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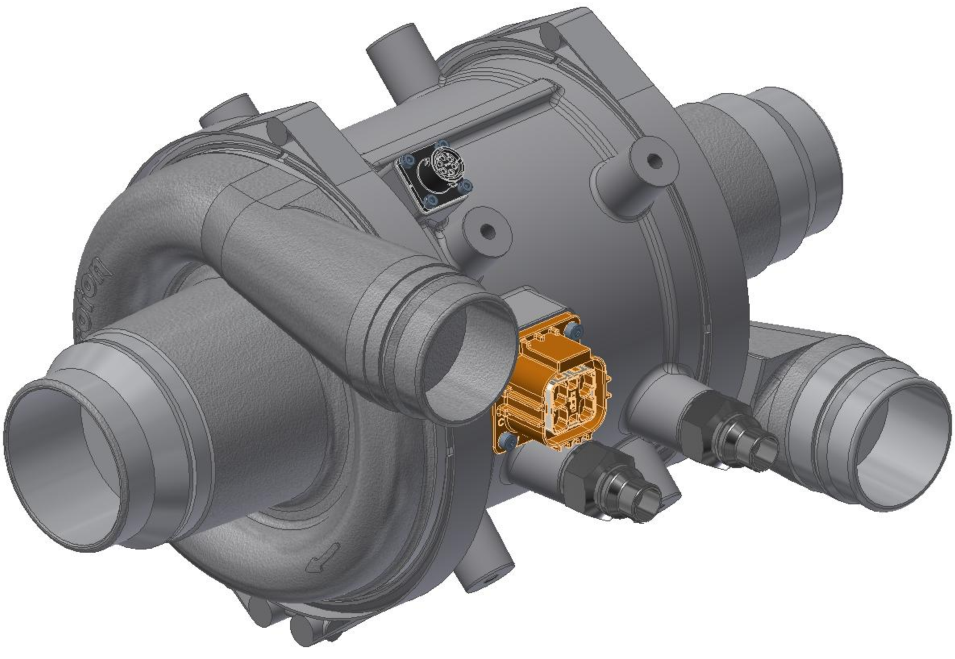
COMTEF

Technology expansion & modularization of compressor systems to increase the efficiency of 70-120 kW PEFC systems



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Abstract

Proton exchange membrane (PEM) based hydrogen fuel cell systems (FCSs) in mobility applications require an air supply with a compressor. In the 70-120 kW FCS power class, several key challenges including, turbine modularity, cost and efficiency trade-offs at current market volumes and high efficiency requirements hinder the adoption of FC technology in this power class. This project targets to solve these problems by expanding a novel gas bearing technology to this power class through developing and employing building blocks including turbine from a high-power baseline compressor. This approach enables the development of a compressor system for medium-power FCs offering superior efficiency and optimized costs at current market volumes, while also quantifying its impact on overall system performance. The research results from this project shall allow the fuel cell research and development community to improve system designs through improved efficiency and costs thereby accelerating the adoption of fuel cell technology and enabling a substantial CO2 emission reduction. Besides the environmental upsides, these research results also promote innovation in the swiss high-tech industry sector for sustainable energy solutions.

Kurzbeschrieb

Wasserstoff-Brennstoffzellensysteme (FCS) auf Protonenaustauschmembran-Basis (PEM) in Mobilitätsanwendungen erfordern eine Luftversorgung mit einem Kompressor. In der Leistungsklasse der FCS von 70 bis 120 kW behindern mehrere zentrale Herausforderungen, darunter die Modularität der Turbine, Kosten- und Effizienzkompromisse bei aktuellen Marktvolumina und hohe Effizienzanforderungen, die Einführung der BZ-Technologie in dieser Leistungsklasse. Dieses Projekt zielt darauf ab, diese Probleme durch die Erweiterung einer neuartigen Gaslagertechnologie auf diese Leistungsklasse zu lösen, indem Bausteine, einschließlich einer Turbine aus einem Hochleistungs-Basiskompressor, entwickelt und eingesetzt werden. Dieser Ansatz ermöglicht die Entwicklung eines Kompressorsystems für Brennstoffzellen mittlerer Leistung, das bei aktuellen Marktvolumina eine überlegene Effizienz und optimierte Kosten bietet, und quantifiziert gleichzeitig seine Auswirkungen auf die Gesamtsystemleistung. Die Forschungsergebnisse dieses Projekts sollen es der Brennstoffzellenforschungs- und -entwicklungsgemeinschaft ermöglichen, Systemdesigns durch verbesserte Effizienz und Kosten zu verbessern, wodurch die Einführung der Brennstoffzellentechnologie beschleunigt und eine erhebliche Reduzierung der CO2-Emissionen ermöglicht wird. Neben den Vorteilen für die Umwelt fördern diese Forschungsergebnisse auch Innovationen in der Schweizer High-Tech-Branche für nachhaltige Energielösungen.

1 Introduction

Context and motivation

Proton Exchange Membrane (PEM) based fuel cell (FC) systems for mobile applications require an oilfree air supply from a gas-bearing compressor system. Since up to 20% of the cost and up to 30% of the electrical consumption of the entire FC system can be attributed to the compressor system it is considered a key element for fuel cell adoption and scaling. Optimizing both, efficiency and costs, for compressors of 70-120 kW FCS is particularly challenging for current market volumes due to available gas bearing technologies and changing turbine modularity requirements. Currently available compressor solutions on the market are providing insufficient levels of combined efficiency and cost targets. This project targets to solve these problems by expanding a novel gas bearing technology to this power class through developing and employing building blocks including turbine from a high-power baseline compressor. This approach enables the development of a compressor system for medium-power FCs offering superior efficiency and optimized costs at current market volumes, while also quantifying its impact on overall system performance.

Project objectives

This project foresees to transfer the new gas bearing technology from a base system for high-power FCS applications of 120-200 kW to mid-power FCS applications of 70-120 kW. Thereby, it aims to provide a requirement matrix for air compressors supplying 70-120 kW FCS including turbine modularity for different market segments and a building block overview for a downscaled turbo-compressor system for 70-120 kW FCSs. Furthermore, an overview of technical implications for turbine modularity/removal including quantification of impact on efficiency is foreseen. In a next step the design of two prototype compressor systems (with two different specification sets, A+B) and the realization of one prototype compressor system (specification set A or B) is part of the project scope. Finally, the prototype compressor system is tested on component and sub-system/fuel cell system level thereby characterizing performance parameters including pressure ratio, mass flow, system efficiency through theoretical and experimental verification methods.

2 Preliminary results

Progress to Date

The project is structured into eight work packages including specification phase, building block matrix creation/extension, development of prototype compressor system A+B, realization of prototype compressor system A or B, verification of prototype compressor system A or B on sub-system/system level, quantification and visualization of results and project reporting. As of today, the specification, building block matrix creation/extension were finished. Currently, the development of both prototype compressor systems for specification set A+B is progressing well and is anticipated to be finalized by January 2026.

Market study

The product area focus for the COMTEF project is on FCS applications ranging from 70-120 kW. Typical mobility applications include passenger cars, light commercial vehicles incl. buses and medium duty vehicles. Besides the mobility applications there is growing interest in stationary and maritime applications. In an initial step an overview of market opportunities for passenger cars, buses/light commercial vehicles and medium-duty vehicles was evaluated for the stack power of 70-120 kW. Best market alignment with the 70-120 kW FCS power class was shown for buses/light commercial vehicles and medium-duty commercial vehicles. A market study with opportunities is shown in Figure 1. To further narrow down the number of specifications sets five high priority customers were identified and specifications sets were assessed based on compressor system building blocks to identify the two specification sets (A+B) to be assessed within the COMTEF project.

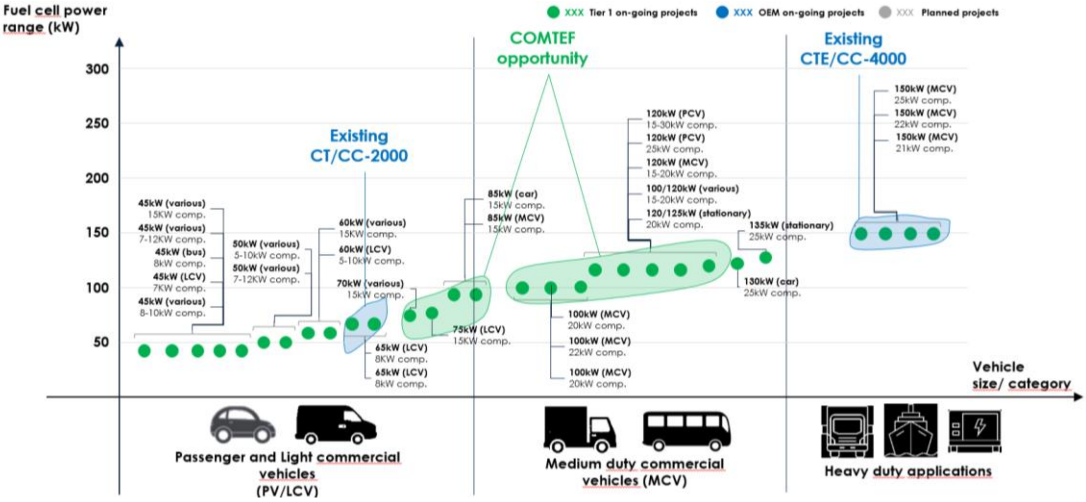

Figure 1: Overview of market study including project opportunities

Building block assessment

Building blocks on compressor side include aerodynamics 1 & 2, housing components, electric motor, rotor, axial and radial bearing, pressure compensation and thermal design, whereas on the inverter side building blocks include input stage, output stage and firmware. Particular emphasis was given to the turbine modularity implications in the building block assessment. The need for a turbine implementation depends heavily on the specific application which differentiate in terms of efficiency, cost and complexity requirements. For example, light commercial vehicles are less likely to incorporate a turbine while marine and stationary applications favor turbines. Possible turbine configurations include compressor and turbine, two-stage compressor or just a single-stage compressor. The overview of turbine modularity/removal assessment on the compressor system building blocks is shown in Table 1.

Table 1: Building block assessment matrix including turbine removal

Building blocks	Use of dummy turbine Dummy Turbine	Redesign of thrust bearing position with pressure compens. concept 1	Redesign of thrust bearing position with pressure compens. concept 2	2-stage compressor
Aerodynamic 1	▪ New compressor aerodynamics needed	▪ New compressor aerodynamics needed	▪ New compressor aerodynamics needed	▪ New compressor aerodynamics needed
Aerodynamic 2	▪ Dummy turbine needed	N.a.	N.a.	▪ New compressor aerodynamics needed
Electric motor	No change	No change	No change	No change
Pressure compensation	Small change necessary, not influencing overall compressor design	No thrust load compensation possible	Thrust load compensation possible ▪ Additional losses due to leakage	Thrust load compensation possible
Journal bearing	CoG of rotor assembly stays the same	Change of CoG can lead to instabilities	Change of CoG can lead to instabilities	CoG of rotor assembly stays the same
Thrust bearing	Fully compensated thrust load	Thrust bearing needs to withstand full thrust load	Fully compensated thrust load	Fully compensated thrust load
Thermal design	▪ Additional losses from dummy turbine	Lower losses overall than base system	Lower losses overall than base system	▪ Additional losses from 2nd compressor stage
Housing	New spiral casing needed for dummy turbine, small adjustment for pressure compensation, rest of the compressor stays similar to base system	New housing design needed ▪ Complete redesign of housing components to incorporate other building block changes	New housing design needed ▪ Complete redesign of housing components to incorporate other building block changes	New spiral casing needed for both stages, small adjustment for pressure compensation
Losses due to air friction, leakage and tip clearance	Increase of ~50%	Baseline	Increase of ~25%	Increase of ~50%
Efficiency loss at 25 kW	-2.6%	Baseline	-1.2%	-2.5%

Requirement matrix

Based on customer requirements, building blocks and market potential two specification sets were identified as high priority prospects; namely specification set A which is a 2-stage compressor configuration without turbine for 120 kW FCSs and specification set B which is a 1-stage compressor including a turbine for FCSs of 100 kW. The finalized requirement matrix is shown in Figure 2.

		Passenger, light - medium duty commercial vehicles (P/L/MCV)	Medium duty commercial vehicles (MCV)	Heavy duty applications
Comp-ressor	Power range comp./ stack (kW)	25 / 100 - 120	20 / 100 - 120	25 / 135 - 200
	Max pressure ratio	4.0	3.10	3.10
	Max mass flow range¹ (g/s)	100 - 125	160 - 190	200 - 254
	2-stage/ turbine	Yes / NO	NO/ Yes	No / Yes
	Allowed volume/ size	Base system	Base system	Base system
	Durability/ start-stop	30kh / >500k cycles	30kh / >500k cycles	30kh / >500k cycles
	Electronics integrated	No	No	No
Con-verter	Output power (kW)	25	25	25
	Input voltage (V)	400 - 800	400 - 800	400 - 800
	Allowed volume/ size (when not integrated)	=CC-4000	=CC-4000	=CC-4000
Sys-tem	System efficiency	65%	65%	65%
	Sensorless & health control	Yes	Yes	Yes
	Functional safety (ASIL level)	No	No	No
	System supplier (comp. + converter)	Yes	Yes	Yes
	Cost sensitivity (comp. + converter)	High	Medium	Lower

COMTEF Specification set A

COMTEF Specification set B

Existing Base system

Figure 2: Requirement matrix for specification set A and B, including base system

Development of prototype compressor system

Based on specification sets A and B the preliminary and detailed design has started, including design of aerodynamics, electric motor, gas bearings, rotor and pressure compensation. The final aerodynamic performance for both compressor designs is shown in Figure 3. The finally achieved aerodynamic efficiency is 74.5% and 75.4 % for specification set A and B respectively. This represents only a slight aerodynamic efficiency decrease of 3.5% and 2.6% for specification set A and B respectively compared to the base system. A preliminary cost comparison of the new gas bearing shows significantly lower manufacturing costs (x1.5) at 1'000 pcs compared to herringbone technology and slightly lower manufacturing costs (x0.14) when compared to a competitor foil bearing at >1'000 pcs.

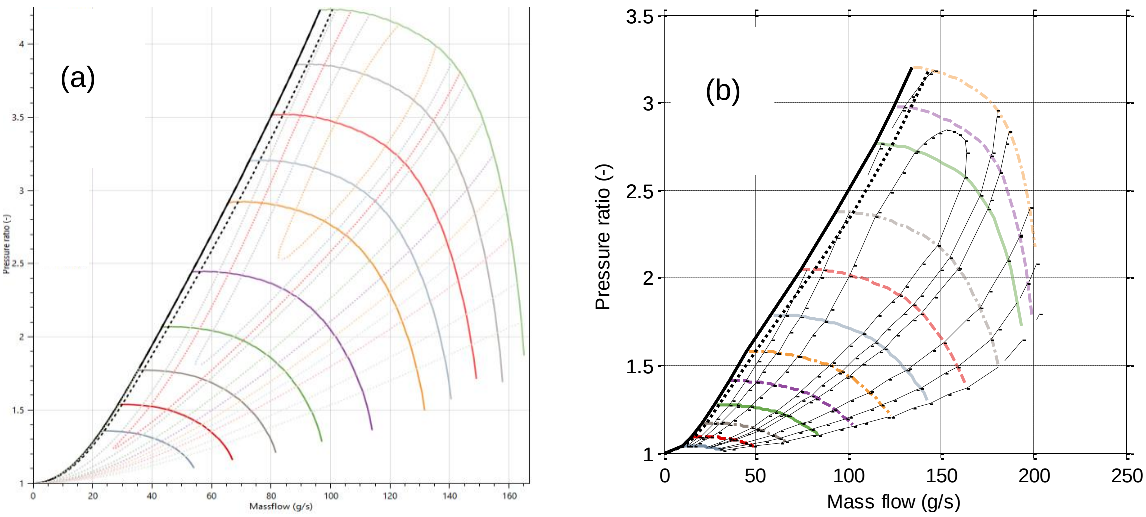

Figure 3: (a) Compressor map for specification set A and (b) compressor map for specification set B at pin = 1 bara, Tin = 20°C.

3 Conclusion and Outlook

Preliminary conclusions

The base system incorporating the new gas bearing technology can be scaled down for use in lower-power fuel cell systems (FCSs). For 70–80 kW FCSs, achievable efficiencies are comparable to those of foil compressor systems. At the 100–120 kW scale, the base system can be adapted to two specification sets: (A) a two-stage compressor without a turbine, or (B) a single-stage compressor with a turbine, both with market demand and efficiency/cost benefits.

Theoretical and analytical assessments indicate that extending gas bearing technology to mid-power fuel cells offers significant cost advantages compared to existing solutions. At production volumes of 1,000 units, costs are projected to be **1.5× lower than herringbone solutions** and **0.14× lower than foil bearing solutions**, while also delivering **6% efficiency gains** over standard foil bearings.

By enabling higher-efficiency compressor solutions in the 70–120 kW FCS range, this technology expansion is expected to reduce CO_2 emissions and accelerate the adoption of fuel cells as a carbon-neutral technology. These results further support innovation in the Swiss high-tech sector, contributing to sustainable energy solutions by providing a framework for efficiency improvements and guiding the design of next-generation compressor and fuel cell systems.

Outlook

The detailed design of the two compressor systems will be completed in the coming months, with finalization anticipated by January 2026. Shortly before this milestone, the specification set to be realized will be selected based on market opportunities and available testing capabilities.

To meet the development timeline, long-lead components will be ordered in December 2025, and system assembly is scheduled for May 2026. Following initial compressor testing, the prototype will undergo both theoretical and experimental benchmarking, as well as validation at the sub-system and full FCS levels. The project will conclude with data post-processing and the delivery of a comprehensive final report.