Standardized compressors for fuel cell applications

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Abstract: Fuel cells for mobile application such as passenger cars, commercial vehicles (forklifts, delivery vans, trucks, buses) and train applications require an air supply with a compressor. Focusing on reducing system costs a standardization of components in the compressor is necessary. This study targets to solve this challenge by a smart combination of compressor system building blocks for different specifications including mainly electric motor, converter, air bearings and compressor wheel. This allows the development of compressor systems with lower cost and lower validation effort than fully application specific compressor systems and higher efficiency than existing, but non-optimal compressor systems. The research results from this project shall allow the fuel cell research and development community to improve efficiency and lower cost, and therewith strengthen the fuel cell technology and market acceptance.

Kurzfassung:
Brennstoffzellen für mobile Anwendungen wie PKWs, kommerzielle Fahrzeuge (Gabelstapler, Auslieferfahrzeuge, LKWs, Busse) und Züge benötigen eine Luftversorgung mit einem Kompressor. Insbesondere unter dem Fokus auf der Reduzierung der Systemkosten ist eine Standardisierung der Kompressor Komponenten erforderlich. In diesem Paper wird die Umsetzung der Standardisierung durch smarte Kombinationen von Kompressor-System-Bausteinen beschrieben. Dies umfasst vor allem die Komponenten Elektro-Motor, Konverter sowie Luftlagerung und Verdichterrad. Damit lassen sich

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Kompressor-Systeme mit geringeren Kosten und niedrigerem Validations-aufwand als anwendungsspezifische Kompressor-Systeme entwickeln. Die Auswirkungen z.B. auf den Verdichterwirkungsgrad werden diskutiert.

Key Words / Schlagworte: Fuel Cell; Electrical compressor; Fuel Cell Compressor; Standardization; System costs

1 Introduction

Fuel cell systems are currently in development and in validation for a large range of applications and at various players, such as OEMs [1] but also at intermediate fuel cell system integrators [2]. Therefore the requirements and specifications for fuel cell systems and more specifically the requirements and specifications of the air supply for the fuel cell stack, depend on the application area, the fuel cell system integrator, but also on the end customer/OEM. Currently, there is still no clear standardization in the compressor system specifications such as input voltage levels, pressure ratios and mass flows. This will change in future, where the larger players will set the standards, but for the intermediate term, the compressor systems have to be somewhat flexible to adapt to the individual specification sets, while at the same time avoiding a fully customized compressor for each application and customer is necessary in order to minimize system costs.

Based on these principles the development strategies for standardized fuel cell compressor are demonstrated in this paper.

2 Fuel Cell System layout

The fuel cell system basically consists of stacks, hydrogen supply (anode), air supply (cathode), exhaust system, low temperature and high temperature coolant circuit as well as the high voltage and low voltage system (compare Figure 1).

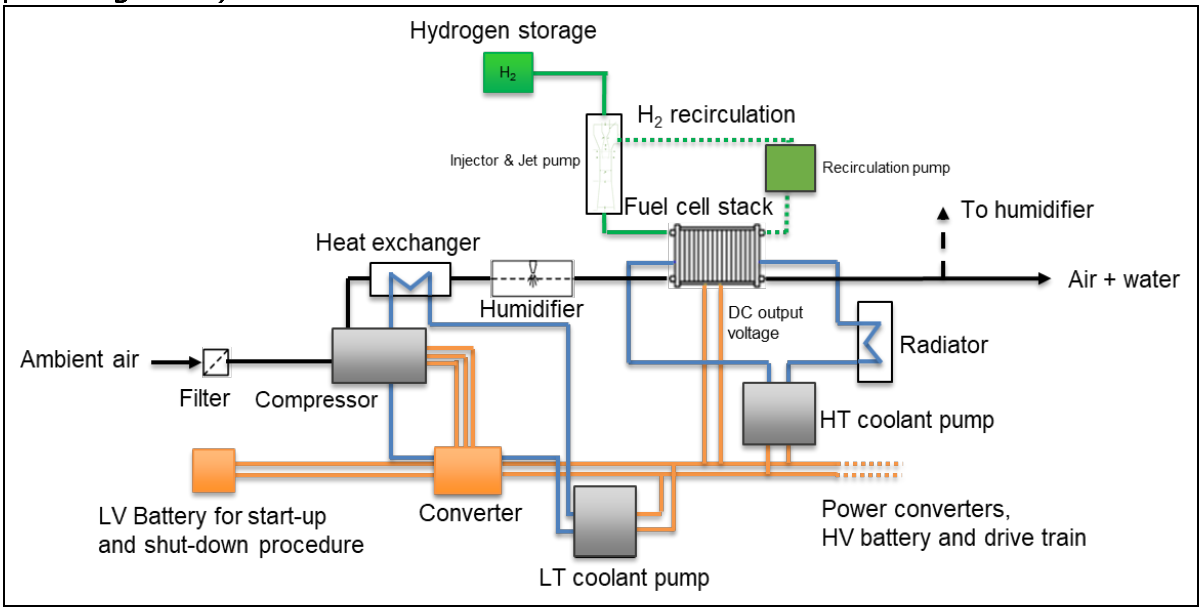


Figure 1: Simplified fuel cell system layout

In the anode path the main components are hydrogen injector, jet pump and recirculation pump. The hydrogen injector introduces the hydrogen to the stack through the jet pump. This injection provokes the motion of the hydrogen towards the stack where it is converted into current based on the inner stack reaction. However, not the complete hydrogen can be transformed. The rest is coming towards the stack anode outlet and is back-fed to the hydrogen circulation mainly by the jet pump which is basically working after the ejector principle. Only in conditions where the hydrogen flow is stalling the recirculation pump will support the back flow to the jet pump.

The cathode path consists mainly of the components air filter, compressor, heat exchanger and humidifier. The air filter is extremely important in order to sort out NO_X, NH_3 and SO_2 since otherwise the stack will be contaminated with these pollutants. The compressor supplies necessary air to the stack. This is on the one hand essential to get in the start-up phase the reaction in the stack running. Here the compressor needs to be supplied from a battery until the stack produces its own current. On the other hand the compressor is the enabler to increase the power density of the fuel cell system. A high boosting power in combination with a high conversion density rate in the stack can lead to a potential for reducing stack size. Consequently the compressed air needs to be cooled in the intercooler. Beyond the mentioned tasks of the compressor, in the shut-down phase the after-run of the compressor is necessary to dry the stack. However, in normal operation the stack needs to be humidified. This is carried out by the humidifier in case the stack has no internal humidification. Therefore the exhaust gas of the stack can be fed back to the humidifier.

For the operation of the fuel cell system a dedicated thermal management is necessary. This normally includes a low temperature - and high temperature coolant cycle. Whereas the high temperature coolant cycle is needed to cool the stack with a supply temperature of around 80° C, the low temperature coolant cycle provides the coolant for the intercooler and the high voltage electronics with a supply temperature of around 30°C.

Each component in the periphery of the stack that is necessary to run the reaction in the stack is called a Balance of Plant (BoP) component. The ideal interaction of the BoP components in all operating modes is implemented in the operation strategy. This strategy can be developed by simulation and is integrated into to controls software of the system.

Beside this the BoP component specification for high system performance and high system efficiency can also be determined by simulation. Therefore a system model is set up (Figure 2). The model reflects the main components of the BoP but beside this also all throttles and valves that are relevant for the system operation.

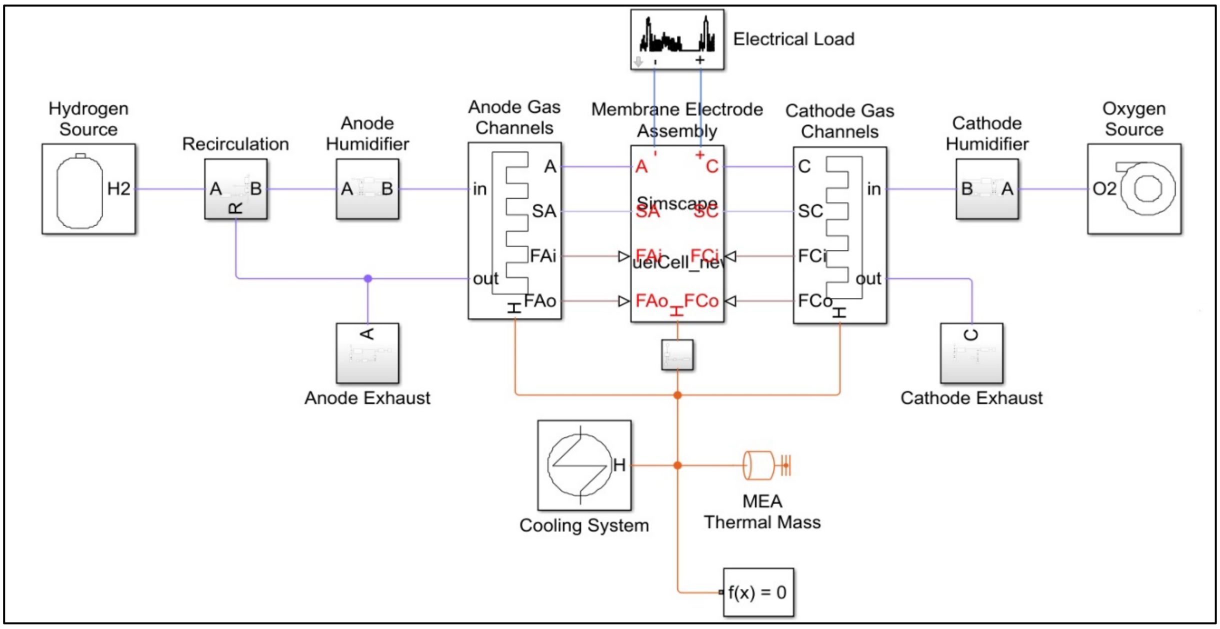


Figure 2: BoP (Balance of Plant) simulation model overview [3]

The driving parameter of the fuel cell system simulation model is the electrical load. The electrical load is determined in the superordinate fuel cell vehicle model based on the driving cycle and operating strategy.

2.1 Fuel Cell compressor specification

As mentioned above the electric load is the input parameter for the specification of the fuel cell system. In order to achieve the electrical load target the necessary air - and hydrogen flow needs to be established in the stack. In the cathode path the compressor ensures the air flow demand. Thus, for standard operating condition, the vehicle drive cycle and operating strategy can be transferred to compressor requirements in terms of air mass flow and pressure ratio. In order to achieve a high overall system efficiency the compressor should run in high efficiency operation. This matching of the compressor to the fuel cell system requirements can also be done in simulation. Mainly the fuel cell operating points idle, continuous and peak power are relevant. Overall the fuel cell system air demand leads to one specific demand line in the compressor map. An example of an ideal compressor matching for a 42 kW fuel cell system is shown in Figure 3.

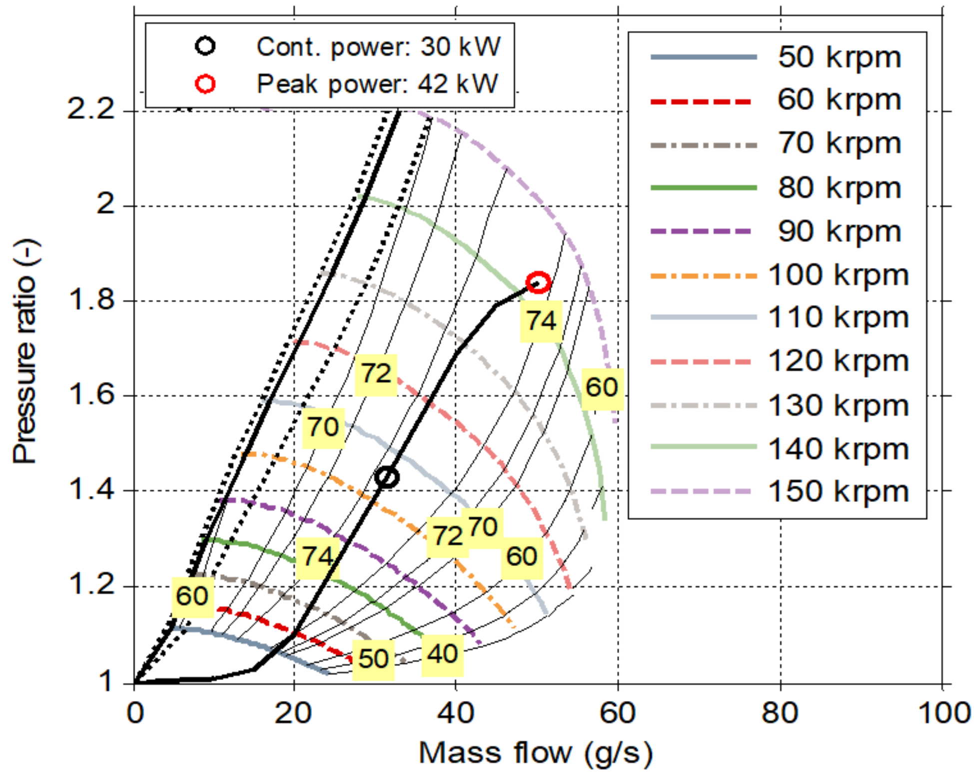


Figure 3: Example of an ideal compressor matching for a 42 kW fuel cell system [4]

However, since fuel cell applications can have different power outputs and therewith different demands on the compressor, different compressor maps are requirement. Thus, the portfolio of Celeroton varies in broad range (Figure 4).

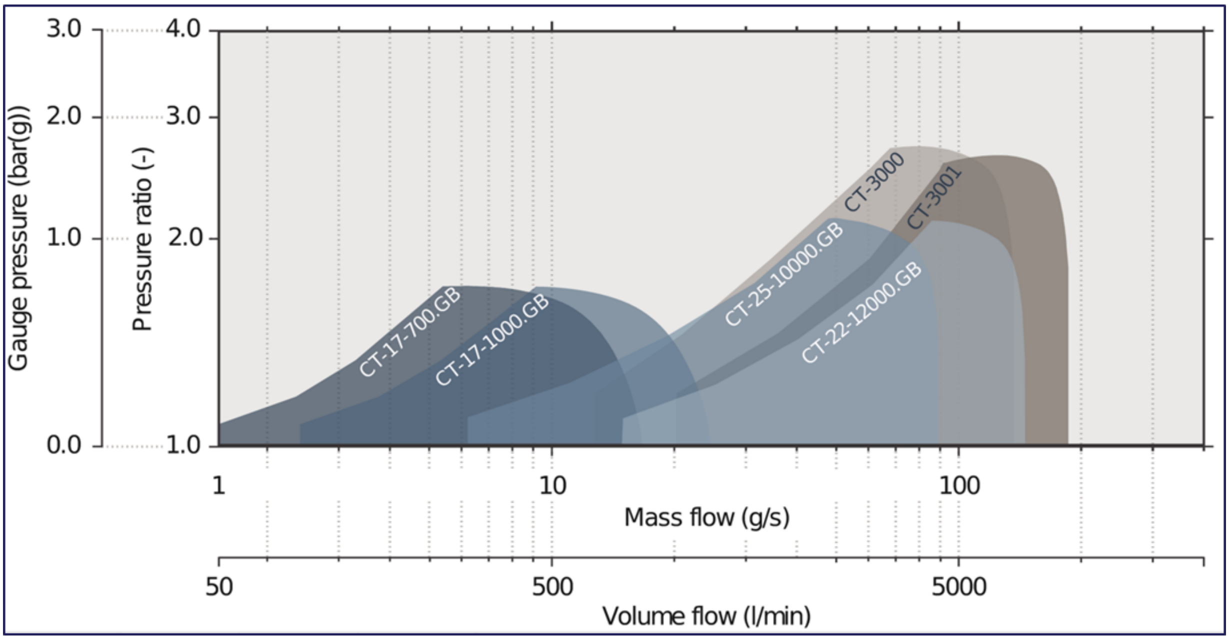


Figure 4: Compressor maps in the CELEROTON portfolio [4]

For standardization it needs to be checked how far these compressor maps can be aligned and which penalty in terms of efficiency need to be taken into account.

In fuel cell systems it is important that the air which is fed to the stack is free of pollutions. This especially includes oil and/or grease. Thus, the bearings of the fuel cell compressor need to run free of lubricants. Therefore the compressor is equipped with air bearings. These bearings have a lift-off speed of about 1% of maximum compressor speed. Above this speed they are running wear free which results in high lifetimes.

Beside this the fuel cell compressor is driven by an electric motor which is fed by the high voltage system of the fuel cell system or battery. This is normally realized by a high voltage converter of the compressor. In order to be capable for different applications the converter is able to use a wide range of input voltage. Furthermore, the CELEROTON converters are able to realize a sensorless speed control and have a low voltage start-up and afterrun capability.

Figure 5 shows the main components of the fuel compressor assembly.

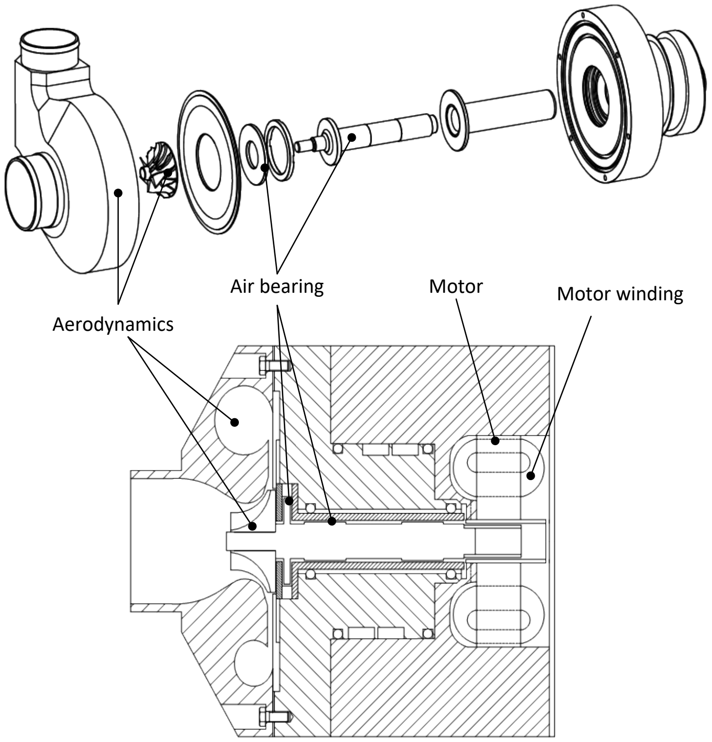


Figure 5: Fuel Cell compressor sub components

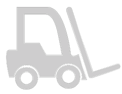
3 Approach of Fuel Cell Compressor standardization

For standardization of the fuel cell compressor a separation into different "building blocks" (BB) based on the subcomponents can be done. These building blocks are:

- BB1: Motor iron/casing
- BB2: Motor winding
- BB3: Aerodynamics
- BB4: Air bearings
- BB5: Converter input stage
- BB6: Converter output stage
- BB7: Firmware

On the one side the standardization offers the opportunity to use more common parts and therewith reduce costs. On the other side penalties needs to be taken into account especially in terms of efficiency. Mainly this trade-off needs to be carefully balanced. First of all it is therefore important to define input set of parameters and set the boundary conditions. These are not only depending on the required fuel cell system power output but also on application specifics. As an example in the 20-45 kW fuel cell power range, there are various redundant fuel cell applications, such as fork lifts for material handling, light commercial vehicles, cars, and even range extender for buses. This, together with the individual system architectures of different customers, results in various compressor system specification sets. Examples of such compressor system specification sets for 20-60 kW fuel cell systems are given in Table 1.

Table 1: Example of fuel cell compressor specification sets

					
Application	Fork lift / material handling	Light commercial vehicle customer A	Light commercial vehicle customer B	Car range extender	Bus range extender
Fuel cell power (kW)	20-30	30-45	30	20-30	20-30
Input voltage (Vdc)	<100 (undefined)	230-380 (HV battery)	120-320 (FC output)	250-450 (fuel cell or HV battery)	180-320 600-750 (FC output) or 600-800 (HV battery)
Battery start	Yes	No	Yes	Yes	Yes / No
Pressure ratio (-)	2.3	2.0	2.1	1.9	1.85
Mass flow (g/s)	33	66	50	30	40
Inlet pressure (bara)	0.9-1.04	0.76-1.04	0.76-1.04	0.76-1.04	0.76-1.04

Based on Table 1 it can be seen that for example the input voltage vary in a range between 100 V and 800V for these applications. This cannot be covered by a single converter at the moment. However, in recent developments at CELEROTON converters have been designed that are able to cover a range of 300V-500 V. One example is the CC-550-7500 (compare Figure 6).

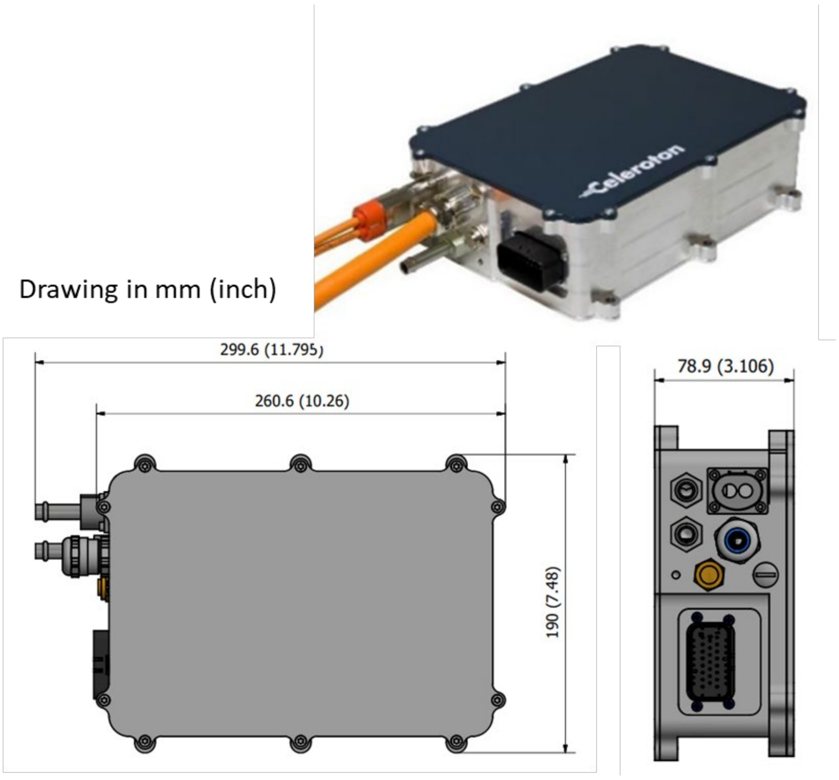


Figure 6: CC-550-7500 converter

For standardization this converter has a same part ratio of 80% with the converter CC-550-5000 with 5 kW output. The basic data of both converters a shown in Table 2.

Table 2: Example of converter standardization

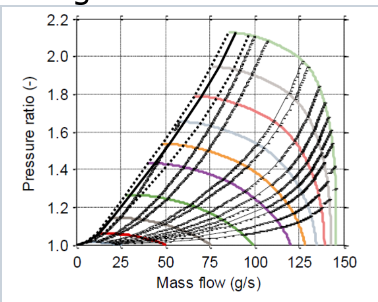
	CC-550-5000	CC-550-7500
HV Input voltage	300 – 500	300 – 500
Max input current	20 A	25 A
Rated output power	5 kW	7.5 kW
LV input voltage	10 – 28 VDC	8 – 36 VDC
Maximum output power for startup from LV	300 W	300 W
Weight	4 kg	5.4 kg

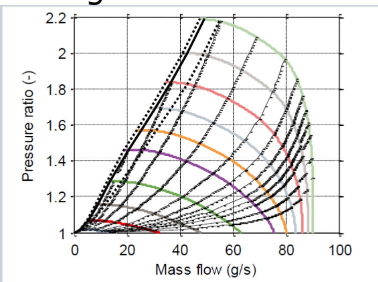
Both converters have integrated a low voltage power input. This is mainly for control and start-up of the turbo compressor from LV-battery. Target of future developments is to realize a standard converter with a power range from 3kW to 7.5kW.

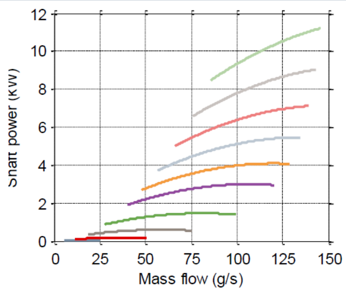
Beside the converter a standardization also on the aerodynamic side of the compressor is necessary. Mainly the different requirements are covered by a different impeller, spiral casing motor winding and motor phase connector whereas the housing and bearings are similar. Based on this approach a same part ratio of 75% can be achieved. As an example table 3 shows a comparison of the compressors CT-22-12000.GB and CT-25-10000.GB.

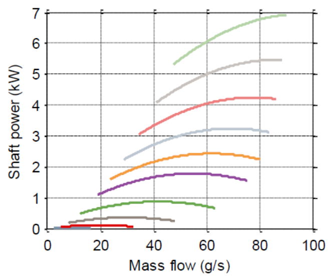
Table 3: Example of aerodynamic standardization

	CT-22-12000.GB	CT-25-10000.GB
Max. pressure ratio	2.1	2.1
Max mass flow	140 g/s	90 g/s
Max. isentropic efficiency	65%	64%
Rated speed	150.000 rpm	150.000 rpm
Acceleration time[1]	<1.5 s	<1.8 s
Maxiumum power	12 kW	7 kW
Weight	10 kg	8.8 kg









As said before when going for a standardization, a penalty of the overall compressor efficiency needs be taken into account. However, in this context it should be mentioned that a more complex compressor with an increased efficiency can be developed. The higher production- and development-costs of such a compressor will be overcompensated due to a higher production number.

4 Summary and Outlook

In the strongly increasing fuel cell sector different applications lead to different requirements and boundary conditions for the fuel cell compressor. On the other hand the TCO and therewith the costs of a fuel cell compressor should be minimized. Thus, it is important to find a way for compressor subcomponent standardization. The study shows how this approach can be realized. The fuel cell compressor is separated into different "building blocks" and each of these blocks is optimized for standardization which means that a significant amount of parts can be kept the same. As an example for the compressor converter a same-part-ratio of 80% for a power range of 3 kW to 7.5 kW will be reached.

The development of standardized parts of the fuel cell compressor will go on in the future. Beside this first steps are made for a standardization of fuel cell systems (e.g. [5]) which will also help to increase the modularity approach in the fuel cell system subcomponents.

Acknowledgements

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