UNIC DF Training

Engine Control System, UNIC-DF

WIN GD

Control Systems Overview

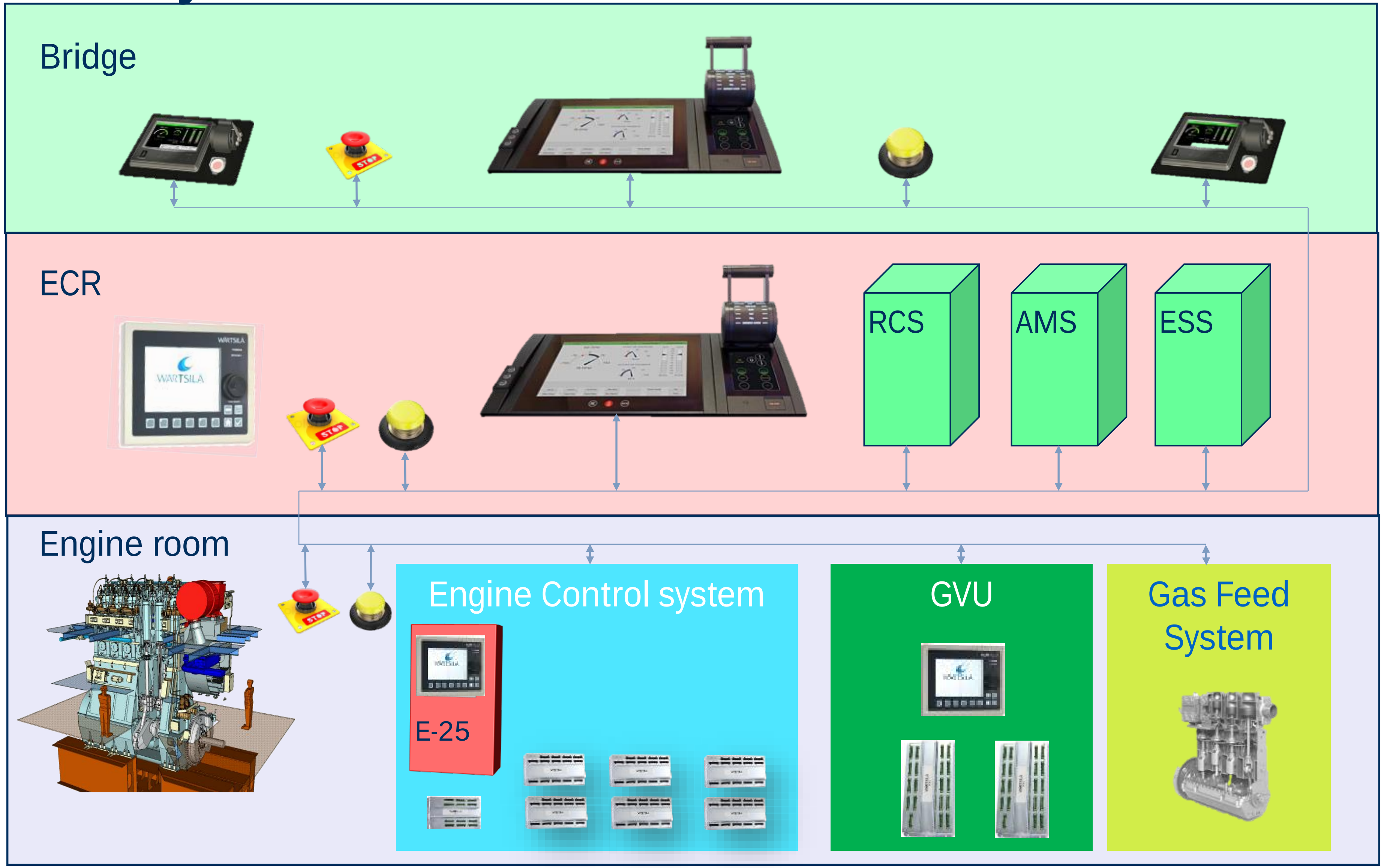
The Control System consists of

- Internal engine control UNIC-flex with
  - UNIC-flex hardware
  - Sensors and Actuators
  - Electronic Governor

- External Propulsion Control System, PCS (normally not WinGD supply) with
  - Remote Control (ECR, Bridge)
  - Safety System

- External Ship's Alarm Monitoring System, AMS (normally not WinGD supply)

Control Systems Overview with GVU



Engine Control System

Engine control system UNIC

UNIC is the core engine control, it processes all actuation, regulation and control directly linked to the engine like:

- Speed control (installations with CPP ➔ speed program in PCS)
- Common rail monitoring and pressure regulation
- Injection, exhaust valve and start valve control and monitoring
- Cylinder lubrication
- Interfacing external systems via CANopen and ModbusRTU
- Engine performance tuning, IMO setting and –monitoring with data storage
- Scavenge Air pressure, Gas rail pressure Control
- Engine power estimation
- Combustion control(Pmax, Pcomp, Miss-Firing and Knock control)
- System diagnostics and failure indication

Engine Control System

Engine control system UNIC

- Each cylinder has its own two CCM modules(One Diesel CCM, one Gas CCM) for the cylinder related functions

- One IOM module per engine for common functions

- One MCM controller module for speed control and other common functions

- Two LDUs in ECR and LOCAL for monitoring, setting parameters and manual engine control

Electronic Modules for ECS

- **LDU-20, Local Display Unit**
  - 2 units per engine
  - external bus interfacing local user interface
- **CCM-20, Cylinder Control Module**
  - 2 units per cylinder
  - cylinder functions
  - distributed engine functions
- **MCM-11, Main Control Module**
  - 1 unit per engine
  - external bus interfacing
  - engine speed control
- **IOM-10, Input Output Module**
  - 1 unit per engine
  - Data acquisition unit

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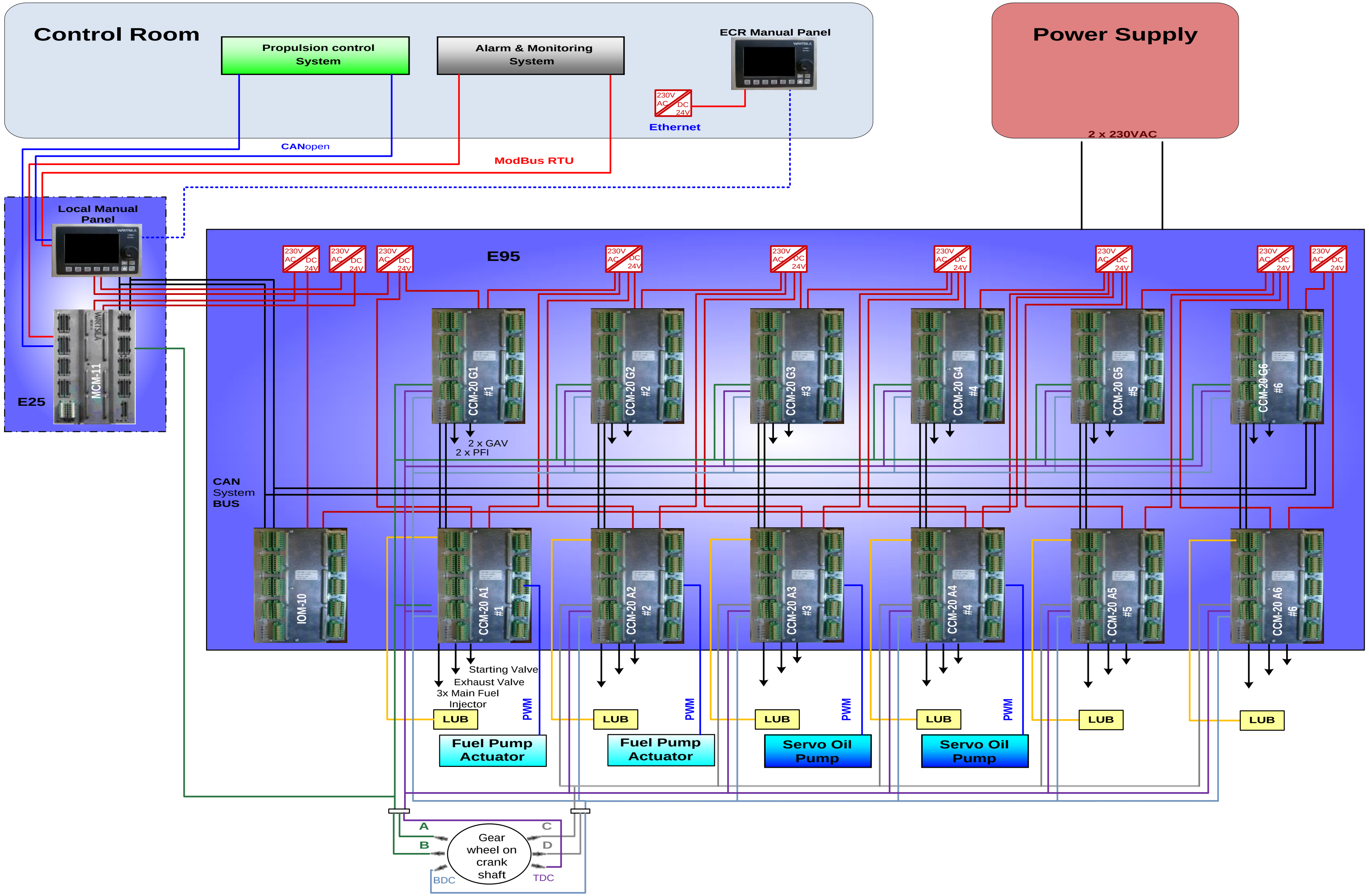
Bus Systems

Bus systems used for UNIC-flex:

- CAN Bus
- CANopen Bus
- ModBusRTU
- Ethernet

Control System Layout



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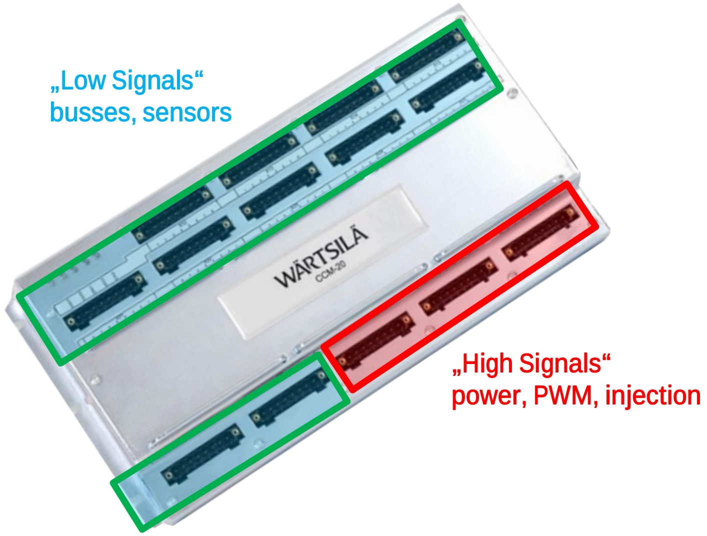
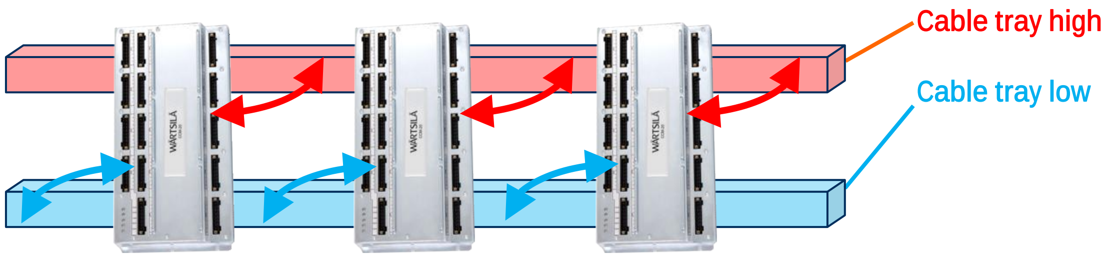
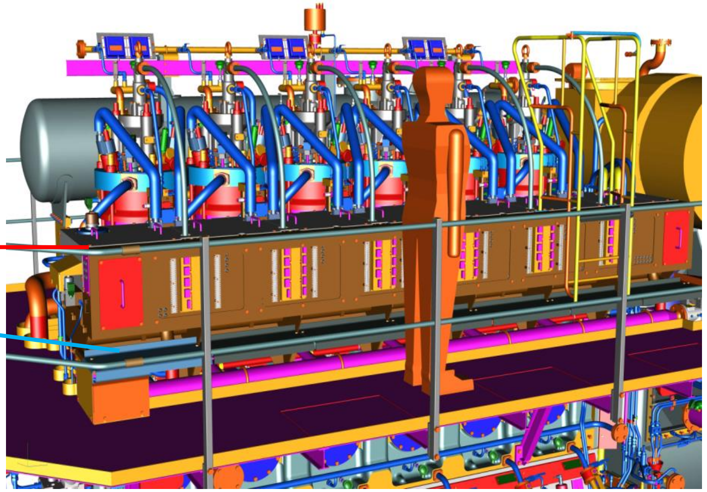
UNIC-flex Functional Design

- The UNIC-flex system is built with multifunctional electronic CCM-20 modules
- Two CCM-20s per cylinder is mounted in front of the rail unit (E95)
- In addition, an MCM-11 module is installed in the local manoeuvring stand (E25)
- The modules communicate between each other on a fast internal CAN system bus
- The internal module layout and the cable trays in the rail unit entirely separate circuits with high EMC noise, like power cables or pulsed current lines (PWM, injectors, VCU, etc.) from sensitive signal or bus cables



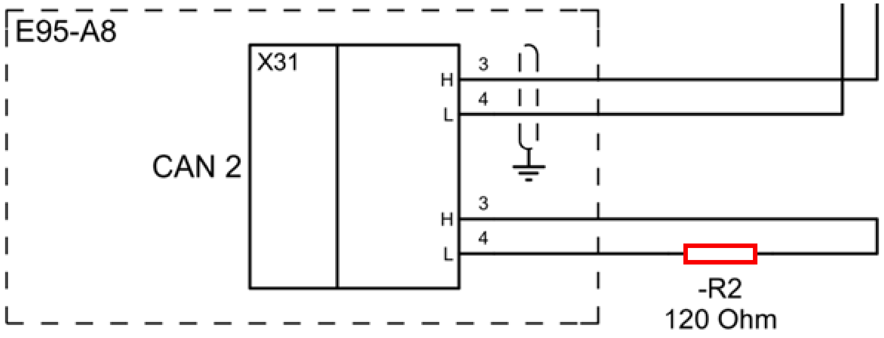


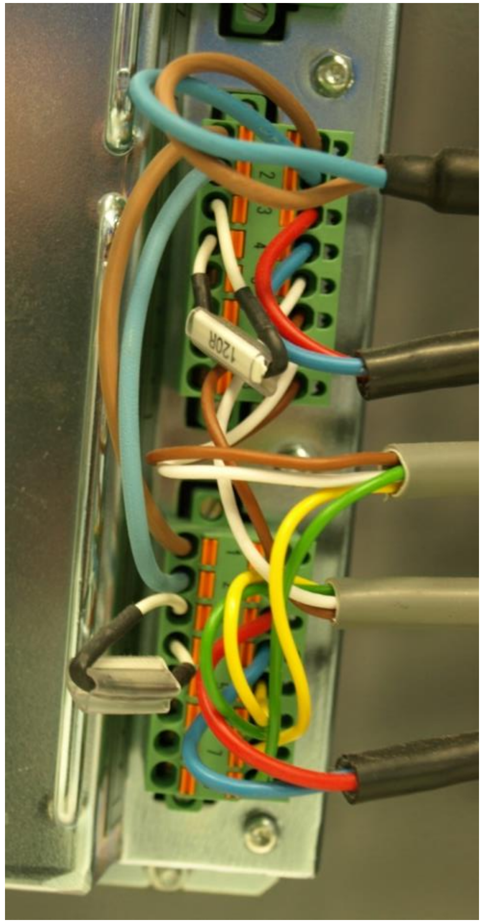


Bus Cabling

Terminator resistors

- At each end of the Bus cable a termination resistor of 120Ω MUST be installed to avoid signal reflection
- LDU has internal terminator resistor which has to be jumped

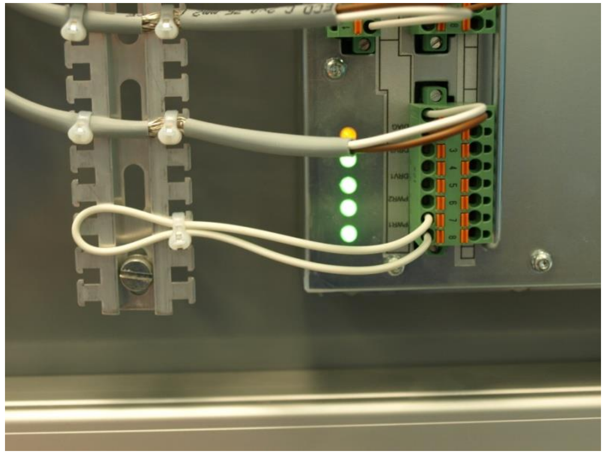




Module Identification

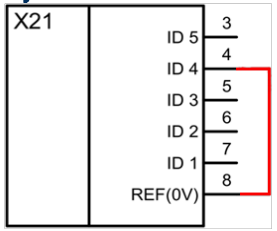
Identification of modules

- Plug X21 is used to define the cylinder where the specific CCM-20 is installed
- MCM is using X21 as well, X31 on IOM and X12 on LDUs
- This hardware code cables belong to the plug and must not be removed

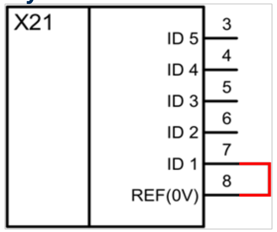


Module	Connection
Cyl. #01	X21; 8-4
Cyl. #02	X21; 8-7
Cyl. #03	X21; 8-6
Cyl. #04	X21; 8-7-6-4
Cyl. #05	X21; 8-5
Cyl. #06	X21; 8-7-5-4
Cyl. #07	X21; 8-6-5-4
Cyl. #08	X21; 8-7-4 + X15; 5-6
MCM	X21; 7-8
IOM	X31; 4-5
LDU ER	X12; 4-8
LDU ECR	X12; 4-7

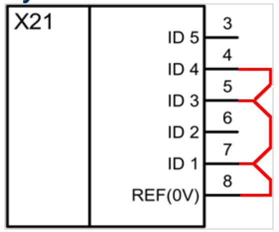
Cylinder #01



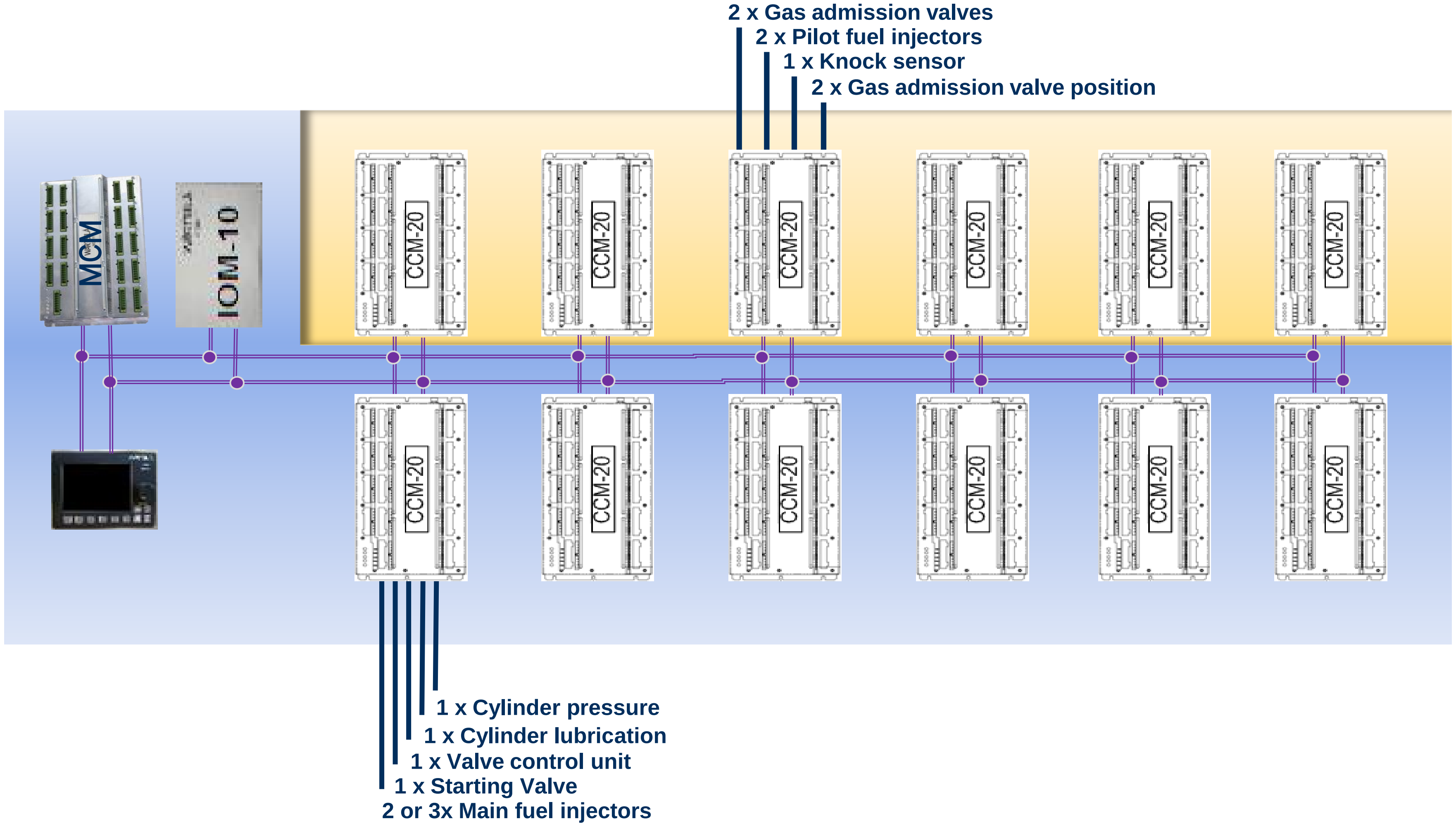
Cylinder #02



Cylinder #06



Cylinder Function



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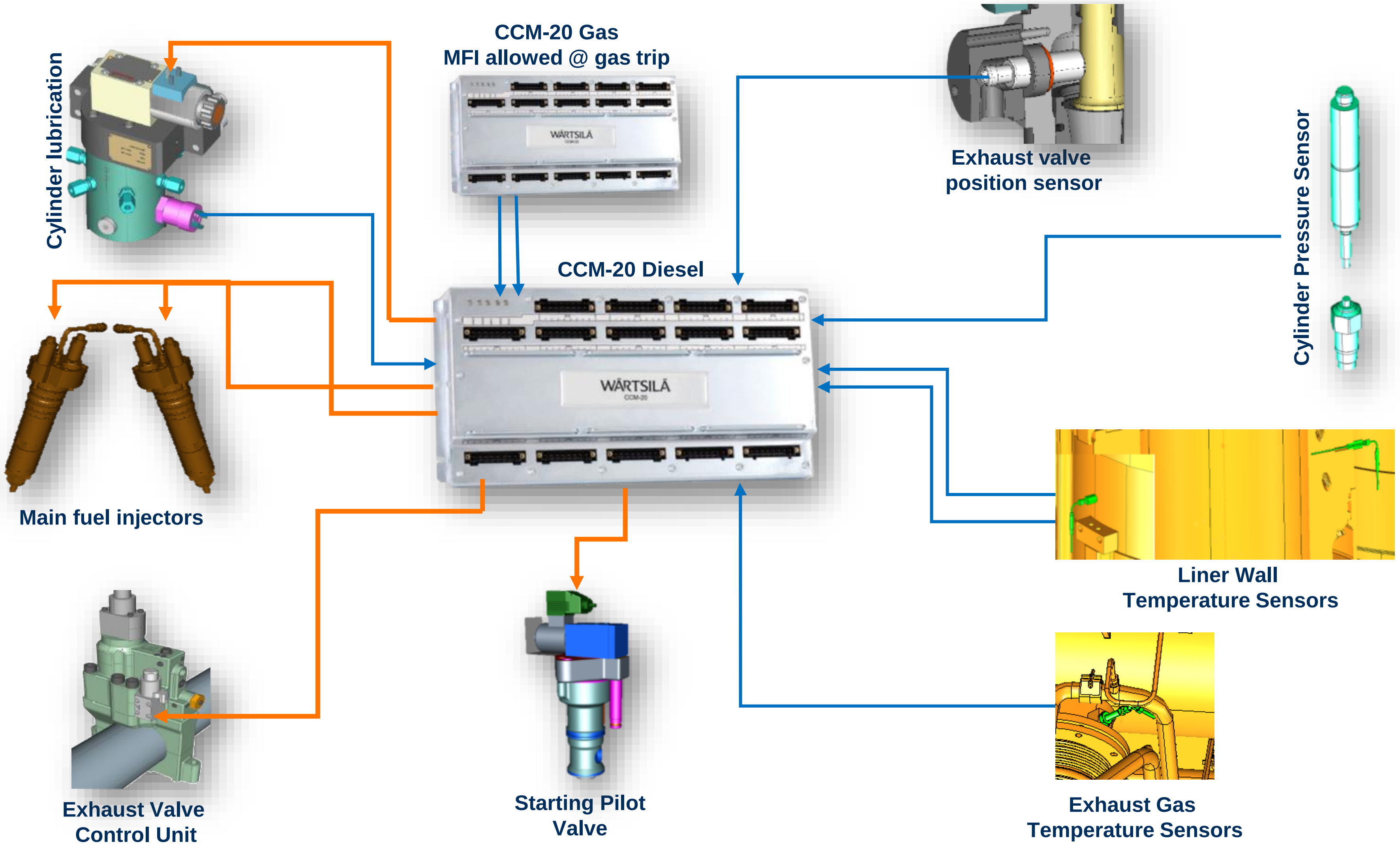
Cylinder Function to CCM-20 Diesel



Common Function to Diesel CCM

Input signals	Output signals
CCM #A1 • Fuel rail pressure sensor #1 (PT3461C) • Shaft power meter (JT5156C) • Servo oil service pump inlet pressure (PT2051C)	CCM #A1 • Fuel pump actuator set point #1 (CV7231C) • Power supply speed sensor B and TDC
CCM #A2 • Fuel rail pressure sensor #2 (PT3462C) • Fuel pressure before supply unit (PT3421C)	CCM #A2 • Fuel pump actuator set point #2 (CV7232C) • Supply speed sensor C and BDC
CCM #A3 • Servo oil rail pressure sensor #1 (PT2071C) • Bearing oil inlet pressure (PT2002C)	CCM #A3 • Servo oil pump set point #1 (CV7221C) • Supply speed sensor D
CCM #A4 • Servo oil rail pressure sensor #2 (PT2072C) • Air spring pressure (PT4341C)	CCM #A4 • Servo oil pump set point #2 (CV7222C) • Pilot fuel oil pump start (XS3465C) moved from G4 with introduction of i-CAT on Jun. 2017
CCM #A5	CCM #A5 • Fuel pump actuator set point #3 (CV7233C)
CCM #A6	CCM #A6
CCM #A7	CCM #A7

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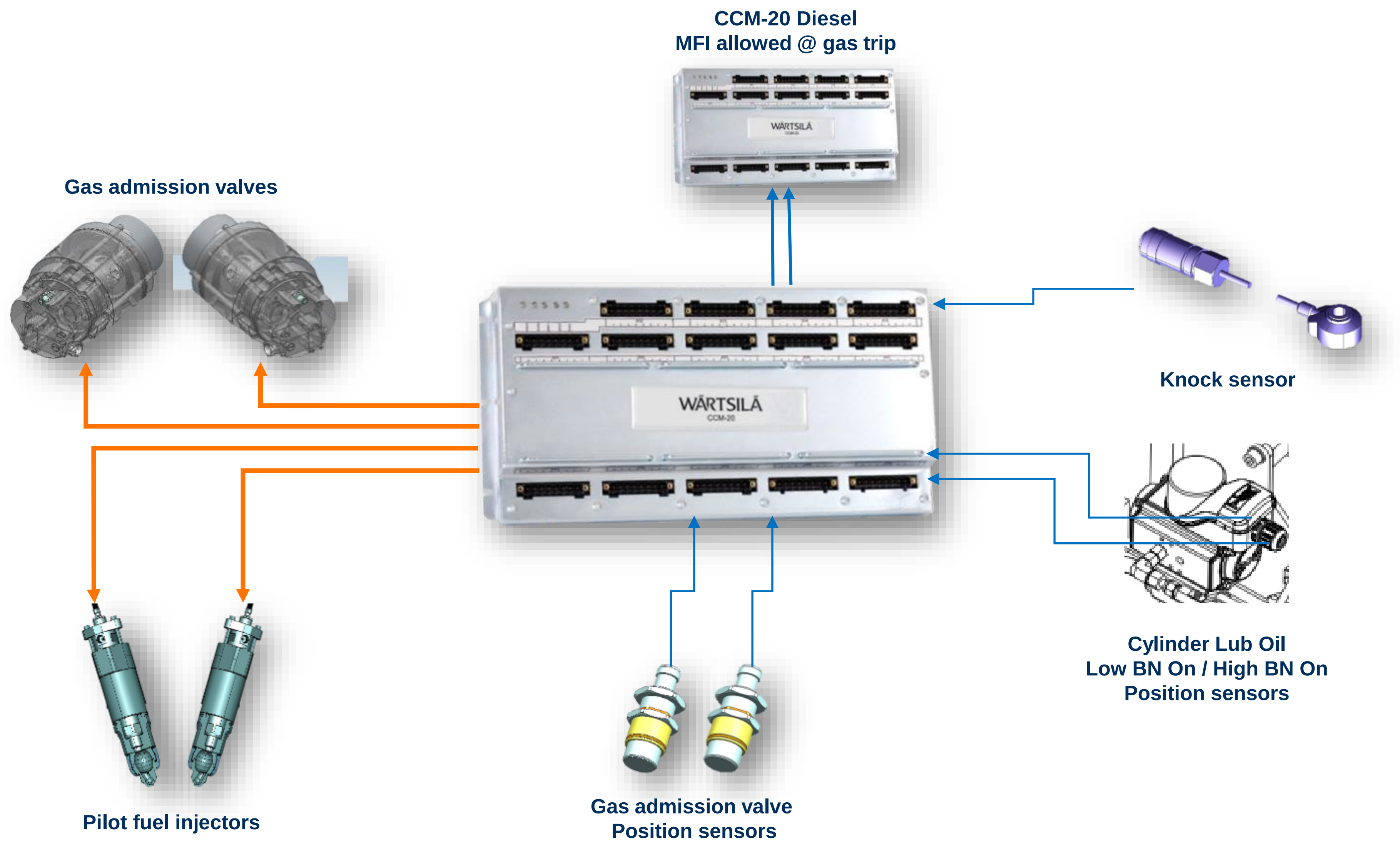
Cylinder Function to CCM-20 Gas



Common Function to Gas CCM-20 with GVU

Input signals	Output signals
CCM #G1 • CYL. Lub. Oil Press Low BN (PT3145C) • CYL. Lub. Oil Press High BN (PT3146C) • CTRL. Air Press. After Changeover VLV (PT4413C)	CCM #G1 • Vent valve fuel side (CV7286C) • CYL. Lub.Oil BN Change-Over valve(CV7147C) with i-CAT
CCM #G2	CCM #G2 • Vent valve exhaust side (CV7287C) • GAV sealing oil shut off valve (CV7296C)
CCM #G3	CCM #G3 • Gas shut off valve fuel side (CV7291C) • Vent valve engine inlet (CV7289C)
CCM #G4 • Gas concentration in piston underside (AE3315C)	CCM #G4 • Gas shut off valve exhaust side (CV7292C) • Pilot fuel pressure control valve (CV7239C) • Pilot fuel oil pump start (XS3465C) moved to D4 with introduction of i-CAT on Jun. 2017
CCM #G5	CCM #G5
CCM #G6	CCM #G6
CCM #G7	CCM #G7

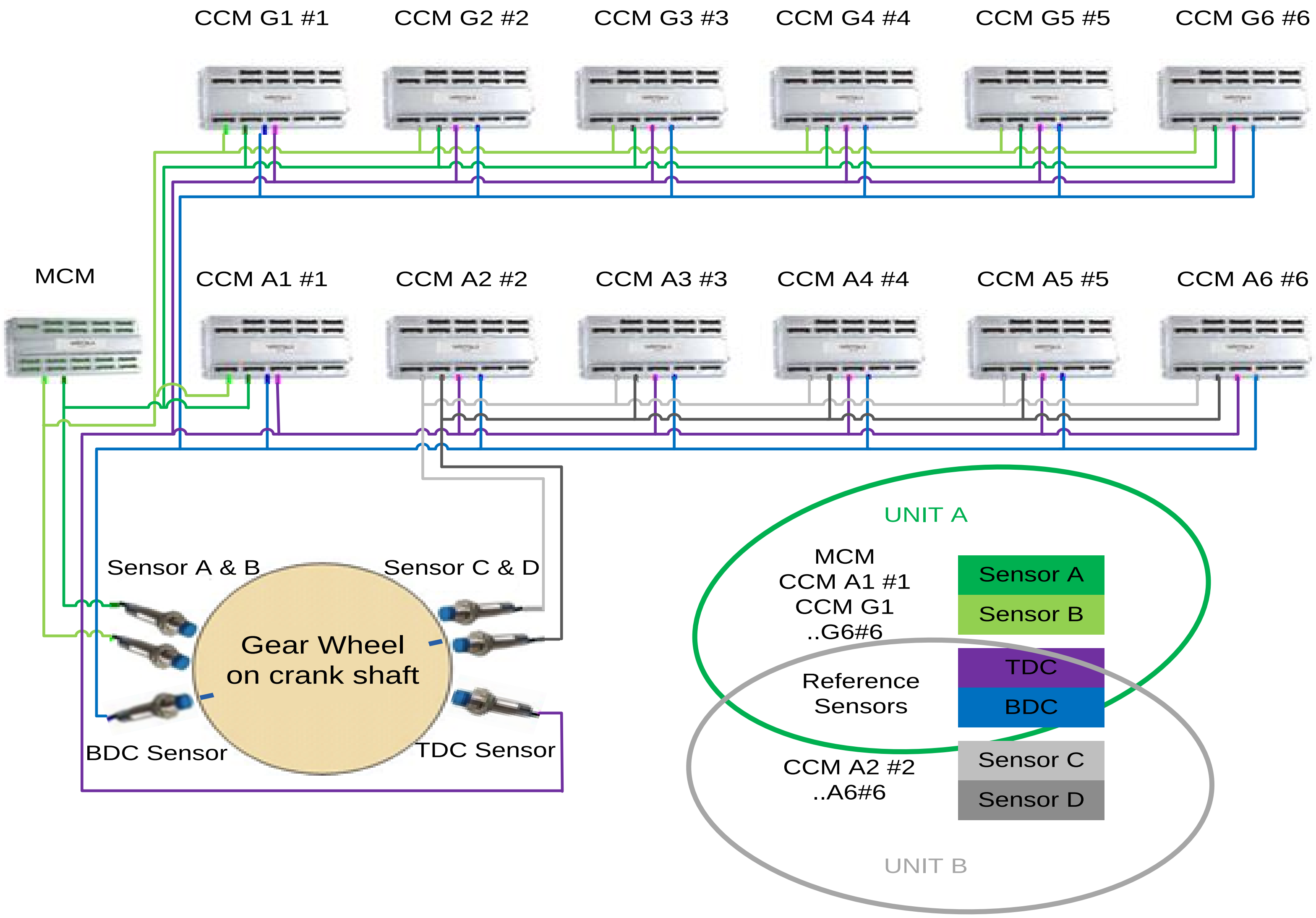
Connection to MCM

Input signals	Output signals
Diesel operation	
• Scavenge air pressure sensor #1 (PT4043C) • Control air pressure engine inlet (PT4421C) • Crosshead bearing oil pressure supply (PT2021C) • Turning gear disengaged #1 (ZS5016C) • Starting air pressure #1 before shut off valve (PT4301C) • Turbo charger speed #1 (ST5201C) • Auxiliary blower #1 running (JS5031C) • Starting air shut off valve manually closed (ZS5018C) • HFO supply (XS3411C)	• Common start air valve #1 (CV7013C) • Auxiliary blower start signal #1 (CY7031C) • Injector Lub. Oil shut-off valve(CV7003) • Supply speed sensor A • Scavenge air bypass control valve (CV7071C) Test engine only
Gas operation	
• GAV sealing lubricating oil pressure (PT2091C) • Exhaust waste gate position (XI7071C) • Pilot fuel oil pressure B (PT3466C) • Shaft locking device engaged (XS5075C)	• Servo oil service pump ON (XS2050C)

Connection to IOM

Input signals	Output signals
Diesel operation	
• Scavenge air pressure sensor #2 (PT4044C) • Turning gear disengaged #2 (PT5017C) • Starting air pressure #2 before shut off valve (PT4302C) • Cylinder cooling water pressure engine inlet (PT1101C) • Auxiliary blower #2 running (JS5032C)	• Common start air valve #2 (CV7014C) • Auxiliary blower #2 start signal (CY7032C)
➢ ICC	
• Scavenge air temperature after cooler A (TE4045C) • Scavenge air temperature after cooler B (TE4046C) • Barometric pressure A (PT4002C) • Barometric pressure B (PT4003C) • TC compressor air inlet temperature A (TE4041C) • TC compressor air inlet temperature B (TE4042C)	
➢ **Gas operation**	
• Pilot fuel pressure inlet (PT3464C) • Pilot fuel temperature inlet (TE3464C) • Pilot fuel pressure A (PT3465C) • Shaft locking device engaged (XS5076C)	• Exhaust waste gate control valve (CV7077C)

Crank Angle connection



Crank angle determination

- Absolute Crank angle must be learned before engine start after:
  - System power reset
  - One module power off at engine standstill
  - CA value of one module differs from others for more than 5~6 degree.

- ECS is to get TDC signal (or BDC signal)

- Two ways for learning CA:
  - Turn the engine by turning gear
  - Automatic crank angle determining algorithm (ADA)

Crank angle: ADA

Automatic crank angle determination:

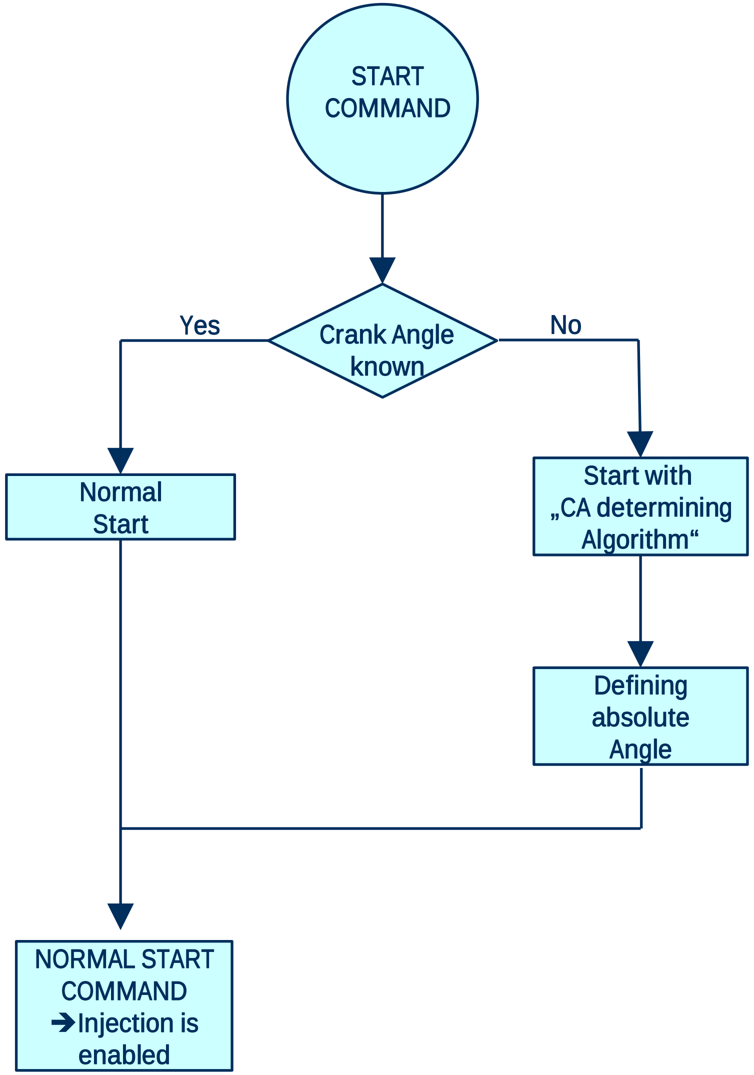
When absolute angle is not available:

- Read the start command from:
  - RCS in any direction (AH/AS)
  - LDU Local or ECR: Start, Air run
- Turn the engine by air to get TDC/BDC valid signal
- Continue engine start

Notes:

During ADA, engine can be turned in any direction.

When engine is running, interruption of one module will not stop engine operation



Cylinder lubrication

- Power dependent

- Fuel depended
  - Low Sulphur fuels (Gas, LFO)
  - High Sulphur fuels (HFO, etc.)

- Oil's BN in use

- Different power dependence curves

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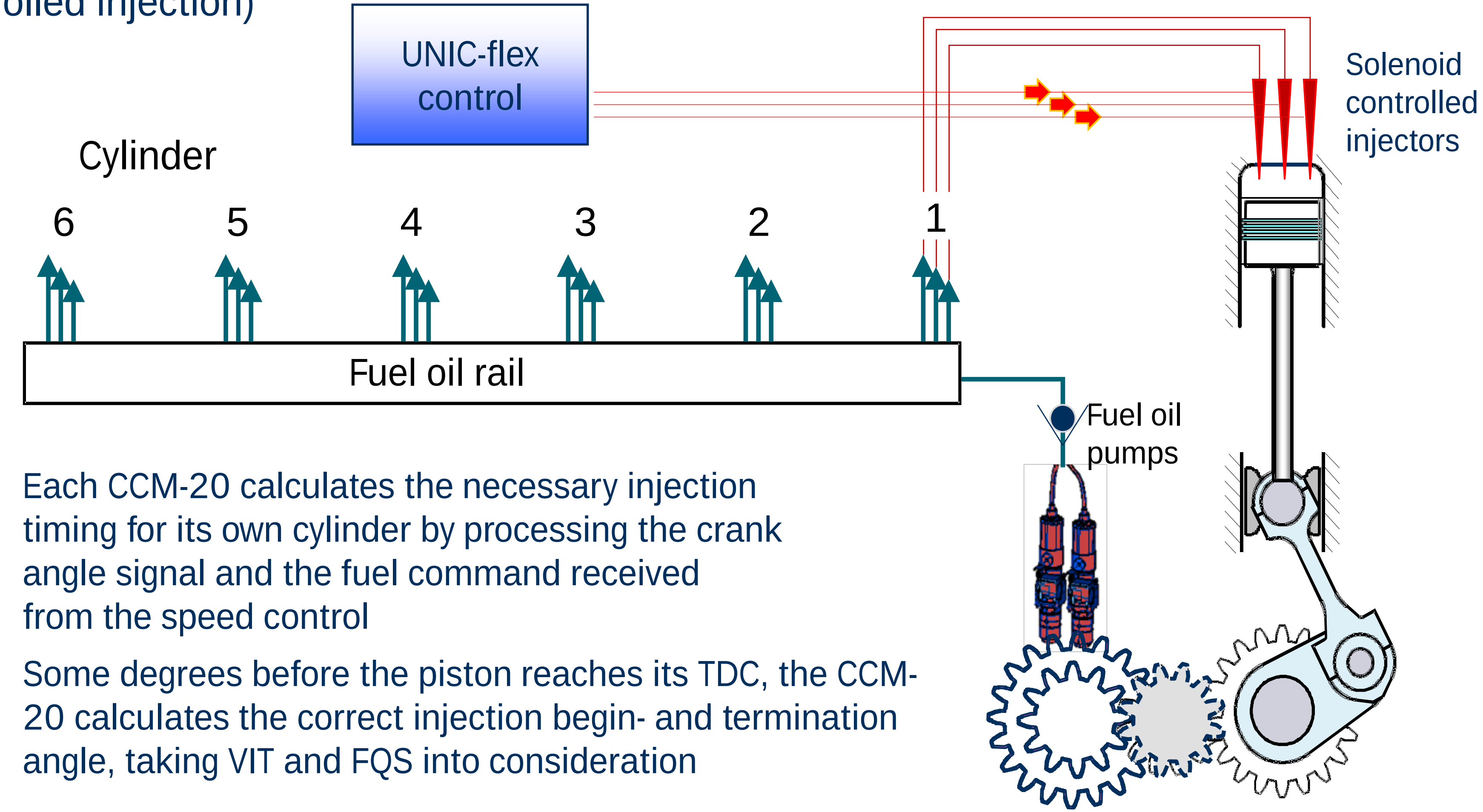
Components for Main fuel Injection

Injection control:

(time controlled injection)

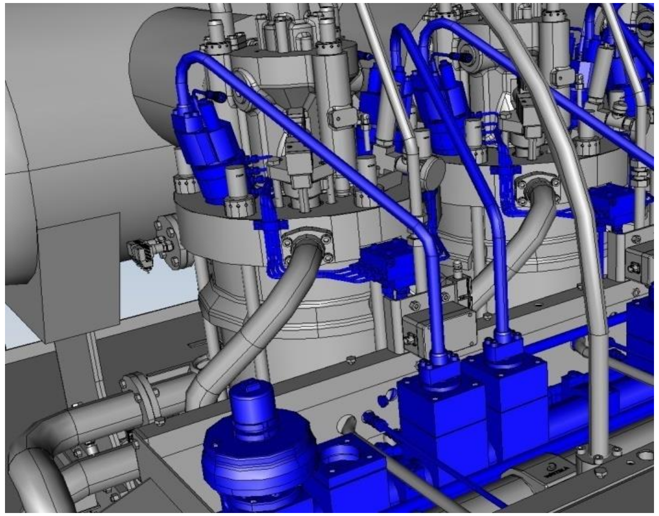


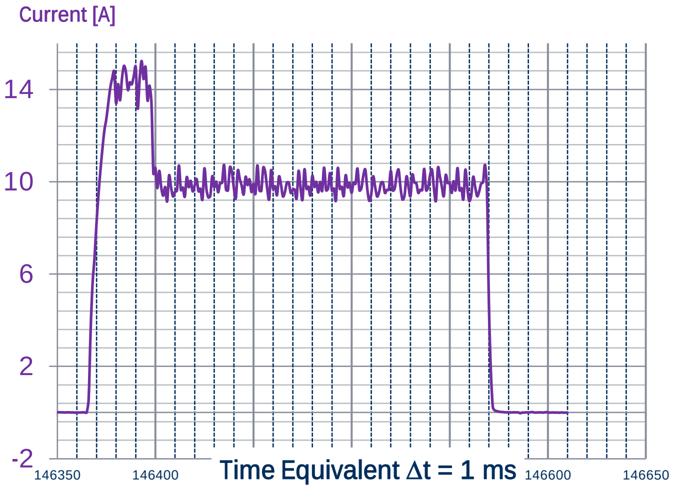
- Each CCM-20 calculates the necessary injection timing for its own cylinder by processing the crank angle signal and the fuel command received from the speed control
- Some degrees before the piston reaches its TDC, the CCM-20 calculates the correct injection begin- and termination angle, taking VIT and FQS into consideration

Time Controlled Injection

Injector solenoid control

- Injection event is “crank angle + time”
- Pull-in phase current level ~15 A (10 A on X72)
- Hold phase current level ~10 A (5 A on X72)
- Closed loop current control
- Pull-in time ~1-2 ms (2.5 ms on X72)
- Total injection signal duration up to 50 ms





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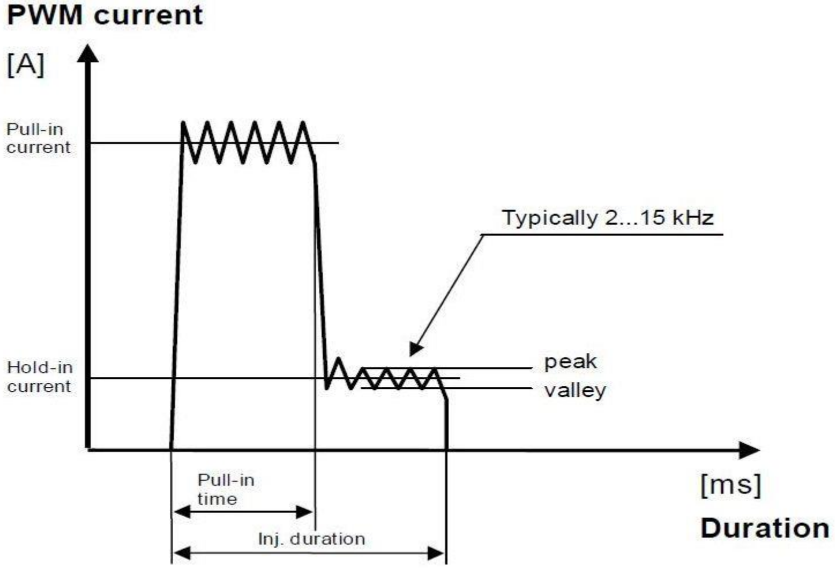
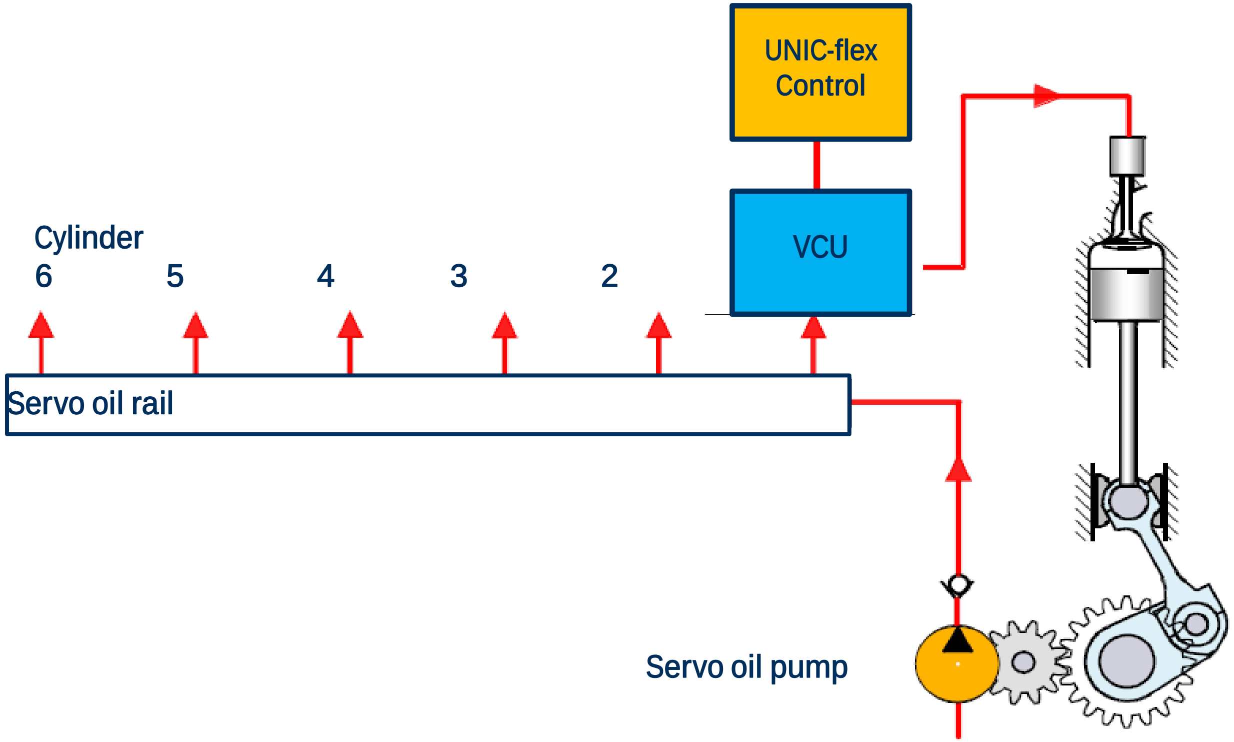


Exhaust Valve Control

Exhaust valve control:

The exhaust valve is opened by servo oil pressure and closed by an air spring, same as with conventional engines. Instead of cam and roller, the actuation is done by means of VCUs. The stroke of the valve spindle is measured by an analogue position sensors for a feedback to the UNIC-flex.



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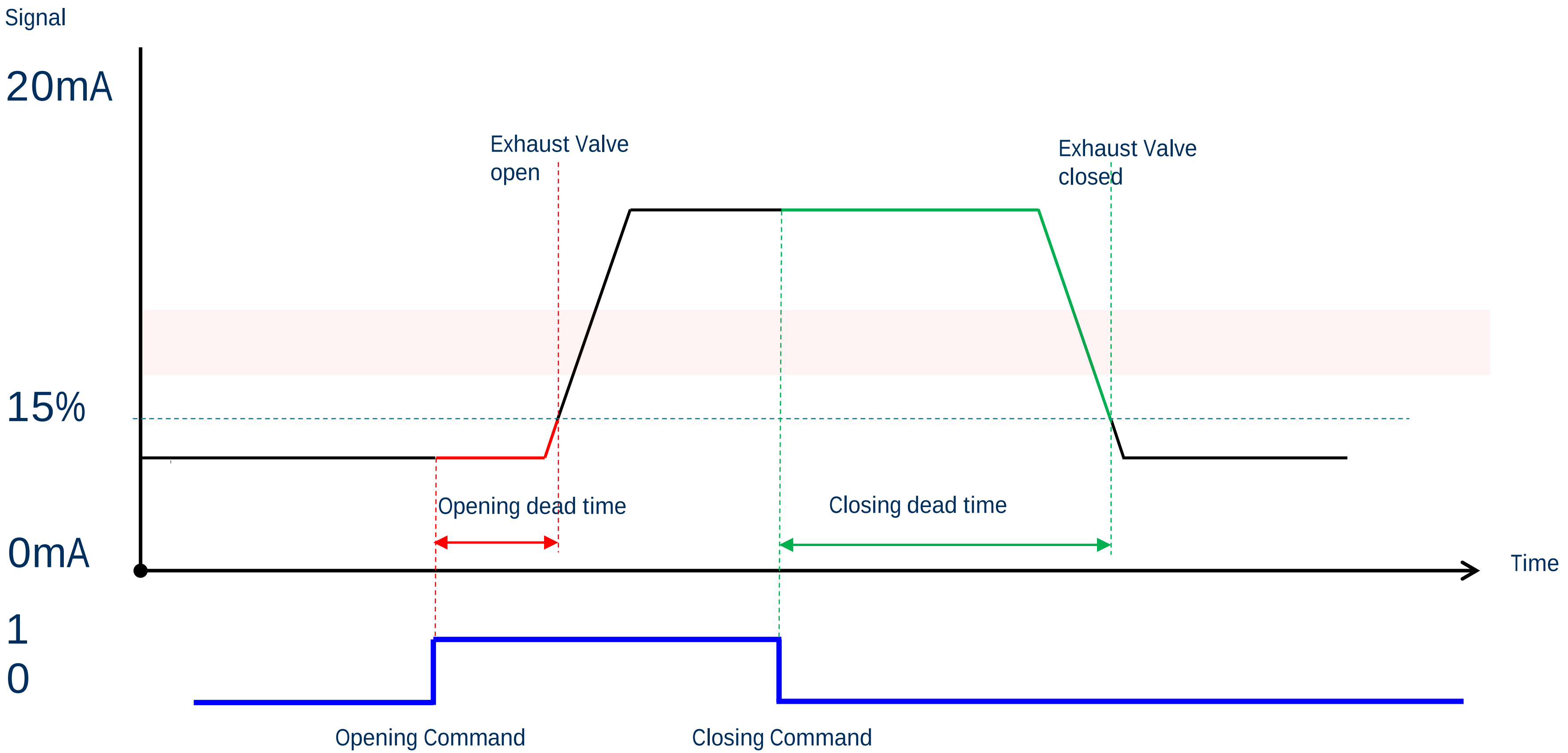
Exhaust Valve Control

Detailed functional description of the exhaust valve control:

- The valve opening angle is calculated according to VEO table (Variable Exhaust valve Opening) by each CCM-20 module, based on measured crank angle and engine running conditions
- The VCU solenoid valves are triggered to the “Open” position. Servo oil pressure operates the piston in the VCU which supplies servo oil to the actuator pipe, which finally pushes down the exhaust valve spindle
- The time between the “Open” command and the initial movement of the spindle is measured. It is called “opening deadtime”
- This deadtime will be considered in the calculation for compensation of hydraulic and mechanic delays
- Analogue to the above mentioned, the valve closing angle is determined and controlled by the CCM-20 according to VEC table (Variable Exhaust valve Closing) and closing deadtime

Exhaust Valve Control



UNIC considers the Exhaust valve as open after 15% of opening stroke (EXH valve opening angle).
The Exhaust valve is considered as closed after 85% of its stroke (EXH valve closing angle).
Therefore, the “Exhaust valve close deadtime” is much longer than “Exhaust valve open deadtime”.

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Nozzle Control

Low load operation

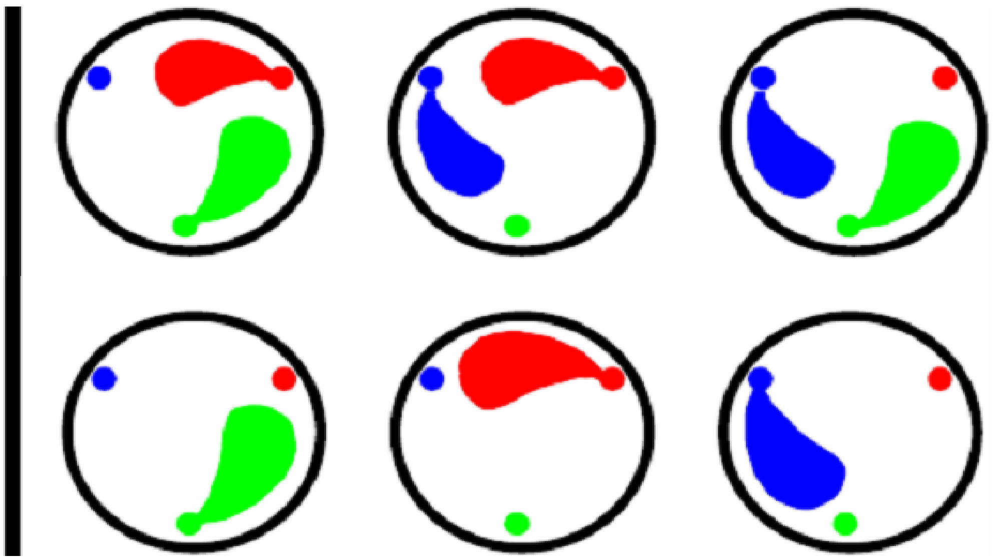
- At low engine load UNIC-flex cuts out one or two of the three injection valves per cylinder
- This is to avoid visible smoke emission and to reduce fuel consumption
- To inject a certain fuel volume with one or two nozzles takes longer than with all three nozzles. This longer injecting time allows a larger part of the fuel to be injected with a controlled pressure and thus improved atomization for an optimized combustion
- To avoid thermal stress to cylinder liners, the active nozzles are cycled every few minutes. Cycling from one nozzle to another is done with some seconds time delay between each cylinder to prevent smoke emission due to “cold” fuel injected through the new active but too hot nozzle

Nozzle Control

Sequential cut-out of injection nozzles for smokeless slow steaming

Smokeless operation at low speed

Usual operation
3 nozzles
in unison



Alternative
2 nozzle
operation

Alternative
1 nozzle
operation

smokeless operation down to 12% rpm R1

FQS, VIT

FQS, VIT:

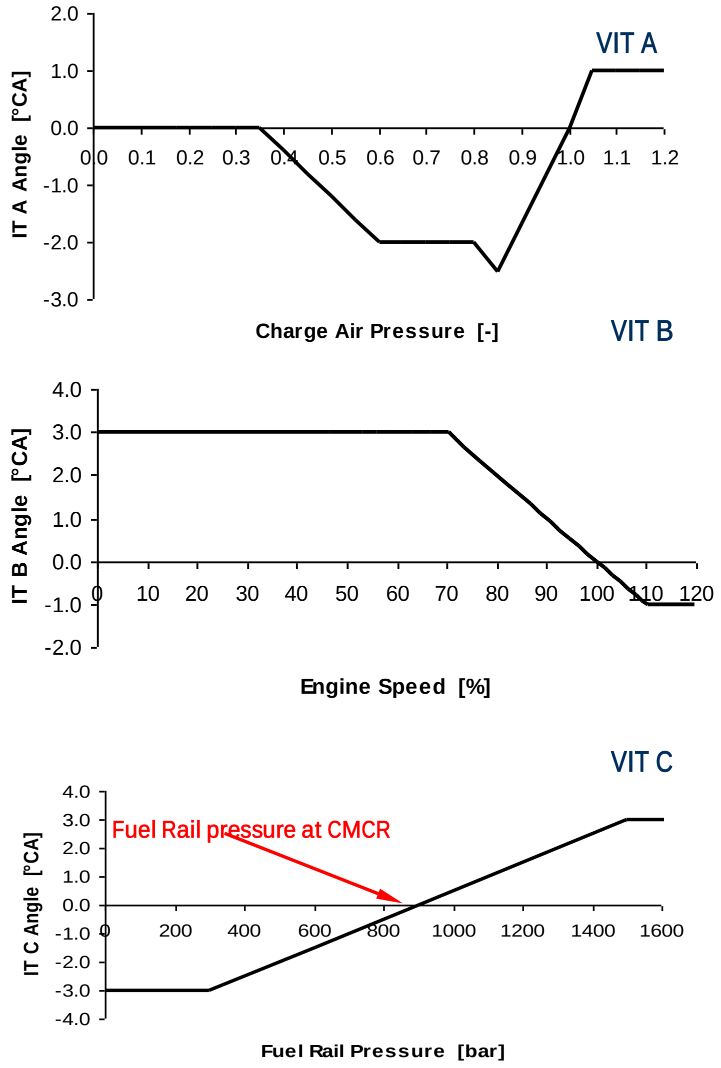
- These functions are known from the conventional engines:
    - **FQS: Fuel Quality Setting**
        - Manual offset for the injection timing in relation to the fuel quality
    - **VIT: Variable Injection Timing**
        - Advance / retard injection according to engine load, speed and fuel rail pressure for optimized fuel consumption and NO_x emission.
- The injection angles are related to the Crankangle (CA) between 0° - 360°

FQS, VIT

FQS, VIT:

- The VIT angle calculation for the X engines depends on **RPM**, **charge air pressure** and **fuel rail pressure**

- This 3rd parameter is introduced to compensate differences in injection timing resulting from different fuel rail pressures
- Higher fuel pressure causes advanced injection and higher P_{max}
- Thus the injection begin angle is retarded a bit with increasing fuel pressure



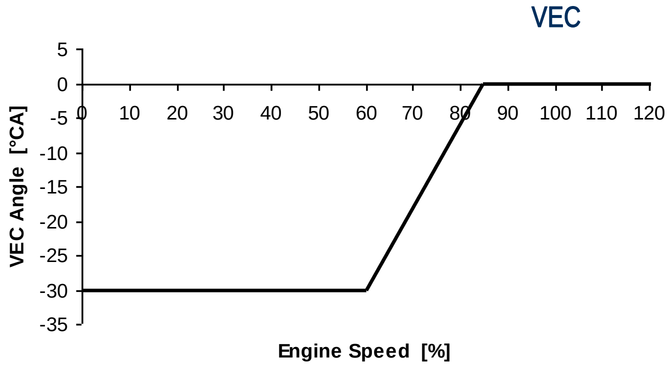
VEO, VEC

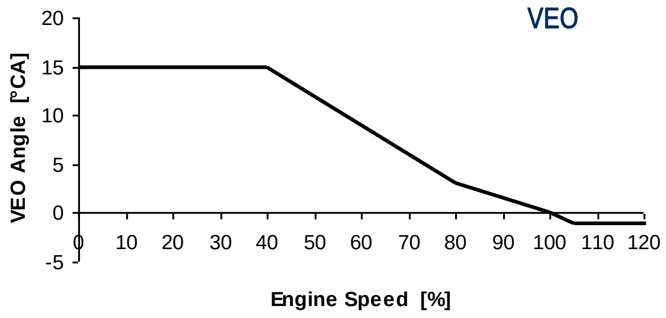
VEC: Variable Exhaust-valve Closing

Adopting compression pressure to keep the firing ratio (P_{max} / P_{compr}) within permitted range during advanced injection.

VEO: Variable Exhaust-valve Opening

Keeps the exhaust gas pressure blowback constant by earlier valve opening at higher speed for fuel economy and less deposits at piston underside.

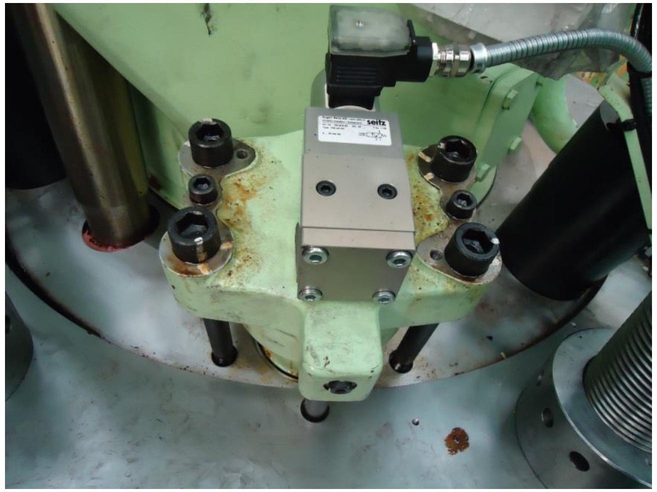




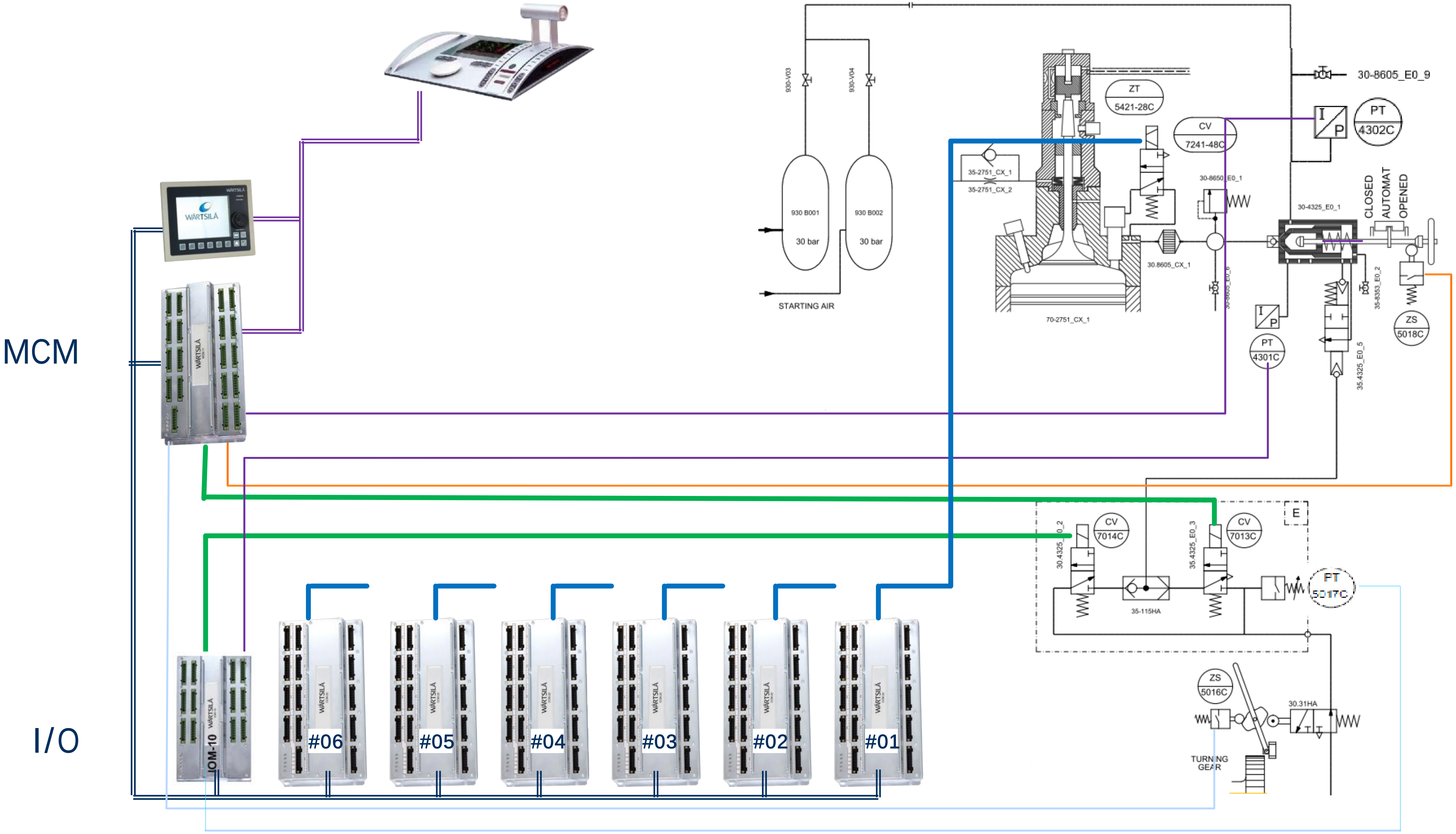
VIT, VEC and VEO are calculated by UNIC-flex and can not be changed manually !

Starting Valve Control

- The automatic main starting air valve is activated by solenoids CV7013C and CV7014C via MCM and IOM, if the remote control sends a START signal over the bus
- The opening and closing of the starting pilot valves is controlled by the corresponding CCM, depending on the crank angle
- The nominal opening angle is ~5°, closing at about 100°
- For slow turning the starting pilot valve will be operated by pulsing signals
- Additionally an air run signal enables to blow the engine with starting air



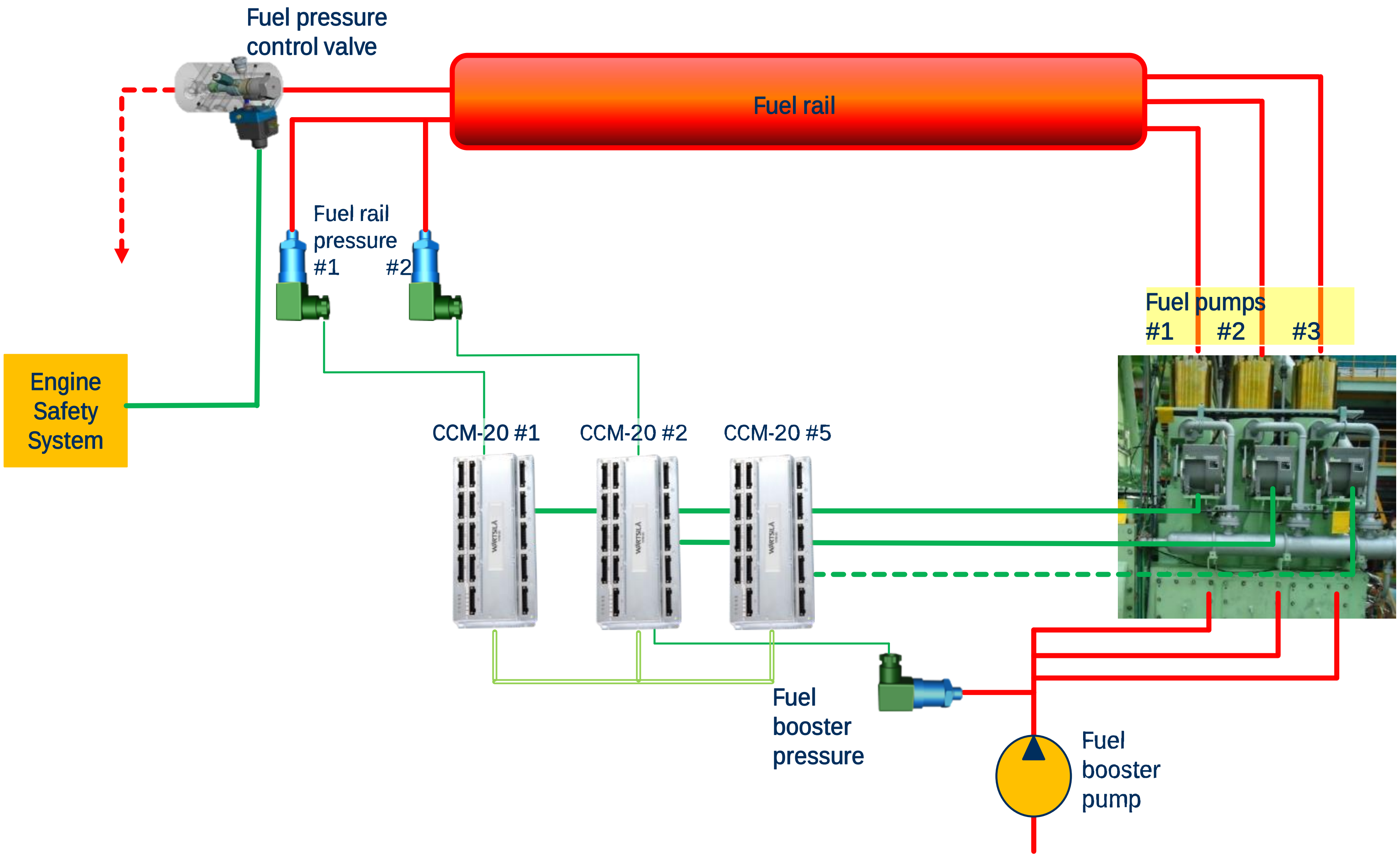
Starting Valve Control



Pressures control

- Main fuel oil rail pressure
- Servo oil rail pressure
- Pilot fuel rail pressure
- Gas fuel rail pressure
- Scavenge air pressure

Main Fuel pressure Control



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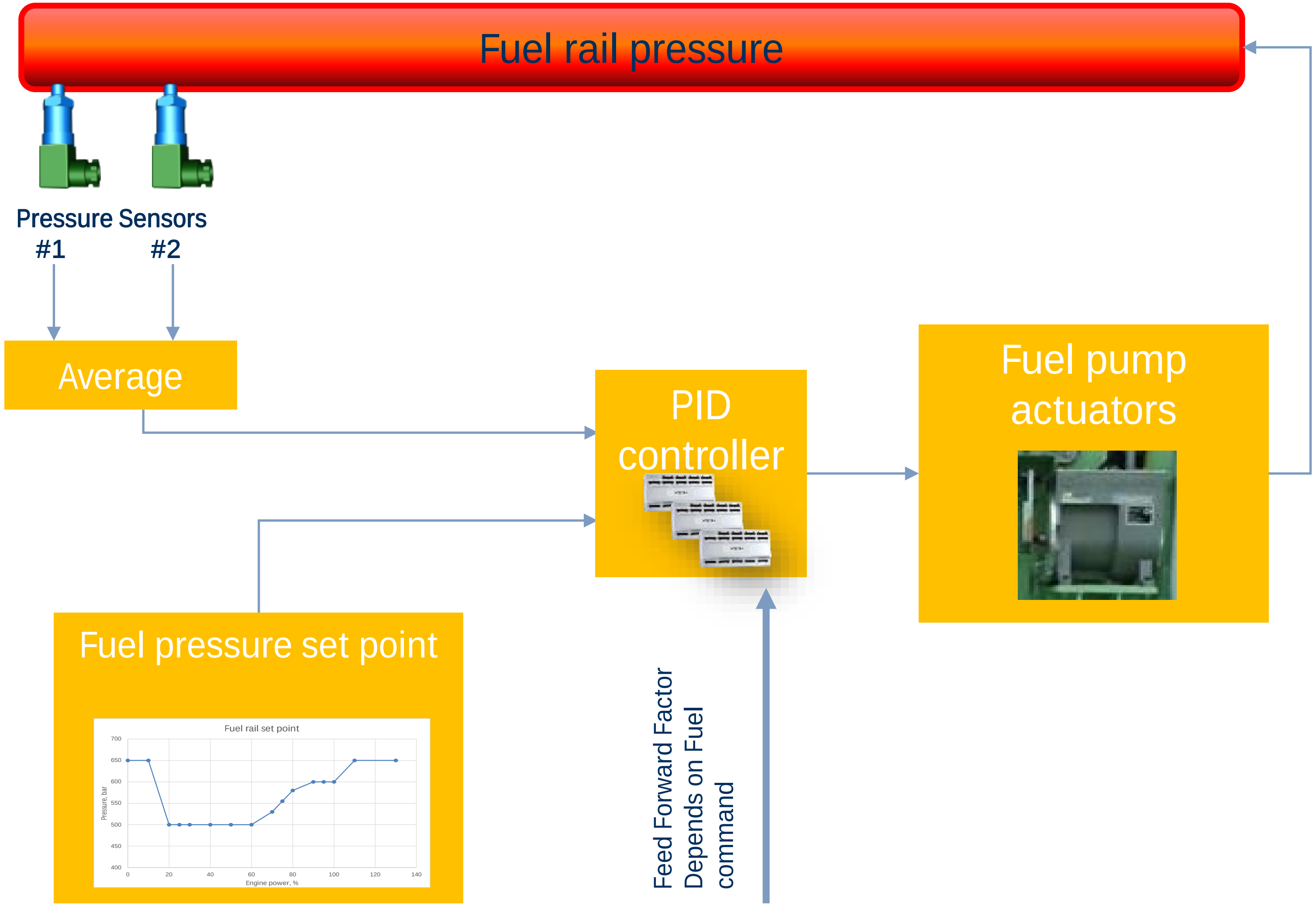
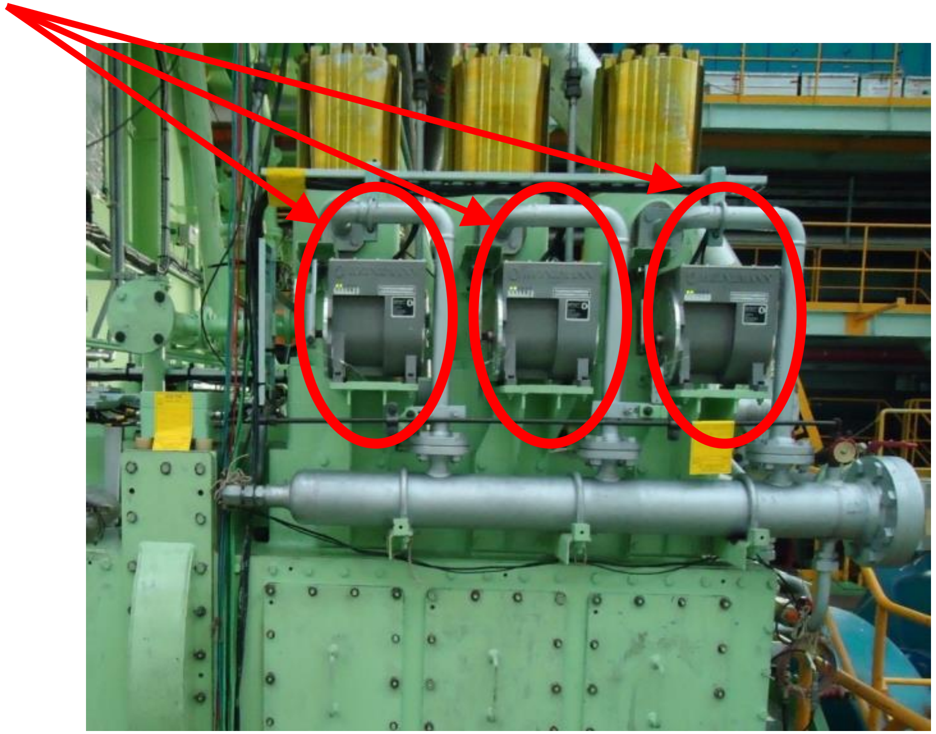
Main Fuel pressure Control



Main Fuel pressure Control

Fuel actuators

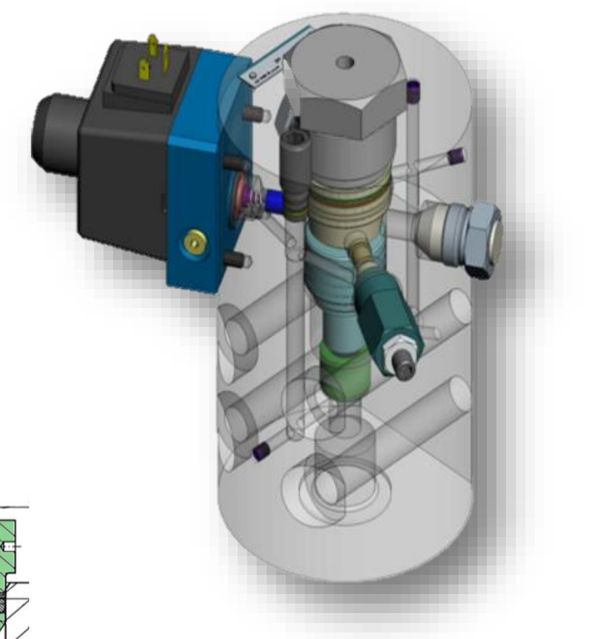
- Each fuel pump equipped with an actuator connected to CCM #1, #2 and #5 depending on number of cylinders
- In case of lost setpoint signal or power failure, the actuator will stay it’s last position

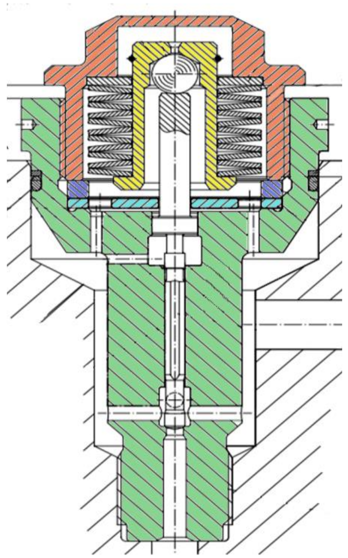


Fuel Pressure Control Valve (PCV)

- Controlled by ESS (fuel rail de-pressurizing in case of shut-down)
- Controls fuel rail pressure in case of the overpressure
  - Opens at 1050 bars (1st stage)
  - Opens at 1150 bar (2nd stage)

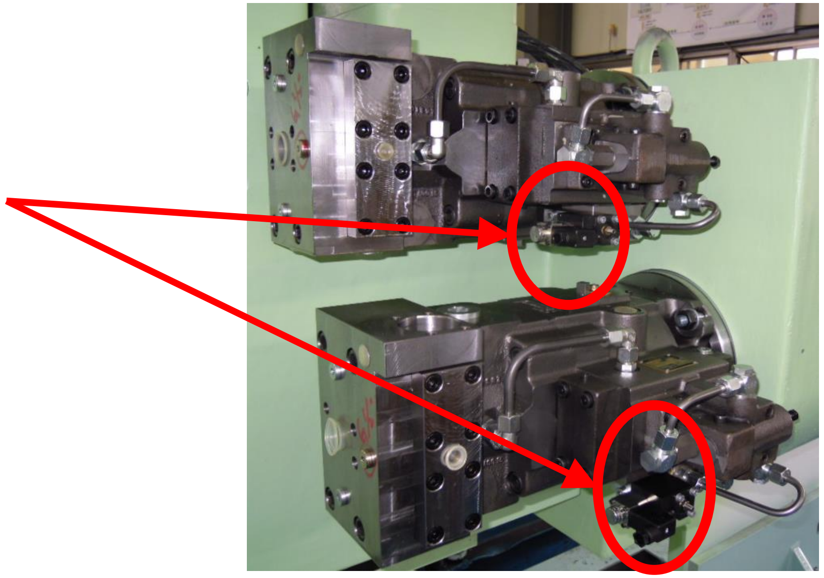
- **Note:** Pressure safety valve opens at1250 bar



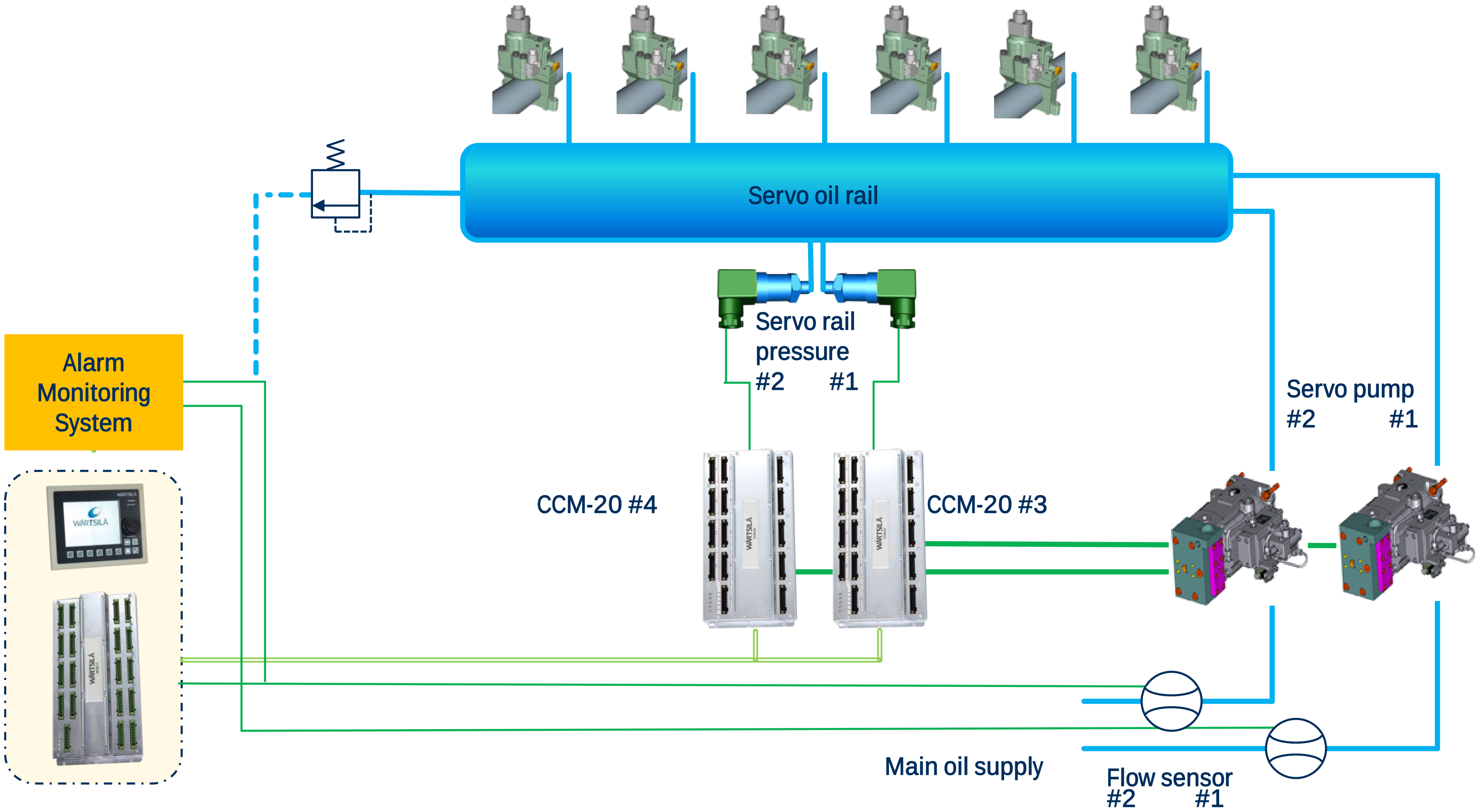


Servo oil pressure Control

- Each servo oil pump equipped with a Compensator Valve, connected to CCM #3 & #4
- The servo oil rail is equipped with two pressure sensors connected to CCM #3 & #4 to measure servo oil rail pressure



Servo oil pressure Control



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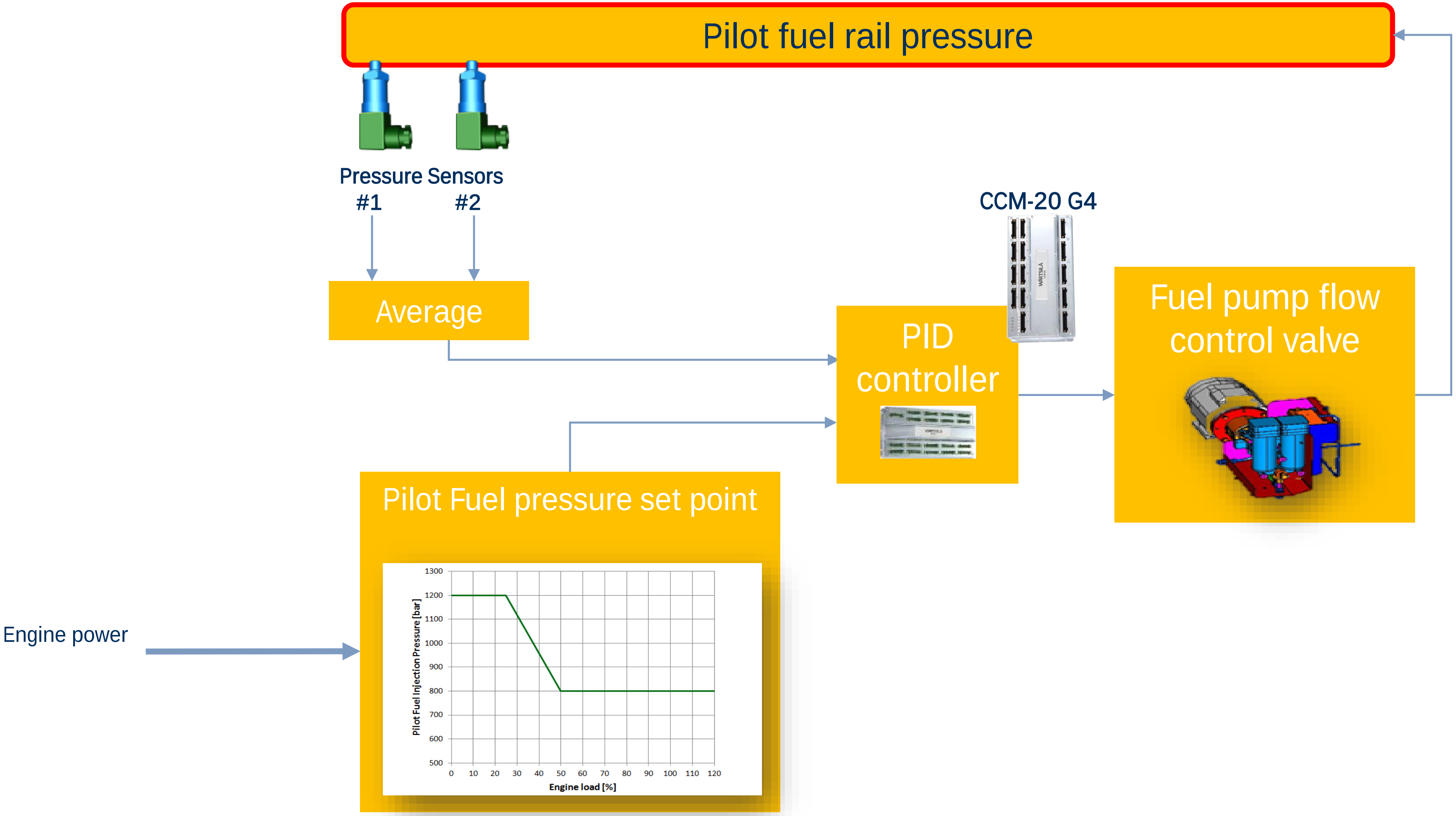
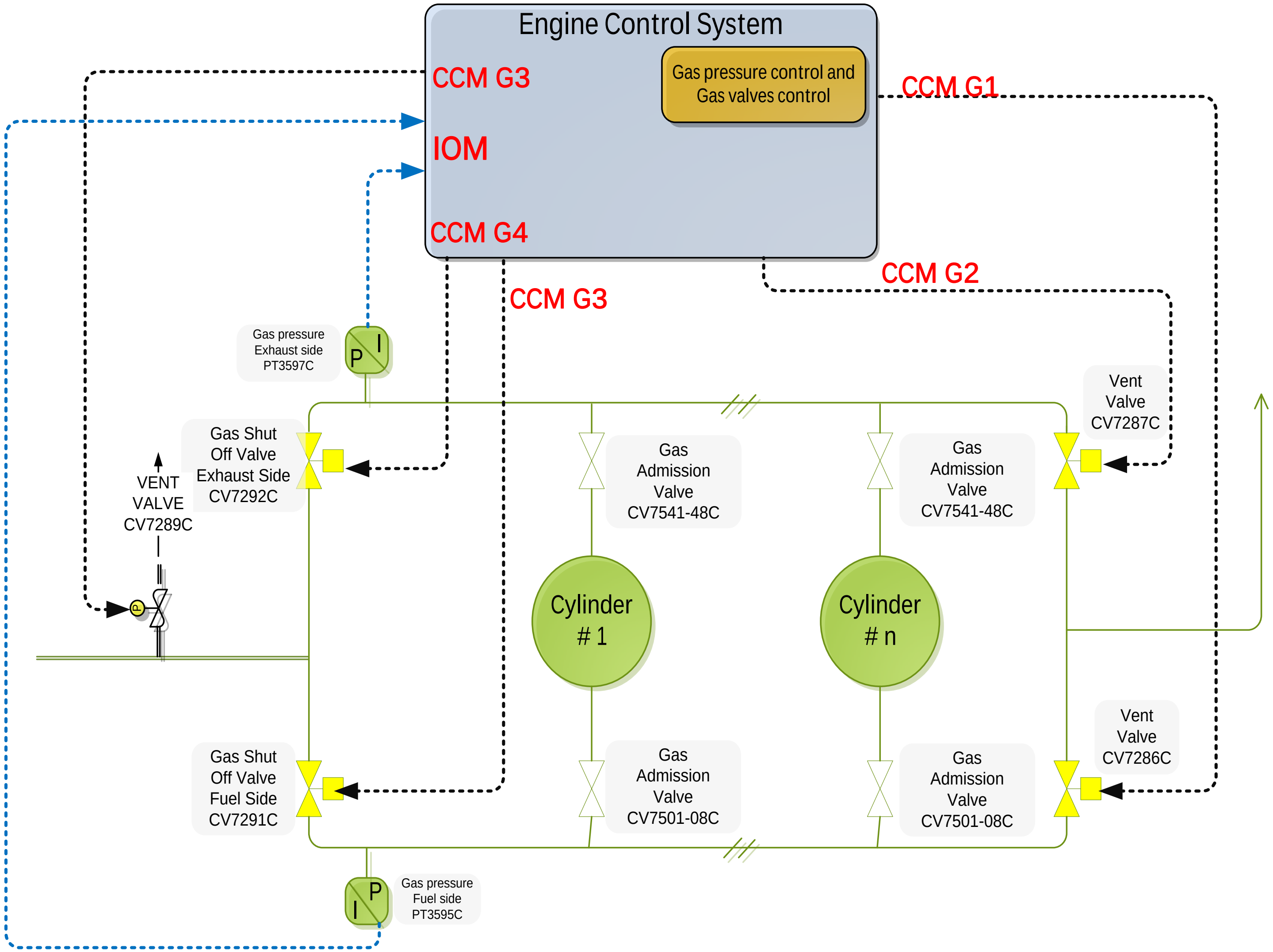
Pilot Fuel Rail Pressure Control



Gas Rail Valves with GVU

Functions:

- Filling
- Venting
- Inerting
- Shut off



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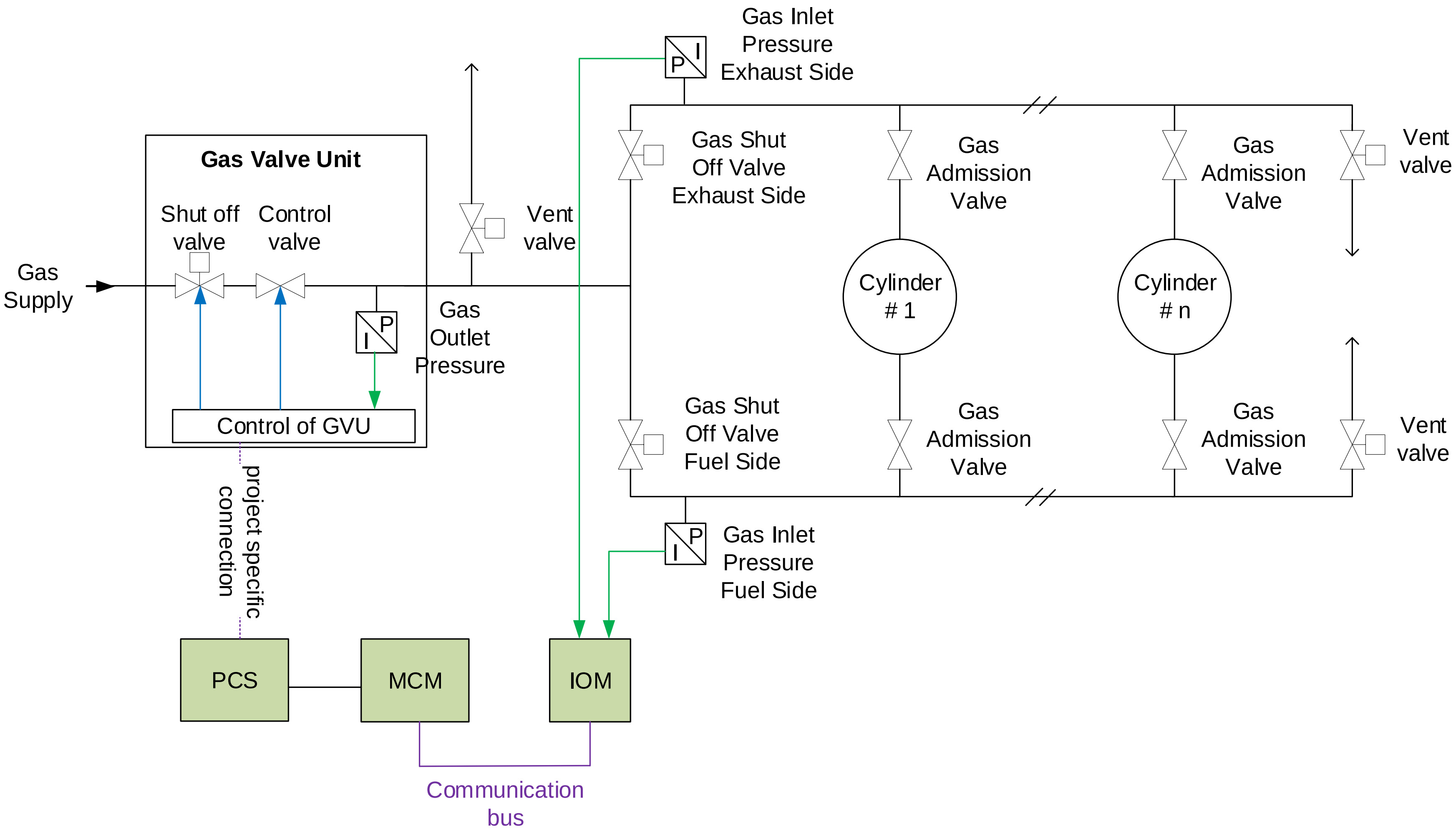
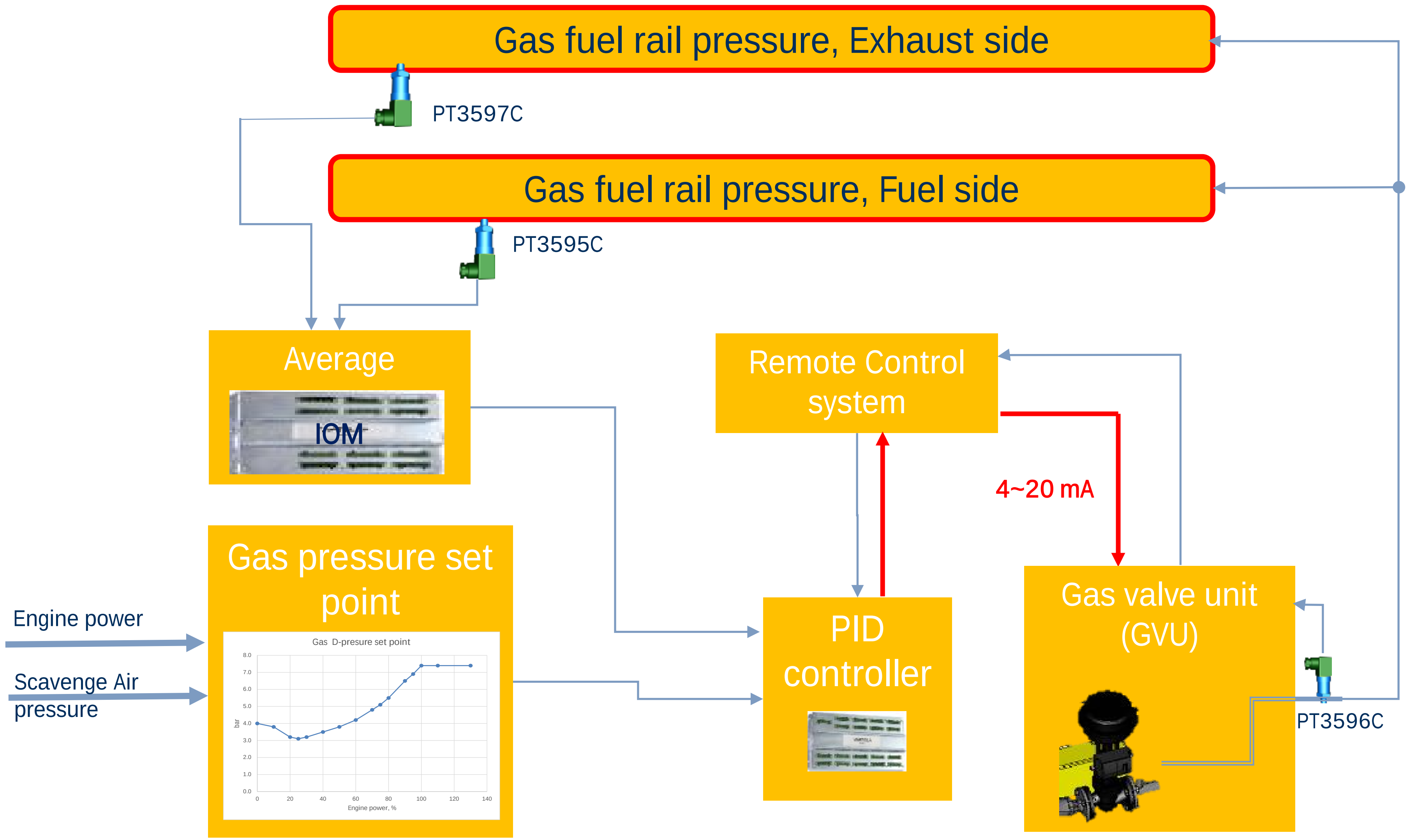
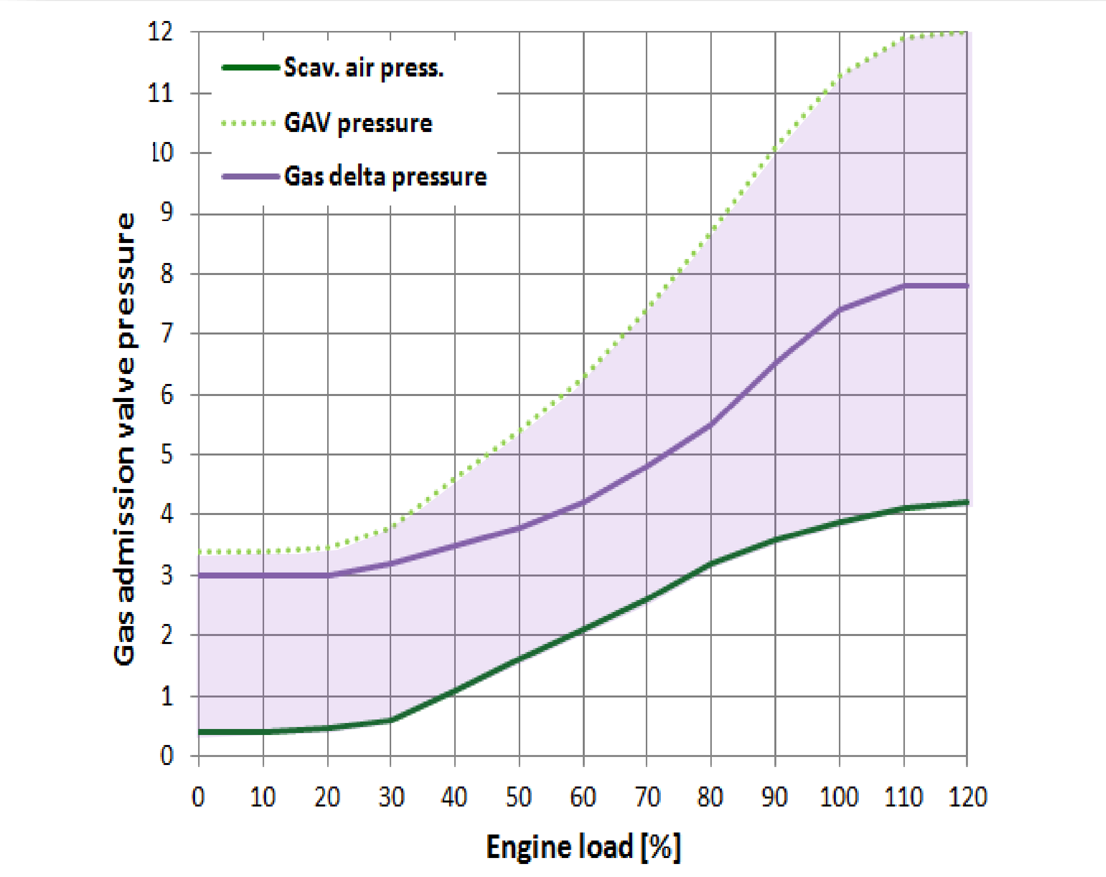
Gas rail Pressure Control with GVU



Gas rail Pressure Control with GVU

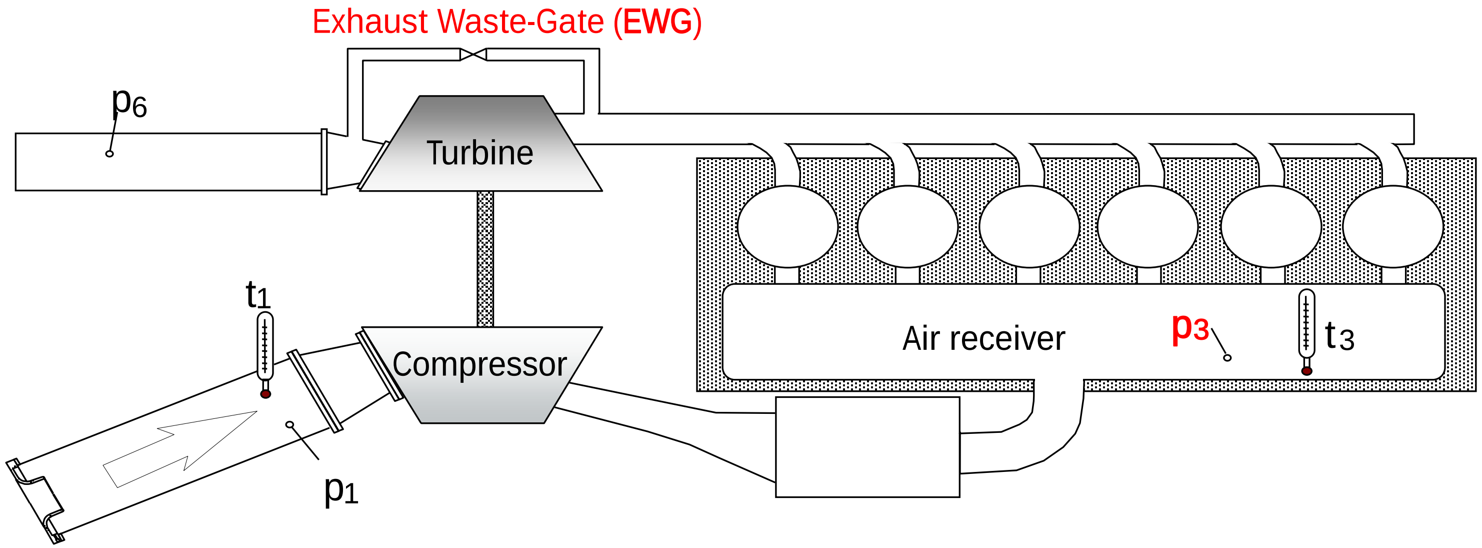


Gas Pressure Set-point



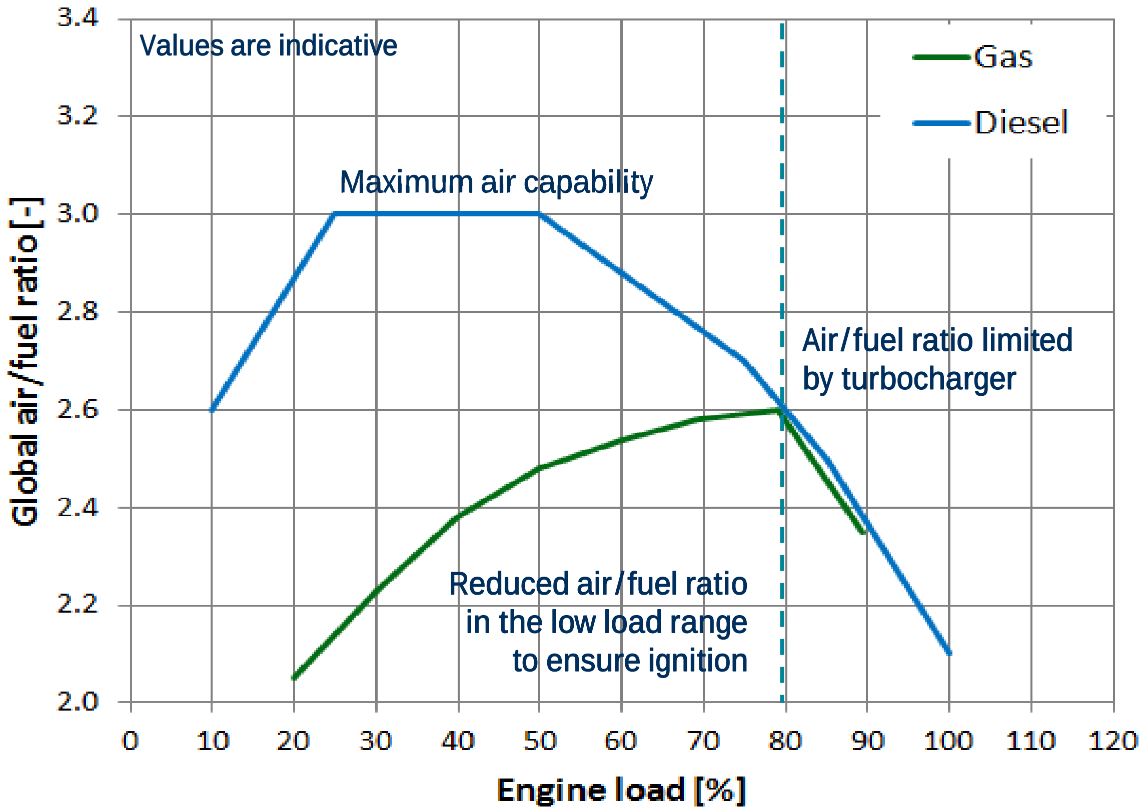
- Gas delta pressure = (gas admission pressure) - (scavenge air pressure)
- This maximum achievable pressure is limited by the pressure after GVU

Scavenge air pressure Control



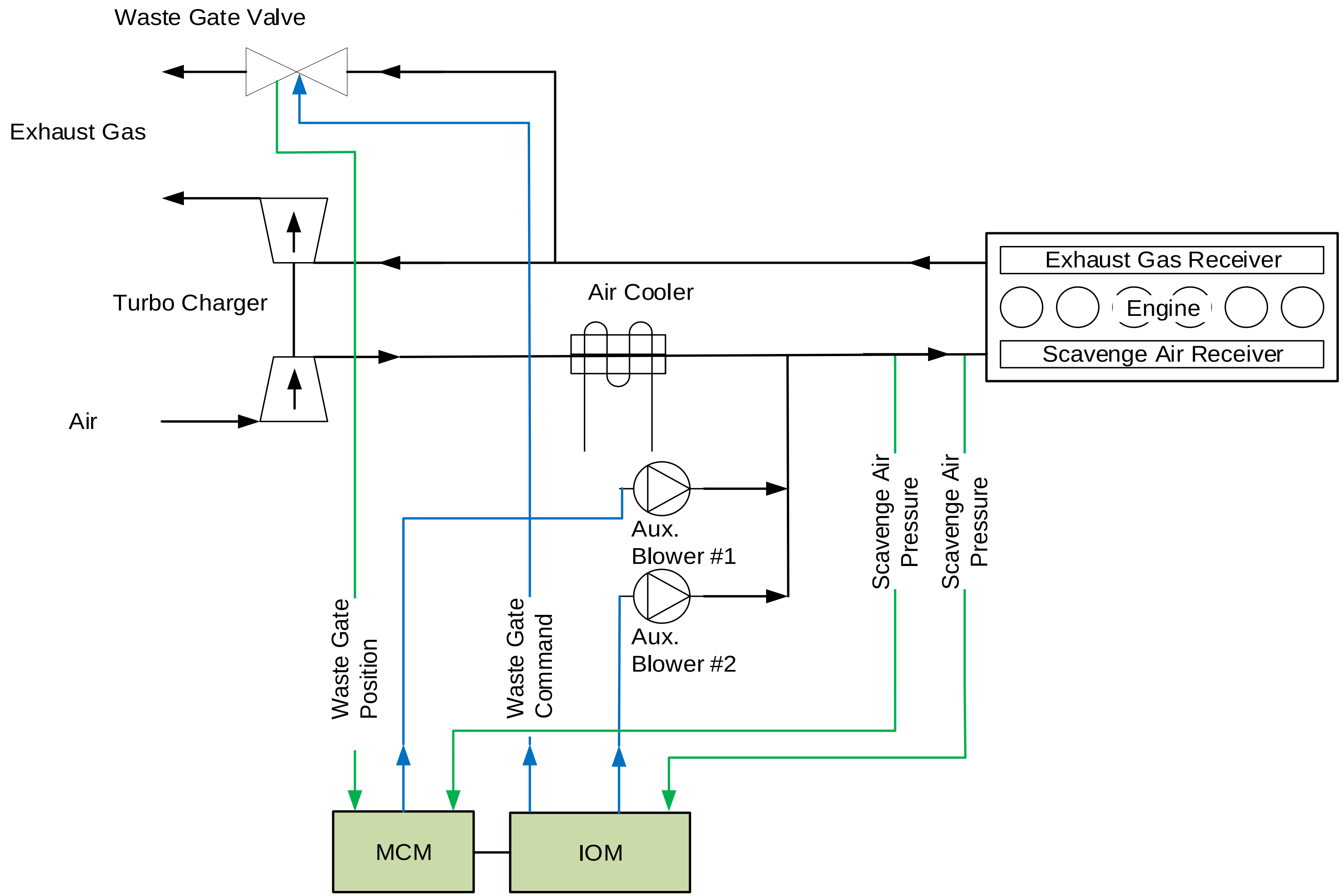
- X-DF engines are equipped with an exhaust gas waste-gate valve, which is controlled electronically.
- The position of the valve is set automatically for reaching a desired air receiver pressure.
- When the valve is completely closed, maximum air receiver pressure is achieved.

Scavenge air pressure - air/fuel ratio

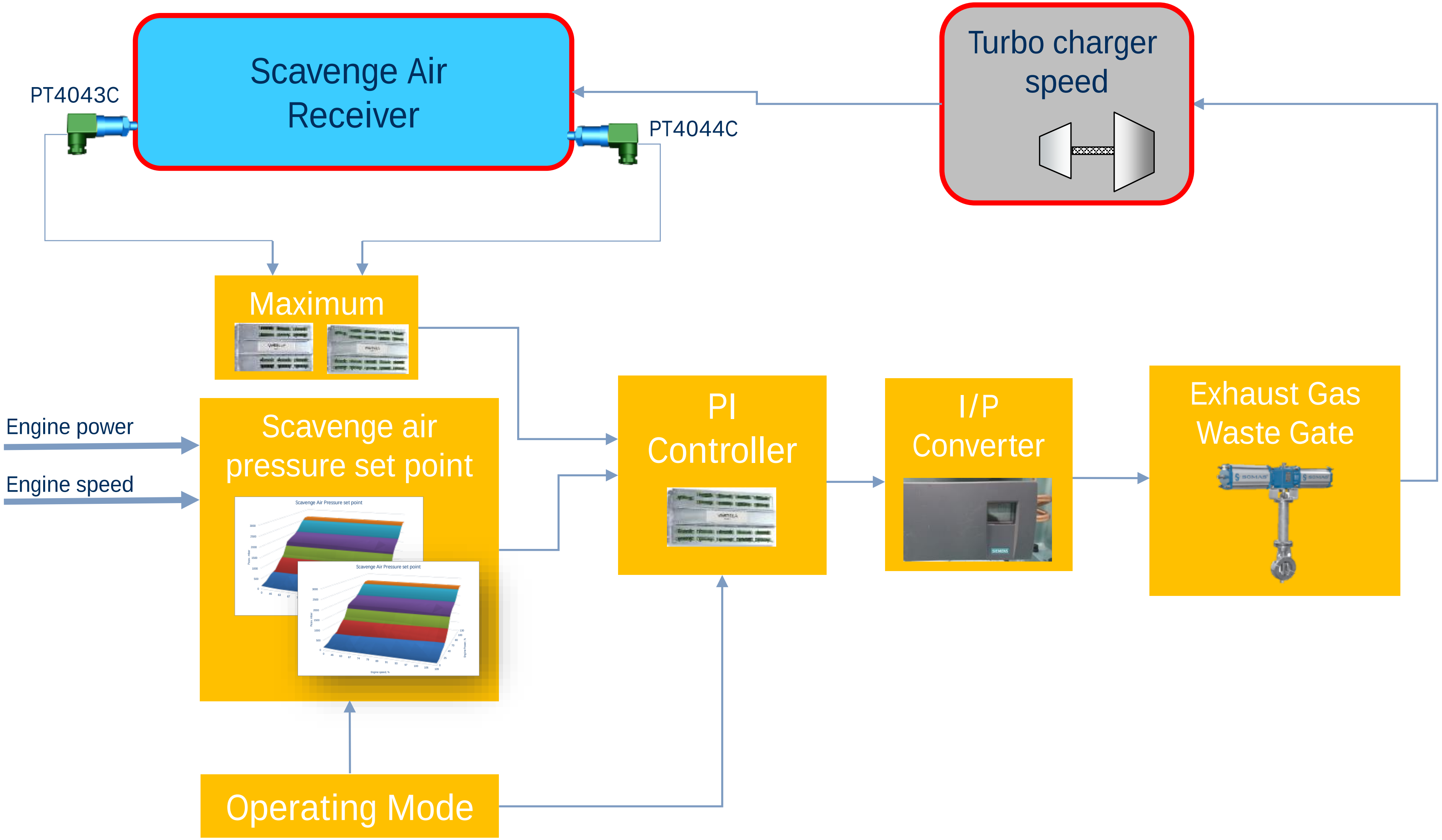


- The air receiver pressure is directly related to the air density in the cylinder and so to air amount which can be trapped.
- In the low load range, in order to improve charge reactivity, the air/fuel ratio is reduced.

Scavenge air pressure Control



Scavenge air pressure Control



Combustion control

- Lean burn combustion
  - Target of control
  - Means of controlling

- DCC (Dynamic Combustion Control)

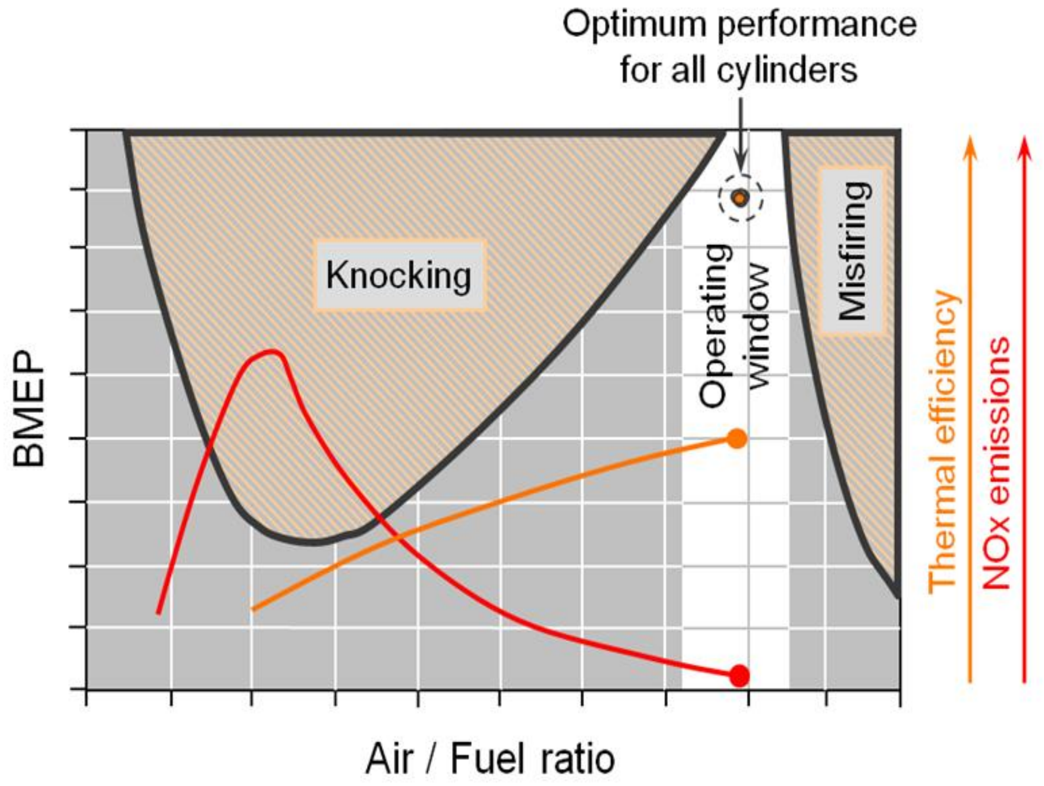
- Compression pressure control
  - Exhaust valve timing (diesel, gas)
  - Balancing (measure)

- Combustion pressure control
  - Injection timing (diesel, gas)
  - Balancing (diesel, gas)
  - Maximum pressure control (diesel), monitoring (gas)

- Knock and Misfiring detection

Combustion Process - Lean burn

- X-DF is a lean burn engine.
- An ignition is initiated by injecting a pilot diesel oil, giving an ignition source for the main fuel charge (gas-air mixture) in the cylinder
- At high loads the misfiring limit is getting closer to knocking limit, which means that the Useful operating window is decreasing
- One of the key measures is to control the combustion process individually in each cylinder, in order to stay within the operating window and have optimal performance for all cylinders regarding safety, efficiency and emissions in all conditions.



Gas combustion control

Means of control

Air

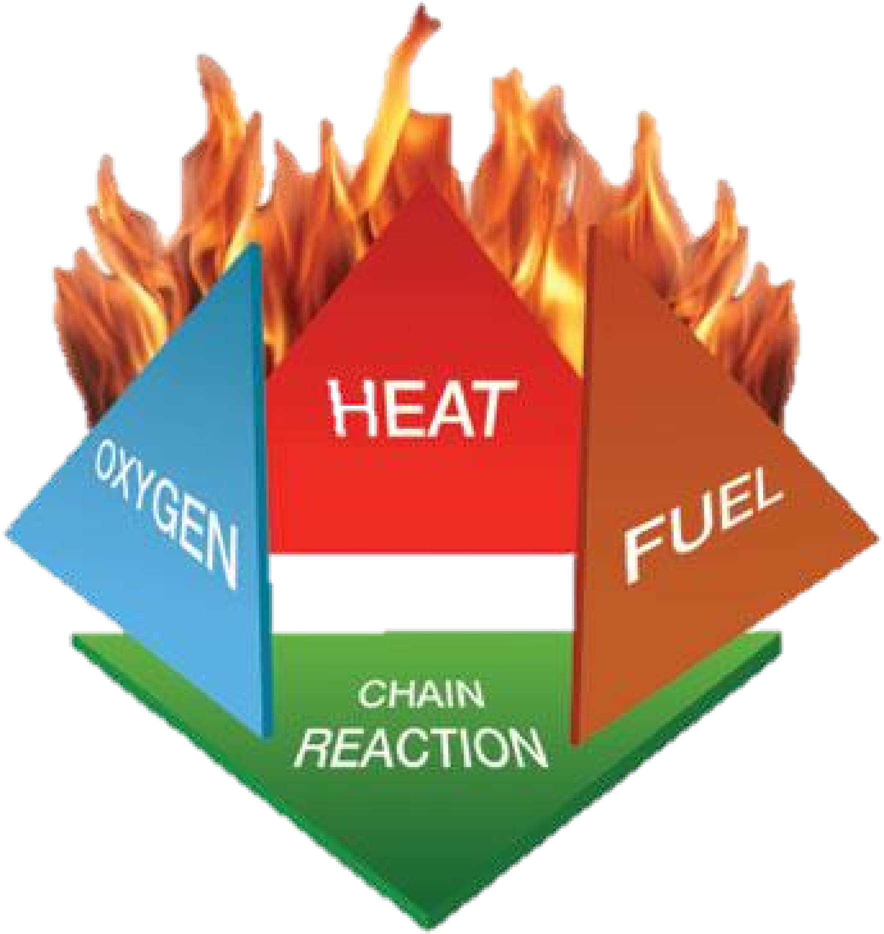
- Exhaust Waste Gate (Scavenge air pressure)
- Exhaust Valve`s timing: VEC (Air charge)

Fuel

- Gas Admission valves: admission time, start admission angle
- GVU: gas pressure

Ignition

- Pilot fuel injection: timing, injection duration



DCC

Dynamic Combustion Control

- The Dynamic Combustion Control (DCC) function ensures that even under hot ambient suction conditions(Tropical conditions) and/or when running on gas with a low Methane Number, the full rated engine power can be achieved in gas mode.

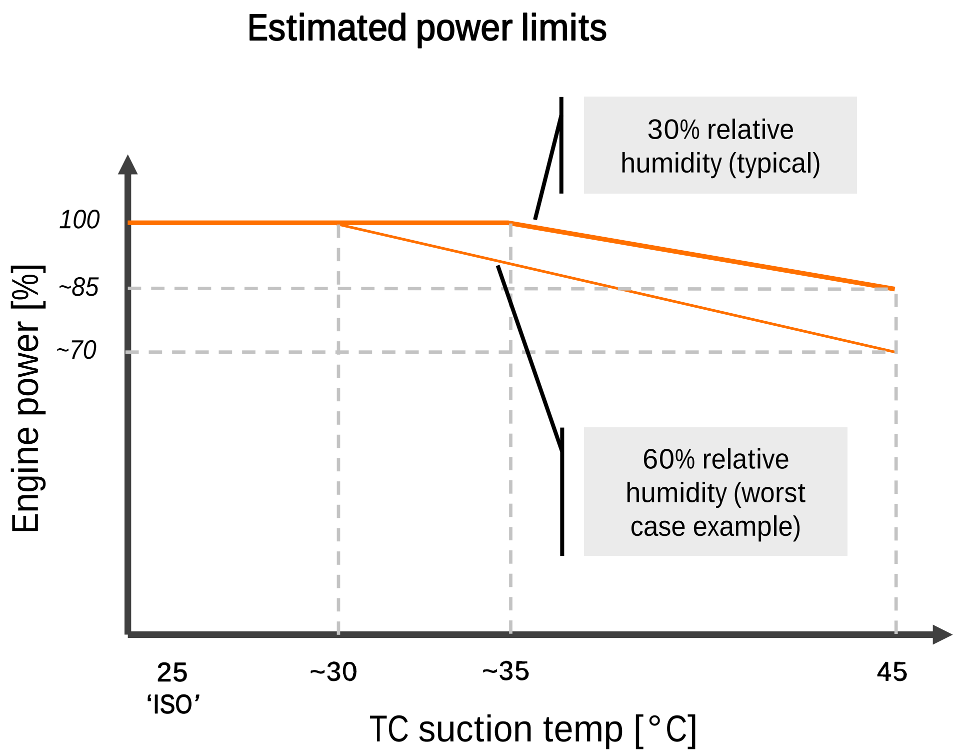
- If critical cylinder pressures are reached at high engine loads, a small additional quantity of liquid fuel is injected with the main fuel injectors. DCC operates with LFO when it gets activated from pure gas mode.

- While DCC is active, also HFO can be used. However, when DCC is not required anymore, a gas trip is released if the fuel system is still running on HFO, in order to prevent the fuel system of being filled with HFO without circulation.

DCC

Impact of ambient conditions

- The maximum power output of high BMEP rated X-DF engines may be limited by ambient conditions (inlet temperature/humidity)
- High ambient temperatures lead to loss in turbocharging/scavenging performance, which may reduce the effective air/fuel ratio (‘lambda’) to a critical level
- Main parameters influencing the power limit:
    - Inlet air temp (density)
    - Inlet air humidity (condensation)
    - Scavenge air temperature
- No accurate prediction of limits possible as heavily depending on TC efficiency etc.
- Engines need to run 100% rated power to pass FAT/TAT and emission certification



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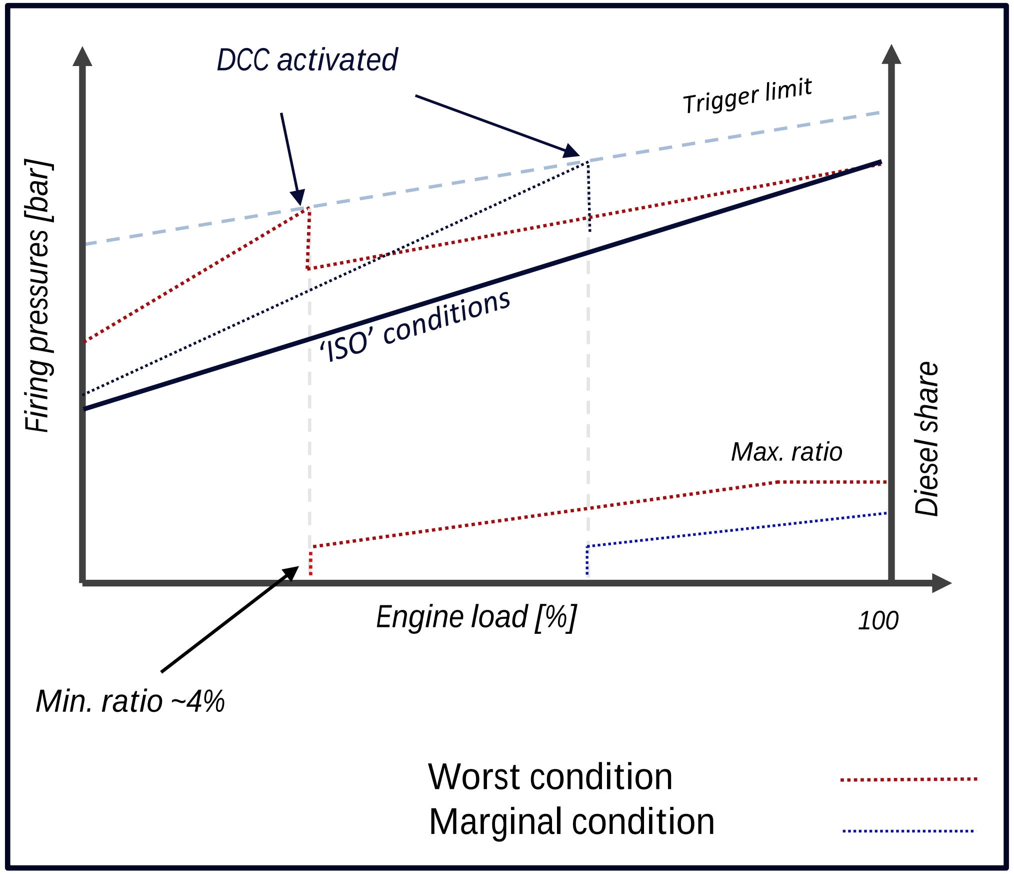
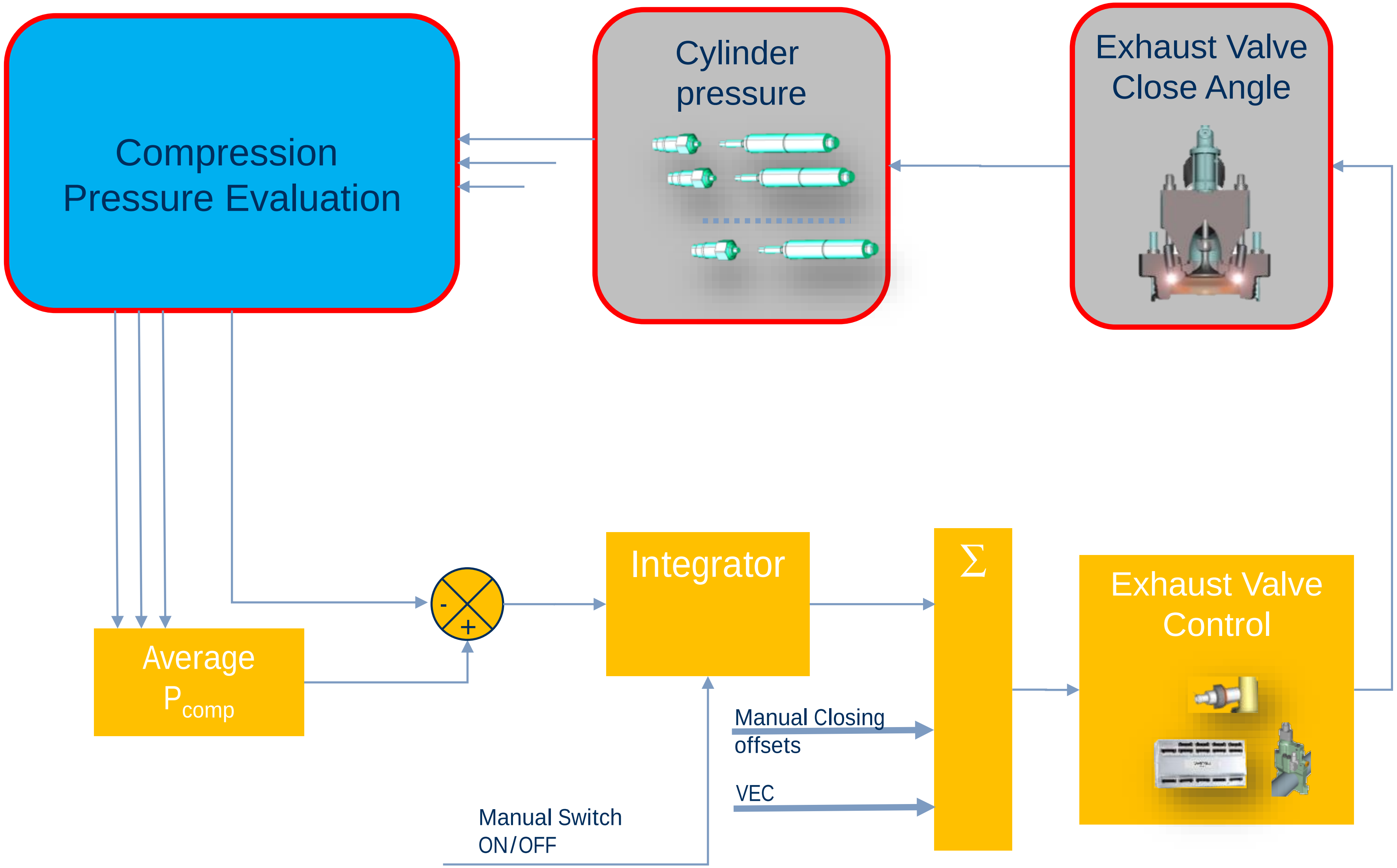
DCC

Full engine output under all conditions

- DCC is triggered when the firing pressure limit is reached at high load at tropical condition and/or low methane number
- Based on additional injection of small quantity of liquid fuel
- Typically below 10 % of energy input
- Engines certified to be fully IMO Tier III compliant with max. diesel amount
- Full engine output available under all conditions
- Standard on all X-DF engines



Compression pressure balancing



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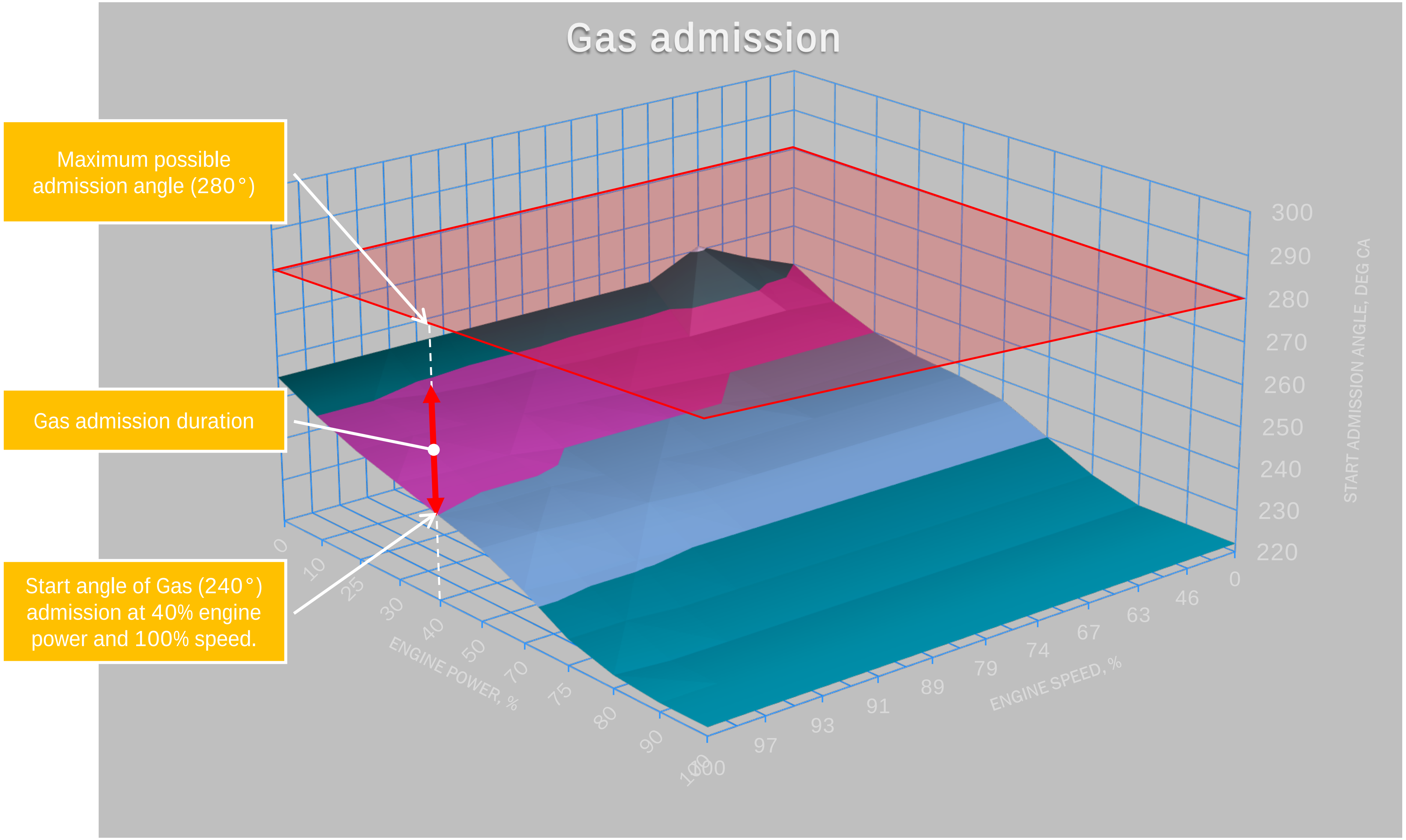
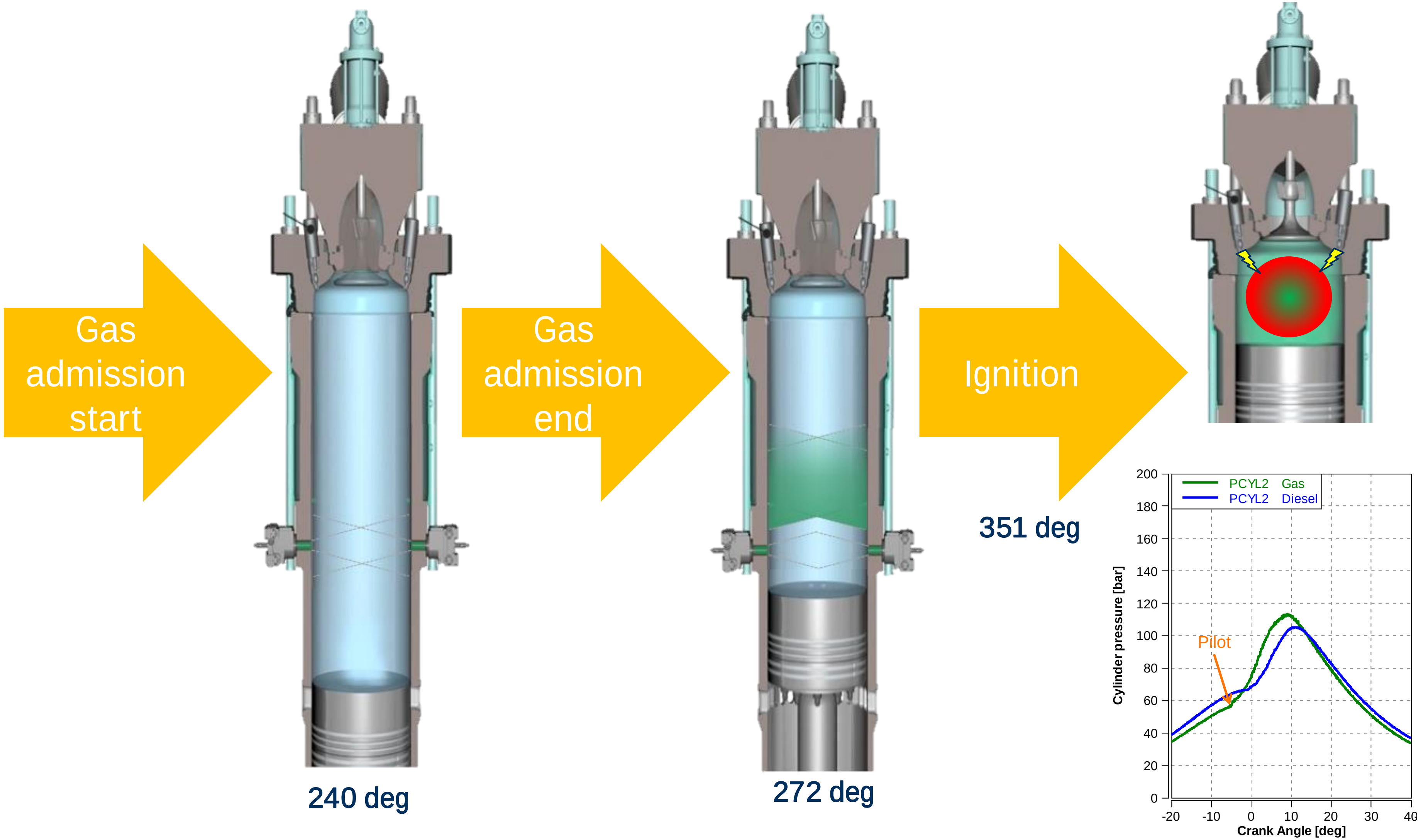
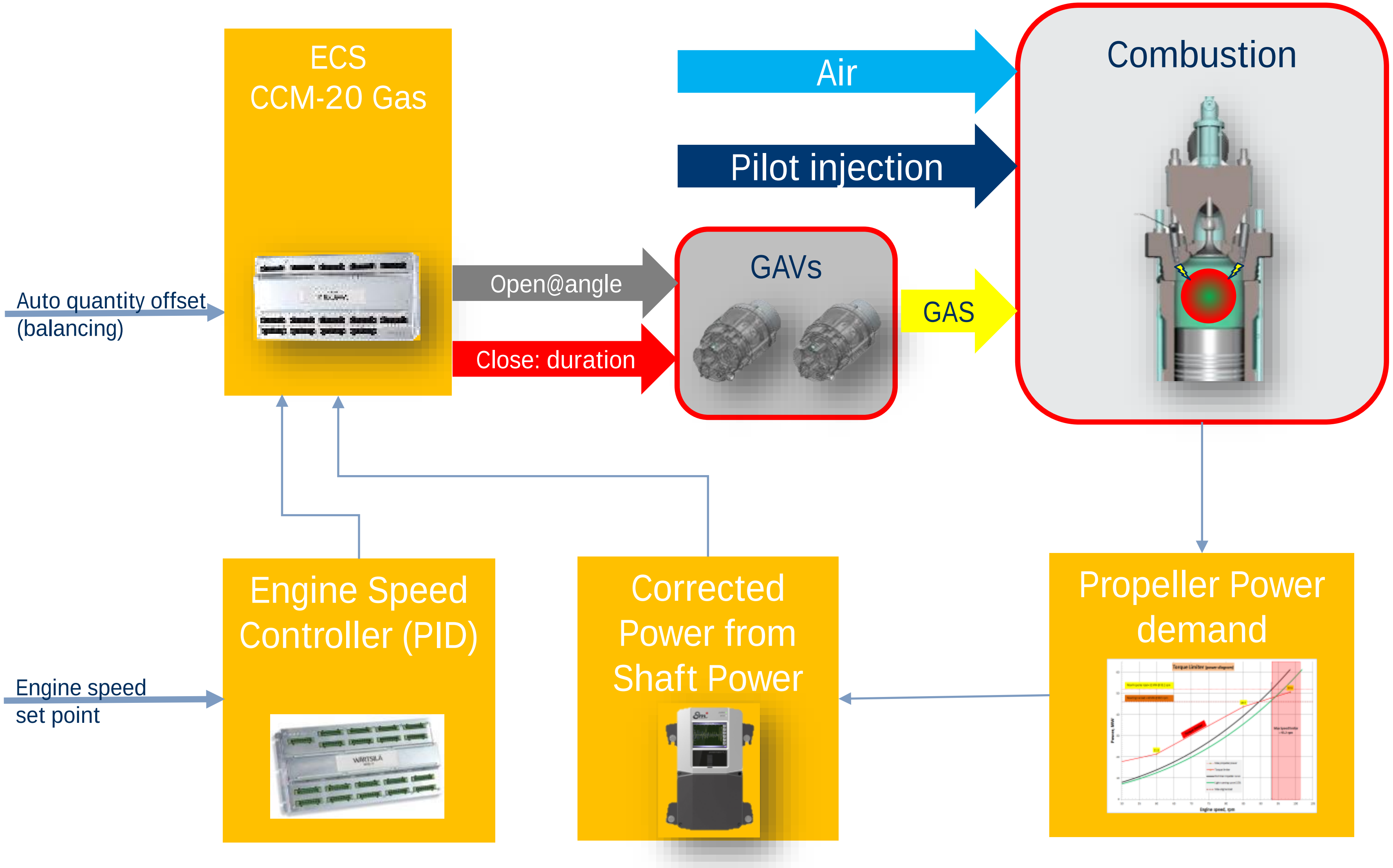
FUEL: Gas Admission



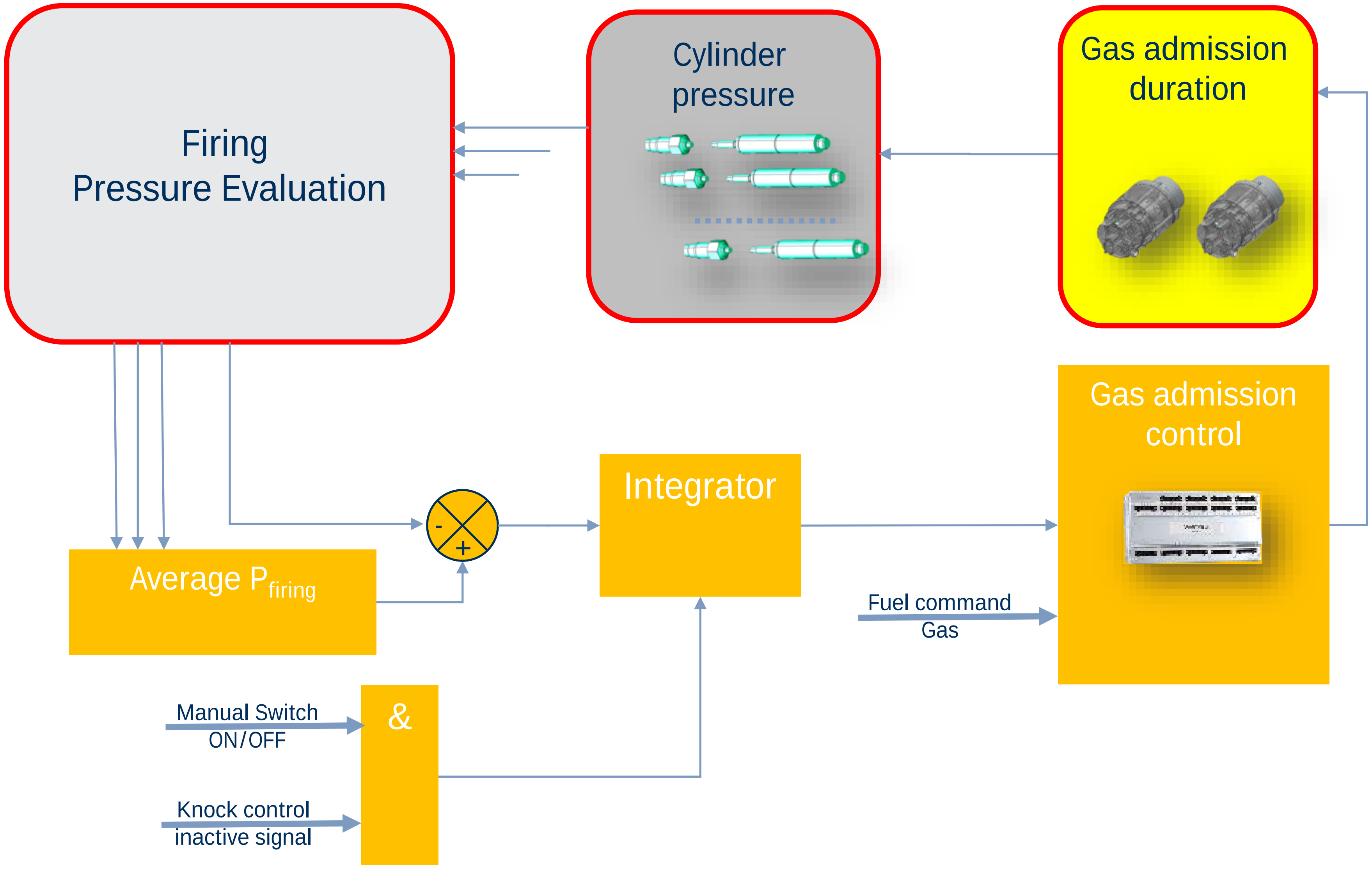
Combustion on Gas fuel



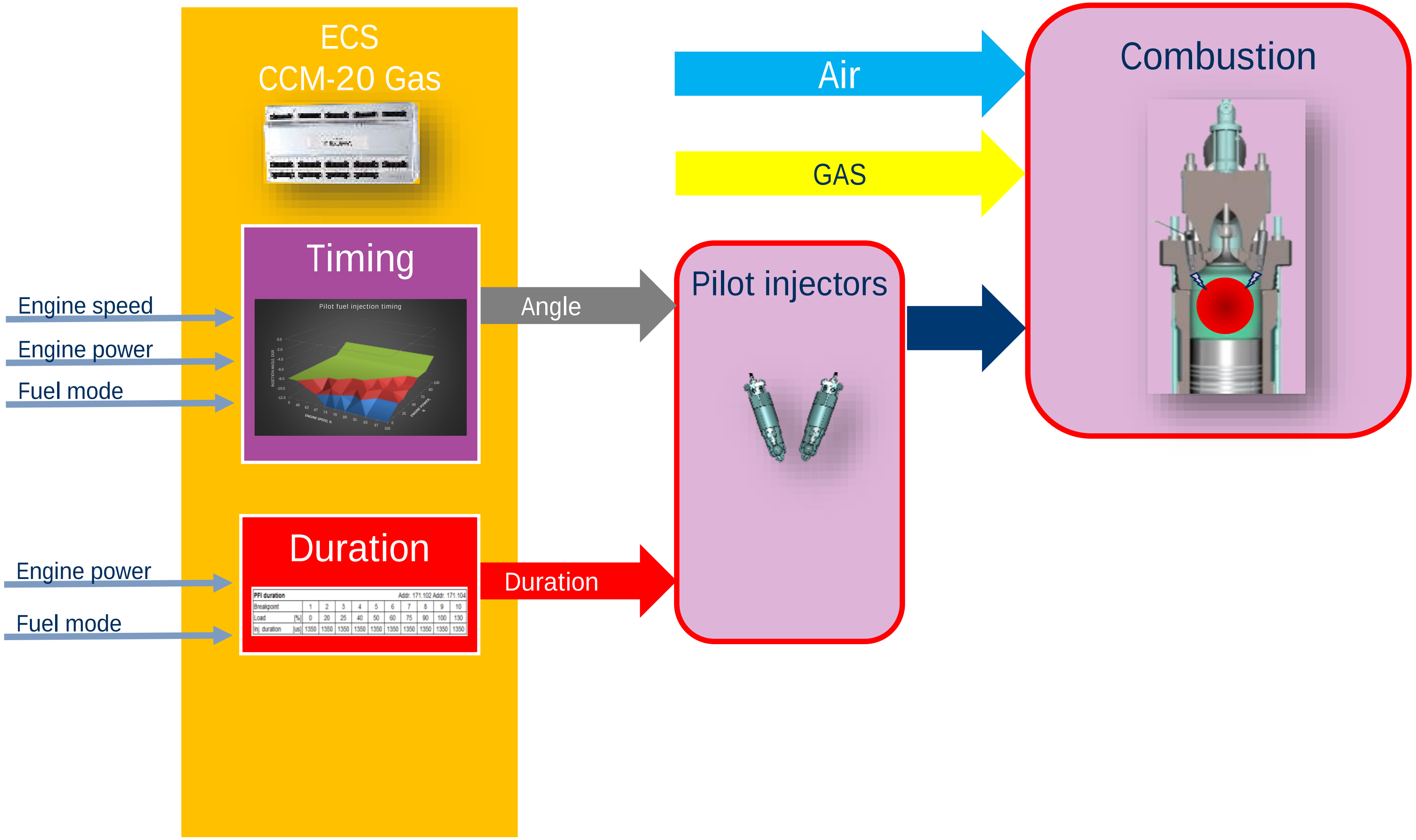
Gas admission control



Firing pressure balancing



Ignition: pilot fuel injection



PFI duration		Addr. 171.102 Addr. 171.104									
Breakpoint		1	2	3	4	5	6	7	8	9	10
Load	[%]	0	20	25	40	50	60	75	90	100	130
Inj. duration	[us]	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350

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Combustion misfiring in Gas

Cylinder misfiring prevention

- Air/fuel ratio:
  - Scavenge air pressure control
  - Gas pressure control
  - Gas admission control
- Pilot fuel ignition

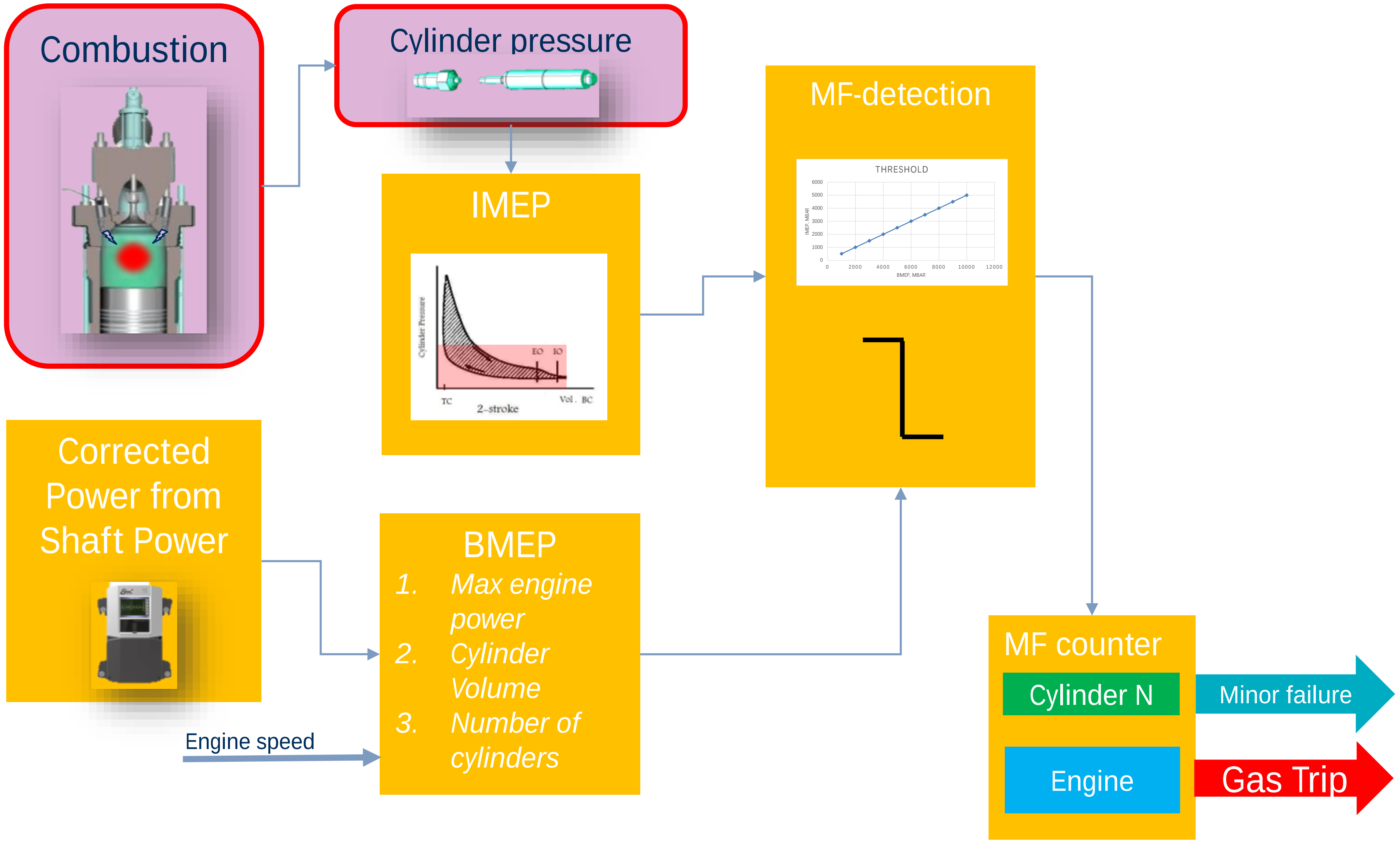
Detection

- Difference between BMEP and IMEP for every cylinder and cycle
- Counts MF-cycles for each cylinder and whole engine (Evaluation window 6 cycles)

Actions

- UNIC Load Limit in Gas mode (Gas mode and one failed pressure sensor)
- Minor failure : misfiring state on single cylinder (Cylinder≥3)
- Gas trip: misfire (Engine≥ 6), too many pressure sensors failed (2 or more).
- Gas interlock: not enough pressure sensors (2 or more) and in diesel mode.
- Alarms: ….

MF detection



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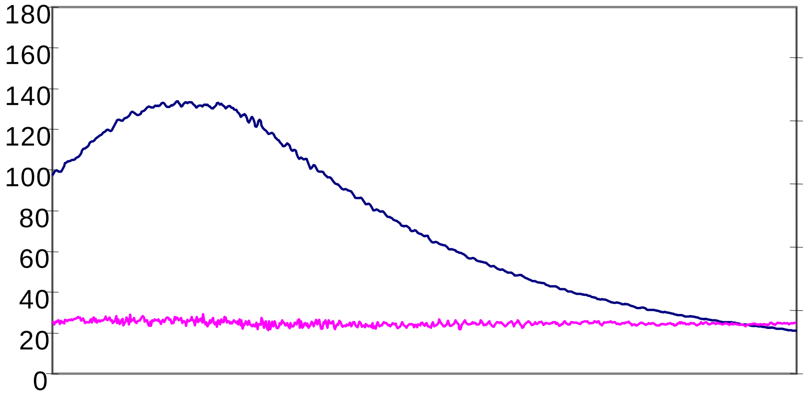
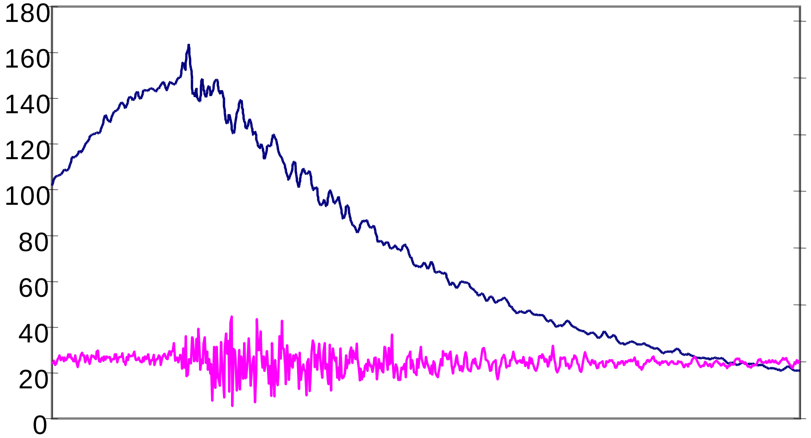
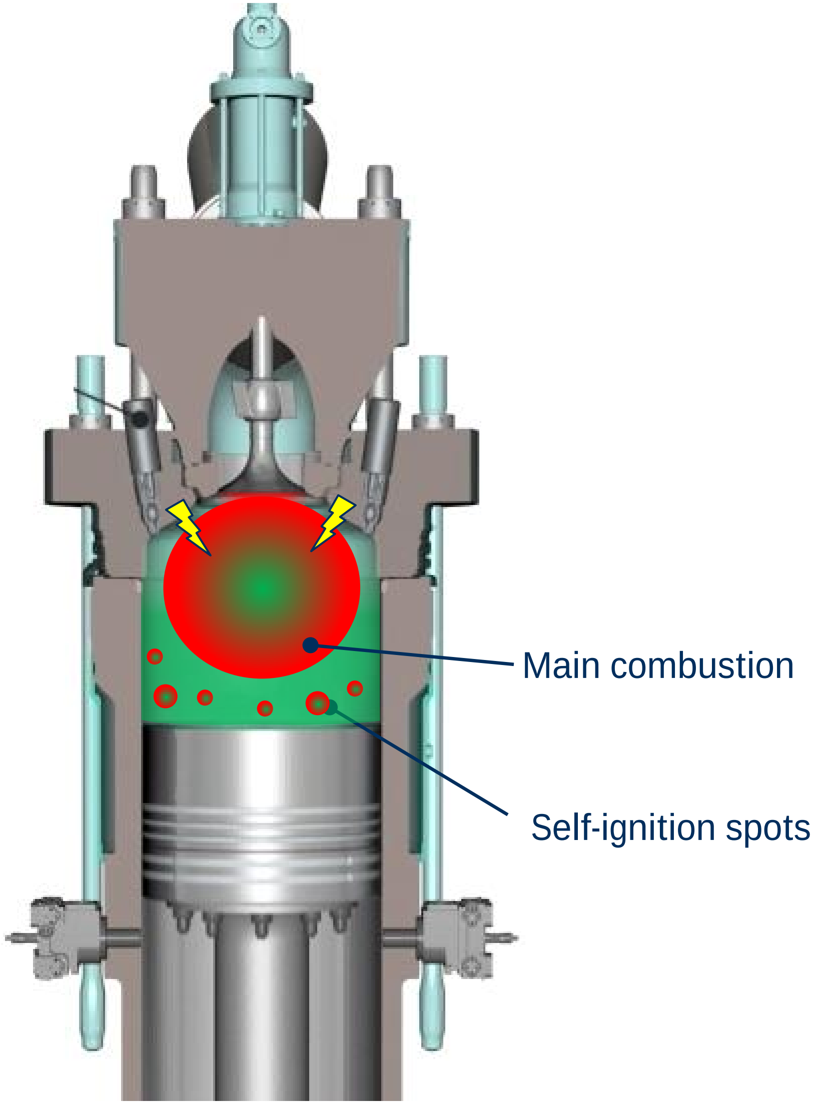
Knock Control

Normal combustion



Knocking combustion





Knock Control

Source:

- Knock sensor
- Cylinder pressure sensor

States:

- Heavy knocking

Actions:

- Gas trip: heavy knock

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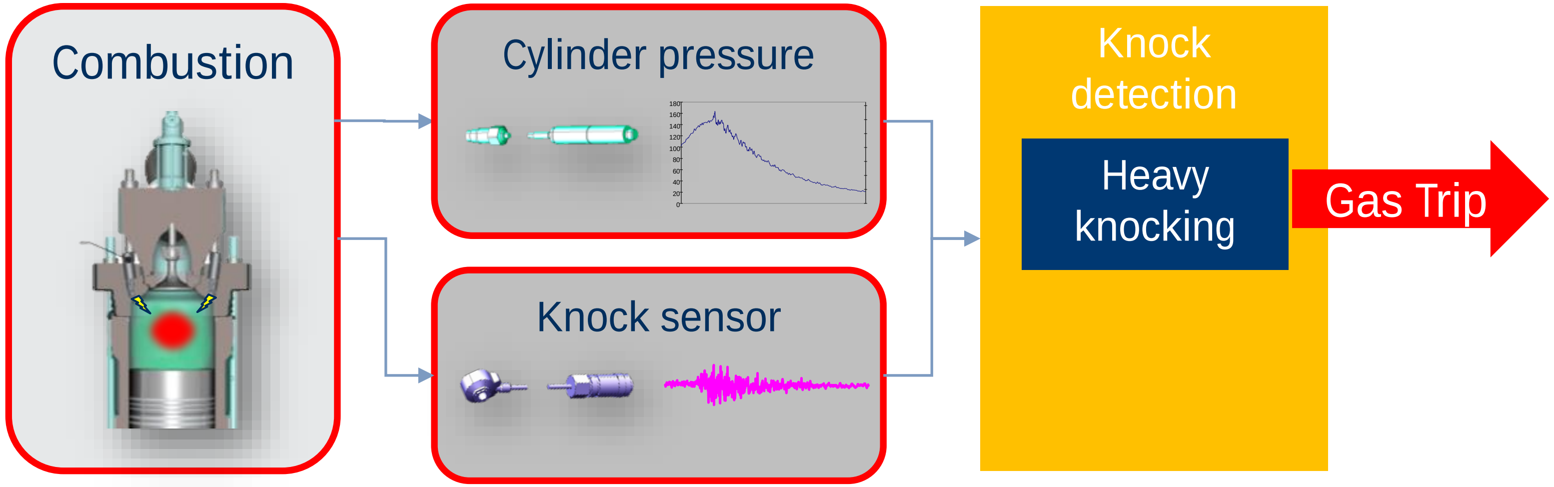
Knock Control



Module Redundancy

Redundancy, emergency operation with faulty control parts:

Control Module CCM-20 Diesel

- If a Diesel CCM-20 module fails or is being switched off during diesel running, the corresponding cylinder is automatically cut out and all its common functions will fail as well. However, all other cylinders and their common functions remain operative
- To enable cylinder lubrication on this cut-off unit, a cable from that flexLube pump to a neighbour CCM-20 can be installed temporary
- Any CCM-20 module can be exchanged easily. The respective software and parameters are stored in the LDU panels and new software can be loaded to the new CCM-20 at engine stand-still.

Control Module CCM-20 Gas

If a any CCM-20 module fails or is being switched off during gas running, then gas trip. And change to diesel running

System Redundancy

CAN Bus, External Bus (CANopen or MODbus)

Always two busses are active. If one bus is interrupted, the second bus is still available for communication. Engine operation is not interrupted

UNIC-flex power supply (E85)

All modules have two redundant power form two different power supplies

Sensors

Most of vital sensors and transmitters are existing twice and their mean values are compared and then used for controlling the engine. If one sensor fails, UNIC-flex indicates the specific sensor failure and continues to work with the remaining one

Sensor Redundancy

Speed and TDC/BDC sensors

- If one of the four speed sensors fails, the remaining three are sufficient for safe operation
- With a faulty TDC or BDC sensor, the engine is still fully operational. However, crank angle determination after system reboot might take a full revolution of the crankshaft

Exhaust valve position sensor

Each exhaust valve drive has a position sensor. If it fails, the corresponding CCM-20 controls the exhaust opening and closing valve angles with the average of opening and closing dead-time from all other cylinders

Pump Redundancy

Fuel pumps and actuators

- If one actuator power fails, the corresponding fuel pump will deliver according to the last known, valid set point. Fuel pump actuators can be fixed to a certain delivery
- The fuel pressure control valve on the free end of the fuel rail limits the rail pressure to 1’050 bar

Servo oil pumps

- If CCM #03 or #04 fails or being switched off, the corresponding servo oil pump will go to a minimum pressure setpoint of approx. 80 bar
- With one damaged servo oil pump the engine remains operational

Other Redundancies

Shut down and Emergency Stop

In Diesel Mode

Stopping the engine in case of emergency can be done in different ways, where each one will stop the engine

- Triggering the emergency stop valve on fuel pressure control valve by ESS
- Fuel zero command released by the governor (All fuel Injection cut-off by UNIC)
- Fuel pump Actuator set “0” position by UNIC

In Gas Mode

- In case of cancellable shut-down, engine operating mode change to Diesel first, then engine will be stopped after shutdown signal become active
- In case of non-cancellable shut-down, engine will stop immediately, and Exhaust ventilation is requested

Other Redundancies

Remote Control

In Diesel Mode

- With remote control out-of-order, the engine can still be operated from the LDU panels in the engine control room or from the local control panel on the engine
- The LDU panels are a part of the UNIC-flex control system, independent from the propulsion system

In Gas Mode

Without RCS, engine can not be operated with Gas