# Project: MSS54

# Module: Lambda control

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# x.2 lambda control readiness

## x.2.1 lambda sensor readiness

Both lambda sensors are checked separately for their readiness for regulation.
There are four probe states: - Probe off (cold or defective)
- Probe activation monitoring
- Probe on (ready for use)
- Probe switch-off monitoring

The **probe off** state is reached after the reset and from the probe off monitoring state if the probe was in the probe off monitoring state for the time K_LA_T_AUS.

The **probe switch-on monitoring** state is entered when the probe voltage is greater than K_LA_USF or less than K_LA_USM.

**The probe** on state is reached when the probe switch-on monitoring state has been in place for the time K_LA_T_ON.

The **probe switch-off monitoring** state is entered when the probe voltage is within the limits K_LA_USM and K_LA_USF.

## x.2.2 Switch-on conditions

x.2.2.1 Engine temperature condition

The engine temperature condition is met if:
At idle: tmot > K_LA_TMOT_LL
No idle: tmot > K_LA_TMOT
with hysteresis K_LA_TMOT_HYS

x.2.2.2 Probe readiness

The probe readiness is fulfilled when the probe is in the probe on or probe off monitoring state.

x.2.2.3 Application release and DS2 shutdown

The constant K_LA_FREIGABE (bit 1 for controller 1 and bit 2 for controller 2) enables the controller.
The lambda controller can be switched off via the DS2 interface (see diagnosis).

## x.2.3 Switch-off conditions

x.2.3.1 Masking

The lambda controller is switched off when one or more cylinders are switched off.
A distinction is made between the two exhaust lines, ie only the control circuit in which the cylinders were suppressed is switched off. Suppression can occur in the following cases: speed limitation, hard speed limitation, ASC intervention, ASG intervention, overrun cut-off, defective ignition channel, etc.

x.2.3.2 Load threshold

The lambda controller is switched off if the load is above a threshold for longer than K_LA_T_TL.

This load threshold is taken from the characteristic curve KL_LA_N versus speed.

x.2.3.3 Operating state !ENGINE RUNNING or B_VMAX_SOFT

If the operating mode is not ENGINE RUNNING or if the soft VMAX limitation is in effect, the lambda controller is switched off.

x.2.3.4 For anti-knock enrichment

The lambda controller is switched off if the knock protection factor ti_f_klops is greater than 1.0.

x.2.3.5 Full load and speed threshold or if the injection time is too short

The lambda controller is switched off when the speed is greater than K_LA_N_VL and the operating state is FULL LOAD.

In overrun mode but not yet at B_SA, the injection time can become so short that the injection valves no longer open properly. The controller would then try to enrich the fuel and reach the limit. To prevent this, the controller is switched off,

if a **tix <** K_LA_TI_MIN

x.2.3.6 Secondary air pump

If the secondary air pump is active or the SLP is controlled via the DS interface, the lambda controller is switched off.

x.2.3.7 Idle speed control defective

If the idle speed control is defective, the lambda controller is also switched off in the "idle" operating state.

x.2.3.8 In case of BA or torque intervention

During acceleration enrichment or torque intervention, the lambda controller is switched off if

- the factor ba_f_ti > K_LA_BA_OFF_POS
- the factor ba_f_ti < K_LA_BA_OFF_NEG
- the factor ti_f_smg_x > 1.0
- the factor ti_f_asc_x > 1.0

x.2.3.9 Probe error

The lambda controller 1 or 2 is switched off if there is a sensor error in the respective bank.

x.2.3.10 Active diagnosis of the secondary air system

The lambda controller 1 or 2 is switched off when the secondary air system is actively diagnosed.

x.2.3.11 Fresh air supply in the exhaust system

When the exhaust system receives fresh air, the lambda controller is switched off.
This can happen if

- the SLP power amplifier has a fault
- the SLP system has an error
- the SLP valve output stage has a fault
- the TE system has a fault
- the TE output stage has a fault

x.2.3.12 Post-cath probe short circuit to UB

If the post-cath probe has a short circuit to UB, the lambda controller is switched off.

x.2.3.13 EVT, ZAS and brakes

In ZAS mode, the control loop is switched off if all cylinders in the control loop are disabled, otherwise not. In braking mode, both control loops are switched off.

## x.3 lambda sensor voltage processing

The lambda sensor voltage is amplified by the sensor amplifier LMxxxx by a factor of 4.5 and converted by the A/D converter. The sensor voltage is calculated as follows:

$$us = \frac{digit * 5000mV}{4.5 * 1024} = digit * 1.08507$$

The formula in the processor is:

us = (K_LA_US_M * digit ) / 1024 ) - K_LA_US_NP

K_LA_US_M Slope in mv/1024 digit
K_LA_US_NP Zero offset shift in mV
Both values are applicable.

## x.4 Lambda sensor heater

The lambda sensor heating relay is always switched off when the operating state is not ENGINE RUNNING.

In the ENGINE RUNNING operating state, the lambda probe heating relay is switched on with a delay after the start has ended. The delay time is calculated from the characteristic curve KL_LAH_T_EIN via the engine temperature when leaving the START operating state.

In the ENGINE RUNNING operating state, the lambda probe heating relay is switched off when the load is greater than a threshold. This threshold is determined from the characteristic curve KL_LAH_N_AUS via the speed. When the load falls below this threshold again with the hysteresis K_LAH_HYS_AUS, the heating is switched on again.

## x.5 lambda controller

There is one lambda sensor for each of the 3 cylinders and therefore also one lambda controller for each of the 3 cylinders.
Cylinders 1, 2 and 3 are controlled by lambda controller 1. Cylinders 4, 5 and 6 are controlled by lambda controller 2.
The lambda controller is a two-point controller of the PITV type, which is a PI controller with a one-sided delay time. A "positive" delay time causes a rich shift and a "negative" delay time causes a lean shift. All three controller parameters (KP, KI, TV) are stored in maps for load and speed.

The two-point behavior comes from the lambda sensor, which is a step sensor and therefore only the sign of the control difference can be evaluated.
Therefore, an oscillation of the manipulated variable f_la_controller occurs with an amplitude that is determined by the proportional component la_kp, the integrator slope la_ki and the control system dead time.

Since the dead time depends on the load and speed (injection, intake, combustion, exhaust, gas transit time to the probe, response time of the probe), the controller parameters must also be gas and speed dependent.
In order to achieve a one-sided lambda shift at different operating points, the controller switchover is delayed by the time tv. The advantage of this method compared to an asymmetrical P-step is that a larger lambda shift can be achieved with the same controller amplitude.

The controller formula is:

f_lax = 1.0 + f_la_kp + f_la_ki

with: f_la_kp = sgn * la_kp

f_la_ki = f_la_ki + (sgn la_ * ki)

la_kp is the initial value of the map KF_LA_KP

la_ki is the initial value of the map KF_LA_KI

sgn = -1, if the sensor voltage us >= K_LA_UREF i.e. the exhaust gases are rich.

sgn = +1, if the sensor voltage us < K_LA_UREF i.e. the exhaust gases are lean.

In case of fat shift.
If the sensor voltage jumps from lean to rich, the integrator is stopped for the time tv. If the sensor voltage jumps back to lean and the time tv has not yet expired, the integrator is started again and continues to integrate until the sensor voltage jumps back to rich. The time tv now continues.

After this time has elapsed, the control variable f_lax jumps by the value
f_la_kp = (-1) * la_kp and the integrator integrates from f_la_ki = f_la_ki + (-1) * la_ki .
If the sensor voltage now jumps from lean to rich, the manipulated variable jumps again by the value f_la_kp = (+1) * la_kp and the integrator integrates to f_la_ki = f_la_ki + (+1) * la_ki.

The lean shift occurs analogously to the rich shift.

## x.6 Lambda adaptation

### x.6.1 principle

The injection quantity is influenced by the adaptation multiplicatively and additively so that the lambda controller corrections are minimal. This means that the desired lambda is set even when the lambda controller is switched off.
The adaptation compensates for aging phenomena and copy control.

The multiplicative factor is effective at high air flow and high load.
The additive value is effective at low air flow and low speed. It compensates for the leakage air.

Since this is a two-part exhaust system with two lambda sensors, the lambda adaptation for the two exhaust lines is also calculated separately.

The adaptation is calculated in the 100msec task.

### x.6.2 adaptation release

The adaptation will be released when
- the lambda control is active and
- the engine temperature has exceeded the threshold K_LAA_TMOT and
- the intake air temperature is less than K_LAA_TAN and
- the load is smaller than a threshold from the characteristic curve KL_LAA_N
- there is no adaptation barrier due to the diagnosis and
- the time since the last probe jump is less than K_LAA_T_US and
- the tank vent valve is closed.

### x.6.3 Adaptation factor: f_ti_a1 and f_ti_a2

The adaptation factor is adapted if
- the air mass is greater than K_LAA_ML_SU2 and
- the load is greater than K_LAA_TL_SU2.

The adaptation factor is calculated using the following formula:

**f_laax = (( f_lax -1 ) / K_LAA_TAU2 ) + f_laax(old)**

The adaptation factor f_laax is limited to K_LAA_FAK_MAX and K_LAA_FAK_MIN.

### x.6.4 Adaptation offset: ti_a1 and ti_a2

The adaptation offset is adapted if - the
air mass is smaller than K_LAA_ML_SO1 and
- the speed is less than K_LAA_N_SO1.

The adaptation offset is calculated as follows:

laa_regx = low-pass filtered lambda control factor ( f_lax ) with the time constant K_LAA_TAU.

First, the average control factor deviation of 1.0 is converted into an injection time.

help = ( laa_regx - 1 ) * tl x 2

The resulting injection time is then integrated (adapted).

**laa_offx = ( help / K_LAA_TAU1 ) + laa_offx**

The integrator output is limited to a minimum and a maximum.

laa_offx is limited to K_LAA_OFFSET_MAX and K_LAA_OFFSET_MIN.

The adapted value laa_offsetx is then weighted (normalized) by the speed.
Here, the speed n40 is limited to a minimum of K_LAA_N_NORM_MIN, since if the speed is too low, the value ti_offset_adaptx could become too large, e.g. if the speed "divests" when starting.

The offset that is included in the injection path is:

**ti_ax = laa_offx * ( K_LAA_N_NORM / n40 )**

## x.7 diagnosis

The lambda controller diagnosis only takes place if
- the lambda controller is active (there is no mixture-influencing error)
- no injection valve is controlled via DS2
- there is no probe error

The upper and lower regulator stops are checked. The two lambda regulators for the two banks are checked separately.
If the lambda controller receives an extended controller factor due to a suspected short circuit to ground of the sensor, the lambda controller diagnosis does not work.

An error (short circuit to positive) is stored if the lambda control factor is limited to the stop K_LA_FMAX for longer than K_LA_T_FMAX. Bit 2 is set in ed_lax.

An error (short circuit to ground) is stored if the lambda control factor is limited to the stop K_LA_FMIN for longer than K_LA_T_FMIN. Bit 1 is set in ed_lax.

# x.8 constants, characteristics, maps, variables

## x.8.1 constants

| | |
|---|---|
| K_LA_FREIGABE | Release constant for switching on and off the Lambda controller and lambda adaptation<br>Bit 0: free<br>Bit 1: Controller 1 enabled<br>Bit 2: Controller 2 enabled<br>Bit 3: free<br>Bit 4: free<br>Bit 5: Adaptation factor enabled<br>Bit 6: Adaptation offset enabled<br>Bit 7: free |
| K_LA_TMOT | engine temperature threshold for lambda activation |
| K_LA_TMOT_LL | Engine temperature threshold for lambda activation in idle |
| K_LA_TMOT_HYS | Motor temperature threshold hysteresis |
| K_LA_T_TL | Delay time for lambda shutdown under load exceedance |
| K_LA_N_VL | speed threshold for lambda shutdown at full load |
| K_LA_UF | Probe voltage for fat threshold at standby identifier |
| K_LA_UM | Sensor voltage for lean threshold at standby detection |
| K_LA_T_EIN | switch-on monitoring time for probe readiness detection |
| K_LA_T_AUS | Switch-off monitoring time for probe readiness recognition |
| K_LA_US_MAX | maximum probe voltage |
| K_LA_US_MIN | minimum probe voltage |
| K_LA_US_TAU | filter time constant for probe voltage |
| K_LA_US_NP | offset for probe voltage conditioning |
| K_LA_US_M | slope of the probe voltage conditioning |
| K_LA_FMAX | maximum lambda correction factor |
| K_LA_FMIN | minimum lambda factor |
| K_LA_T_FMIN | time threshold for lower controller stop |
| K_LA_T_FMAX | time threshold for upper controller stop |
| K_LA_US_REF | sensor voltage at lambda 1.0 |
| K_LAH_HYS_AUS | Load hysteresis for lambda heating shutdown |
| K_LAA_TAN | switch-on threshold of the intake air temperature |
| K_LAA_TMOT | switch-on threshold of the engine temperature |
| K_LAA_TAU | Time constant for the low-pass filter to smooth the lambda factor |
| K_LAA_FAK_MAX | Maximum value of the adaptation factor |
| K_LAA_FAK_MIN | minimum value of the adaptation factor |
| K_LAA_ML_SO1 | upper air mass threshold for the adaptation offset |
| K_LAA_ML_SU2 | lower air mass threshold for the adaptation factor |
| K_LAA_N_SO1 | upper speed threshold for the adaptation offset |
| K_LAA_TL_SU2 | lower load threshold for the adaptation factor |
| K_LAA_TAU1 | time constant for the adaptation offset |
| K_LAA_TAU2 | time constant for the adaptation factor |
| K_LAA_T_US | time threshold since the last probe jump |

K_LAA_OFFSET MAX upper limit of the adaptation offset

K_LAA_OFFSET_MIN lower limit of the adaptation offset
K_LAA_N_NORM standardized speed for weighting the adaptation offset

K_LAA_N_NORM_MIN minimum speed for weighting of the adaptation offsets

### x.8.2 characteristics

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|---|---|
| KL__LA_N | KL for load threshold for lambda shutdown via speed |
| KL_LAA_N | KL for load threshold for lambda adaptation via speed |

### x.8.3 maps

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|---|---|
| KF_LA_KP | KF for proportional part of the lambda controller |
| KF_LA_KI | KF for integral part of the lambda controller |
| KF_LA_TV | KF for delay time of the lambda controller |

### x.8.4 variables

| | |
|---|---|
| st_la | global status byte for Lambda<br>Bit 4: Probe 1 is defective<br>Bit 5: Probe 2 is defective |
| st_la_e1 | Status byte for switch-on conditions of the lambda controller 1<br>Bit 0: Lambda controller 1 active<br>Bit 1: Condition for probe 1<br>Bit 2: Motor temperature condition<br>Bit 3: Controller enable by K_LA_FREIGABE Bit 1<br>Bit 4: Lambda sensor 1 off<br>Bit 5: Lambda sensor activation monitoring1<br>Bit 6: Lambda sensor 1 on (ready for operation)<br>Bit 7: Lambda sensor switch-off monitoring 1 |
| st_la_e2 | Status byte for switch-on conditions of lambda controller 2<br>Bit 0: Lambda controller 2 active<br>Bit 1: Condition for probe 2<br>Bit 2: Motor temperature condition<br>Bit 3: Controller enable by K_LA_FREIGABE Bit2<br>Bit 4: Lambda sensor 2 off<br>Bit 5: Lambda sensor activation monitoring2<br>Bit 6: Lambda sensor 2 on (ready for operation)<br>Bit 7: Lambda sensor switch-off monitoring 2 |
| st_la_aus | Status byte for switch-off conditions of both lambda regulator<br>Bit 0: Cylinders 1,2 and/or 3 are hidden<br>Bit 1: Cylinders 4,5 and/or 6 are hidden<br>Bit 2: Load threshold exceeded<br>Bit 3: START or soft VMAX limitation (B_VMAX_WEICH |

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|---|---|
| | Bit 4: Knock protection factor or reset factor are active<br>Bit 5: Full load and n > K_LA_N_VL<br>Bit 6: With secondary air injection<br>Bit 7: free |
| st_laa | status byte of the lambda adaptation<br>Bit 1: Lambda adaptation enabled for controller 1<br>Bit 2: Lambda adaptation for controller 2 enabled<br>Bit 5: Adaptation factor enabled<br>Bit 6: Adaptation offset enabled<br>Bit 7: Adaptation blocked due to diagnostic error |
| la_time1 | Time at which the load threshold for the lambda circuit was exceeded |
| la_time2 | time of entry into the lambda sensor states ON or OFF MONITORING for probe 1 |
| la_time3 | time of entry into the lambda sensor states ON or OFF MONITORING for probe 2 |
| us1 | lambda sensor voltage 1 |
| us2 | lambda sensor voltage 2 |
| la_kp | proportional part from the map |
| la_ki | integral part from the map |
| la_tv | delay time from the map |
| tv1 or tv2 | current counter readings of the current delay times for lambda controller 1 or 2 |
| st_la_reg1 or 2 | Status word of lambda controller 1 or 2 |
| f_la1 or 2 | Lambda controller factor (control variable) of lambda controller 1 or 2 |
| f_la_kp1 or 2 | Proportional part of the lambda controller factor for lambda controller 1 or 2 |
| f_la_ki1 or 2 | Integral component of the lambda controller factor for lambda controller 1 or 2 |
| usx_wechsel_time | time of the last probe jump |
| f_ti_adapt1 or 2 | total adaptation factor for the injection path |
| f_laa1 or 2 | adaptation factor 1 or 2 |
| laa_off1 or 2 | Adaptation offset 1 or 2 without speed weighting with 32 bit resolution |
| ti_a1 or 2 | Adaptation offset 1 or 2 with speed weighting for the injection path |
| ed_lax | Status variable for lambda controller:<br>Bit 1: lower controller stop<br>Bit 2: upper controller stop<br>Bit 5: Error in error filtering<br>Bit 6: Error entered in the error memory |