VDMA

ADVANCING EUROPE'S MACHINERY INDUSTRY

FUEL CELLS WORKING GROUP
HARMONIZATION

Harmonization of the Balance-of-Plant (BoP) component requirements for LT PEM Fuel Cells

VDMA recommended practice

ADVANCING EUROPE'S
MACHINERY INDUSTRY

Contents

1. Executive summary

Fuel cell technology can play an important role in the decarbonization of many industry segments. Because of their capability to provide power in highly dynamic applications, low-temperature polymer electrolyte membrane (LT-PEM) fuel cell systems are preferred for automotive applications. To enable the market penetration of this technology, cost targets have to be met as well as functional and lifetime requirements. Increasing the annual production volume of Balance-of-Plant (BoP)-components contributes to the reduction of component cost. To realize these economies of scale, pre-competitive harmonization of non-differentiating component properties should be envisioned.

A project group, consisting of members of the VDMA Fuel Cells Working Group, has investigated the harmonization of BoP component interface dimensions in the cathode air and hydrogen recirculation path as a recommendation for system design, based on the required medium mass flow to achieve the rated system power, and the pressure drop created by medium flowing through the component´s interfaces. Table 1 collects the recommended diameters:

Table 1: Recommended interfacial diameters for BoP components

Air Mass flow	**20 g/s**	**70 g/s**	**150 g/s**	**220 g/s**	**420 g/s**
Recommended inner diameter – carhode air path	20 mm	35 mm	55 mm	65 mm	90 mm
Recommended inner diameter – hydrogen recirculation path (Pos. 1-2)*	6 mm	6 mm	8 mm	8 mm	12 mm
Recommended inner diameter – hydrogen recirculation path (Pos. 3-6)*	12 mm	16 mm	26 mm	26 mm	32 mm

* segmentation as per chapter 5.1

Deviations from this, e.g. due to packaging constraints, need to be balanced against the resulting effect on pressure drop und thus overall system energy efficiency,

2. Motivation and aim

To enable the market uptake of fuel cell technology, not only performance targets must be met, but also cost targets. As the actual series volumes for a project are still low compared to series volumes for internal combustion engine-powered vehicle projects, amortization of the cost for customer-specific development of BoP components, e.g. design, testing, and tooling, is challenging. One way to tackle this challenge is to realize “economies of scale” by harmonizing non-competitive, non-differentiating functional, dimensional and testing requirements, enabling cost savings and a higher speed from customer wish to customer satisfaction. In this approach, the component itself is considered as a “black box”, and only inlet and outlet dimensions are considered. Inside the “black box”, physical parameters, e.g. temperature, pressure, and cleanliness, are changed as necessary for proper functioning of the fuel cell stack. The first step towards harmonization is to define performance classes which connect system power to necessary mass flow of the medium.

The aim of this document is to provide guidance on duct diameters in BoP components in the cathode air path as well as the anode recirculation path, based on the necessary mass flow for individual power classes, considering resulting flow velocities, pressure drop and packaging in a segmented cathode air and anode recirculation system, considering specific conditions, e.g. temperature, pressure and humidity. Consequently, inlet and outlet connections can be harmonized, offering the opportunity for volume bundling in a given power class, leading to lower development, tooling and test cost while enhancing development speed. The proposed harmonization shall not hinder the development of product-specific features (USPs) and innovation (inside the “black box”).

3. System power classes

LT-PEM fuel cells cover a broad range of automotive applications, from range-extenders to electric propulsion of heavy-duty trucks. To cover this, systems from app. 20 kW to 400 kW power are in use. To achieve the expected power output, a related air mass flow must enter the stack.

As the pressure drop created by the air flowing through the ducts and inlets is a crucial parameter for diameter definition typical air mass flows were chosen for defining system classification.

Table 2: Mass flow classes for fuel cell systems

Performance class	Low	Medium	High	High+	Max
Air mass flow range	5 – 20 g/s	35 – 70 g/s	85 – 150 g/s	170 – 220 g/s	240 – 420 g/s
Air mass flow used as design criteria	20 g/s	70 g/s	150 g/s	220 g/s	420 g/s
Hydrogen / recirculation mass flow range	0.25 – 1 g/s	0.75 – 1.5 g/s	1.25 – 2.5 g/s	2.75 – 3.5 g/s	3.5 – 7 g/s
Hydrogen / recirculation mass flow used as design criteria	1 g/s	1.5 g/s	2.5 g/s	3.5 g/s	7 g/s
Typical system power	≤ 20 kW	30 – 60 kW	80 – 130 kW	150 – 200 kW	350 – 400 kW

4. Cathode Air Path

4.1 Architecture of the cathode air path

To enable the description of the function of and requirements for the individual BoP components, a generic system was defined by the project group:

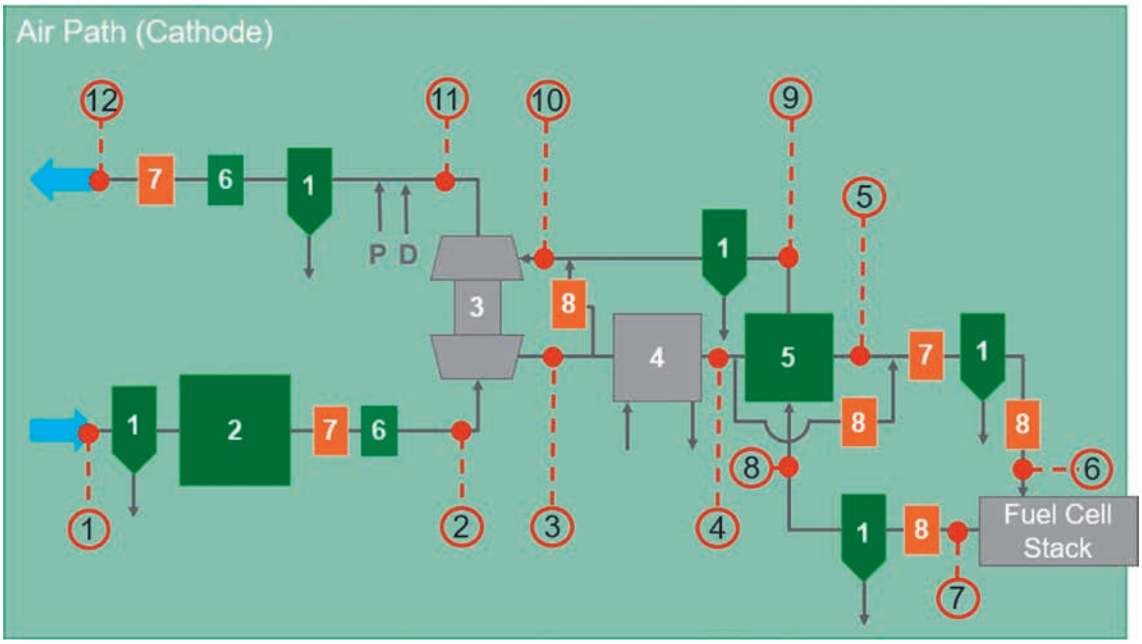

Figure 1: Generic cathode air path layout

Source: MANN+HUMMEL GmbH

The generic system consists of the components according to Figure 1:

Table 3: BoP components in a generic cathode air path layout

Component no.	Component	Remarks
1	Cathode water separator(s)	Several possible positions shown
2	Cathode air filter	
3	Compressor	
4	Charge air cooler	
5	Humidifier	
6	Resonator(s)	Several possible positions shown
7	Sensor(s)	Several possible positions shown
8	Flap(s)	Several possible positions shown

Not all components might be needed in actual cathode air paths designs. For components like cathode air water separators (1) and resonators (6), positions in the system may vary.

4.2 Typical operating conditions

The task of a BoP component in the cathode air path is to change physical parameters of the air between the inlet and the outlet. Here, segments have been defined in which these specific changes take place:

Table 4: Positions in a generic cathode air path layout

Position no.	Description
1	Ambient air inlet
2	Compressor inlet
3	Charge air cooler inlet
4	Humidifier inlet (dry)
5	Humidifier outlet (dry)
6	Fuel cell stack inlet
7	Fuel cell stack outlet
8	Humidifier inlet (wet)
9	Turbine water separator inlet
10	Turbine inlet
11	Turbine outlet
12	Cathode air exhaust outlet

At these positions, the typical temperatures, pressures, relative humidities and contact media are present:

Table 5: Functional requirements on components at different positions of the generic cathode air path layout

Position no.	Temperature [°C]	Pressure [hPa abs.]	Relative Humidity [%]	Contact media
1	-25 – +60	700 – 1100	10 – 100	(Liquid) water, particles, harmful gases
2	-25 – +60	700 – 1100	10 – 100	
3	90 – 140, peak 220	Up to 3000, peak 3500	5 – 10	
4	65 – 90	Up to 3000, peak 3500	5 – 20	
5	65 – 90	Up to 3000, peak 3500	50 – 80	
6	65 – 90	Up to 3000, peak 3500	50 – 80	
7	65 – 95, peak 105	Up to 2500, peak 3000	50 – 100	(H2 in idle state, acidic water)
8	65 – 95, peak 105	Up to 2500, peak 3000	50 – 100	(H2 in idle state, acidic water)
9	65 – 95, peak 105	Up to 2500, peak 3000	50 – 100	(H2 in idle state, acidic water)
10	65 – 95, peak 105	Up to 2500, peak 3000	50 – 100	(H2 in idle state)
11	40 – 50, peak 80	700 – 1100	50 – 100	(H2 in idle state)
12	-25 – +80	700 – 1100	50 – 100	(Liquid) water, H2)

Extreme conditions were not considered.

4.3 Additional requirements

In addition, further requirements on BoP components have been identified for component cleanliness, ion leaching, leakage, pressure resistance, pressure pulsation, resistance against hydrolysis, and hydrogen resistance. Requirements were rated qualitatively as “low”, “medium”, and “high”, or “no requirement (no req.)”. The fuel cell stack and compressor were considered as “scope out”, and the positions of the vertical lines were chosen to reflect that requirements do not change abruptly at inlet / outlet, but gradually.

Table 6: Additional requirements on components at different positions of the generic cathode air path layout

Position	1	2	3	4	5	6	7	8	9	10	11	12
Cleanliness	high						medium			low		
Ion leaching	low			high					low			
Leakage	low	*	high							*	low	
Pressure resistance	no req.	*	high – 1.5 x of maximum operating pressure**							*	no req.	
Pressure pulsation	no req.	*	high – pulsation from 0 to maximum operating pressure***							*	no req.	
Hydrolysis resistance	low			high						*	low	
Hydrogen resistance	low					*	high			*	low	

*: scope out

**: in accordance to DIN EN IEC 62282-2-100

***: number of cycles to be defined in concrete projects

4.4 Recommended diameters for BoP component in- and outlets

To propose actual diameters at component in- and outlet, flow velocity simulations on straight tubes with varying diameters were carried out with parameters either representing ambient and fuel cell operating conditions with the following parameters:

Table 7: Simulation parameter sets for ambient and fuel cell operating conditions

	Ambient condition (AMB)	Fuel cell condition (FC)
Temperature	20°C	80°C
Pressure	1013 hPa	2000 hPa
Relative Humidity	50%	80%

Often, laboratory tests are run under ambient conditions according to table 7.

For selection of preferred diameters, resulting flow velocity values of 55 – 60 m/s under ambient condition and 35 – 40 m/s for fuel cell operating conditions were targeted. The results are shown in the table below:

Table 8: Recommended inner diameter of cathode air path components, based on flow velocity simulations.

Air mass flow	20 g/s	70 g/s	150 g/s	220 g/s	420 g/s
Recommended inner diameter	20 mm	35 mm	55 mm	65 mm	90 mm

5. Anode Recirculation Path

5.1 Architecture of the anode recirculation path

To enable the description of the function of and requirements for the individual BoP components, a generic anode system was defined by the project group:

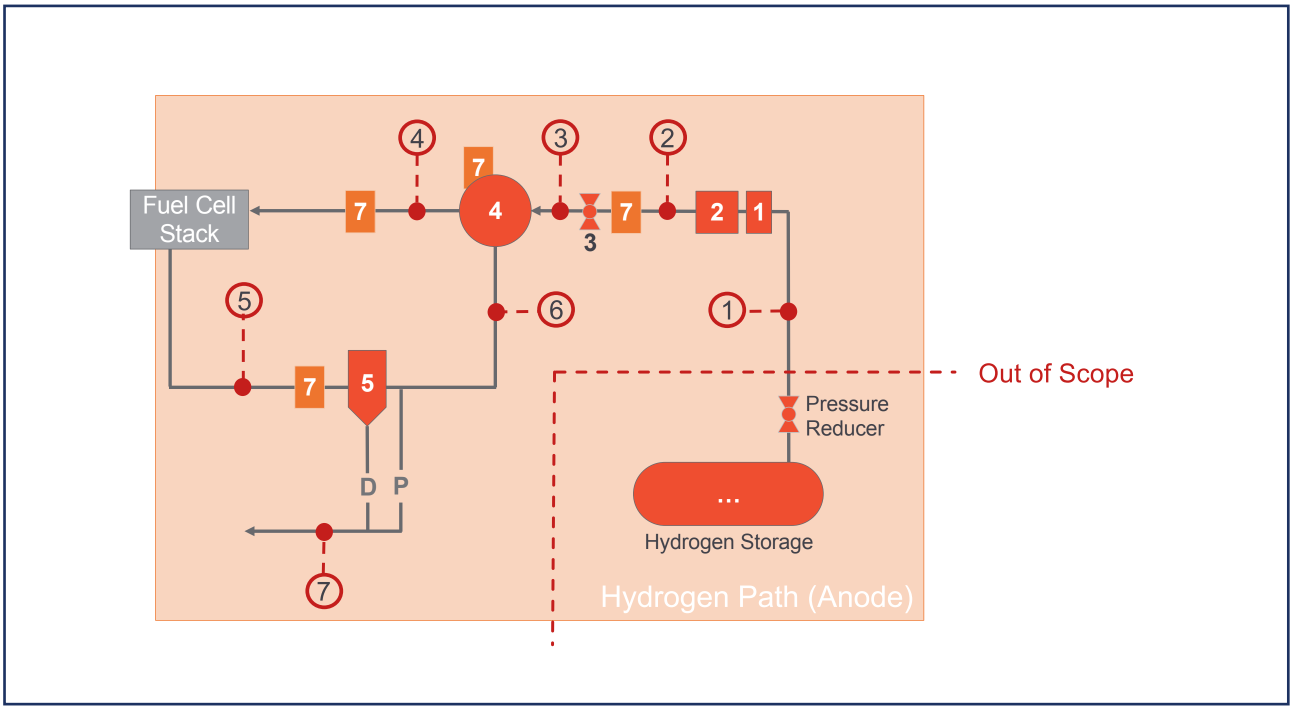

Figure 2: Generic anode recirculation path layout

Source: Rheinmetall AG

The generic system consists of the components according to Figure 2:

Table 9: BoP components in a generic anode recirculation path layout

Component no.	Component	Remarks
1	Hydrogen filtration	
2	Hydrogen pre-heater	Optional
3	Hydrogen dosage	
4	Recirculation Unit	Might be active or passive or a combination of both
5	Water separator	
D	Drain valve	
P	Purge valve	
7	Sensor(s)	Several possible positions shown

Not all components might be needed in actual hydrogen recirculation path designs.

5.2 Typical operating conditions

The task of a BoP component in the anode recirculation path is to change physical parameters of the medium between the inlet and the outlet. Here, segments have been defined in which these specific changes take place:

Table 10: Positions in a generic anode recirculation path layout

Position no.	Description
1	Hydrogen medium pressure section
2	Fuel cell system inlet
3	Recirculation inlet
4	Fuel cell stack inlet
5	Fuel cell stack outlet
6	Recirculation unit inlet
7	Anode exhaust

At these positions, the typical temperatures, pressures, relative humidities and contact media are present:

Table 11: Functional requirements on components at different positions of the generic anode recirculation path layout

Position no.	Temperature [°C]	Pressure [hPa abs.]	Relative Humidity [%]	Hydrogen concentration [%]	Liquid Water
1	20	15,000	0	100	No
2	75	15,000	0	100	No
3	75	3,500	0	100	No
4	75	3,500	80	75	Low
5	75	3,500	100	50	High
6	75	3,500	100	50	Low
7	75	1,000	100	50	High

Extreme conditions were not considered.

Since within the recirculation loop mass and volume flows will vary, following mass flows should be considered for the design of the components:

Table 12: Expected mass flows at different positions of the generic anode recirculation path layout

Position no.	Mass flow [g/s]				
	Low	Medium	High	High+	Max
1	1	1.5	2.5	3.5	7
2	1	1.5	2.5	3.5	7
3	1	1.5	2.5	3.5	7
4	5	11.5	22.5	30.5	57
5	4	10	20	27	57
6	4	10	20	27	50
7*	n/a	n/a	n/a	n/a	n/a

* The purge and drain valves operate cyclically, resulting in instationary operating conditions.

5.3 Additional requirements

In addition, further requirements on BoP components have been identified for component cleanliness, leakage, pressure resistance, pressure pulsation, and hydrogen resistance. Requirements were rated qualitatively as "low", "medium", and "high", or "no requirement (no req.)".

Table 13: Additional requirements on components at different positions of the generic anode recirculation path layout

Component	1	2	3	4	5	6	7
Cleanliness	high						medium
Leackage	low						
Pressure resistance	high – 1.5 x of maximum operating pressure*						
Pressure pulsation	low		high – pulsation from minimum to maximum operating pressure**				
Hydrogen resistance	high						

*: in accordance to DIN EN IEC 62282-2-100

**: number of cycles to be defined in concrete projects

5.4 Recommended diameters for BoP component in- and outlets

To propose actual diameters at component in- and outlet, flow velocity calculations on were carried out with the operating conditions from Table 11 and Table 12. The diameters are optimized for the use of VDA quick connectors:

Table 14: Recommended inner diameter for anode recirculation path components, based on flow velocity calculations.

<table>
<tr><th rowspan="2">Position no.</th><th colspan="5">Inner Diameter [mm]</th></tr>
<tr><th>Low</th><th>Medium</th><th>High</th><th>High+</th><th>Max</th></tr>
<tr><td>1</td><td rowspan="2">6</td><td rowspan="2">6</td><td rowspan="2">8</td><td rowspan="2">8</td><td rowspan="2">12</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td><td rowspan="4">12</td><td rowspan="4">16</td><td rowspan="4">26</td><td rowspan="4">26</td><td rowspan="4">32</td></tr>
<tr><td>4</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td></tr>
<tr><td>7</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td><td>n/a</td></tr>
</table>

5.5 Recommended sealing and connection systems

Flat-sealing connections are preferable to thread-sealing systems.

5.6 Labeling of media connections

All media connections of the installed components should be clearly labelled. Marking in accordance with DIN 2403 is preferred. Accordingly, pipes and connections carrying hydrogen should be marked in signal red (RAL 3001). The inlet and outlet positions should be easy to identify.

6. Glossary

AMB	Ambient conditions (laboratory condition)
BoP	Balance-of-Plant
FC	Fuel cell system operating conditions
LT-PEM	Low-Temperature Polymer Electrolyte Membrane
No req.	No requirement
VDMA	Largest industrial association in Europe

7. Acknowledgements

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8. Appendix

Representation of simulation results, chapter 4.4:

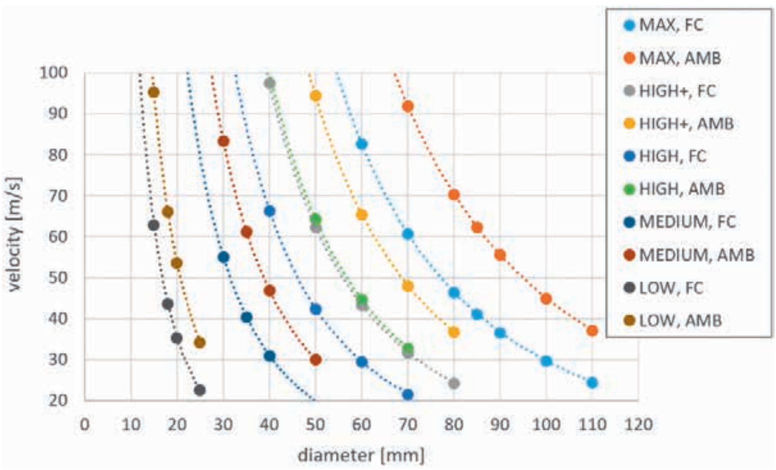

Figure 3: Results from flow simulations

Source: MANN+HUMMEL GmbH

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