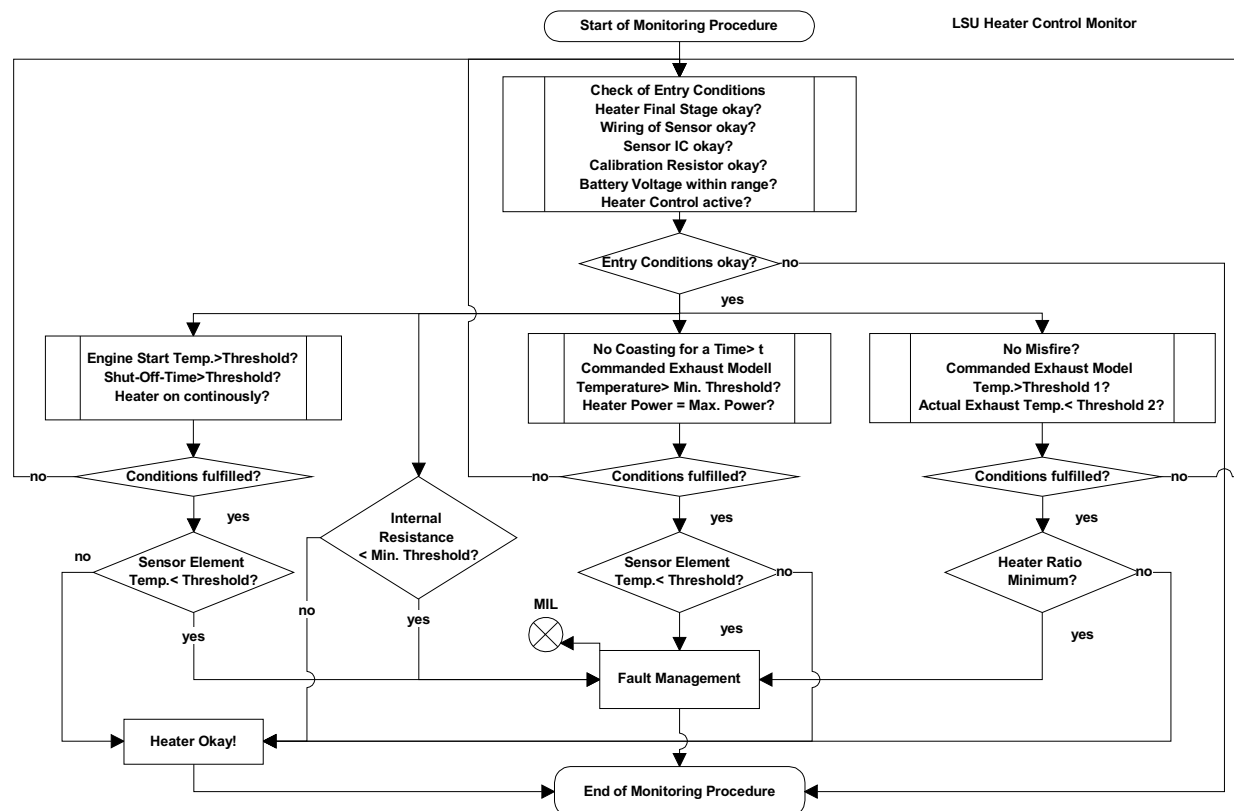


Figure 69: Flow chart O2 Sensor Heater Control upstream catalyst (1)

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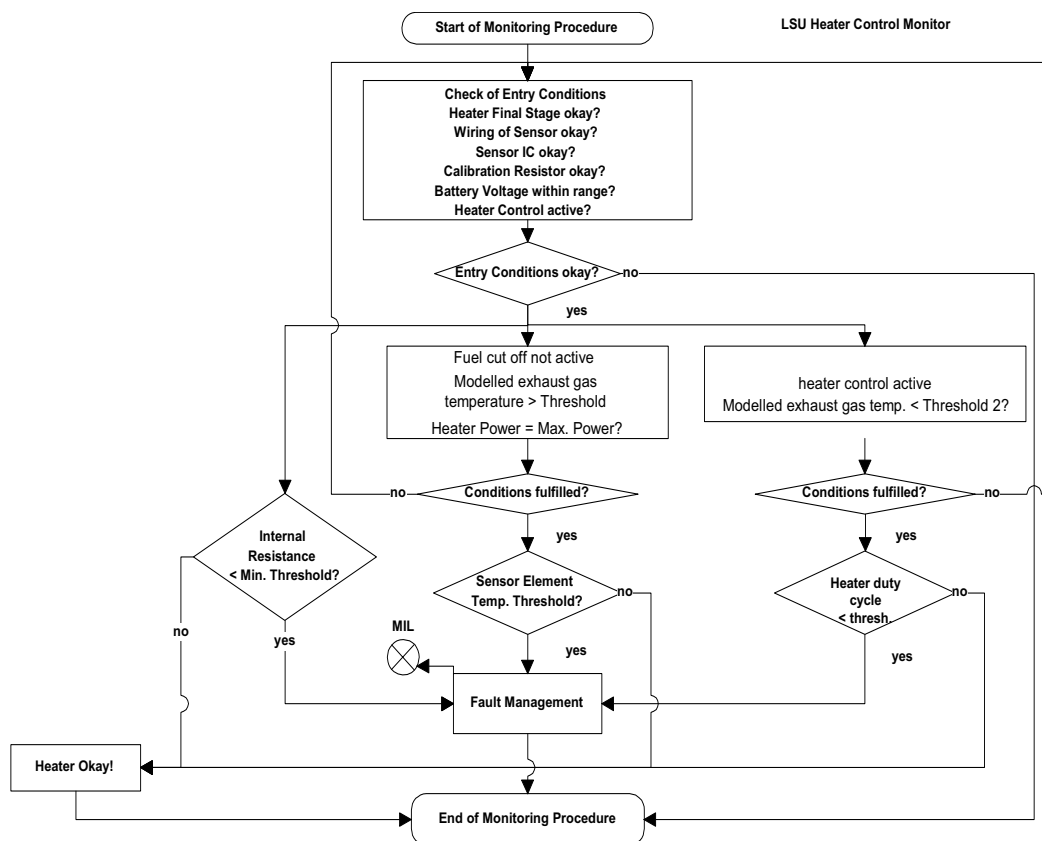


Figure 70: Flow chart O2 Sensor Heater Control upstream catalyst (2)

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7.5 Secondary downstream oxygen sensor (RO2S) dynamic

In case of oxygen sensor (LSF1, second sensor) signal shows permanently “lean” voltage, ECM is forcing an enrichment of mixture. If sensor voltage shows still lean, a “stuck low” fault is detected.

In case of oxygen sensor (LSF1) signal shows permanently “rich” voltage, ECM enables lean out of mixture. If sensor voltage shows still rich, ECM is watching the sensor signal during the next coasting condition. In case of no signal change during coasting, a “stuck high” fault is detected.

The third control loop (if applicable) is designed as commanded control and based on the Oxygen sensor (LSF2, third sensor) post main catalyst. The controller maintains an optimal constant voltage of the third control loop. The target voltage depends on the operating point and is taken from a map. During active control, the target voltage switches between rich and lean. In case of no reaction of the Oxygen sensor (LSF2) output according the commanded control, ECM is forcing the same enrichment/ lean out of fuel mixture in order to monitor the sensor output voltage.

The diagnosis of the aging of the rear O2 sensor consists of an oscillation check and a threshold check during fuel cut-off. The diagnosis runs continuously.

General Monitoring Conditions

- the canister purge system diagnosis has detected no faults
- no faults of the canister purge valve's power stage diagnosis
- no battery voltage faults
- the downstream oxygen sensor connectors are correctly matched with their corresponding banks (only for 2 bank systems)

7.5.1 Diagnosis of aging of RO2 Sensor - Oscillation check (second sensor)

During normal engine operation the normalized A/F ratio and hence the voltage of the RO2 sensor oscillates about the set point value. The oscillation check triggers a test function if the measured voltage of the O2 sensor signal permanently lies below or above the set point value for a calibrated period of time. The test function applies a rich A/F mixture if the voltage is below the set point value or a lean A/F mixture if the voltage is above the set point value.

If the voltage doesn't cross the set point value in the expected direction after applying a lean or rich A/F mixture, a malfunction is detected and a minimum or maximum fault **LASH** will be respectively set.

Monitoring conditions for oscillation check

- all general monitoring conditions have been fulfilled
- the proportional part of the mixture control system on the downstream side of the main catalyst has been activated
- the mass airflow is greater than calibration
- the canister purge valve is inactive
- fuel control error threshold has not been exceeded
- no critical misfiring rate.

7.5.2 Threshold check during trailing throttle fuel cut-off (second sensor)

This check determines whether the voltage of the RO2 sensor signal exceeds a calibrated threshold for a calibrated period of time during fuel cut-off. A malfunction is detected and a signal fault **LASH** is set if this is true.

Monitoring conditions - threshold check during trailing throttle fuel cut-off

- all general monitoring conditions are fulfilled
- fuel cut-off for a calibrated period of time
- the required mass airflow for response rate determination has been reached
- no electrical faults of the downstream HO2S
- no electrical fault of the downstream HO2S' heater

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- no electrical fault of the downstream HO2S heater's power stage
- the modeled exhaust gas temperature on the downstream side of the catalyst is above a calibrated threshold
- the downstream HO2S has been sufficiently heated up
- the dew-point temperature on the downstream side of the catalyst has been exceeded.

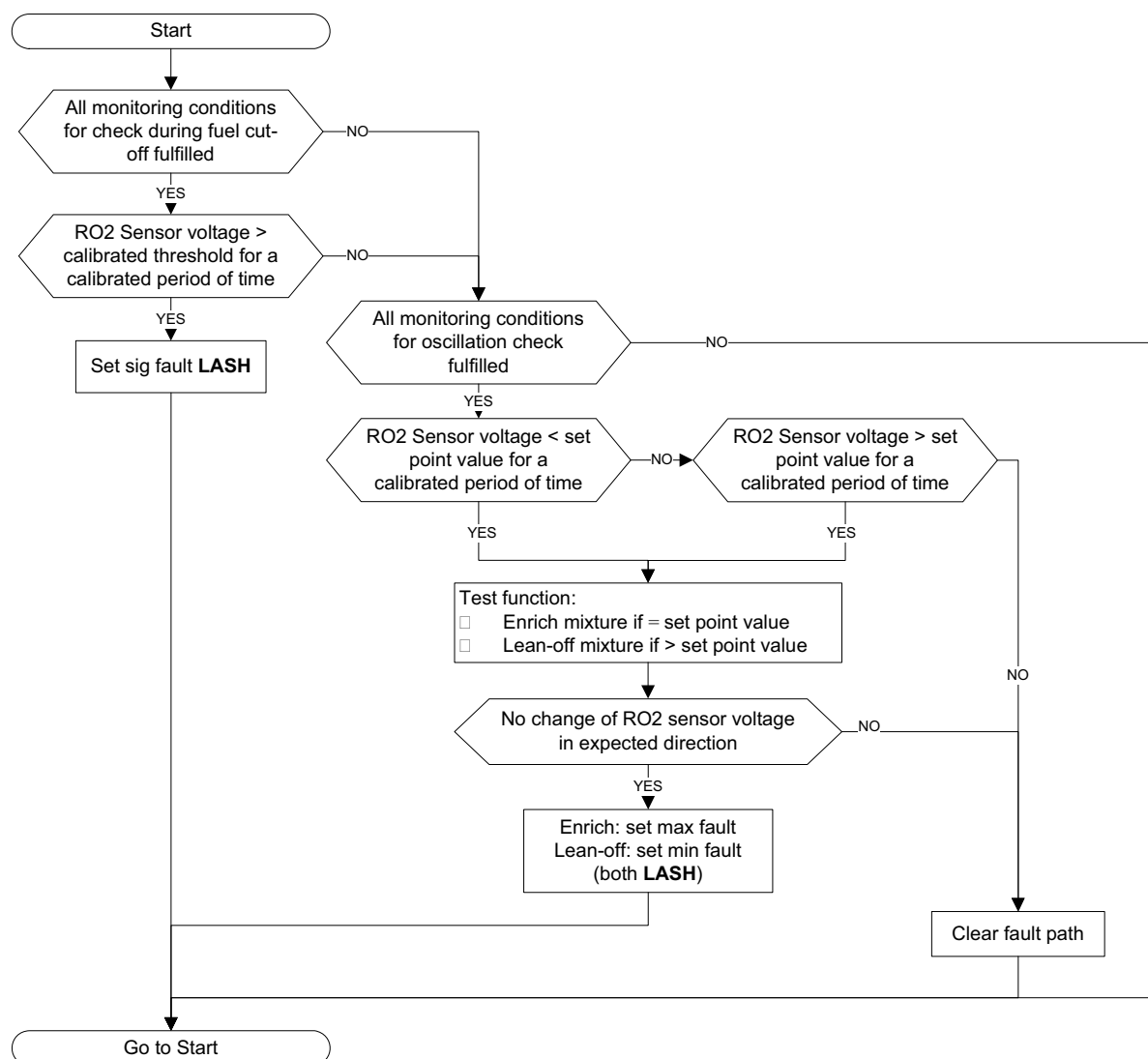


Figure 71: Flow chart RO2 sensor dynamic monitoring (second sensor)

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7.5.3 Oscillation check - minimum and maximum faults (third sensor)

During normal engine operation the normalized A/F ratio and hence the voltage of the HO2S (on the downstream side of the front catalyst) oscillates about the set point value. The oscillation check triggers a test function if the measured voltage of the HO2S' signal permanently lies below or above the set point value for a calibrated period of time.

The test function applies a rich A/F mixture if the voltage is below the set point value or a lean A/F mixture if the voltage is above the set point value. If the voltage doesn't cross the set point value in the expected direction after applying a lean or rich A/F mixture, a malfunction is detected and a minimum or maximum fault **LASF** will be respectively set.

Maximum Fault (stuck lean)

A maximum fault is set when despite maximum A/F mixture enrichment the sensor's voltage remains below a calibration. The fault is either immediately set, provided the fuel tank has been validated and is neither empty nor on reserve, or after a calibrated delay time if the fuel level sensor is defective.

Monitoring Conditions for Maximum Fault

- the O2 sensor (downstream front catalyst) is ready for operation
- either the proportional part of the A/F mixture control has been enabled or
- a calibrated delay time has elapsed or
- a fault of the upstream HO2S has been suspected and
- the mass air flow exceeds a calibration
- the operation readiness of the O2 sensor (downstream front catalyst) has been delayed
- either the monitor is enabled by the diagnostic system manager (VR6FSI engine only) or (for Jetta engines only) the following enable conditions must be fulfilled:
 - the secondary air system diagnostic isn't active (only for Jetta engine)
 - the condition for canister purge valve control isn't set
 - mixture adaptation faults threshold have not been exceeded
 - no critical misfire rate exceeded
 - no faults of the canister purge system
 - no faults of the canister purge valve's power stage
 - no supply voltage errors
 - no faults from O2 sensor (downstream front catalyst) aging diagnosis
 - no exchanged O2 sensors upstream of catalyst (only for VR6FSI engine).

Minimum Fault (stuck rich)

A minimum fault is set when the O2 sensor's voltage permanently lies above the maximum expected value, even when lean mode operation is at its limit and when the voltage permanently lies above a calibration during trailing throttle fuel cutoff.

Monitoring Conditions for Minimum Fault

- all the monitoring conditions for maximum faults are fulfilled and
- all signal fault monitoring conditions are fulfilled.

7.5.4 Signal fault - voltage threshold check during trailing throttle fuel cut-off (third sensor)

A signal fault is set when the voltage permanently lies above a calibration during trailing throttle fuel cut-off.

Monitoring Conditions for Signal Fault

- trailing throttle fuel cutoff condition is fulfilled
- a calibrated delay time after trailing throttle fuel cutoff has elapsed
- the integrated mass air flow during fuel cutoff exceeds a calibration
- the modeled exhaust gas temperature at the O2 sensor's location (downstream front catalyst) lies above a calibration
- and this signal check has additionally been either enabled by the diagnostic scheduler (VR6FSI engine only) or all of the following conditions are additionally fulfilled (Jetta engine only):

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- the diagnosis of the O2 sensor (downstream front catalyst) has been performed and no faults were detected
- the O2 sensor heater (downstream front catalyst) diagnostic has been performed and no faults were detected
- no O2 sensor (downstream front catalyst) heating errors
- the dew point temperature at the O2 sensor's location has been exceeded
- the O2 sensor has been heated enough.

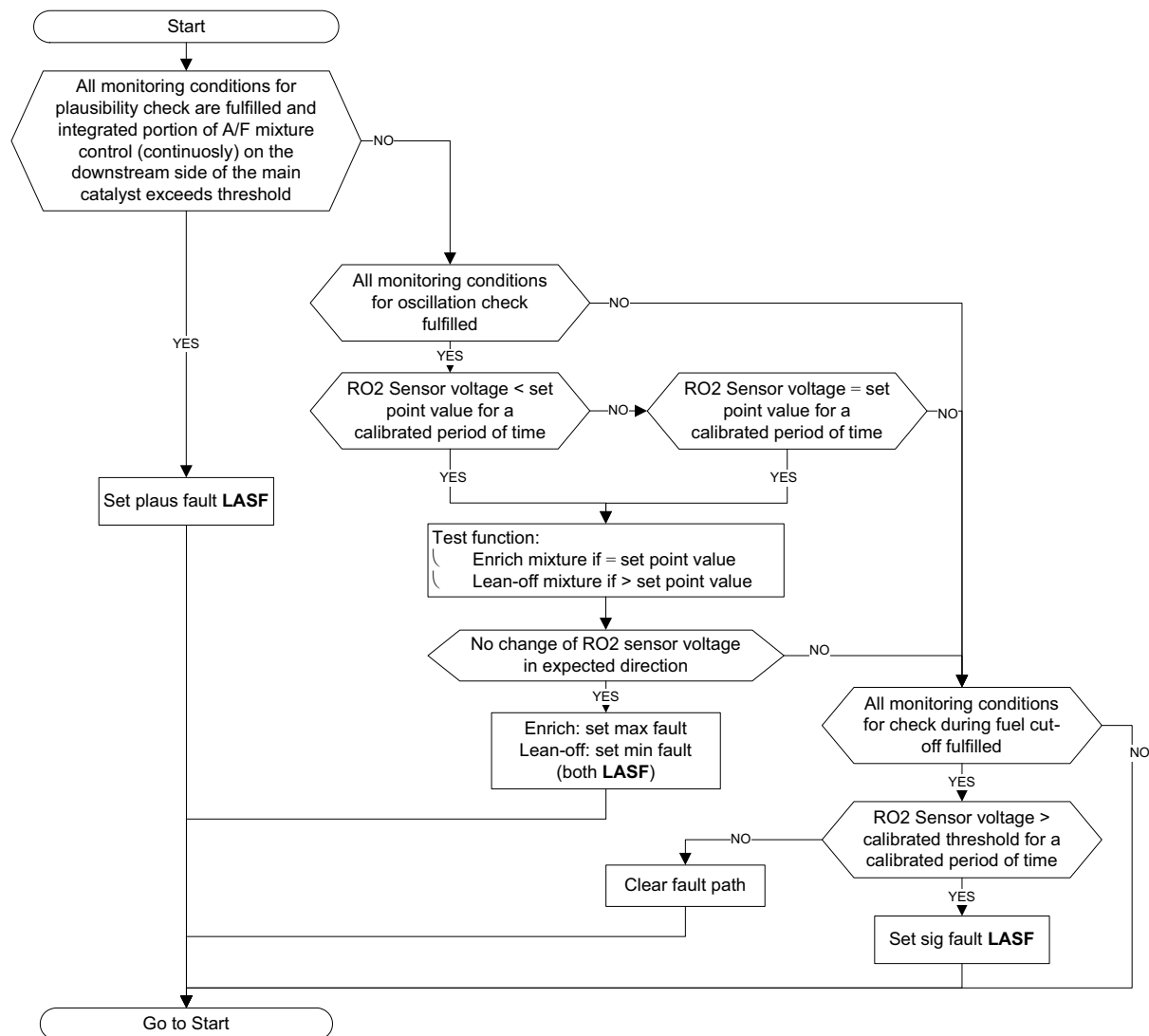


Figure 72: Flow chart RO2 sensor dynamic monitoring (third Sensor)

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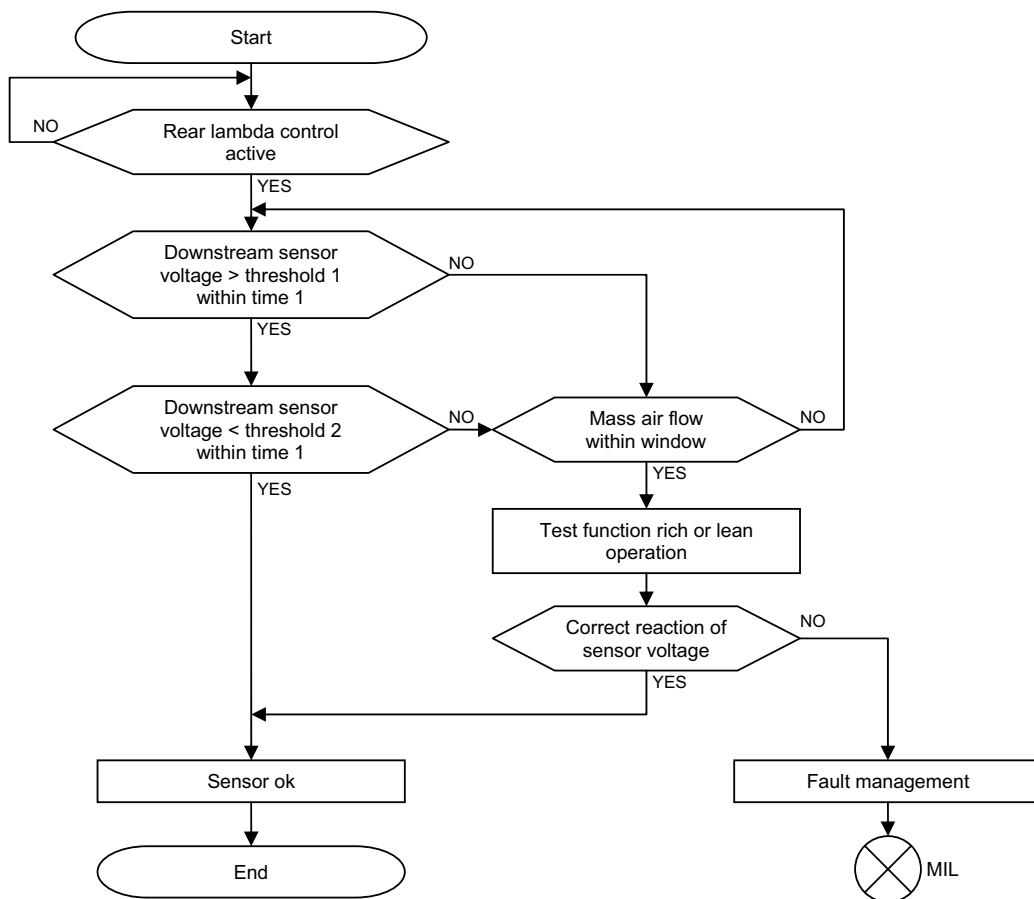


Figure 73: Flow chart oscillation monitoring (RO2 Sensor)

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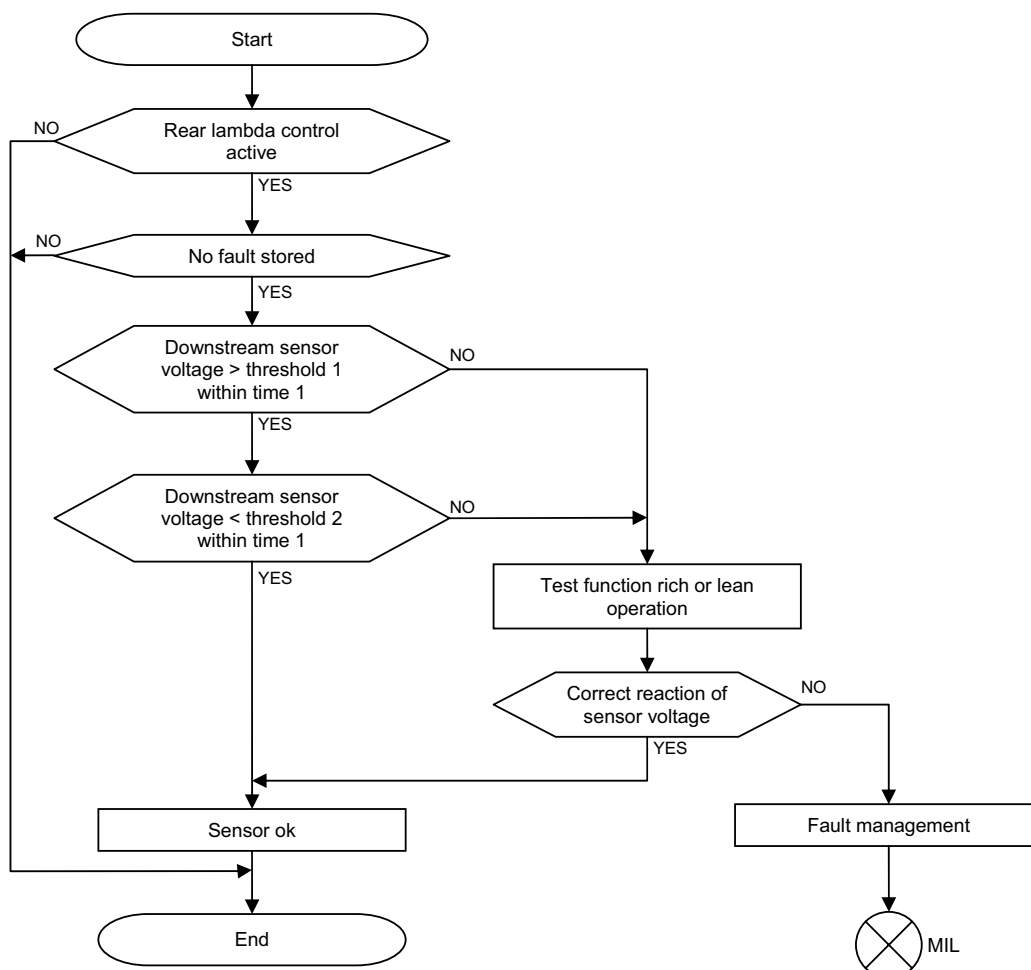


Figure 74: Flow chart oscillation monitoring (second and third sensor)

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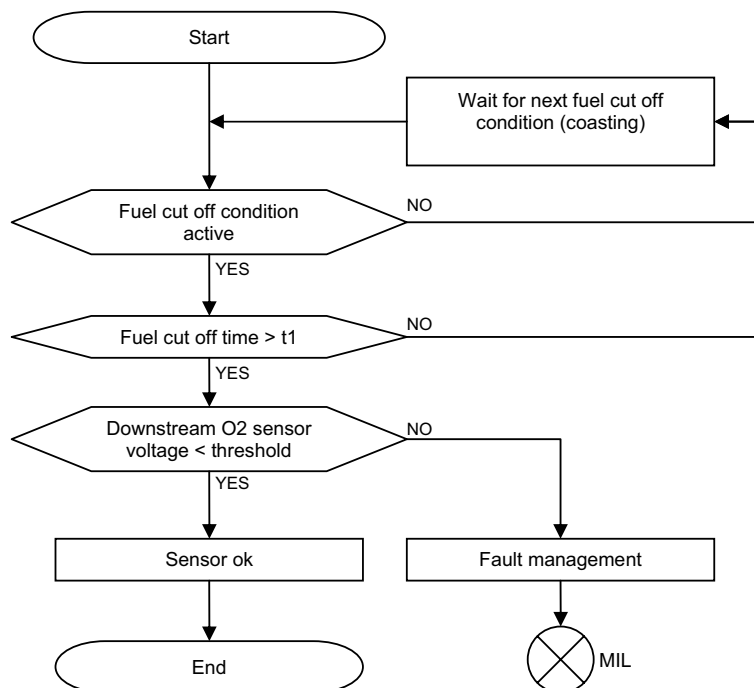


Figure 75: Flow chart fuel cut-off monitoring (second and third sensor)

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7.6 Signal range and electrical circuit monitoring of the secondary oxygen sensors

This diagnostic monitors the second and the third sensor of bank 1.

Sensor 2	Sensor 3		
P0138	P0144	Short to battery	Out of range high
P0137	P0143	Short to ground or short circuit between signal wire and ground wire	Circuit continuity
P0140	P0146	Open circuit ground wire	Circuit continuity
P0136	P0142	Heater coupling	Circuit continuity

7.6.1 System overview

Both the downstream oxygen sensor of the precatalyst and the downstream oxygen sensor of the main catalyst are monitored.

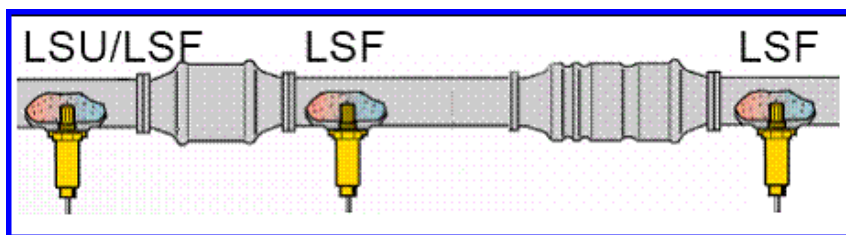


Figure 76: System Overview – downstream oxygen sensors

7.6.2 General description

The diagnostic monitors the two-step oxygen sensors in the exhaust system for wiring faults and effects of heater switching couplings onto the sensor signal. Short circuits to ground and to battery, and open circuits in the signal wiring and the ground wiring, are detected. If a fault is detected in a sensor, the operational readiness will be withdrawn.

The sensor voltage range for a faultless sensor is 0 to 1 Volt. As it is not possible to measure negative sensor voltages in the control unit, signal range exceedances can only be detected for voltages greater than 1 Volt. Since the sensor voltage for open circuits and shorts to ground remains within the plausible range, an additional evaluation criterion is required: the sensor voltage charged with a load impulse is measured, as it is also utilized to measure the internal resistance of a sensor.

7.6.2.1 General enable conditions (for all the following diagnostics)

Physical Enable Conditions

- ➔ Speed for running engine detected (typical speed > 80 rpm)
- ➔ Vehicle system voltage > threshold value (typically 11 V)

Enable Conditions for “Operational Readiness of the Oxygen Sensor fulfilled” (to cover the case that the sensor is faultless):

- ➔ The sensor voltage has exceeded the cold sensor range of +/- 450 mV (typically lower than 400 mV, or greater than 600 mV but lower than 1080 mV)
 - ➔ see illustration below
- ➔ Sensor is sufficiently heated. This criterion is defined as
 - Sensor is sufficiently heated up AND
 - Dew point in the vicinity of the sensor is exceeded (can optionally be calibrated)

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OR

Enable Conditions for “Theoretical Operational Readiness of Oxygen Sensor fulfilled” (to cover the case that the sensor voltage does not exceed the voltage range due to an open circuit):

- ➔ The sensor is sufficiently heated for an extended defined time period AND
- ➔ The dew point in the vicinity of the sensor is exceeded (can optionally be calibrated)

Definition of a Sufficiently Heated Sensor

- ➔ The modeled exhaust gas temperature in the vicinity of the oxygen sensor exceeds a threshold value
OR
- ➔ The heating power exceeds a threshold value for a defined time period
AND
- ➔ No heater output stage fault is present in the current driving cycle (monitor is activated immediately after the sensor heating is activated)

Conditions for Setting the Operational Readiness of the Downstream Oxygen Sensor, and Fault Detection

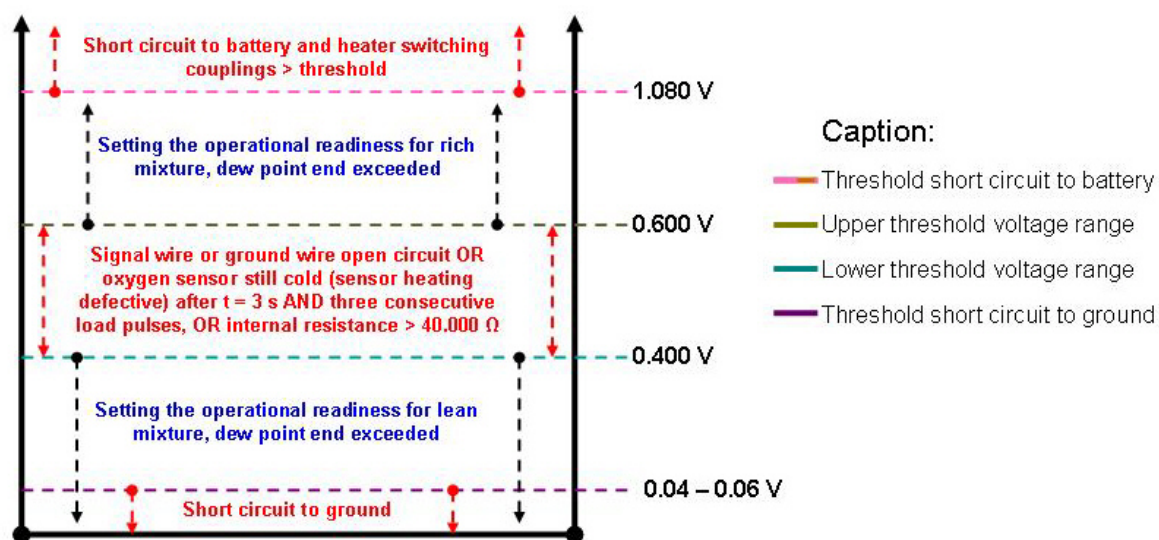


Figure 77: Conditions for setting the operational readiness of the RO2 sensor, and fault detection

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7.6.2.2 Short circuit to battery, P0138 / P0144

Additional enable condition for this diagnostic:

- Setpoint lambda value > 0.995

Monitoring strategy

Measurement and Evaluation of the Sensor Voltage

Malfunction criteria

In order to prevent sensor voltage peaks > 1 V caused by heater couplings, the diagnostic is not activated before the sensor has sufficiently heated up. These heater couplings occur quite frequently when two-point sensors with a planar sensor element are used.

The condition "sensor sufficiently heated" is set TRUE, when either the heating power exceeds a defined heating power threshold value or the modeled exhaust gas temperature exceeds a temperature threshold value for a defined time period, and when the completed heater output stage diagnostic has not detected a fault in the current driving cycle.

When, during sensor operation between slightly rich ($\lambda > 0.995$) and lean, a voltage is detected that exceeds a threshold value for a defined time period (typically 1.08 V), the fault P0138 for the sensor 2 of bank 1, or the fault P0144 for the sensor 3 of bank 1, is set, and the operational readiness of the sensor is withdrawn.

Conditions for Setting the Operational Readiness of the Downstream Oxygen Sensor

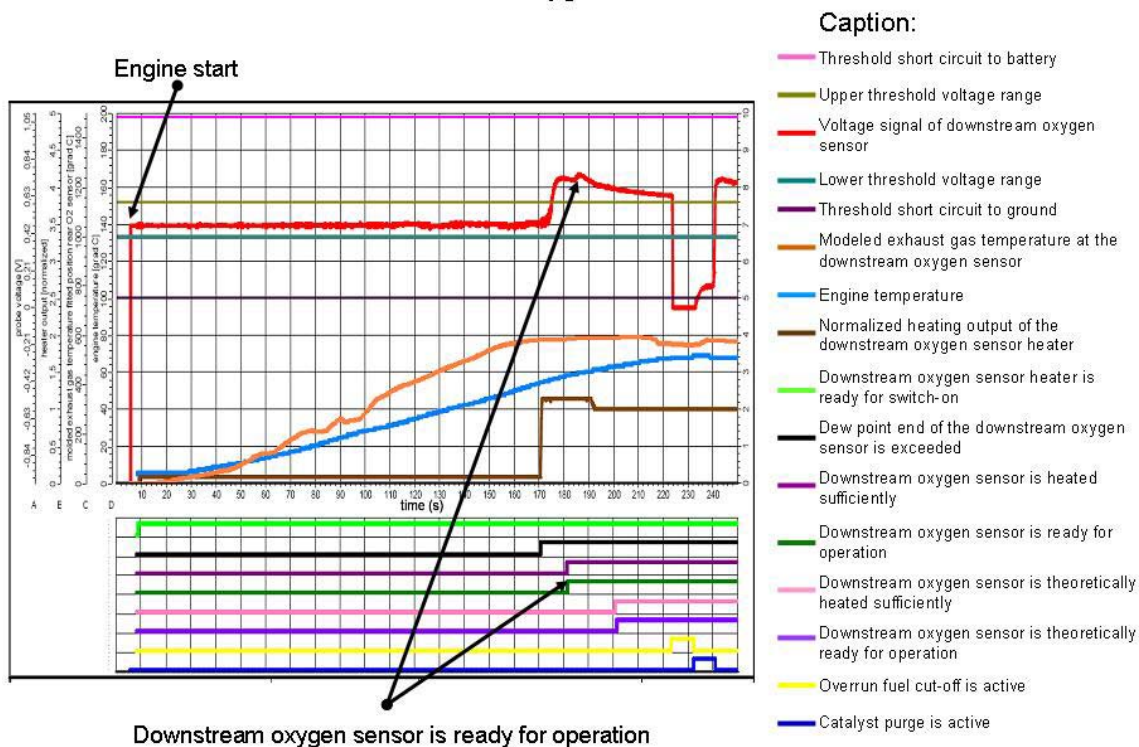


Figure 78: Conditions for setting the operational readiness of the downstream oxygen sensor

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Flowchart

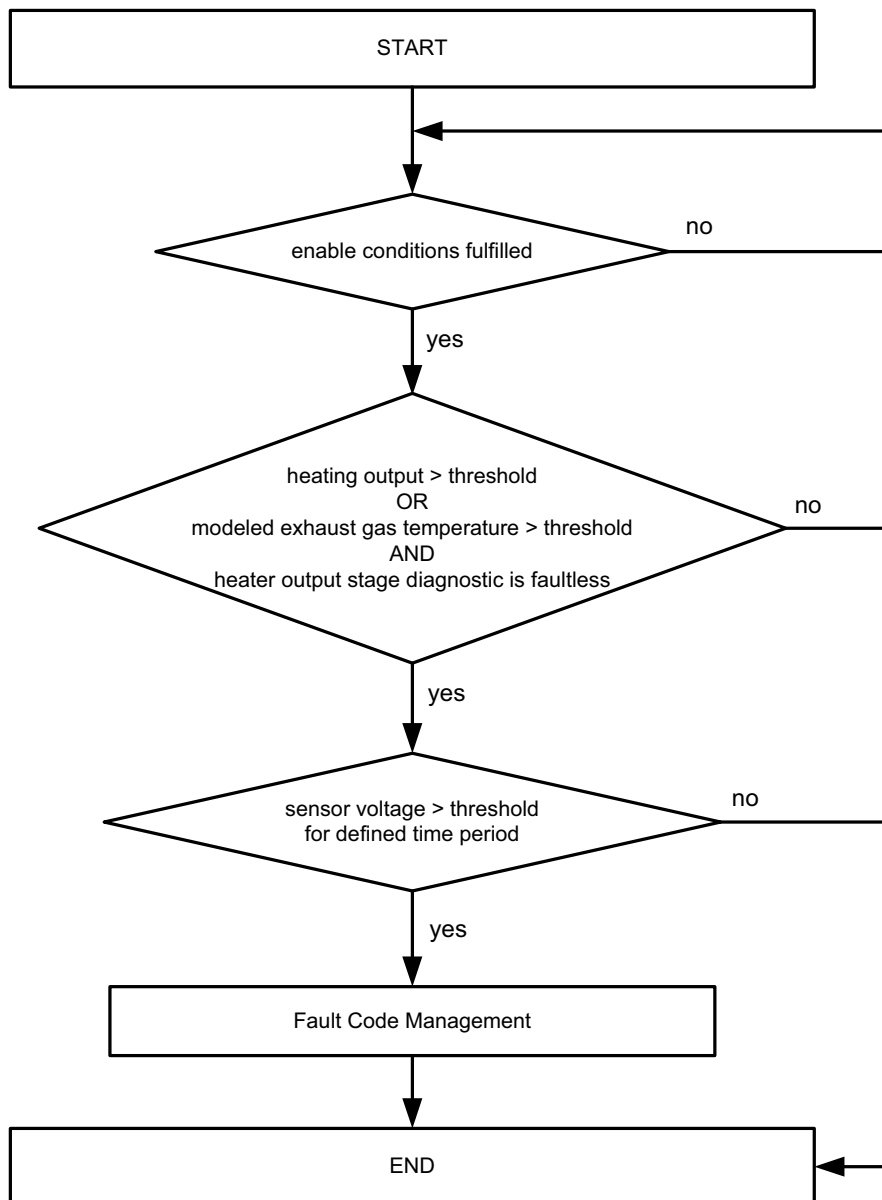


Figure 79: Flow chart short circuit to battery

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7.6.2.3 Short circuit to ground, P0137 / P0143

Additional enable conditions for this diagnostic:

- Overrun fuel cut-off inactive
- Catalyst purge inactive (after overrun phase)

Monitoring strategy

Measurement and evaluation of the sensor voltage, when charged with load pulses

Malfunction criteria

When the sensor voltage remains below a minimum threshold value (typically 40 to 60 mV) for a defined time period (typically 3 s), and if during this period neither overrun fuel cut-off nor catalyst purge after overrun is active, a fault is indicated and the corresponding flag is set. This fault indication triggers the request of three consecutive load pulses. For each of these load pulses, the unloaded and the loaded sensor voltages are measured.

When the mean value of the differences between the loaded and the unloaded sensor voltages is lower than a minimum calibratable threshold value, the fault P0137 for the sensor 2 of bank 1 or the fault P0143 for the sensor 3 of bank 1 is set, and the operational readiness of the sensor is withdrawn.

The measurement with load pulses corresponds to the measurement of the sensor internal resistance, as it is utilized for determining the sensor temperature, and for the heater diagnostic.

Determination of loaded / unloaded sensor voltage and internal resistance

The internal resistance of the oxygen sensor's Nernst cell can be determined by using a pulsed pump current. Since the internal resistance increases substantially when the heater is defective, or when the heating power is considerably decreased, with the exhaust temperature not being too high (typically $T < 700\text{ °C}$), the internal resistance is used, indirectly, to monitor the sensor heating. Additionally, the internal resistance may be used as a criterion for the electrical wiring diagnostic.

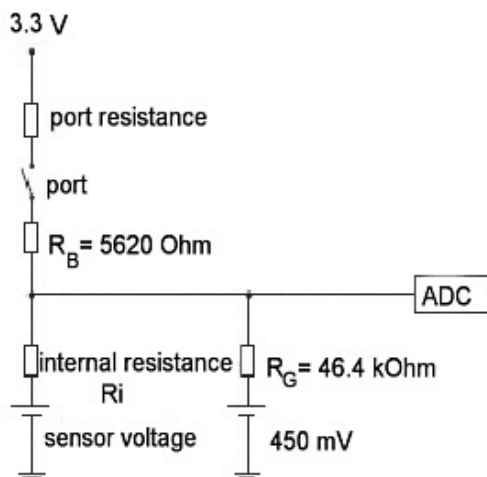


Figure 80: Electrical wiring for measuring unloaded / loaded sensor voltage, and for determination of internal resistance

The load resistance R_B is dimensioned in a way that a pump current of 0.5 mA flows into the oxygen sensor. Measuring the internal resistance is effected as follows:

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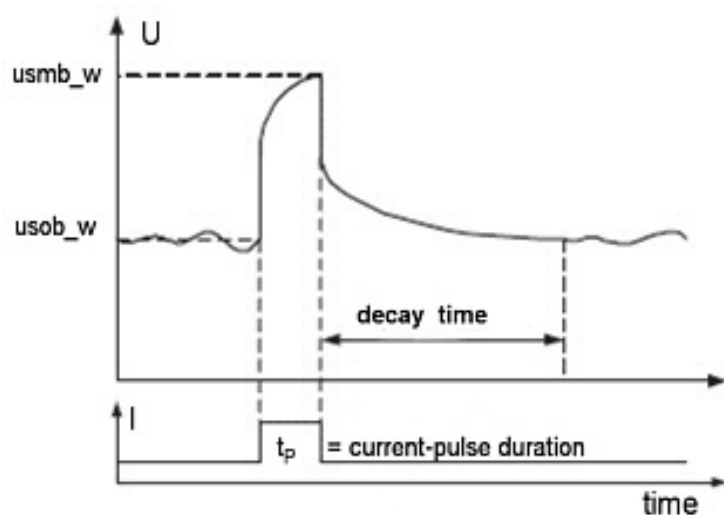


Figure 81: Principle of internal resistance measurement

In order to determine the internal resistance R_i of the Nernst cell, the unloaded and the loaded sensor voltages are measured. The last measured voltage value before the activation of the voltage pulse is stored. Applying the current pulse to the oxygen sensor causes a voltage drop at the internal resistance of the Nernst cell, and thus an increase in the sensor voltage.

The internal resistance is calculated by the following formula:

$$R_i' = \frac{usmb_w - usob_w}{3.3V - usmb_w} \cdot R_B$$

$usmb_w$ = loaded sensor voltage
 $usob_w$ = unloaded sensor voltage
 R_B = load resistance

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Flowchart

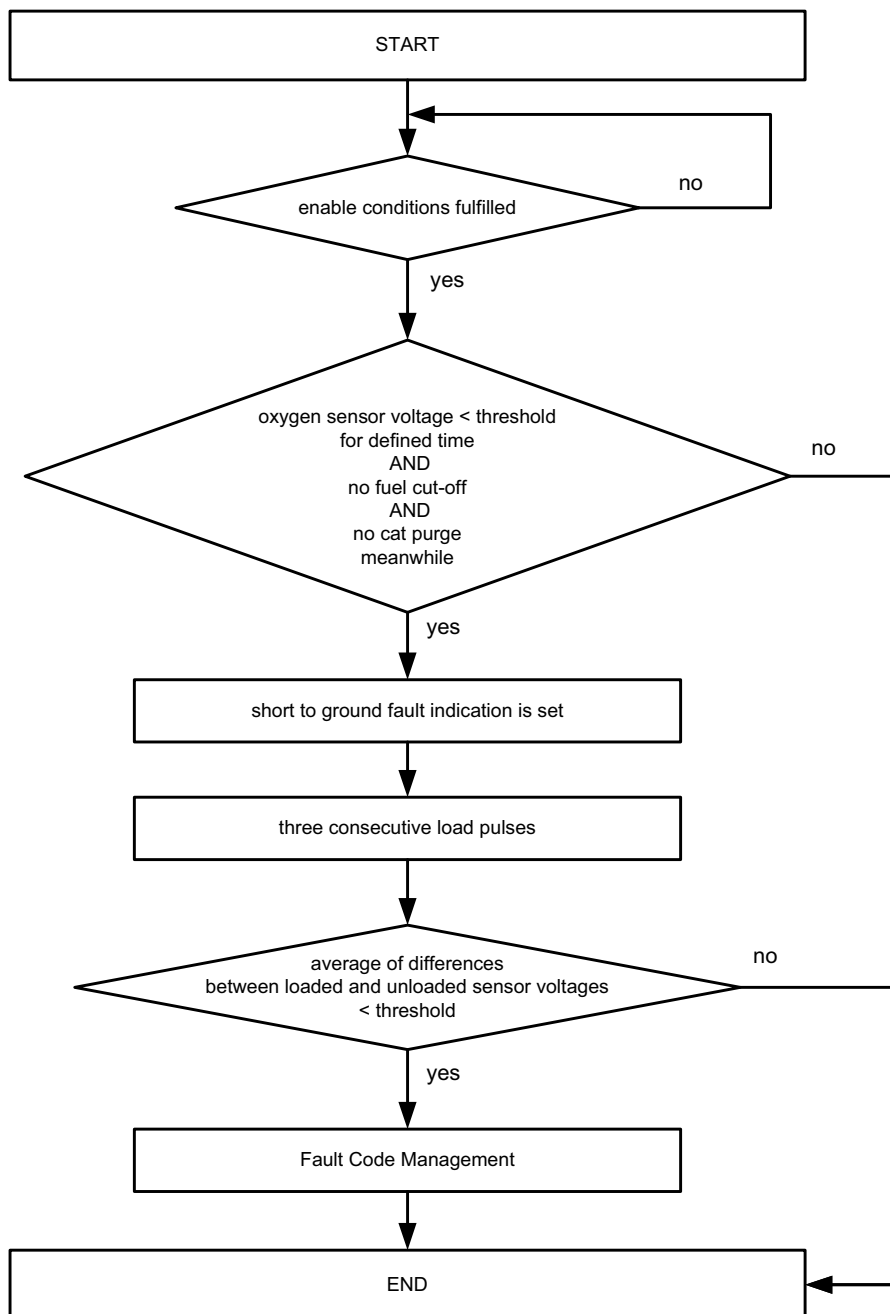


Figure 82: Flow chart short circuit to ground

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7.6.2.4 Signal wire or ground wire, open circuit - P0140 / P0146

Monitoring strategy

Due to the wiring arrangement in the ECU (high-resistance connection of the sensor to a countervoltage of 450 mV), exceedances of the +/- 450 mV voltage range indicate that the internal resistance of the Nernst cell has exceeded a defined threshold. Therefore, these exceedances of the above voltage range are also utilized to detect the operational readiness of the oxygen sensor.

Depending on the current exhaust gas composition in the exhaust system, the oxygen sensor voltage drops below the minimum (lean) voltage threshold value (typically 400 mV), or it exceeds the maximum (rich) threshold value (typically 600 mV), however remaining below the short circuit voltage threshold value (typically 1.08 V).

Malfunction criteria - signal wire, open circuit

When the sensor voltage remains within the voltage range of +/- 450 mV, the oxygen sensor is either too cold, or the signal wire is interrupted.

When the sensor voltage remains within the voltage range of approximately 400 to 600 mV after the sensor has reached its operational readiness, or the sensor has reached its theoretical operational readiness for a defined time period (typically 3 s), a fault is indicated.

This fault indication triggers the request of three consecutive load pulses. For each of these load pulses, the unloaded and the loaded sensor voltages are measured.

When the mean value of the differences between the loaded and the unloaded sensor voltages is greater than or equal to a threshold value, the fault P0140 for the sensor 2 of bank 1 or the fault P0146 for the sensor 3 of bank 1 is set, and the operational readiness of the sensor is withdrawn.

Malfunction criteria - ground wire, open circuit

Additional enable condition for this diagnostic:

- To ensure that there is a valid measurement of the sensor internal resistance, the number of internal resistance measurements must exceed a threshold value (typically 6 to 10).

Using planar sensors, heater couplings onto the sensor signal may occur at high exhaust temperatures and an interrupted ground wire. Therefore the voltage does not necessarily have to remain within the +/- 450 mV range.

For this reason, another diagnostic path exists to reliably detect an interrupted ground wire. When the internal resistance exceeds a maximum threshold value (typically $> 40.000 \Omega$) and the modeled exhaust gas temperature exceeds a maximum threshold value (typically 660°C), the fault P0140 for the sensor 2 of bank 1 or the fault P0146 for the sensor 3 of bank 1 is set, and the operational readiness of the sensor is withdrawn.

A fault must be assumed if the sensor voltage does not exceed the voltage range defined for a cold sensor, despite sufficient heating, for an extended time period (approx. 20 s), even if no open circuit fault has been detected by the current-pulse method. In this instance, the operational readiness is forced. This is to enable fault detection by the oscillation monitoring of the secondary oxygen sensor and, consequently, a "stuck lean" fault is registered. Hence, it is even possible to detect a manipulation by simulating the presence of the sensor with a fixed voltage between 400 mV and 500 mV applied to the sensor signal pin.

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Flowchart

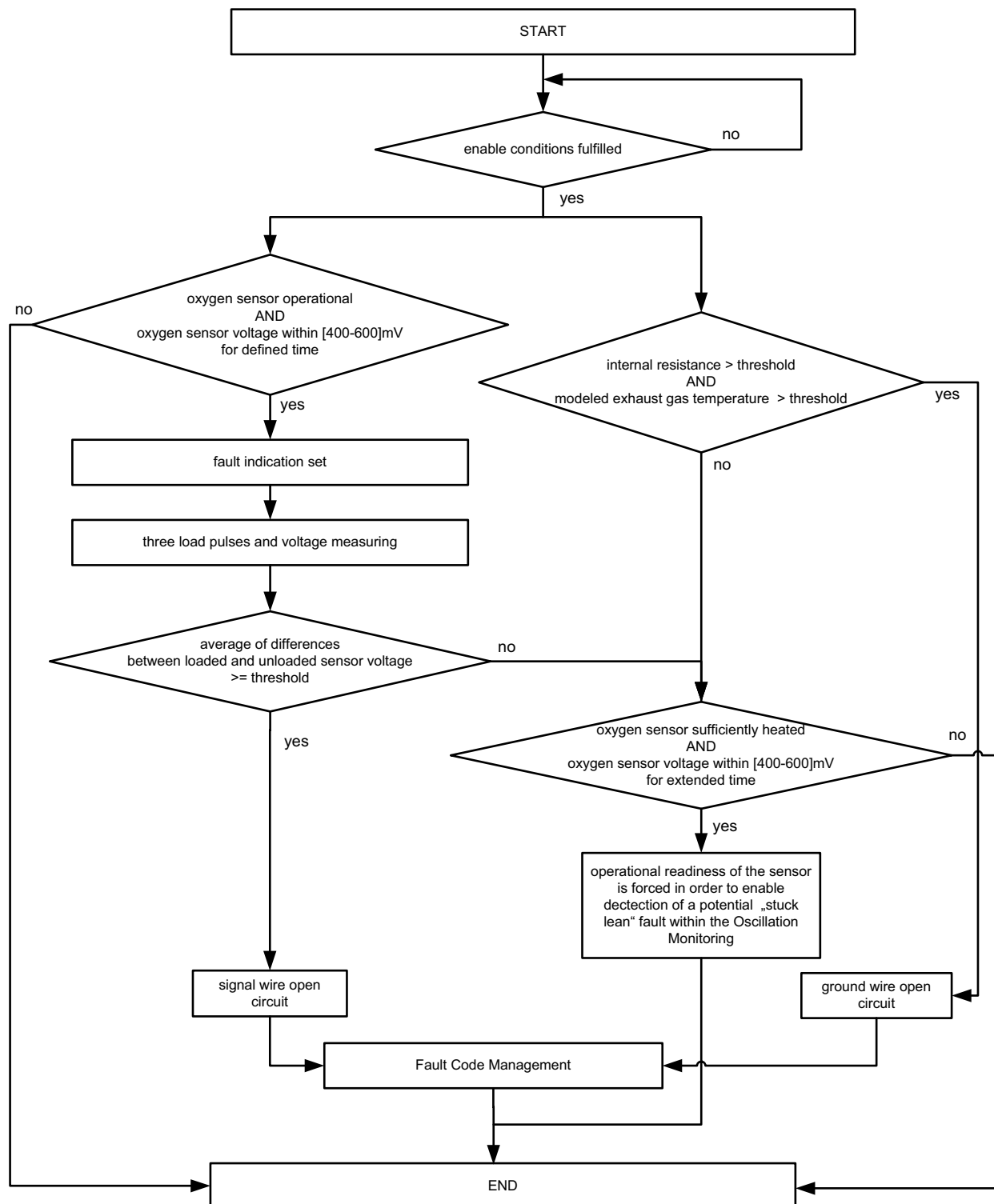


Figure 83: Flow chart signal or ground wire, open circuit

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7.6.2.5 Coupling of the heater switching onto the sensor signal, P0136 / P0142

Additional enable conditions for this diagnostic:

- In order to avoid diagnostic errors while the sensor is still too cold, the dew point in the vicinity of the sensor must have been exceeded for a calibrated time period.
AND
- Heater activation is off (PWM signal)

Monitoring strategy

A short circuit between the oxygen sensor heater and the oxygen sensor signal wire may cause heater couplings, which disturb the sensor signal. This fault case cannot be detected by the short circuit to battery detection, as the measured sensor voltage is implausibly high for a short time only, when the heater is switched off. The heater coupling diagnostic is based on measuring the corresponding sensor voltage at heater switch-off and comparing it to a defined threshold value.

Malfunction criteria

If the above threshold value is exceeded, a counter is incremented. When this counter exceeds the respective threshold value, the fault P0136 for the sensor 2 of bank 1 or the fault P0142 for the sensor 3 of bank 1 is set, and the operational readiness is withdrawn.

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Flowchart

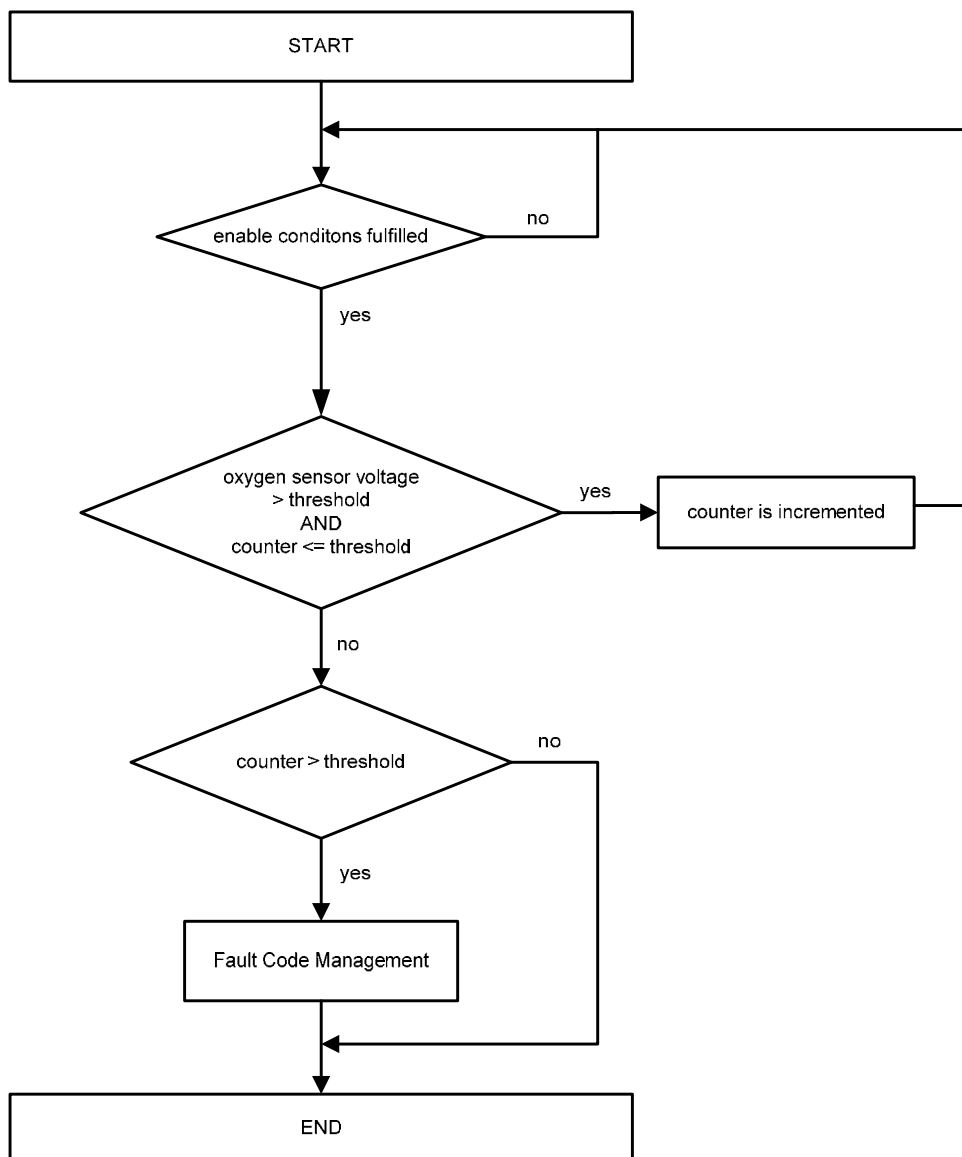


Figure 84: Flow chart coupling of the heater switching onto the sensor signal

7.6.3 In-Use Monitoring Performance Ratio

Since all above diagnostics are continuous monitors, neither numerators nor denominators are created.

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7.7 RO2 Sensor response time and transition time monitoring

7.7.1 Response rate monitoring (second and third sensor)

Aging, contamination or insufficient heating of the secondary (third) HO2S may slow down the sensor's response rate. A slow response rate could influence the catalyst diagnostic and can lead to higher emissions. Therefore this diagnostic function monitors the HO2S Response Rate. The monitor is designed to be executed repeatedly (multiple times) within the same driving cycle as long as the enable conditions are fulfilled or fulfilled again and consist of two monitoring functions. The Response Rate and the Transition Time monitoring function. The diagnostic function is executed while fuel cut-off during coast down driving condition is present. The diagnostic results are updated depending on the driving profile and the length of the fuel cut-off period. Typical monitoring frequency during a FTP72 is at minimum one to two events, during the Unified Cycle approximately 5 events and during normal driving on road in customer's hand the typical frequency is 10 to 15 events (based on engineering evaluation of road-data).

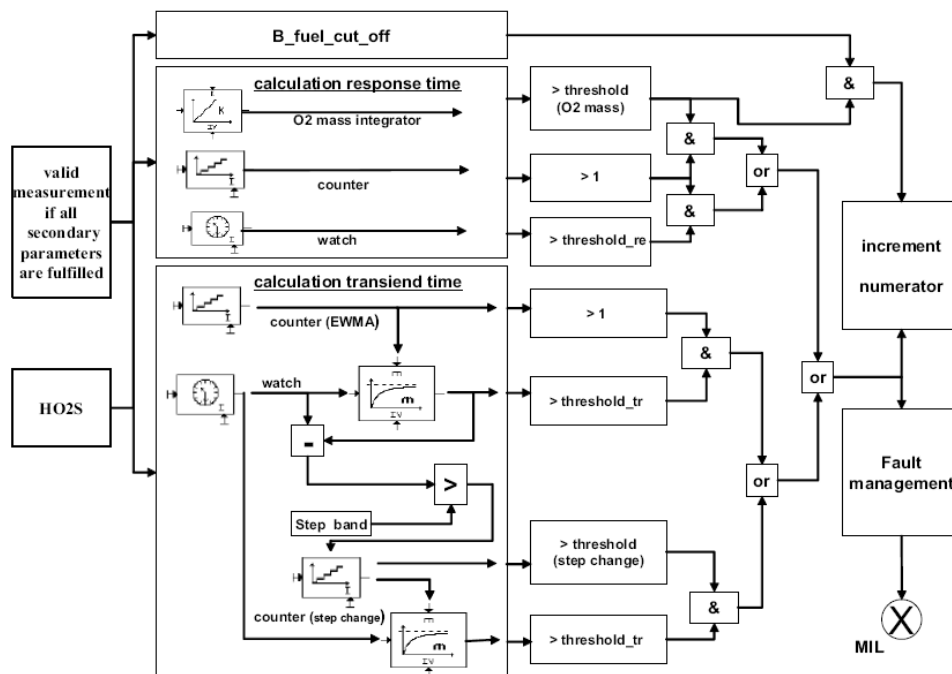


Figure 85: Second and third sensor – Functional schematic diagram

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Diagnostic Enable / Disable Conditions

Physical Parameters:

- HO2S ready
- Exhaust temperature post catalyst above an applicable level (typical value: 500°C) (dew point exceeded; to ensure homogeneous temperature distribution in the catalyst)
- Internal resistance of the HO2S is less than an applicable value
- HO2S voltage able to cross control level (typical value: 0.6-0.65V) of fuel trim (optional parameter)
- Exhaust mass flow exceeds an applicable value (typical value: ~15-25 kg/h)
- Slope of exhaust mass flow post catalyst is less than an applicable value ((typical value: Delta mass flow of ~10 kg/h)

Disable Conditions:

- Cycle flag of aging diagnostic HO2S post catalyst (lash) not set or failure(s) detected
- Cycle flag of EVAP purge diagnostic not set or failure(s) detected
- Cycle flag HO2S front catalyst not set or failure(s) detected
- No failures detected on final stage for O2S heater

Signal Evaluation / Validation:

For a robust monitoring function the HO2S signal needs to fulfill the following conditions ensuring a certain level of signal quality:

- HO2S voltage post catalyst exceeds a certain level (typical value: ~0.55-0.6V) before fuel cut-off occurs
- Fuel cut-off is present (Bit for this condition is set)
- HO2S in front of the catalyst is ready and shows definitely "lean" (e.g. Lambda is equal or greater than 10). The front HO2S signal range maximum value is equivalent to a Lambda of 16!
- The signal of the HO2S is monotone decreasing (outlier detection)*
- No HO2S faults detected by the dynamic diagnostic within the actual driving cycle

Outlier Detection

The outlier detection is necessary to exclude interferences of the catalyst during fuel cut-off conditions on the HO2S signal.

The rich-to-lean dynamic diagnostic of the HO2S post catalyst is based on the physical / chemical effect that during fuel cut-off the Lambda value changes in a step response from Lambda equal one to a Lambda equal or greater than 10 indicating the Oxygen storage capability (OSC) of the catalyst is exceeded. In reality the signal behavior of the rear O2S shows occasionally during fuel cut-off a first decrease of sensor voltage to approximately 0.4 Volts, remains at that voltage level for a certain time and then falls again to a voltage of 0.1 Volts. In this specific case the measured transition time is above the fault threshold of the diagnostic but can not be counted as a O2S failure because the event is based on chemical reaction within the catalyst.

Explanation of chemical effect:

At the beginning of the fuel cut-off the CO post catalyst reaches a minimum level because of the increase of Oxygen available in the catalyst allowing an increase in CO-conversion rate into CO₂, the O2S voltage decreases to approximately 0.4 Volts and stays at that level until the OSC of the catalyst is exceeded and the Oxygen level post catalyst increases causing another O2S voltage drop to approximately 0.1 Volts. This interference of the catalyst on the O2S voltage must be excluded from further evaluation by the monitor to prevent false failure detection by the response time diagnostic.

The described physical / chemical effect on the rear O2S signal is shown in figure below.

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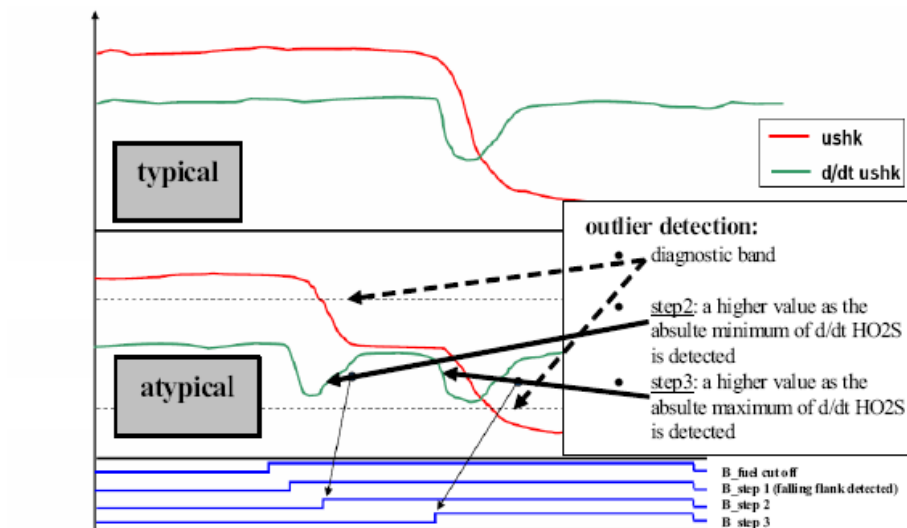
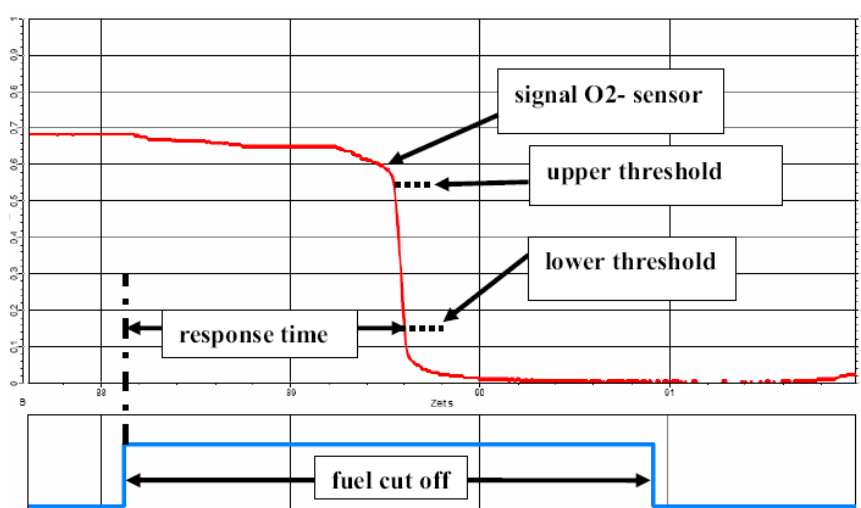


Figure 86: Second (Third) HO2S – Outlier Detection Chart

7.7.2 Monitoring of the response time

Definition

Once fuel cut-off is present, the response time is defined as the O2S signal time needed to fall below a certain voltage level (typical value: ~0.15V). This part of the diagnostic replaces the former diagnostic of the O2S aging-monitor (DLSAHK) conducted during fuel cut-off.



Second (Third) HO2S – 'Response Time'

Figure 87: Monitoring of response time

Application of response time diagnostic

The main factors influencing the response time diagnostic are the exhaust mass flow, engine operating condition and the aging level of the catalyst. The maximum time allowed needs to be determined on the catalyst with the highest OSC value (e.g. new catalyst). The evaluation of the response time therefore is a measure whether the O2S signal is capable to show a voltage drop below a certain level within a certain time.

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If the enable conditions are fulfilled and the O2S signal falls below an applicable voltage level (typical value: ~0.15 Volts) or the mass of Oxygen lead into the catalyst is above an applicable value (typical value: ~ 2.5 g O2) the measured value of response time is valid. Every valid value is evaluated and counted. The memory of response time and counted events will be cleared with power fail or with the OBD fault memory deleted by use of a Generic Scan Tool (GST).

If the event counter exceeds an applicable level the cycle flag can be set or in case of a response time measured exceeding the applicable fault threshold the diagnostic trouble code (DTC) is stored.

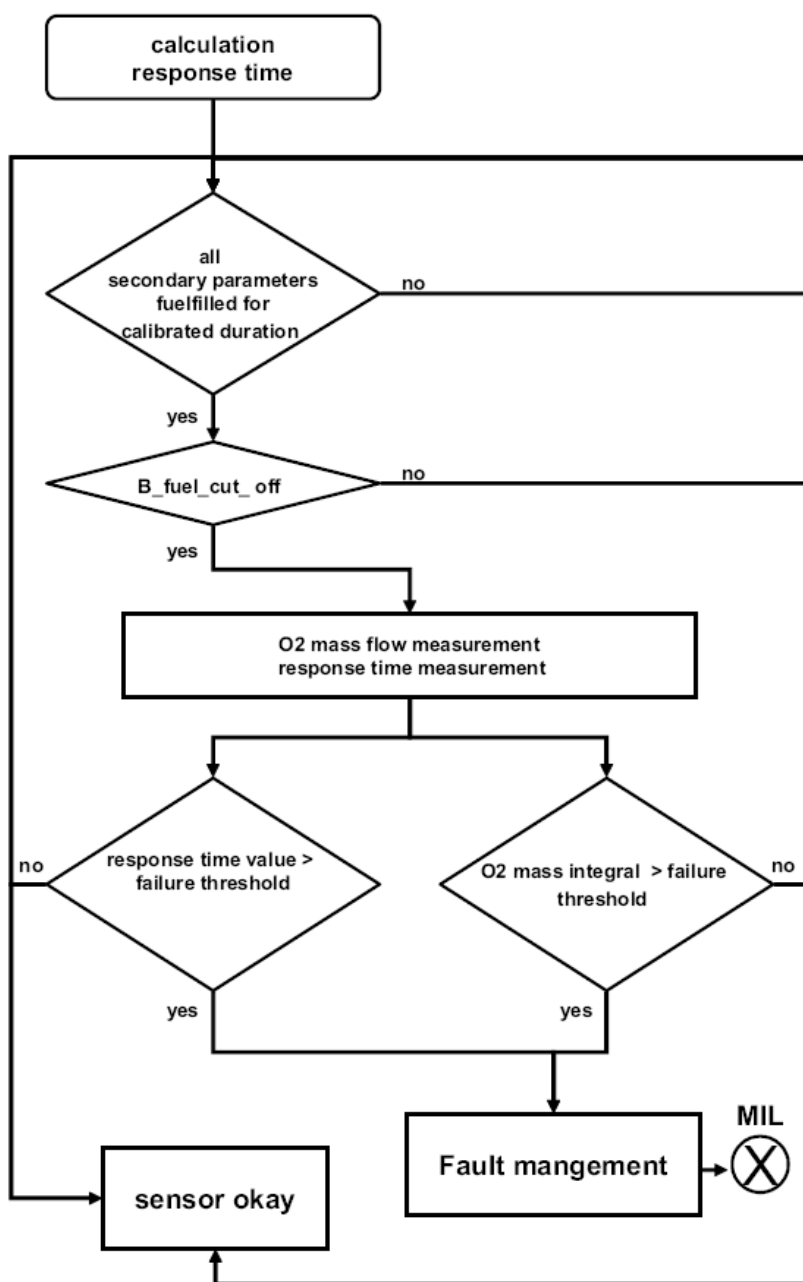


Figure 88: Second and third sensor – Calculation RO2S response time check

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7.7.3 Monitoring of transition time

Definition:

The transition time is defined as the time the O2S signal needs to pass-through an applicable voltage band (typical range: ~0.4-0.2V). This diagnostic function shall ensure that the reduced O2S signal dynamic (e.g. due to aging) exceeds a specified time threshold. This function is also used to improve the monitoring capability by minimizing the theoretical possibility of “false passes” of an aged catalyst caused by reduced HO2S dynamic.

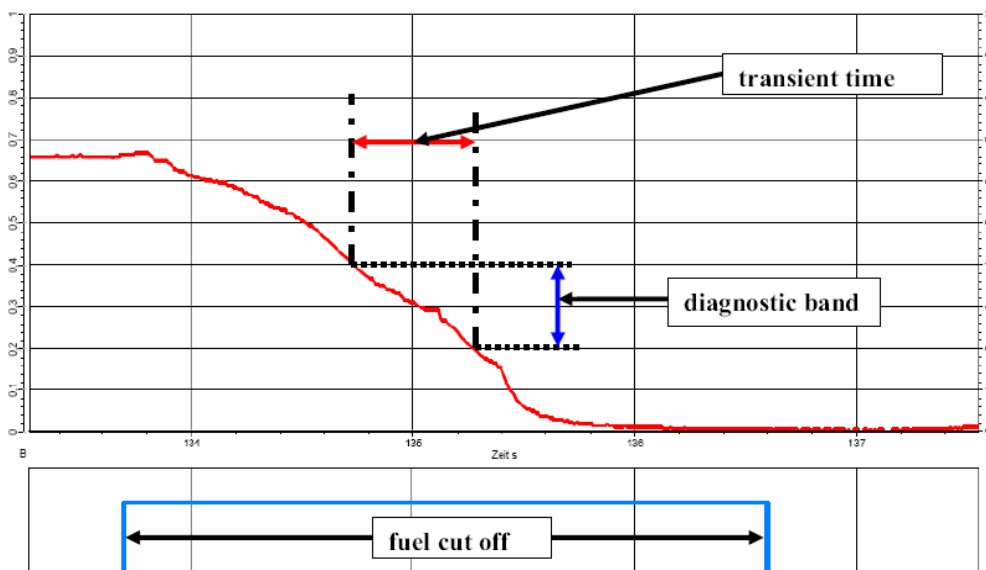


Figure 89: Second and third Sensor – transition time

Application of transition time diagnostic

If all enable conditions are fulfilled and the difference between actual and stored transition time value is less than a calibrated value (typical value: ~0.3V) the valid measured value is filtered (moving average) and an event counter is increased. The filter features a “step change” capability in case of difference between actual measured transition time and previously stored transition time is greater than a calibrated value (typical value: ~0.3V) a second filter (arithmetic mean value) and a second event counter is used. This ensures an adequate system reaction in cases of suddenly occurrence of great deterioration in O2S dynamic by storing a diagnostic trouble code in a shorter time. The memory of transition time and counted events will be cleared with power fail or with the OBD fault memory deleted by use of a Generic Scan Tool (GST).

If the event counter exceeds an applicable level the cycle flag can be set or in case of the filtered transition time exceeding the applicable fault threshold the diagnostic trouble code (DTC) is stored.

The following schematic shows the principle of the diagnostics

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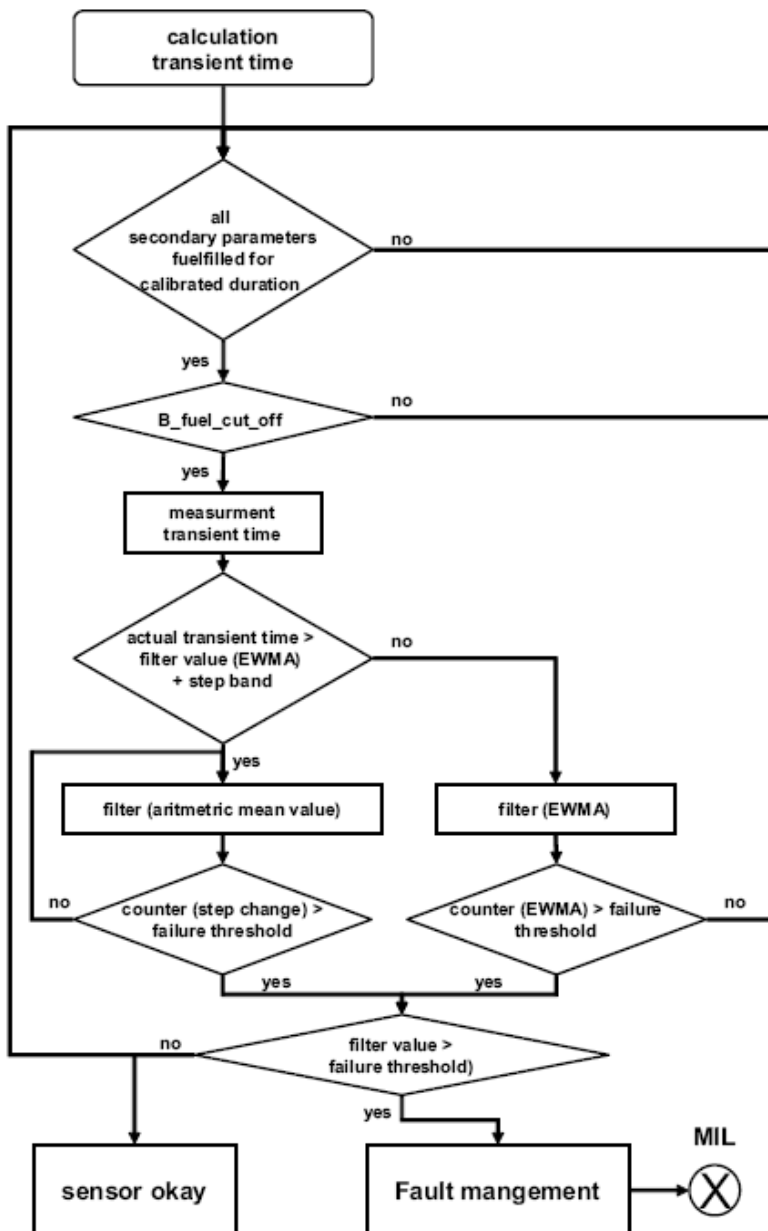


Figure 90: Second and third sensor – Calculation RO2S transition time check

7.7.4 In-Use Monitoring Performance Ratio

The incrementing of the numerator, the denominator and the ratio calculation for the HO2S “Response Rate” monitor is executed by the “IUMPR-Kernel” as a subroutine. Like all monitors for which a standardized tracking and reporting of the in-use performance is required, the HO2S “Response Rate” monitor reports to the “IUMPR Kernel”-function via status flags.

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Incrementing the numerator

The numerator is incremented, once per driving cycle in case of a fault is detected or if the Oxygen mass flow integral exceeds an calibrated value (typical value: ~2.5 – 3.5 g O₂) and a certain number of valid measurements has been conducted (typical value: ~1 - 3 measurements).

Incrementing the denominator

The denominator is incremented if the standardized conditions are fulfilled within the actual driving cycle and the monitor is not inhibited due to already stored faults or faults detected on the sensors necessary to determine the denominator itself.

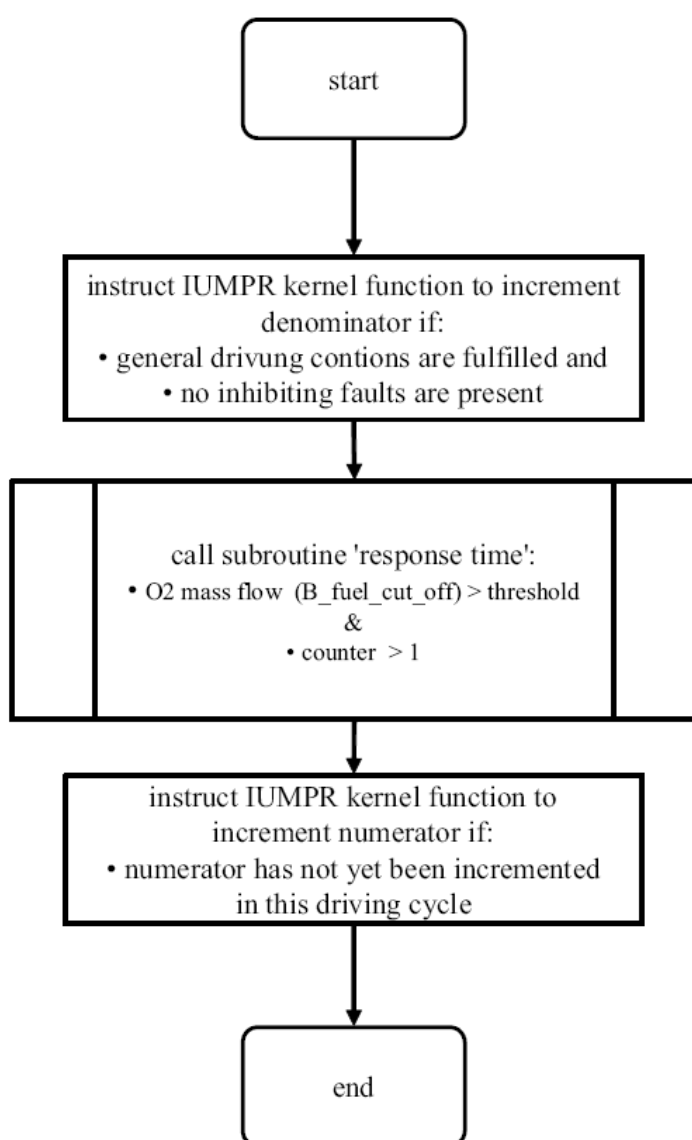


Figure 91: Second and third sensor – main RO2S check

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7.8 RO2 Sensor heater

For diagnostic of the sensor heater a specific current pulse is supplied via a load resistance and the voltage is measured. The intern resistance of the sensor heater is calculated with the voltage deviation. The result will be compared with a reference resistance map which considers ageing and sampling deviations. In case of internal resistance > map resistance the diagnosis stores a fault and the MIL will be illuminated.

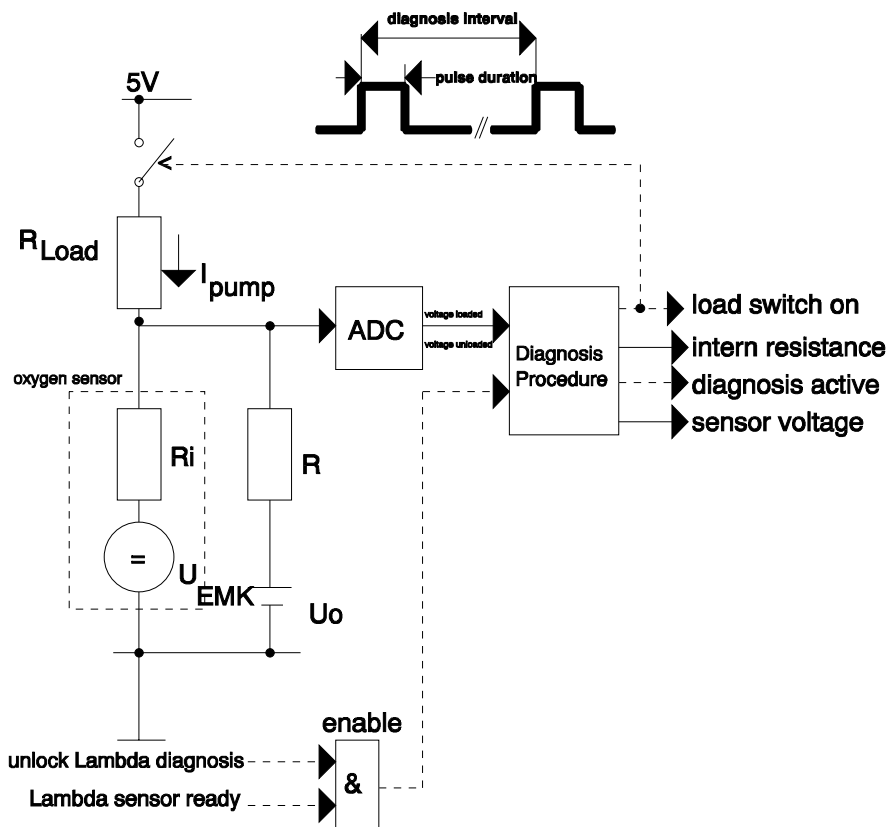


Figure 92: Monitoring structure RO2 Sensor heater

For proper function of the Oxygen sensors, their ceramic elements must be heated. A non-functioning heater delays or prevents the proper signal output for closed loop control and thus influences emissions. The heating up is controlled by the heater control.

This chapter describes the sum of all possible heater checks of the downstream HO2S.

The diagnosis of the heater of the downstream HO2S monitors the internal resistance of the Nernst cell. The internal resistance of the Nernst cell depends on both the electrical power of the heater and the exhaust gas temperature.

The resistance of the Nernst cell is measured and compared with the calculated temperature-dependant reference value. If the measured resistance exceeds the calculated reference value for a calibrated period of time, a malfunction is detected and a plausibility fault **HSB** (second sensor) / **HSF** (third sensor) is set.

Monitoring Conditions

- no faults of power stage of RO2 Sensor heater
- no faults of RO2 Sensor
- modeled exhaust gas temperature at the vicinity of the downstream front catalyst O2 Sensor lies within calibrated range
- engine soak time exceeds calibrated threshold

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- intake air temperature exceeds calibrated threshold
- battery's voltage lies within calibrated range
- engine is running
- engine start is finished
- voltage supply for heater of oxygen sensor is active
- measuring of internal resistance is active
- no signal interruption of RO2 sensor's ground
- no fuel cut-off
- enabled by the diagnostic scheduler

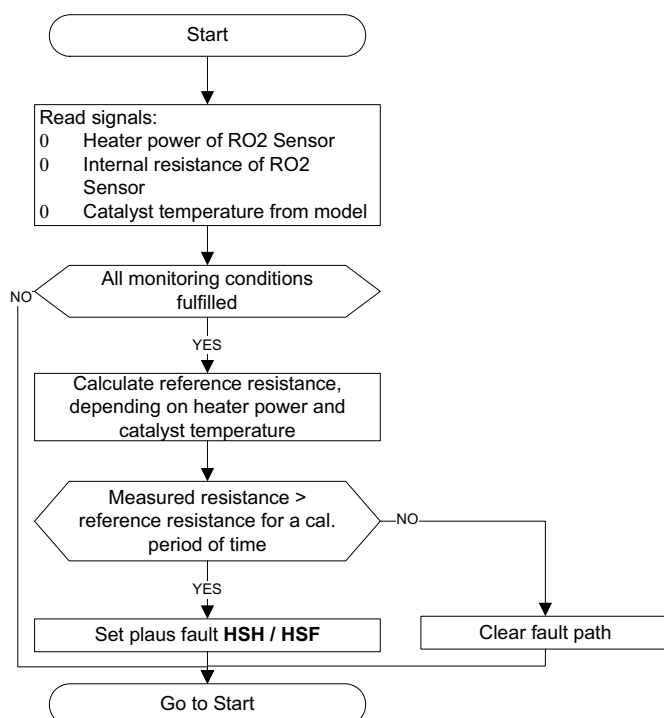


Figure 93: Flow chart heater diagnosis of RO2 Sensor

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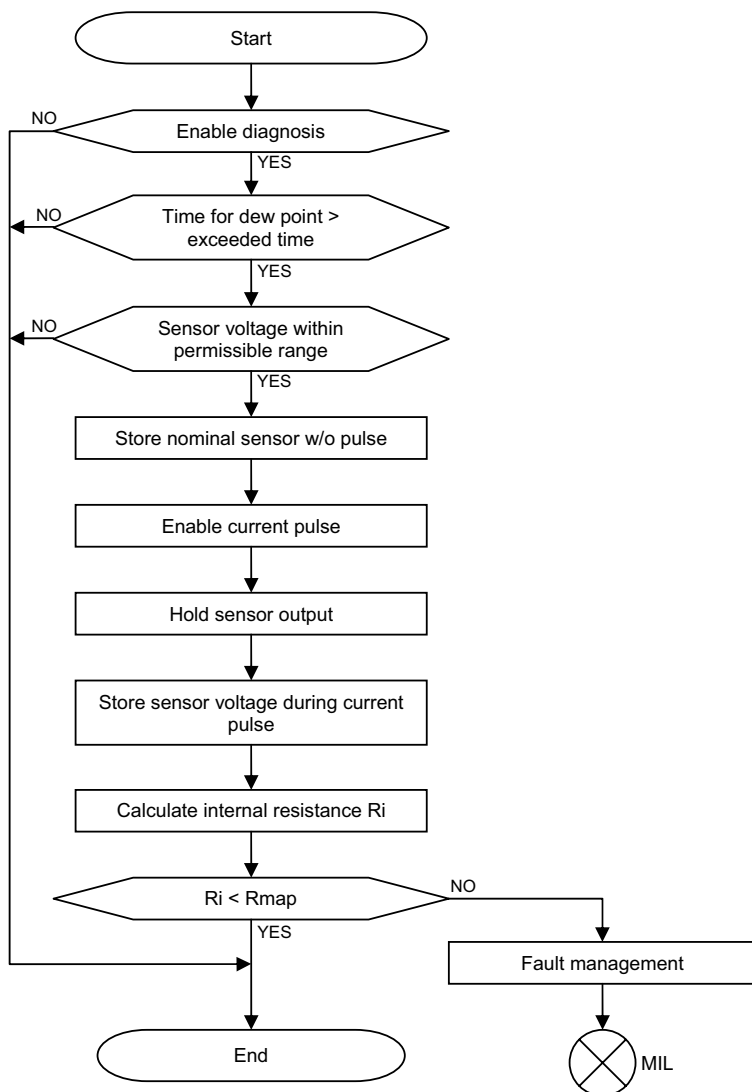


Figure 94: Flow chart RO2 Sensor heater

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8 EGR MONITORING

not applicable

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9.1 PCV Monitoring for 6.8 V8 engine

Applicable only for test groups:

OBD Group Name	Test group	Engine	Models	Standard	Controller / OBD II strategy
BBE-V	BBEXV06.84LA	6.8 V8T - 2 bank	Bentley Mulsanne	LEV II Bin 5	Bosch ME(D)17 BE-V

9.1.1 General Description

The PCV system uses a proprietary PCV valve and two one-way valves, as shown in Figure 95.

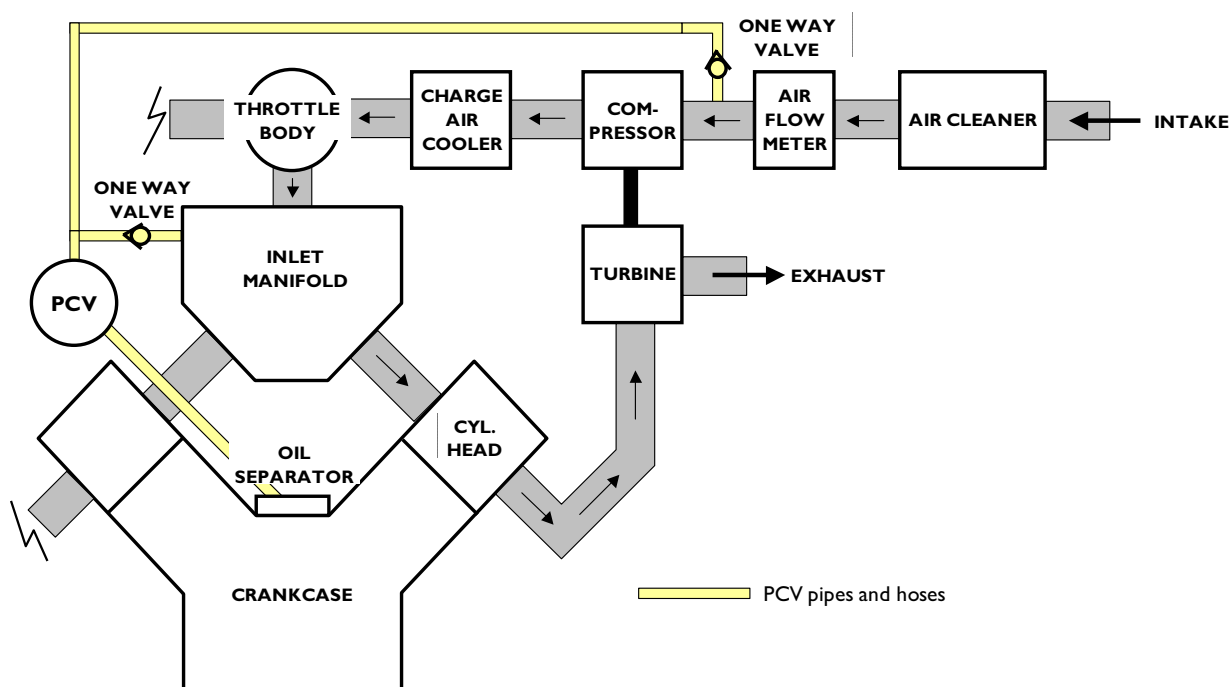


Figure 95: PCV schematic

The system is configured to ventilate the crankcase by means of inlet manifold depression under part load operation, when the turbochargers are off boost. Figure 96 illustrates the part load circuit. One of the one way valves prevents inlet manifold vacuum leaking back to the compressor inlet.

Under high load, on boost, operation, positive pressure in the inlet manifold is prevented from entering the crankcase by the second one way valve. Increased air velocity through the turbocharger inlet housing creates a depression in the PCV circuit to ventilate the crankcase. Figure 97 illustrates the full load circuit.

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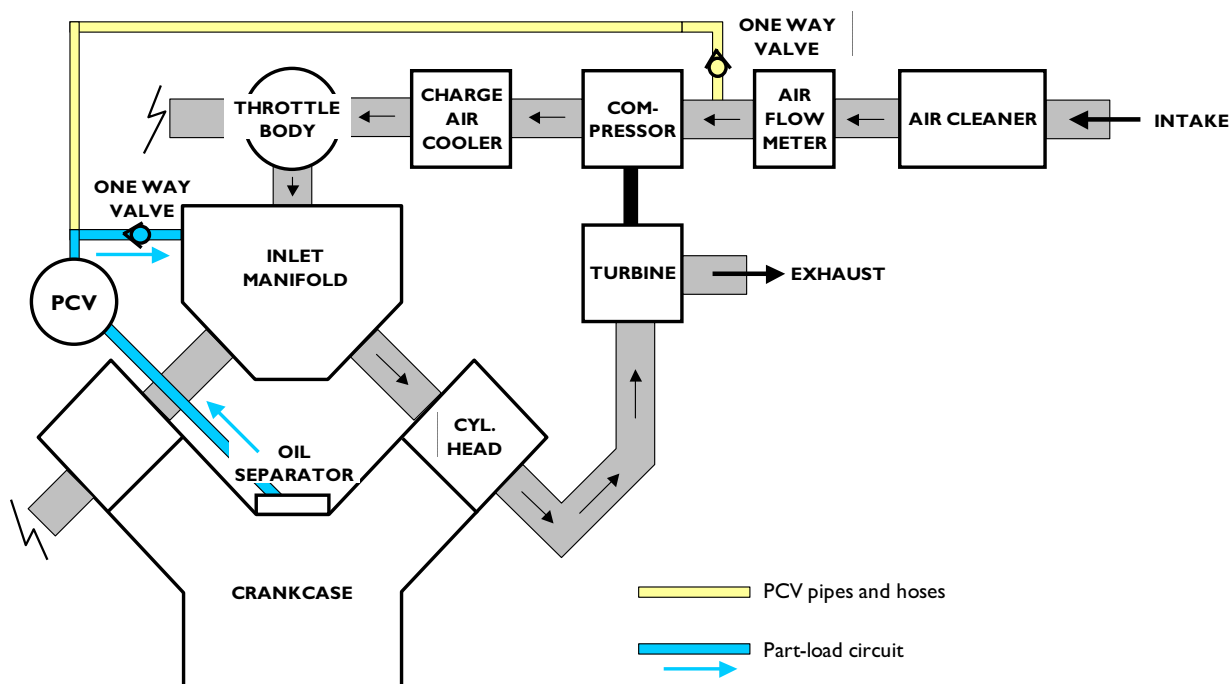


Figure 96: PCV part-load circuit

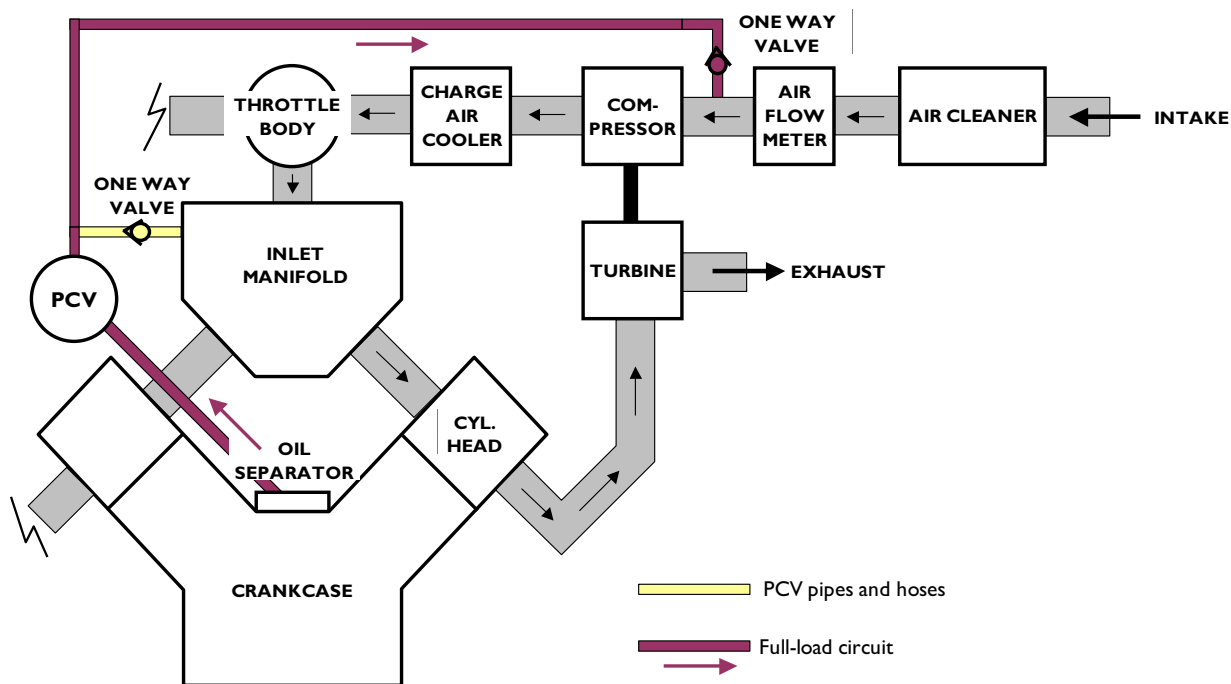


Figure 97: PCV full-load circuit

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9.1.2 OBD monitoring concept

The system has been designed such that most disconnections result in an air leak at the inlet manifold that can be detected by the fuel system monitor.

Disconnection of one part of the system (between one way valve and turbocharger inlet housing) is not detectable.

Design countermeasures have been implemented to ensure that this part of the system is significantly more difficult to disconnect than the adjacent parts. Figure 98 illustrates those parts of the circuit where disconnection is and is not detectable.

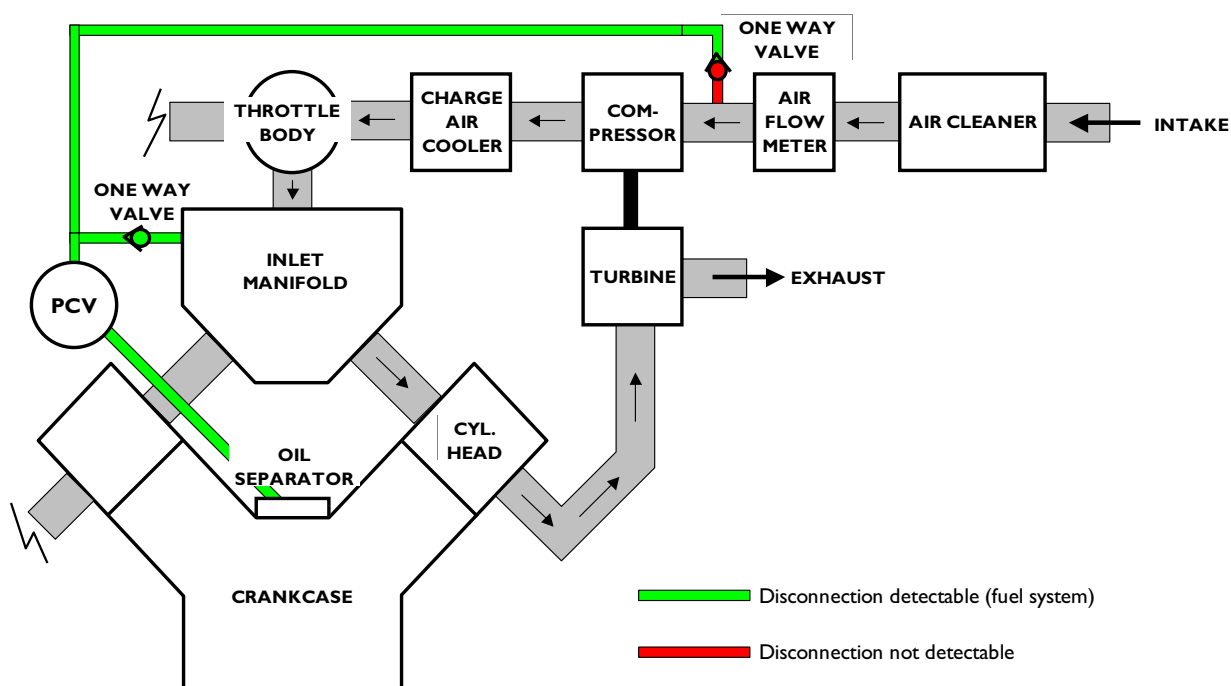


Figure 98: Disconnection detectability

Figure 99 is a view of the PCV components highlighting the part of the circuit where disconnection is not detectable.

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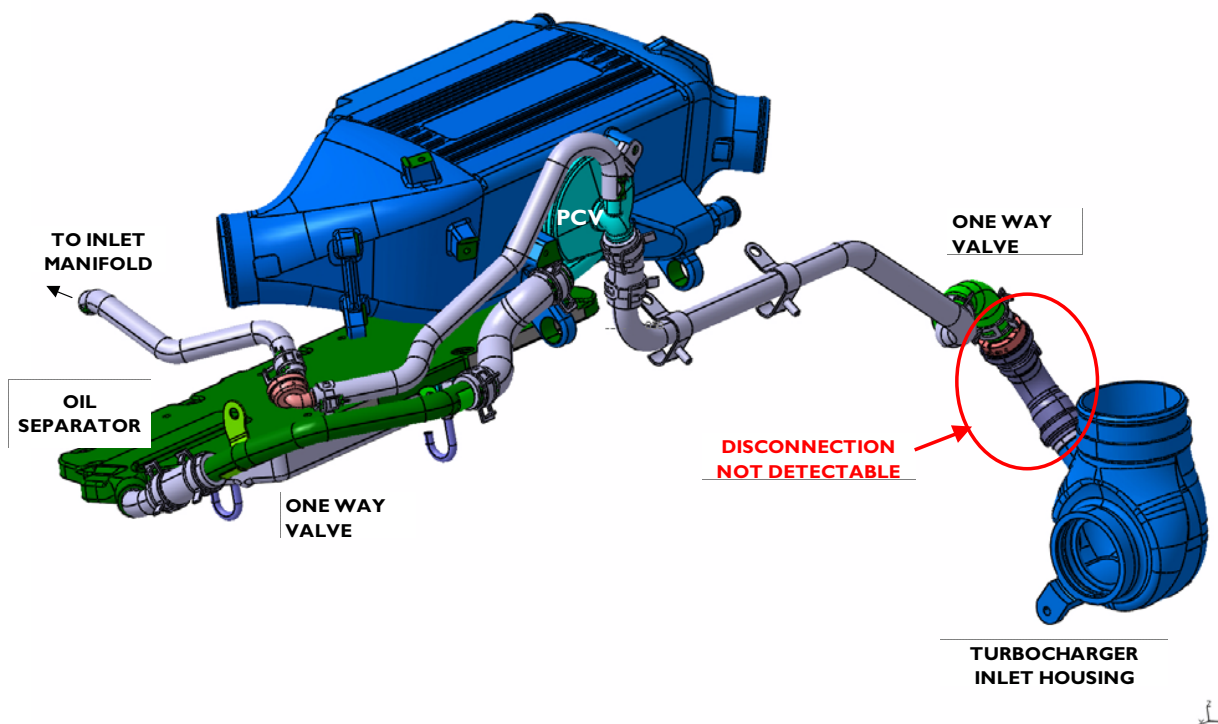


Figure 99: PCV component view

9.1.3 Design countermeasures

1) Plated steel spigot permanently attached to cast aluminium turbocharger inlet duct using Loctite 648 adhesive (Figure 100).



Figure 100: Permanently attached spigot

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2) Hose from one way valve to spigot secured using "one time fit" crimp clamp (Figure 101).

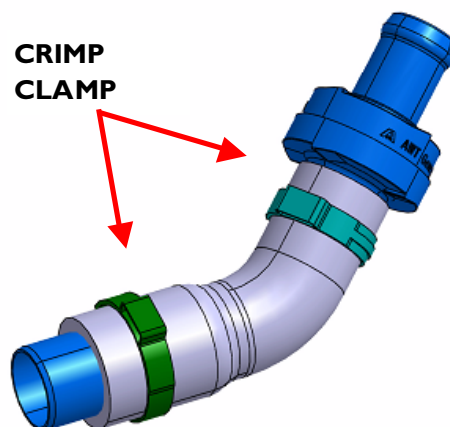


Figure 101: Clipping of hose from one way valve to spigot

3) Entire hose and crimp clamps enclosed in heat shrink sleeving to render them inaccessible (Figure 102).

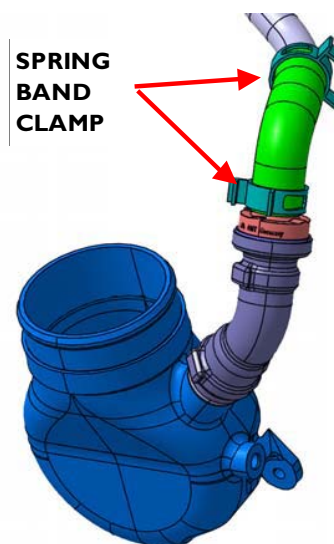
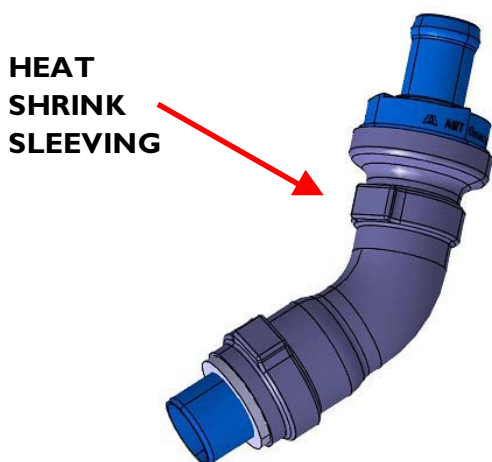


Figure 102: Application of heat shrink sleeving

4) Hose to one way valve secured using releasable (and re-useable) spring band clamp to provide serviceable connections (Figure 103).

Figure 103: Provision of serviceable connections

5) For service, the turbocharger inlet duct is supplied as an assembly with the one way valve, connecting hose secured by crimp clamps and enclosed in heat shrink sleeving.

This system design was presented and approved at VW/ARB meeting September 2, 2008.