**Project: MSS60**

**Module:** **Operating Mode Manager**

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**Changes:**

|  |  |  |
| --- | --- | --- |
| **Version** | **Date** | **Comment** |
| S310 | 2.8.2004 | First version |
| S320 | 8.11.2004 | Add Minihub mode |
| S330 | 1.12.2004 | Calculation of wi misplaced in the moments manager |
| S330 | 1.12.2004 | Renaming evt\_state to bm\_evt\_state |
| S330 | 4.12.2004 | Minihub changed from 4V to 3V |
| S340 | 8.12.2004 | Manual mode no longer has its own mode (bm\_evt\_state) |
| S360 | 20.2.2005 | Image of hysteresis changed by KF\_BM\_AUSWAHL was misunderstood |
| S360 | 30.5.2005 | Operating mode transitions now implemented |
| S370 | 1.7.2005 | Brake operation added 4-stroke |
| S380 | 18.10.2005 | 12-stroke operating mode newly added |
| S380 | 18.10.2005 | Operating mode transitions revised in documentary |
| S380 | 2.11.2005 | In case of transition from braking mode AÖ=140KW before AÖ=180KW |
| S380 | 2.11.2005 | Transition from ZAS changed: AÖ now realized via KL |
|  |  |  |

**Table**

Amendments 2

1 Functional description 2

1.1 Description of operating modes 2

1.1.1 Closing time of the inlet valves 2

1.1.2 Number of operated valves 2

1.1.3 Cylinder shutdown 2

1.1.4 12-stroke operation 2

1.1.5 Ministroke for inlet 2

1.1.6 Brake operation 4-stroke 2

1.2 Transitions of operating modes 2

1.2.1 Different number of active outlet valves 2

1.2.2 Transition to cylinder shutdown 2

1.2.3 Transition from cylinder shutdown 2

1.2.4 Transition from fired to braking mode (4-stroke) 2

1.2.5 Transition of brakes to fifled (4-stroke) 2

1.2.6 Transition of ZAS to 12-stroke 2

1.2.7 Transition from 12-stroke to ZAS 2

1.2.8 Transition from 4-stroke to 12-stroke 2

1.2.9 Transition from 12-stroke to 4-stroke 2

1.3 Calculation of operating mode 2

1.4 Function diagram 2

2 Data of the mode manager 2

# Description

In order to enable optimal throttle-free operation of the EVT motor throughout the operating range, different operating modes of the valve drive must be adjusted. For this purpose, a suitable operating mode is selected in this function depending on load and speed. The current modes of operation are briefly described below:

## Description of modes

The following terms are used for the following description:

|  |  |
| --- | --- |
| **Label** | **Description** |
| UTH | Lower dead point before the high-pressure phase (combustion) |
| Ao | Outlet Opens |
| As | Outlet Closes |
| Eo | Entrance Opens |
| It | Entrance Closes |
| Cycle  Work game | The cycle or working play here denotes the entire motor process that begins with the charge change when the outlet valve is opened. The first valve activities are thus EO and AS. The charge change is then terminated by ES. Now the compression and combustion takes place with expansion. The last action of a work game is AO. |
| Cycle consistency | Cycle consistency describes that all valve control times EO, AS, ES and AO, as well as ignition and injection for each working play are held together for each cylinder. Cycle consistency only affects dynamic operations. Cycle consistency is an important prerequisite for an EVT motor control unit, since due to the digital control of the valves, each valve control time can be greatly changed from work play to work play and it is necessary to ensure that all parameters of a working play fit together. |
| Pmi | Indexed medium pressure [bar].  Calculation: Integral p dV via a working game divided by cylinder volume |
| Wi | Indexed specific work [kJ/dm3].  Calculation: Integral p dV via a working game divided by cylinder volume  (equals the value of pmi \* 0.1) |

### Closing time of the inlet valves

These methods for load control differ by the position of the closing time of the inlet valve. Both FES and SES can be combined with all other processes, e.g. cylinder shutdown, ministroke or 12-stroke process.

#### FES (Early Admission Closes)

In fES mode, the inlet valve is closed in front of the UTH to set a desired torque. After closing the inlet valve, an expansion takes place up to the UTH. Since the subsequent compression in the p-V diagram is almost on this expansion line, no losses are incurred as a result.

#### Late Entrance Closes (SES)

Although the SES mode has disadvantages compared to FES in terms of fuel consumption and dynamics, it is used at higher engine speeds (above 4000 rpm) because at high speeds the actuators are not sufficient to realize the FES operating mode. In the SES mode, the inlet valve is closed to adjust a desired torque after the UTH. At low torques, the time of closing the inlet valves would be so late that an inadmissible heating of the suction tube would occur and the time of closing the inlet valves would come close to the ignition time. Therefore, the load range for SES downwards is limited to a load of pmi = approx. 5 bar. To adjust lower engine loads, the SES method must be combined with a cylinder shutdown or an i-clock process (e.g. 12-cycle method). This combination lifts the load per fired cylinder.

### Number of operated valves

These operating modes differ in the number of operated valves per working game. They can be combined with all other methods, e.g. cylinder shutdown or i-clock process.

#### 4 Valve operation (4V)

In 4V operation, 2 inlet valves and 2 outlet valves are operated per working game.

#### 3 Valve operation (3V)

In 3V operation, 2 inlet valves and 1 outlet valve are operated per working play. In order to achieve an even load on both outlet valves, the other outlet valve is operated alternately per working play.

#### 2 Valve operation (2-V)

In 2V operation, 1 inlet valve and 1 outlet valve are operated per working play. Since only one injection nozzle is used per cylinder, which injects the fuel into both inlet channels, both inlet valves are operated alternately from work play to work play. In each working game, the diagonally arranged outlet valve is actuated. This means that, for example, in a work game, inlet1 and outlet2 are pressed and in the following work game entry2 and outlet1 (see picture). Due to the symmetrical arrangement of the channels, a reproducible charge change is achieved.

Entrance1

Entrance2

Outlet1

Outlet2

### Cylinder shutdown

During cylinder shutdown, cylinders 2 and 3 are switched off, i.e. only cylinders 1 and 4 are fired. The valves of the switched-off cylinders are kept in a closed state.

### 12-stroke operation

The 12-stroke process corresponds to a 4-stroke procedure in which 8 empty cycles are inserted. One bar corresponds to 180 degree crank angle with a 4-cylinder, i.e. a complete upward movement or a complete downward movement of the piston. Thus, a working play of a 12-stroke process thus takes 6 crankshaft revolutions.

In the operating mode 12-stroke process (bm\_evt\_state = 7), all cylinders are ignited once in the time when the first cylinder makes 3 working cycles. This changes the distance between the high-pressure processes (see Table 1).

|  |  |  |  |
| --- | --- | --- | --- |
|  | | **4 -Clock** | **12 - Clock** |
| **N44 / 4 - cylinder** | Za | 180 °KW | 540 °KW |
| **N64 / 8 - cylinder** | Za | 90 °KW | 270 °KW |

Table 1: Distance of HD processes N44 / N64

By increasing the number of cycles, the shift of operating points and also the operating area will be further extended by the load control procedure SES. One can speak of an increased form of cylinder shutdown. The 12-stroke process takes place in 4V mode.

Figure 1.1: Pressure curves in the 12-stroke process (4-cylinder, comparison to 4-stroke operation)





Figure 1.2: Pressure curves in the 12-stroke process (8-cylinder, comparison to 4-stroke operation)

Advantages 12-stroke operation:

* Wall film effects in stationary mode are reduced due to the same ignition distances for all cylinders
* The cooling of the cylinders is avoided by the changing "switch off" of the cylinders
* Consumption reduction due to displacement of operating point
* Reduction of valve drive power
* Empty cycles can be represented almost without loss of charge change

The control edges for EÖ and ES are controlled in the 3rd ASP using the 12-stroke process, the control edges for AÖ and AS in the 1st ASP of the respective cylinder. This results in a high-pressure process in every 3rd ASP.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Clock | | 1 | | 2 | | 3 | | 4 | | 5 | 6 | 7 | 8 | 9 | 10 | | | 11 | | 12 |
| Operation Cylinder | | Expansion | | Pushing out | |  | | | | | | | | | | | | Sucking | | Compression |
| Operation Valves | | AÖ AS | | | | | Valves closed | | | | | | | | | | EÖ ES | | | |
|  | **⭍** | |  | | ~~Injection of one-on-one~~ | | | |  | | | | | | | Injection of one-on-one | | |  | | |

Table 2: Sequence of cycles in 12-stroke mode (no temporal representation)

### Minihub for inlet

In the mini-stroke process, in contrast to the normal full stroke method, the valves are held at a small valve stroke (ministroke). This is possible via a controlled actuator operation using an actuator strokesensor. The mini-stroke reduces the suction tube pressure shafts because the valves are not closed so abruptly. The valve set-up speed can be minimized more easily because only low strokes and speeds are used. In addition, for low speeds and engine loads, a possibility is offered for generating turbulence and mixture preparation, which can improve the engine efficiency. The ministroke can also be changed as a parameter. Thus, the size of the ministroke is available as an additional parameter for setting a motor load. In the Minihub mode, only the inlet is operated with a small amplitude, the outlet with a full stroke. Two inlet valves and only one outlet valve (3V) are operated tobegged.

### Brake operation 4-stroke

Due to special valve control times, the motor can be used for braking, whereby the braking torque can be infinitely adjusted via the valve control times. Only the outlet valves are used to avoid flushing the fresh mixture. In the area of the lower dead point, the outlet valves are closed. Subsequently, a compression takes place until a desired pressure is reached, at which the outlet valve is opened. The compressed gas now flows from the cylinder into the exhaust system. When the piston moves downwards, gas from the exhaust system is sucked into the cylinder. In order to achieve maximum braking effect, the described procedure should be repeated at each crankshaft rotation. This corresponds to a 2-stroke procedure.

Brake operation should only be possible from a speed of double idle speed (currently n=1400 min-1). During braking operation, a high negative p**mi** is intentionally generated in order to delay the vehicle without the mechanical brakes.

During braking operation, no fuel is injected and the charge change losses are only realized via the outlet valves. The negative moment is achieved by closing the outlet valve around the lower dead point and opening it at a certain cylinder pressure, thus causing compression losses. The entrances remain closed.

Figure 2 4-Stroke Brakes

In four-stroke braking, the outlet valve is closed around the lower dead point (540°KW n. ZOT). The location of AS thus determines the respective filling. Depending on the desired braking torque, AÖ is between UT and OT (180°....360°KW n. ZOT). The later the opening time, the higher the compression losses and thus the braking performance to be achieved.

The maximum possible braking torque is limited by the cylinder pressure at the time of AÖ. If the cylinder pressure at AÖ is too high, the valve cannot open against the gas force and is only opened at an indeterminate time after OT, which means that the braking power is not clearly definable. This would also reduce the braking torque, as the valve opens during the decompression phase.

Brake operation is only carried out via the outlet valves to avoid pushing through air. In addition to the acoustics, the high pressure amplitudes would also be problematic in the case of a suction-side realization of the brake operation.

## Transitions of operating modes

In contrast to the transition functions of conventional engines, these transitions only consider the transition from one work play to the next, individually for each cylinder. First, only the valve drive-specific transitions are to be implemented. The transitions for the fuel path will be implemented at a later time. In the following description, the first work game with Arbeitsspiel\_1 and the subsequent cylinder with Arbeitsspiel\_2 is denoted.

### Different number of active outlet valves

Since the opening of the outlet valves (AÖ) is always the last action of a work play, the number of open outlet valves does not match the number of valves to be closed when transitions from 4V operation to 3V or 2V operation. In this case, AÖ belongs to Arbeitsspiel\_1 and AS to Arbeitsspiel\_2, i.e. 2 outlet valves are opened, but only one outlet valve is closed. In this case, special treatment must be carried out which closes the second outlet valve at the same time as the first outlet valve. In reverse transition from 3V or 2V operation to 4V operation, only one outlet valve is opened, but both outlet valves are to be closed. In this case, the closing of the 2nd outlet valve must be suppressed.

### Transition to cylinder shutdown

The transition from a working game in which a cylinder is operated to a working game in which the cylinder is switched off should be as follows:

1. Normal outlet opening as last action of the fired work game
2. Exhaust closing in charge change-OT

Now all valves are closed and as long as the cylinder shutdown is active, no valves should be operated.

### Transition from cylinder shutdown

In the PV diagram of a switched-off cylinder, the compression and expansion lines are almost coincident on top of each other. In the lower dead point, a strong vacuum is achieved. If the outlet valve were to be opened at that time, the exhaust gas would flow into the cylinder at the speed of sound, swirling oil. This oil would enter the exhaust system unburned during the subsequent compression. In order to avoid this problem, the outlet valve should be opened as late as possible.

The transition from a work game in which a cylinder is switched off to a fired work play should be as follows:

1. Exit Open is replaced by the value from the **characteristic KL\_BART\_AO\_ZAS.**
2. Now all valve control parameters of the fired work game can be used. (Don't forget that all open outlet valves must be closed!)

### Transition from fired to braking mode (4-stroke)

During the transition from fired operation to braking mode, the first ASP still uses the AÖ control edge from the fired operation and the AS control edge is already used by the brake.

The entry control edges are suppressed.

Example (fired operation -> brakes):

**Transition**

|  |  |  |  |
| --- | --- | --- | --- |
| **Fired** | **Transition** | **Brakes** | **Brakes** |
| **AÖ** FES  = 180 | **AÖ** FES  = 180 | **AÖ** BB  = 320 | **AÖ** BB  = 320 |
| **AS** FES  = 360 | **AS** BB  = 540 | **AS** BB  = 540 |  |
| **EÖ** FES  = 360 | **EÖ** BB  =  **--** | **EÖ** BB  =  **--** |  |
| **ES** FES  =440 | **ES** BB  = -- | **ES** BB  = -- |  |

**Fired**

**Brakes**

### Transition of brakes to refined (4-stroke)

During the transition from braking to fired operation, the already calculated control edge for AÖ (by the value AÖ=140°KW n. ZOT ) must be overwritten.

Example (brakes -> fired operation):

**Transition**

|  |  |  |  |
| --- | --- | --- | --- |
| **Brakes** | **Transition** | **Fired** | **Fired** |
| **AÖ** BB  = 320 | **AÖ** BB  = **320 140** | **AÖ** FES  = 180 | **AÖ** FES  = 180 |
| **AS** BB  = 540 | **AS** FES  = 360 | **AS** FES  = 360 |  |
| **EÖ** BB  = -- | **EÖ** FES  = 360 | **EÖ** FES  = 360 |  |
| **ES** BB  = -- | **ES** FES  =440 | **ES** FES  =440 |  |

**Fired**

**Brakes**

### Transition from ZAS to 12-stroke

During the transition from operation with ZAS, the control edges for AÖ and AS are controlled in the first ASP, the control edges EÖ and ES are not controlled.

The control edges AÖ and AS are only reactivated 3 ASP later, the control edges for EÖ and ES are reactivated after 8 empty cycles.

Injection for all cylinders must be activated and must be controlled with 8 empty cycles, as shown in Table 2.

Care must be taken to ensure that the transition between the two modes is only possible when there is an overlap in the high-pressure process of the active cylinders of both modes. (see⇒ Table 3 and Figure 1.4.: Changing ZAS to 12-stroke is only possible here in the areas marked in red.)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ZAS ⇒ 12 T | 12 T ⇒ ZAS | 4 T ⇒ 12 T | 12 T ⇒ 4 T |
| N44 | 1080 | 540[[1]](#footnote-1) | 180[[2]](#footnote-2) | 540 |
| N64 | 540 | 2701 | 902 | 270 |

Table 3: KW difference for possible BA changes

Figure 3: Possible transitions of ZAS in 12-stroke (active with ZAS Zyl 1 and 4)



### Transition from 12-stroke to ZAS

When switching from 12-stroke operation to ZAS operation, the control edges for the inlet valves must be controlled again in the 1st ASP.

The cylinders are controlled after the ignition sequence 1-3-4-2 (4-cyl), the cylinders 2 and 3 (or 1 and 4) are not controlled (=> ZAS operation).

A change from 12-stroke to ZAS is possible every 540 °KW [270 °KW]. Depending on which cylinder has an overlap in the HD process at the time of change, it is decided which group will enter ZAS mode.

The transition 12-stroke → ZAS does not have to occur at the times when there is an overlap in the HD process.

### Transition from 4-stroke to 12-stroke

The change from 4-stroke to 12-stroke mode can be made every 180 °KW [90°KW]⇒ (Table 3). The change takes place "step by step", i.e. that each cylinder that has finished the HD process in 4-stroke changes to the 12-stroke mode and is then operated with new ignition sequence and ignition distance.

### Transition from 12-stroke to 4-stroke

The change from the 12-stroke to the other operating  modes takes place anlog to the transition 12-stroke ZAS. However, all cylinders are controlled according to the "normal" ignition sequence.

The transition from 12-stroke operation to 4-stroke operation can take place every 540 °KW on the 4-cylinder, but generally always at the time when there is a overlap ping-out of the HD processes. (see⇒ Figure 4 A change from 12-stroke to 4-stroke is only possible here in the magenta-marked areas.)

Figure 4: Possible transitions 12-stroke ⇒4-stroke



## Calculation of operating mode

The main part of the function is theLook-Up-Table **KF\_BM\_AUSWAHL** and **KF\_BM\_AUSWAHL\_KATH** for cat heating (only in the next SW version!!!). This look-upUptable calculate, without interpolation of the z‑values, via the inputs **wi** and **n** the operating mode **bm\_evt\_state**.

Table 4 shows the definition of **bm\_evt\_state:**:

|  |  |
| --- | --- |
| **bm\_evt\_state** | **Mode** |
| 0 | Cylinder shutdown + SES + 4 valves |
| 1 | Cylinder shutdown + FES + 3 valves |
| 2 | FES / 2V |
| 3 | FES / 3V |
| 4 | FES / 4V |
| 5 | SES / 4V |
| 6 | Brakes 4 cycle |
| 7 | 12 clock / 4V |
| 8 | Cat heating / 3V |
| 9 | Cat heating / Minihub |
| 10 | Cat heating / cylinder shutdown |
| 11 | Minihub / 3V |
| 12 | Full load / 4V |
| 13 | Start |
|  |  |
|  |  |

Table 4 Modes of operation

In order to prevent a back and forth jumping in a load state between the states, the inputs are switched via a hysteresis.

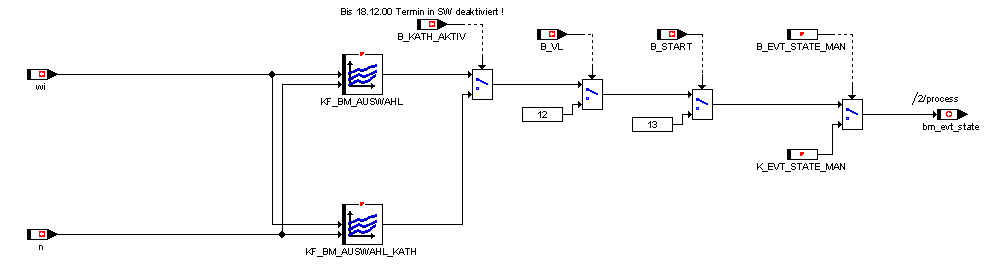
Figure 5 Hysteresis of the axes of KF\_BM\_AUSWAHL



Only when the input size enters the hatched surfaces can the state change. The spaces remain undefined and **bm\_evt\_state** retains the last value. The distance between the support points of the speed axis shall not be less than 200 rpm. The same applies to the wiaxis, again the distance must not be less than 0.05!

It is important to determine the support points for the different operating modes in **KF\_BM\_AUSWAHL**  and  **KF\_BM\_AUSWAHL\_KATH** is the conformity with the boundary support points of the corresponding base data set – control edges, ignition angle, air mass, throttle angle angle and preposition angle (see evt\_momentenrealisierung.doc)!

## Function diagram



# Data of the mode manager

The function is calculated in the angle-synchronous task in the master.

Description of the variables:

|  |  |  |
| --- | --- | --- |
| bm\_evt\_state | Operating state evt | Ub |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

Description of the application data:

|  |  |  |
| --- | --- | --- |
| KF\_BM\_AUSWAHL | Characteristic field operating state vt | uw/uw/ub |
| KF\_BM\_AUSWAHL\_KATH | Kennfeld Operating status evt for cat heating | uw/uw/ub |
| B\_EVT\_STATE\_MAN | Switching to manual bm\_evt\_state bm\_evt\_state | Ub |
| K\_EVT\_STATE\_MAN | manual bm\_evt\_state default | Ub |
| KL\_BART\_AO\_ZAS | Control edge AO at transition from ZAS | uw/uw |
|  |  |  |

1. Change to the next possible cylinder group [↑](#footnote-ref-1)
2. Change in stages [↑](#footnote-ref-2)