STASHH

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PUBLIC

Final Design of OP Mobility

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Abstract: This deliverable contains the supplier specific design of the FCM according to the WP3 Standard

Revision History

Date	Description	Author
2024/Aug/13	First draft	Werner Rumpl (OPmobility)
2025/Feb/20	Final QA	Federico Zenith (SINTEF)

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1 Introduction

The FCM50 from OPmobility is intended to be used for several applications such as bus, coaches, trucks, light commercial vehicles, generator sets and machinery. The targeted 50kW and A size therefore represents a solid power baseline for single deployment or for higher power demands, the FCM50 can be easily scaled up by piling the modules in parallel.

2 WP3 standard overview

The following sub-sections provide an overview of the WP3 standard definition, which is necessary to verify the compliance of the FCM design according to the StasHH definitions. The exact and binding requirements are listed in the official documents. A minimum power output of 30 kW (Beginning of life, BOL) of the FCM is mandatory for the StasHH standard.

2.1 Standard size definition

Three series of FC boxes were defined within the standard: A, B, and C series. For the A-series a doubling in the height direction is possible, which will be denoted with the subscript AA. The B-series allows for doubling or tripling in height direction denoted with the subscript BB and BBB respectively. The dimensions of the boxes can be found in Table 1 and the following tolerances in all directions are tolerated: +0/-100 mm.

Table 1: dimensions FC module A, B and C

StasHH	Length / mm	Width / mm	Height / mm	Expected PEM kW
A	1.020	700	340	50
AA	1.020	700	680	110
AAA	1.020	700	1020	160
B	1.360	700	340	70
BB	1.360	700	680	145
BBB	1.360	700	1.020	220
C	1.700	700	340	90

The respective volumes of the different sizes are as follows:

- A external volume is max. 0.243 m^3
  AA external volume is max. 0.486 m^3
  AAA external volume is max. 0.729 m^3
- B external volume is max. 0.324 m^3
  BB external volume is max. 0.647 m^3
  BBB external volume is max. 0.971 m^3
- C external volume is max. 0.405 m^3

A visual representation of the A to C series boxes including the multiple sizes is shown in Figure 1.

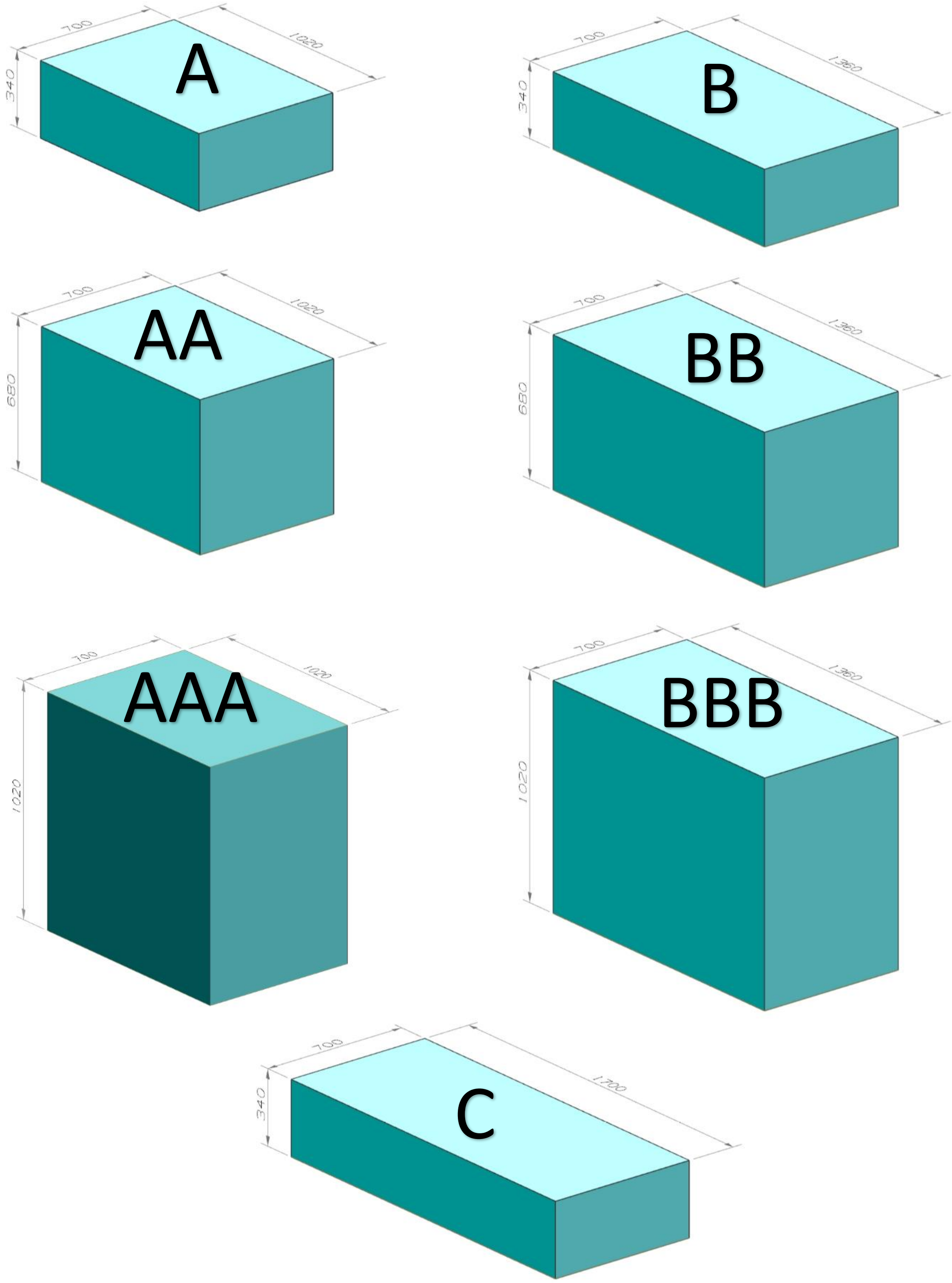


Figure 1: FC modules A, B and C

The orientation of all FC boxes is fixed according to the Length x Width x Height definition except for the A(A) boxes which can be orientated optionally on its side. This is not a StasHH requirement. The optional orientation on the side is shown in Figure 2

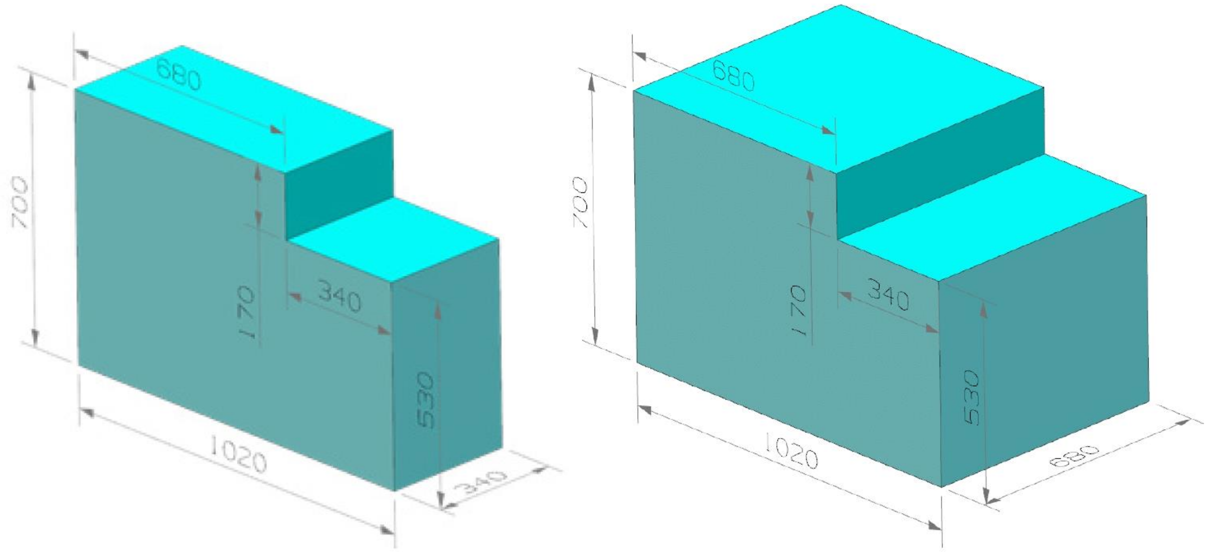


Figure 2: A and AA on their side

2.2 Standard interface definition

The interface areas and requirements for the pneumatic, hydraulic, and electronic connections are defined in the following.

2.2.1 Interface area

The interface area can be on two different sides. At least all pneumatic and hydraulic connections are within this interface area (except eventually the drain or (box) ventilation). Sides are defined with FC module in horizontal position:

1. In corner 3, on the L x H side FC module. See Figure 3. The dimensions of the interface area will be max. 340mm x $Depth_{main}$ x Module Height
2. In corner 4, on the W x H side FC module. See Figure 3. The dimensions of the interface area will be max. 700mm x $Depth_{main}$ x Module Height

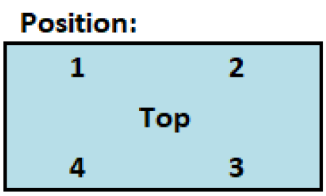


Figure 3: Top view of FCM for interface area definition

“$Depth_{main}$” or “D_{main}” is defined as the minimum depth needed to stay within the overall FC module volume (defined in D3.2), with connected male and female connectors.

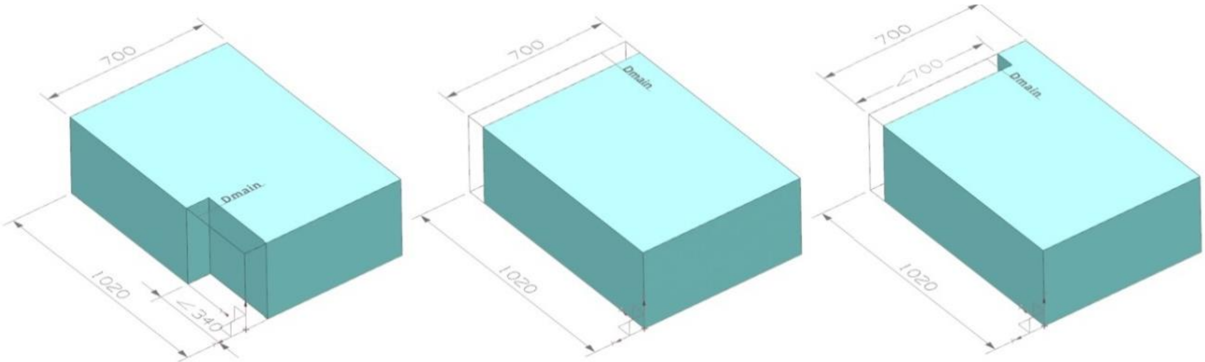


Figure 4: FCM interface areas possibility (1st side)

The size definitions of the interfacial areas can also be found in a tabulated manner in Table 2

Table 2: Dimensions FC module interface areas (1st side)

Interface 1st side	Length / mm	Depth / mm	Height / mm
A	Max. 340	$\geq D_{main}^{x}$	340
AA			680
AAA			1.020
B			340
BB			680
BBB			1.020
C			340

Interface 1st side	Length / mm	Depth / mm	Height / mm
A	Max. 700	$\geq D_{main}^{x}$	340
AA			680
AAA			1.020
B			340
BB			680
BBB			1.020
C			340

*Depth is min. Depth needed to stay within overall FC module volume with connected interfaces

Optionally, a second interface area can be utilized under the following conditions:

3. The main side complies with 1. with depth “Dmain”, and the second side complies with 2. with depth “Dsub”

OR

4. The main side complies with 2. with depth “Dmain”, and the second side complies with 1. with depth “Dsub”
5. Both connections areas are mechanically redundant, i.e., all pneumatic and hydraulic connections are on both sides (except eventually the drain or (box) ventilation)

“$Depth_{sub}$” or “D_{sub}” is defined as the minimum depth needed to stay within the overall FC module volume, with not connected male or female connectors.

Table 3: Dimensions of FC module interface areas (optional 2nd side)

Interface 2nd side	Length or width / mm	Depth / mm	Height / mm
A			340
AA			680
AAA			1.020
B	Max. 340 or 700	$\geq D_{sub}{}^{x}$	340
BB			680
BBB			1.020
C			340

An exemplary image of the optional second interface area is depicted in

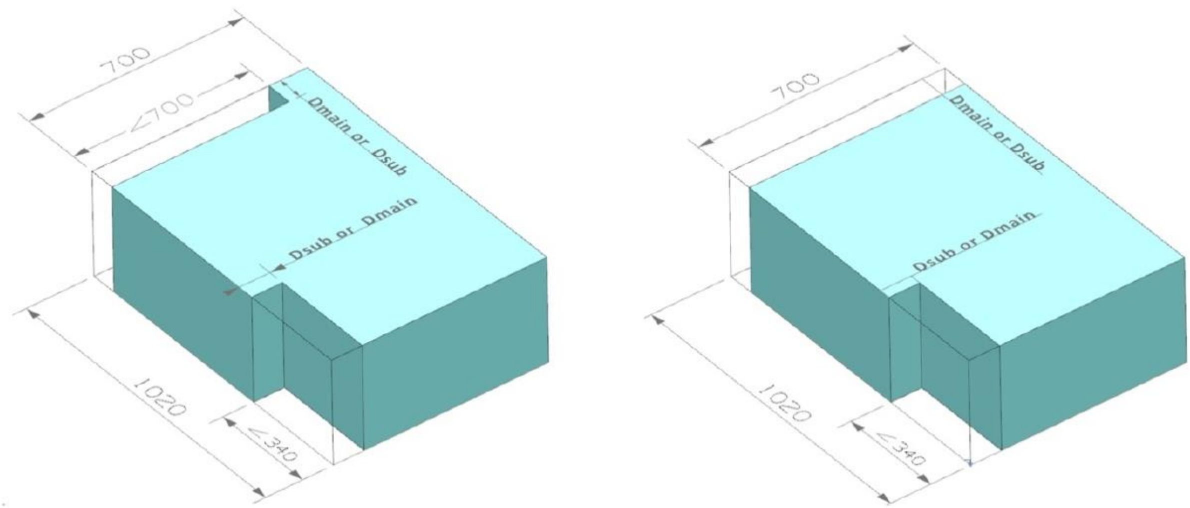


Figure 5: Example of FC module interface area with 1st side and optional 2nd side

2.2.2 Hydraulic, pneumatic, and electrical interfaces

All hydraulic and pneumatic interfaces must comply with the following conditions:

- All the pneumatic and hydraulic connections, excluding the optional drain or (box) ventilation, are positioned in the defined interfaces areas
- The connections' principle will be fixed for all FCMs, but can be different depending on usage. For example, for air this can be a hose, for hydrogen a pipe. See Table 4
- The connection size ranges (in mm) are defined, but will vary with the power range of the FC module Table 4.
- The electrical and I/O communication can be positioned anywhere within the chosen overall dimensions of A, B and C.

Table 4: Hydraulic and pneumatic interfaces of FC modules

	Interfaces	Inner diameter / mm Nominal power				Remark
		≤ 70 kW	71 - ≤ 100 kW	101 - ≤ 130 kW	131 - ≤ 160 kW	
Hydrogen	Pipe fitting	6-8	8-12	12-16	16-20	6-22 bar
Air	Nozzle + Hose	30-60	45-75	60-90	75-105	
Steam	Nozzle + Hose	30-60	45-75	60-90	75-105	
Drain	Nozzle + Hose	6-8	8-12	12-16	16-20	optional
Cooling FC	Nozzle + Hose	20-40	30-50	40-60	50-70	In/Out
Cooling -E	Nozzle + Hose	15-35	20-40	25-45	30-50	Optional
Breather	Banjo	M14x1.5	M14x1.5	M14x1.5	Tbd	Optional
Ventilation	Nozzle + Hose	20-40	20-40	20-40	20-40	Optional

An additional condition for the main hydraulic and pneumatic connections is that they may not interfere in the horizontal and vertical directions, see Figure 6.

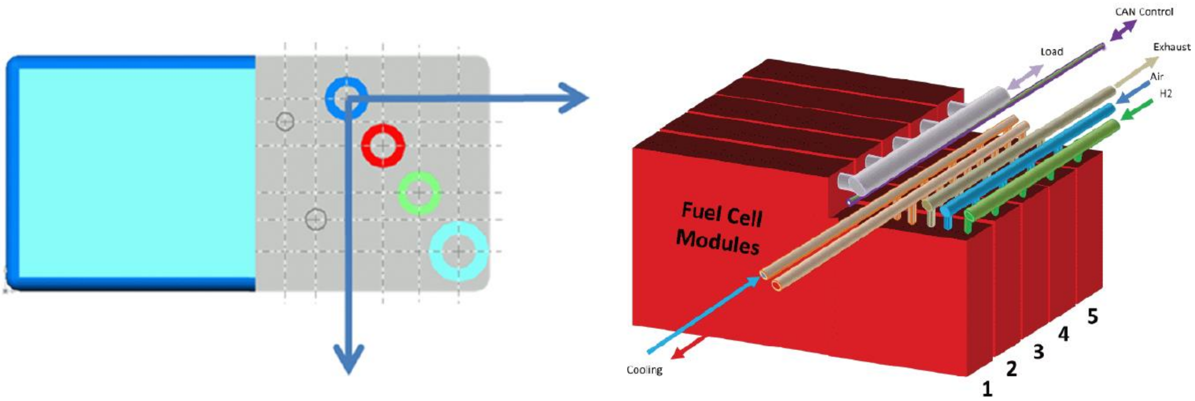


Figure 6: Non-interfering hydraulic and pneumatic connections

2.2.3 Low and high voltage connectors

Within StasHH the pins for the LV and HV connection are specified but not the specific connector.

High voltage connector:

The connector must have two pins, plus and minus. Additionally, it must withstand the maximum FCM voltage and current. Connectors, already utilized in heavy-duty applications are preferred.

Low voltage connector:

The LV connector must withstand up to 100 A and cable lugs are suggested.

2.3 Standard API definition

2.3.1 Physical connector

For the physical connector for the communication with the FCM only the pins are specified and not the connector itself. It is proposed to use an 18 pin connector to include additional functions of needed. The connector shall at least have an ingress protection level of IP54 with a proposed pinout, depicted in Figure 7.

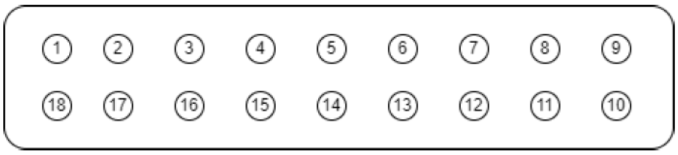


Figure 7: Pinout

The physical connector shall have enough pins to transfer all electrical signals needed and must fulfil the requirements resulting from the working environment or use case of the application.

The following pins must be included in the connector:

1. CAN ground
2. CAN high
3. CAN low
4. OPTIONAL shield
5. Wakeup signal
6. Emergency stop

The following optional pins are also specified:

7. OPTIONAL HVIL in
8. OPTIONAL HVIL out
9. OPTIONAL 24V
10. OPTIONAL ground for LV power
11. OPTIONAL CAN high for DC/DC or secondary FCM
12. OPTIONAL CAN low for DC/DC or secondary FCM
13. OPTIONAL CAN high manufacturer specific diagnostic bus
14. OPTIONAL CAN low manufacturer specific diagnostic bus

The remaining pins 15 to 18 are intended for future use and additionally deployments

2.3.2 State machine

The state machine shall at least contain the following states:

- Idle:
  In this state the FCM has LV power sufficient to activate the FCCU. This state corresponds to “Power on” in J1939. Periodic counter messages are transmitted
- Standby:
  No HV output power but necessary subsystems are powered and ready such that it can start producing output within a short time. Error and diagnostic messages can be sent
- Starting:
  FCM is transitioning from standby to running state. Power is ramping up and HV bus is enabled – Module can consume and provide energy
- Running:

FCM is active and delivering power. Power may be limited due to derating which will be indicated by FCM
- Stopping:
  FCM is ramping down and returning to standby state. HV bus must be enabled during shut-down procedures.
- Error:
  Error state must be enabled from any other state. FCM shall be brought in a safe state

Proprietary substates can be defined by the FCM manufacturers.

For further information see D3.4 document.

2.3.3 Messages

In the following the messages that are used in the communication between the application ECU and FCCU are listed:

- State machine control
- State machine feedback
- Emergency stop request
- Reference power value
- FCM actual current and voltage
- Power limits
- Voltage limits
- High voltage bus information
- FCM temperature
- Time and date
- Ambient conditions
- Vehicle speed
- FCM gas leakage
- Alarm messages

For a generic description of the messages including a mapping to a J1939 message, please refer to the official D3.4 document.

3 Design of [Enter supplier name]

The FCM50 from OPmobility is intended to be used for several applications such as bus, coaches, trucks, light commercial vehicles, generator sets and machinery. The 50kW BOL power can be easily scaled up to several hundreds of kW. The 50kW and the A size standard therefore represents a solid power baseline. The integrated galvanic isolated HV DC/DC converter separates the stack module's electrical potential from the application's one, which is the main reason for this mentioned simple scaling up the power, while respecting electrical safety requirements. The media interfaces are vertically and horizontally not in line to each other for providing easy access during integration and stacking up the FCMs without any interferences at the media interfaces.

3.1 Key technical specifications

The mandatory key technical specifications are listed in Table 5.

Table 5: Mandatory technical specifications of FCM according to StasHH

Requirement	StasHH requirement	FCM
Service life / h	> 15.000	15.000
Geographical heights / m	< 3.000m with derating	< 3.000
IP class	> IP54	I6k6
Low voltage / V	24DC	24 DC
High voltage output / V	160 – 850 DC	520-850 DC
Operational ambient temperature / °C	-25 to 45	-25 to 45
Conductivity glycol / µS/cm	< 6 (ASTM D 1125	< 5
H_2 input pressure / bar	6 - 22	8-12
Hydrogen quality	ISO 14687 or SAE J2719	ISO 14687 or SAE J2719

Additional technical specifications of FCM are listed below in Table 6

Table 6: Additional key technical specifications of FCM

Requirement	FCM
Net continuous system power output P_{net} BOL / kW	50
Net continuous system power output P_{net} EOL / kW	43
Weight / kg	230
DC/DC included in FCM / -	Yes
Peak system efficiency / %	50
System efficiency at P_{net} BOL	46.9
System efficiency at P_{net} EOL	40.5
Gravimetric system power density @ BOL / kW/ton	217
Volumetric system power density @ BOL / kW/m³	231

3.2 Exterior design

The exterior design of the FCM with all main dimensions is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.** to Figure 13

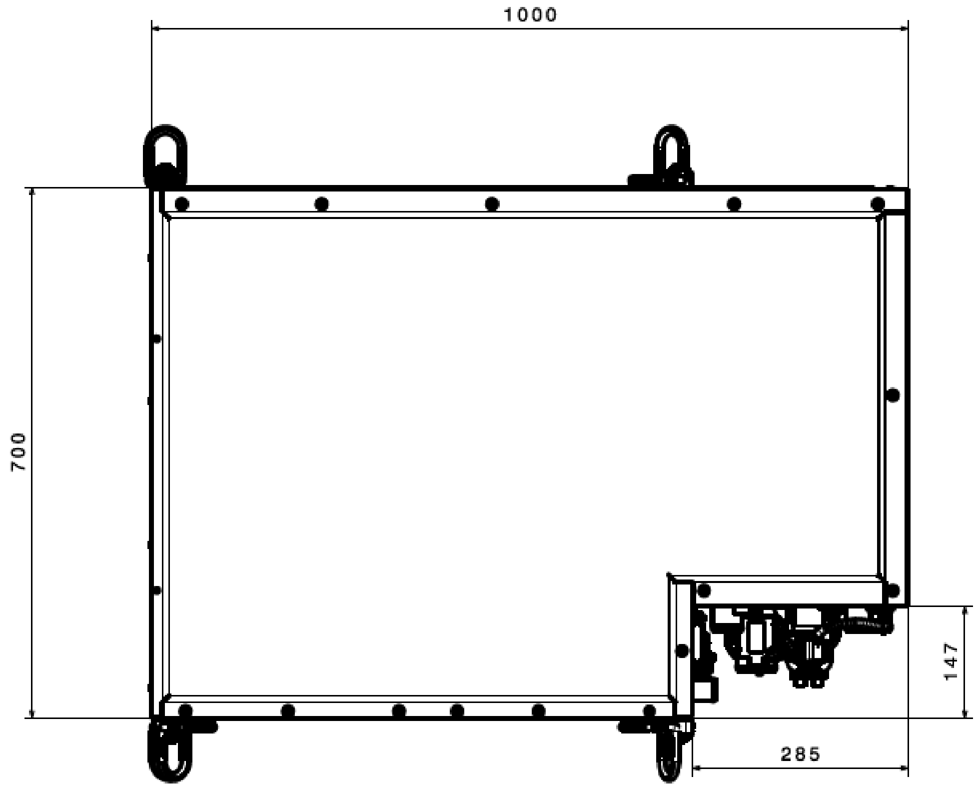


Figure 8 : Top View

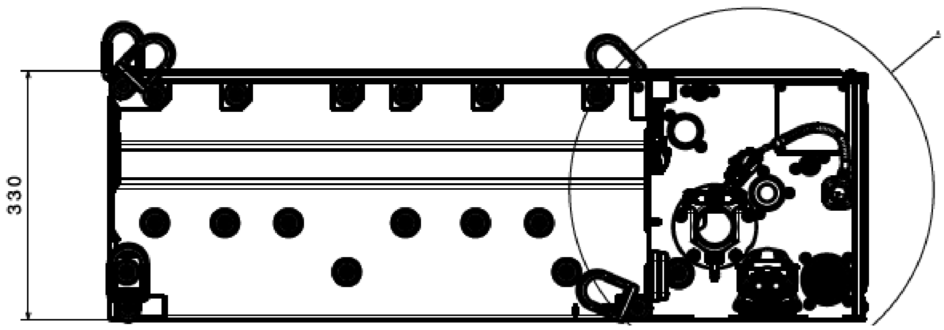


Figure 9: Front view

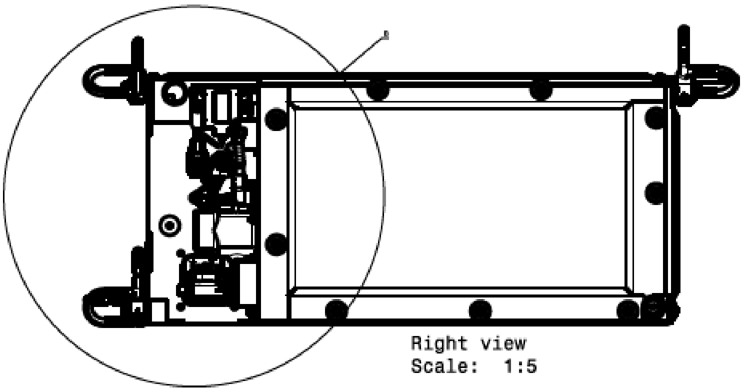


Figure 10: Rigth View

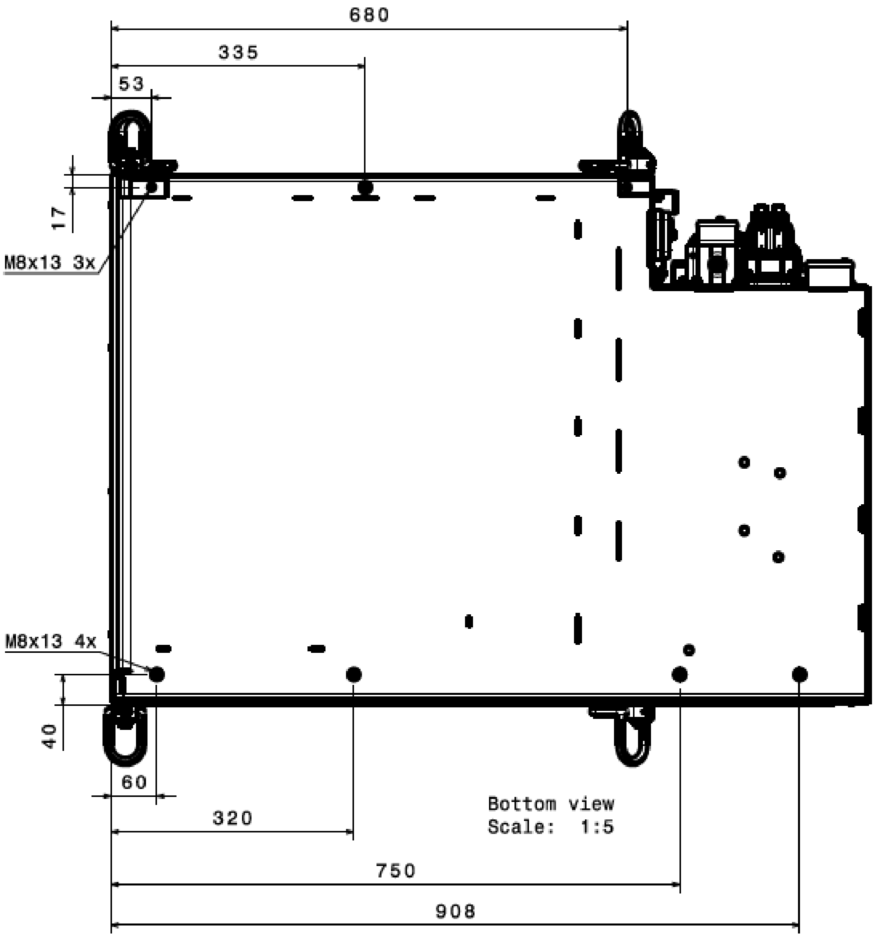


Figure 11: Bottom View

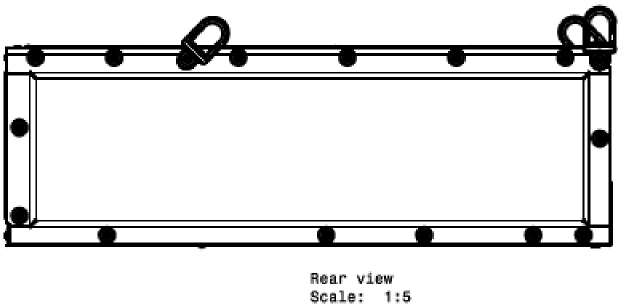


Figure 12: Rear View

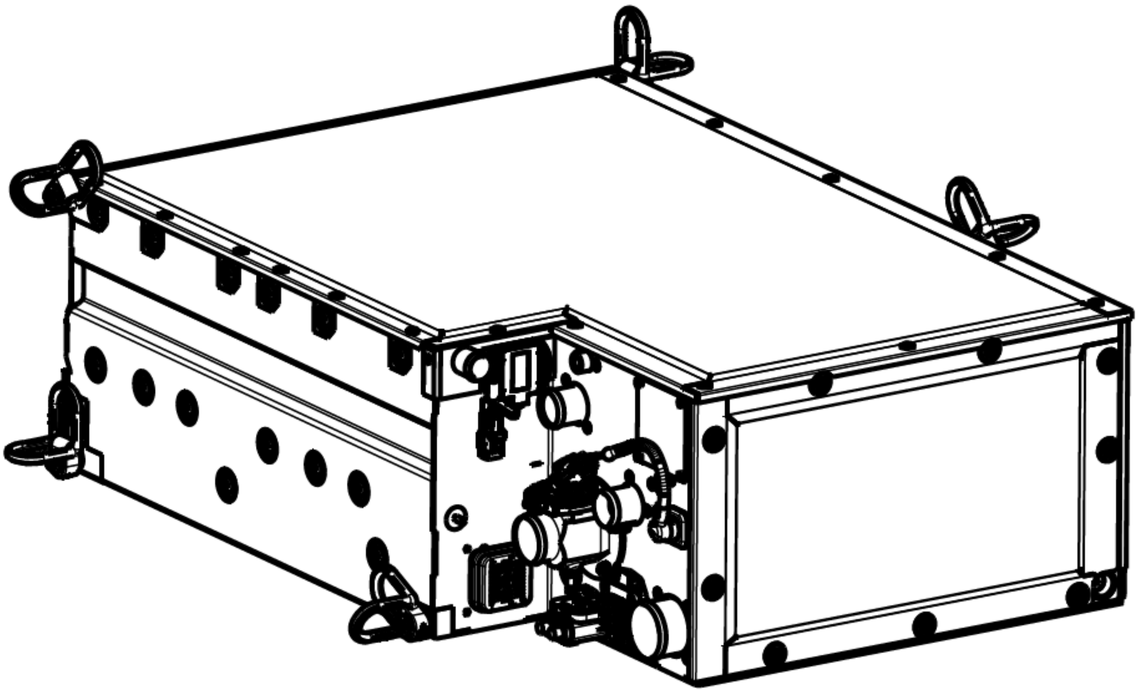


Figure 13: Isometric View

3.3 Module Pictures

Pictures of the module built for testing shown in Figure 14.

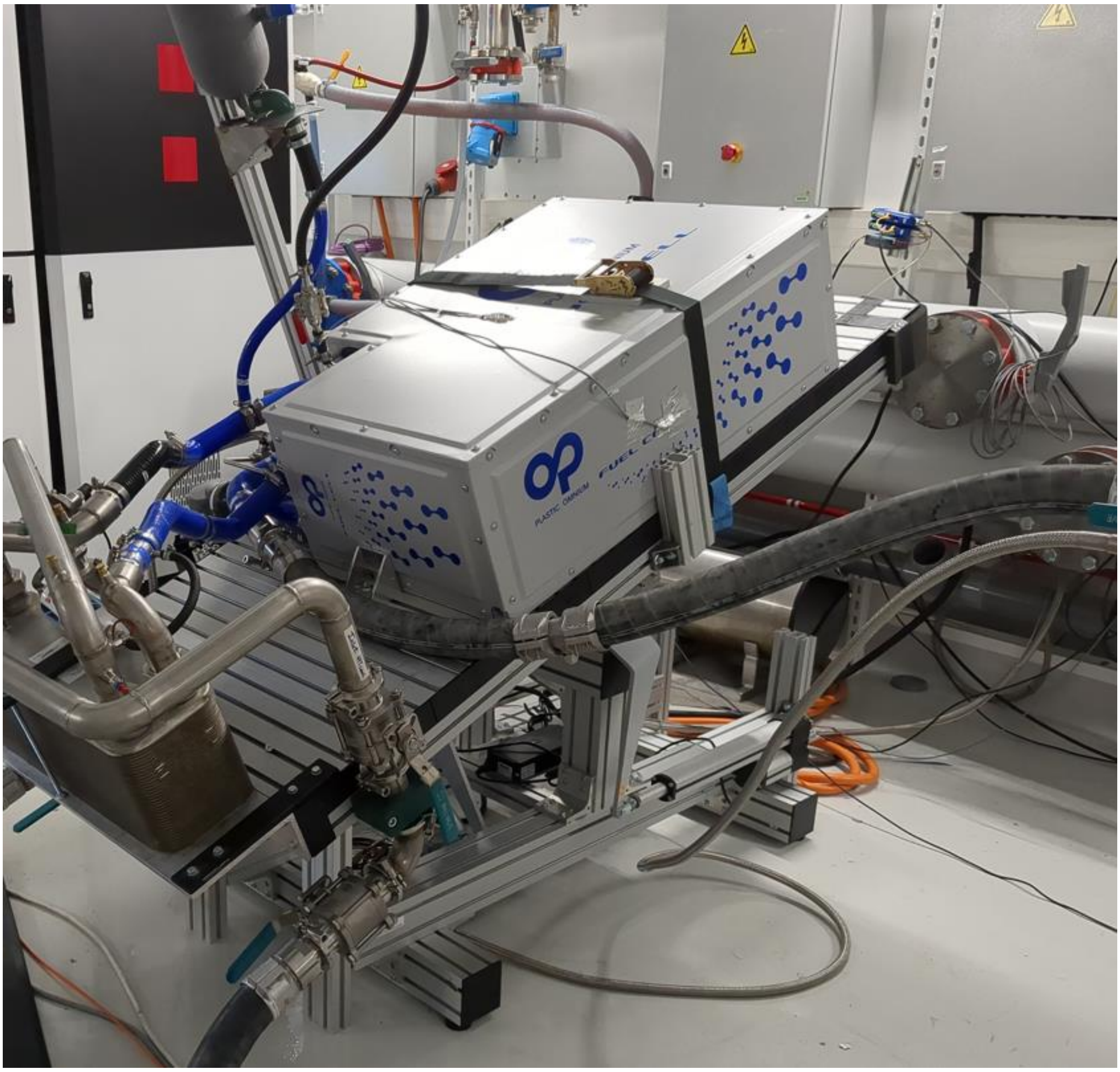


Figure 14: Module installed on the test bench

3.4 Interface specification and area

3.4.1 Interface area including hydraulic and pneumatic interfaces

The design and dimensions of the interface area is depicted in Figure 15.

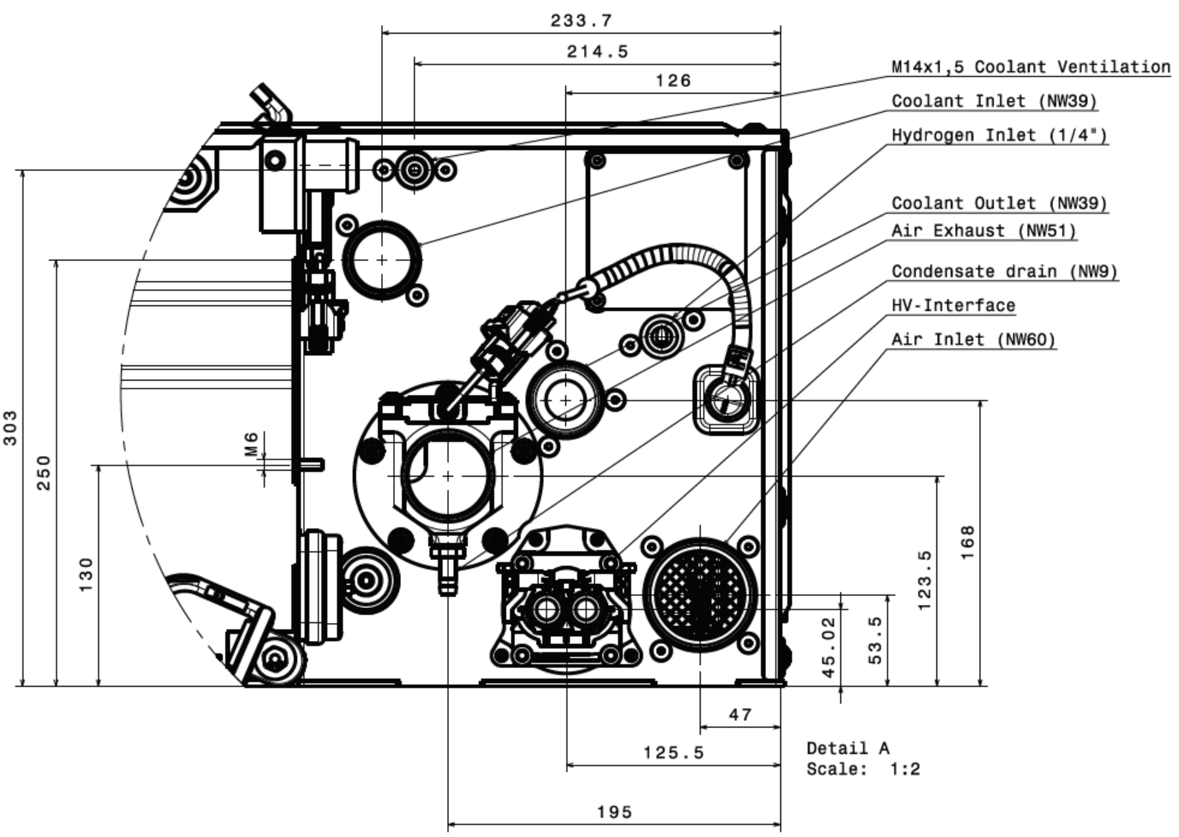


Figure 15: Main interface area of FCM

An extended interface area is utilized, and the dimensions of the extended interface area are depicted in Figure 15.

Due to the size of the integrated components, the air exhaust and coolant outlet interface position slightly interfere with each other in the horizontal axis. The components interface was directly guided to the interface of the module without any redirecting or change in the cross section. Several design studies have been undertaken and the current solution represents the best fit to maintain the outer shell interface cut out requirement of the A FCM Size.

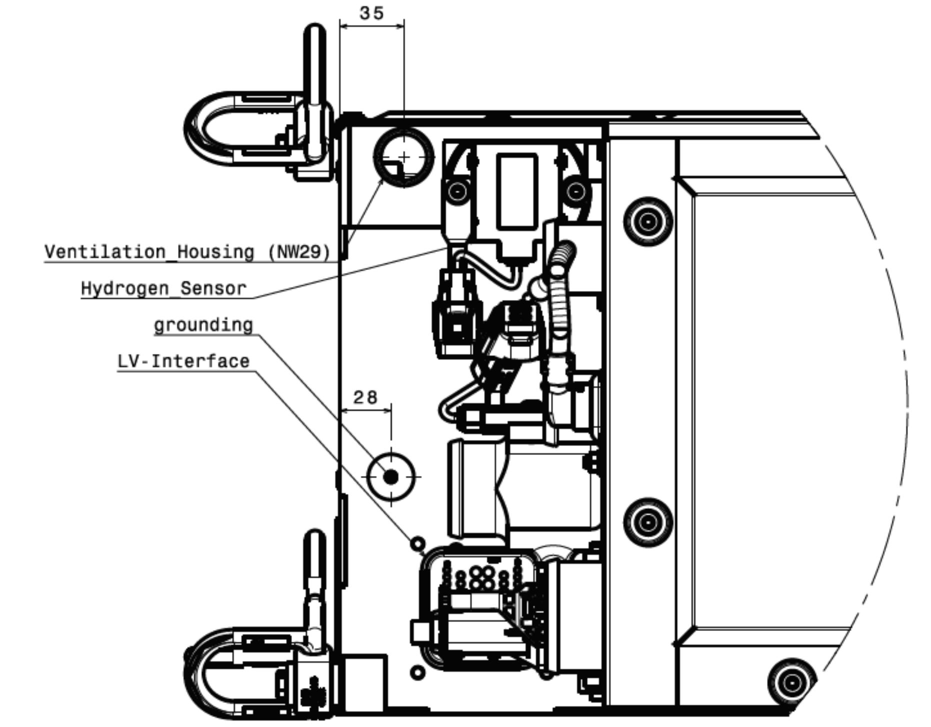


Figure 16: Extended interface area of FCM

The positioning of the pneumatic and hydraulic connections of the FCM within the interface area are shown in Figure 17. The specifications of the interfaces are summarized in Table 7.

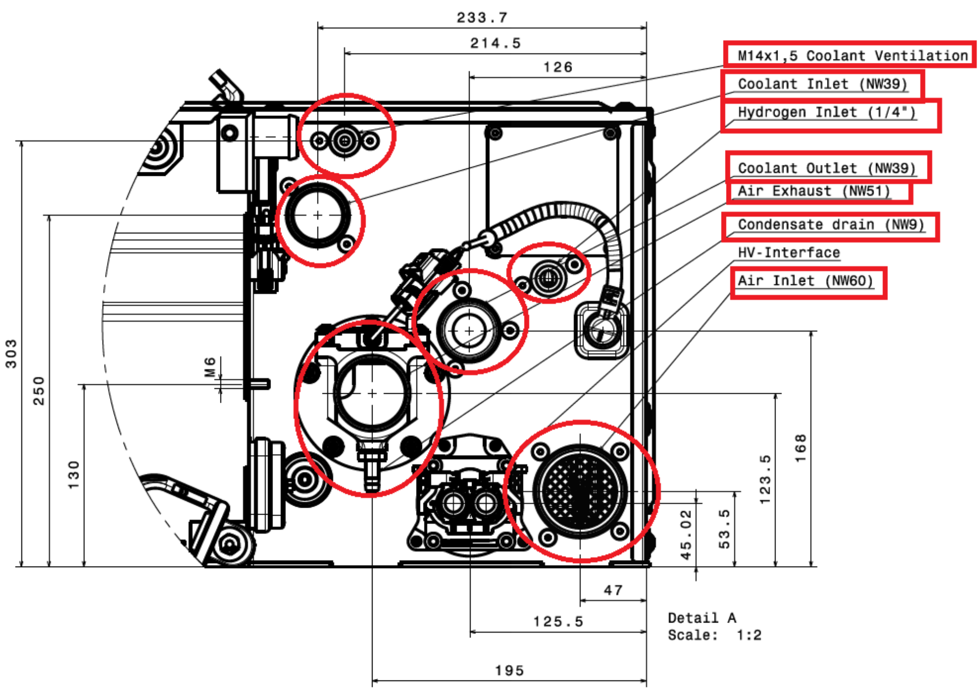


Figure 17: Position of hydraulic and pneumatic connections of FCM

Table 7: Specifications of hydraulic and pneumatic interfaces

	Interface type
Hydrogen	BSP G ¼"
Air	Nozzle d = 60 mm
Steam	Nozzle d = 52 mm
Drain	Nozzle D = 7.5 mm
Cooling FC	Nozzle D=39mm
Breather	M14 x 1,5
Ventilation	Nozzel D=29mm
Note: all diameters are refer to the outer dimension of the interface	

3.4.2 Electrical interfaces

Within this chapter the electrical interfaces and specification of the connectors are summarized.

3.4.2.1 LV

The location of the LV connector is shown in Figure 16: Extended interface area of FCM. It contains 48 pins, which can take 3 different cross sections, enough to conduct signals and power (up to 6mm2) over the same plug.

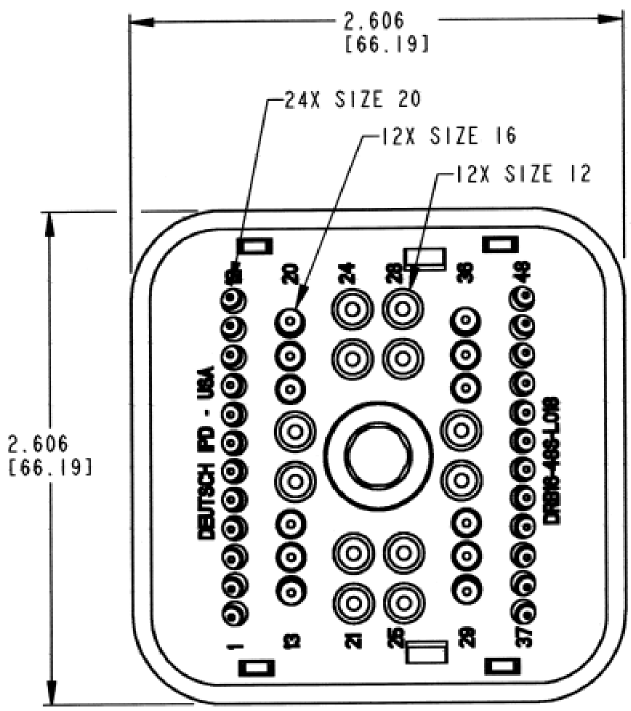


Figure 17: LV interface

LV interface plug specification:

Manufacturer	TE Connectivity
Type	Deutsch
Material Number	DRB16-48SAE-L018
Crimp Contact	gold plated

3.4.2.2 HV

The location of the HW connector is shown in Figure 15: Main interface area of FCM. It contains 2 power pins and 2 pins for HVIL.

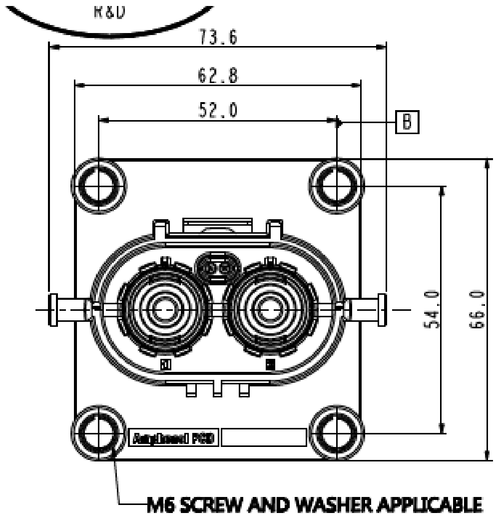


Figure 18: HV interface

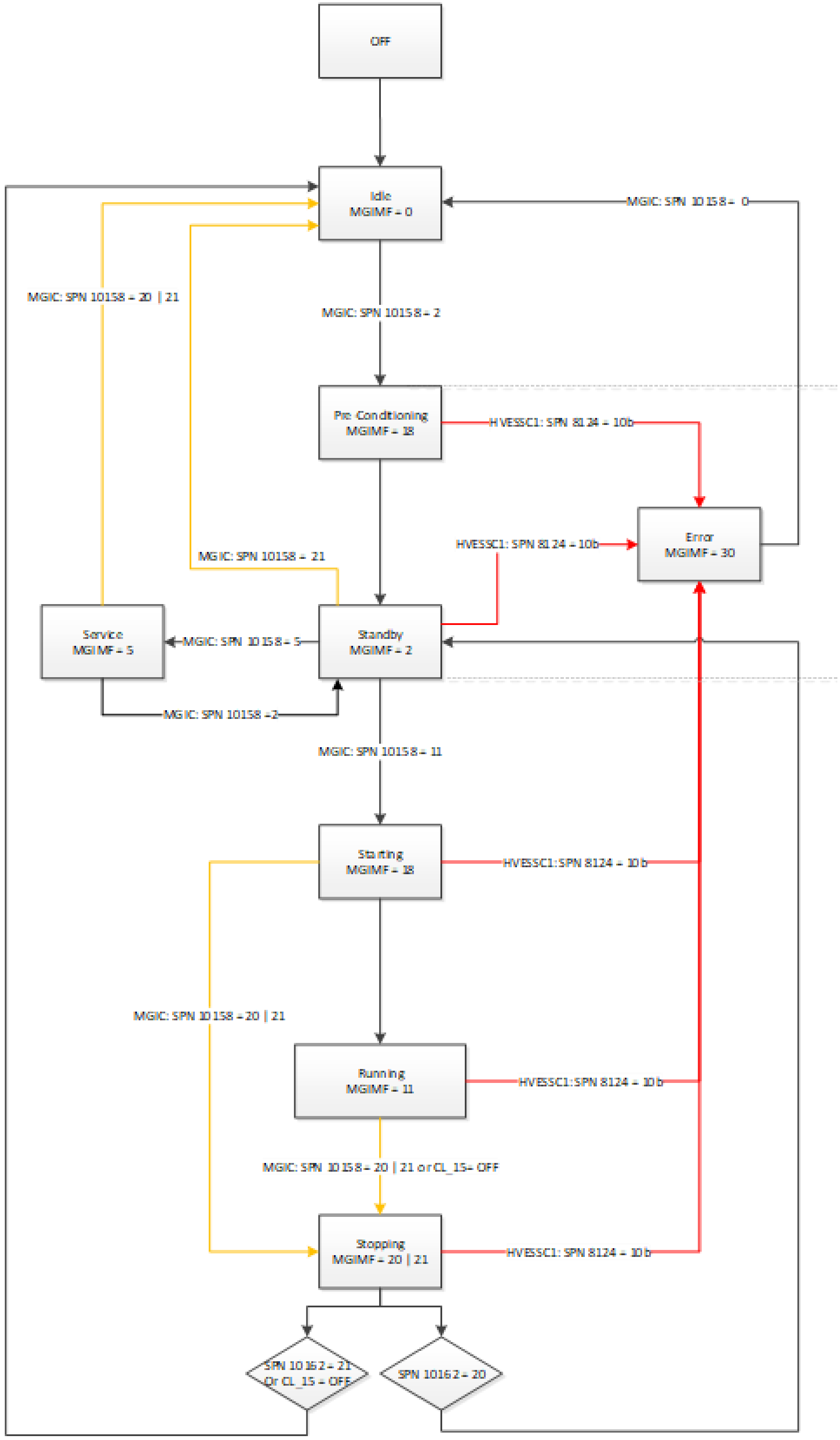
HV interface plug specification:

Manufacturer	Amphenol Tuchel Industrial GmbH
Type	HVSL800
Material Number	HVSL800062A135

3.4.2.3 Communication

The CAN Interface is provided via the 48 pin LV interface.

3.5 API definition



State	Description
Idle	The FCM has LV voltage power such that the FCCU is active. This state corresponds to the "Power on" state in J1939. Periodic counter messages are transmitted.
Pre-Conditioning	The FCM checks the isolation resistance value at the stack HV potential. If the value is lower than 100kOhms or 200Ohm/Volts, then the FCM starts circulating the coolant through the external coolant loop in order to increase the isolation resistance by passing the coolant through the DI Filter. A timeout is triggered if the desired resistance value is not reached within a pre-defined time period. The timeout will put the FCM into the Error state.
Standby	The FCM does not output power on the HV interface yet, but the necessary subsystems are powered and ready such that it can start producing output within a short time. Error and diagnostic messages can be sent.
Starting	The FCM is transitioning from the standby state to the running state. During this state the delivered power is ramping up, and therefore the power level is not well-defined. The HV bus is enabled, and the module can consume or provide energy.
Running	The FCM is active and delivering power. The power may be limited due to derating which will be indicated by the FCM.
Stopping	The FCM is ramping down the delivered power and returns to standby state. The HV bus must be connected during shut-down routines. The output power is not well-defined during ramp down.
Error	The FCM can enter this state from any state. The Error state is also the “Safe State” where all actuators are powered off and the DC/DC does not transfer any power from the stack to the application.
Additional State: Service	The FCM can be used to vent the cooling loop during commissioning or maintenance work.