TURBO COMPRESSORS FOR A SUSTAINABLE MOBILITY

Sustainable propulsion systems for passenger and freight vehicles are one of the major challenges in reshaping Switzerland's energy supply. Among the multitude of technical problems is the development of compact turbo compressors, which play a central role in hydrogen-powered electric trucks, for example. Over the past ten years or so, the company Celeroton (Volketswil/ZH) has developed products for this young market.

Martin Bartholet shows one of the test benches used by Celeroton engineers to test the operating behavior of turbo compressors.
Photo: B. Vogel

A technical report about the results of the research in the field of fuel cells. The Swiss Federal Office of Energy supports relevant research topis in this field. The report has been published in the technical magazine TIR transNews (issue September 2020).

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Federal Office of Energy SFOE

«Record Drive: Highest Speed in the World,» was the headline of an article in the German magazine «Focus» published in 2008: Christof Zwyssig, while preparing his PhD thesis at the Chair of Power Electronics at ETH Zurich, had developed a new type of drive train, which reached the incredible number of one million revolutions per minute.

Twelve years have passed since that headline and from that speed record. Now an economically self-sustaining Swiss industrial company with 38 employees has emerged, which occupies a spacious floor in a commercial property in Volketswil. Zwyssig founded Celeroton in 2008 with Martin Bartholet, also a doctoral student at ETHZ. Their business idea is compressors with very high speeds. The advantage of turbo compressors is that they can be built very compactly - making them suitable for applications where space is at a premium, such as in vehicles. The turbo compressors also do not need lubricants, since the shaft no longer rests on ball bearings but «floats» on a gas bearing.

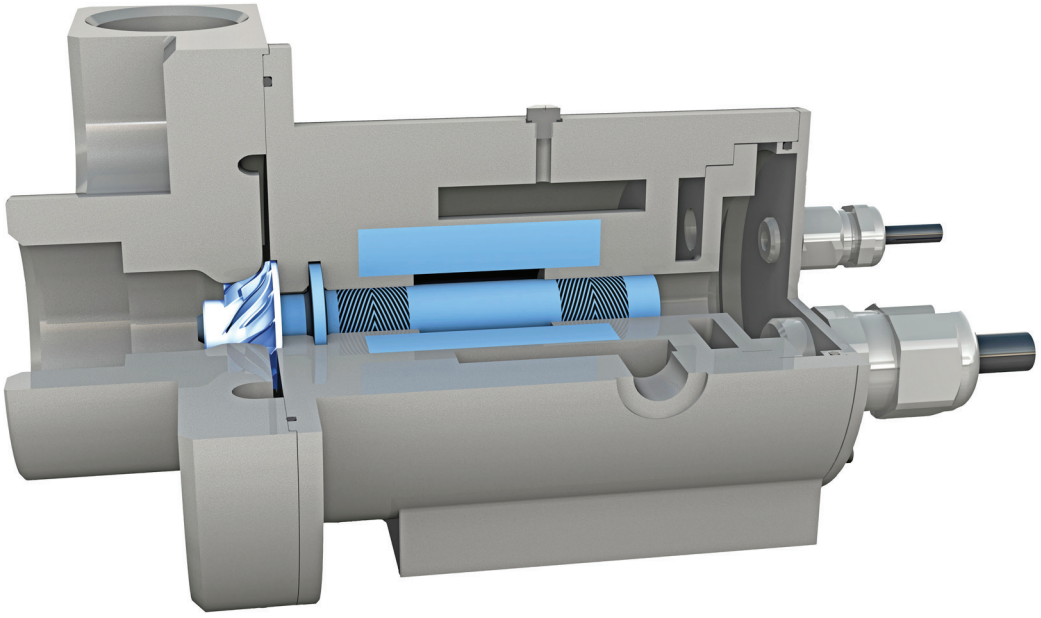
Compressors with 150 to 20'000 Watts

The fist-sized turbo compressors are used for decentralized compressed air supply or for cleaning lenses in inspection systems. The main area of application, however, is fuel cell systems for vehicles, which convert hydrogen (from the tank) and oxygen (from the ambient air) directly into electrical energy (see Figure p.4 / bottom). For high efficiency and thus high-power density, air is supplied in compressed form, which is achieved by means of special turbo compressors. These compressors are driven by an electric motor that draws its power from the fuel cell (and thus reduces its power output by 10 to 20%). Turbo compressors with their associated electronics are important components, along with hydrogen tanks, humidifiers, cooling circuits and hydrogen recirculation, which complement the actual fuel cell stack. They must be designed in such a way that the overall system operates efficiently and cost-effectively.

«Celeroton's innovation is the integrated system of turbo compressor and control electronics,» says Managing Director Dr. Martin Bartholet and adds: «We are pursuing miniaturization and are only achieving even greater efficiency.» The compressors cover a power range from 150 watts to 20 kW. If, for example, a forklift truck is supplied with electricity via a fuel cell (10 kW), a turbo compressor with an output of about 1 kW is required. The hydrogen-powered version of the Renault Kangoo features a 10 kW fuel cell as range extender with a 700 W turbo compressor. A 40-ton truck from Hyundai Motor typically contains a 190 kW fuel cell with a turbo compressor with an output of about 20 kW. «Our target market is European manufacturers of light commercial vehicles. We do not supply the vehicle manufacturers, but rather the manufacturers of the fuel cell systems,» Bartholet notes.

Control Electronics Simplified in Design

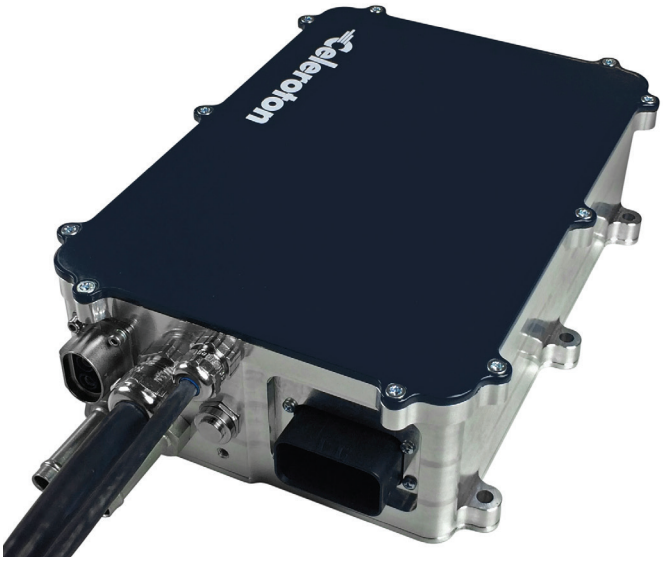
Compressors are widely used and well proven in stationary industrial applications. However, the construction of high-



The heart of the turbo compressor is the gas-bearing shaft with the impeller, which radially deflects and thus compresses the air flowing in from the left. The impeller rotates at up to 280,000 revolutions per minute. A synchronous motor with permanent magnet serves as the drive. Illustration: Celeroton

speed, compact turbo compressors for mobility applications requires intensive effort in research and development. In contrast to other manufacturers of air-bearing turbo compressors, Celeroton supplies not only the compressor but also the associated electronics for controlling the compressor motor as an optimally matched system from a single source. In recent years, Celeroton has carried out various research projects on design, operational and manufacturing issues. The Swiss Federal Office of Energy has supported relevant research questions.

In a project completed in 2018, a new, simplified electronic system for controlling turbo compressors in the 3 to 5 kW power range was developed (see photo on the right). Previously, three electronic components (one compressor electronics, two DC-DC converters) were needed to control the turbo compressor in order to ensure power supply during the start process (from the battery) and while driving (from the fuel cell). By integrating these three components into a single control electronics, the system has been simplified. It also made the compressor's power supply more efficient and reduced manufacturing costs. The prototype of the control electronics was further developed internally and is now on the market under the designation CC-550-7500.



Integrated compressor electronics (CC-550-7500 converter), as used in a 60kW fuel cell system, where three components are combined. This can reduce the energy consumption of the compressor by an estimated 10%. Photo: Celeroton

Reliable Operation Without Condensation

Not only are design issues important, but also the operation of fuel cells in mobile applications raises questions. The primary concern is that condensation could occur in the compressor shortly after startup, when it is still cold, if the fuel cell vehicle is driving in an area with warm, humid air (for example in a tunnel heated by the earth's interior or a heated garage).

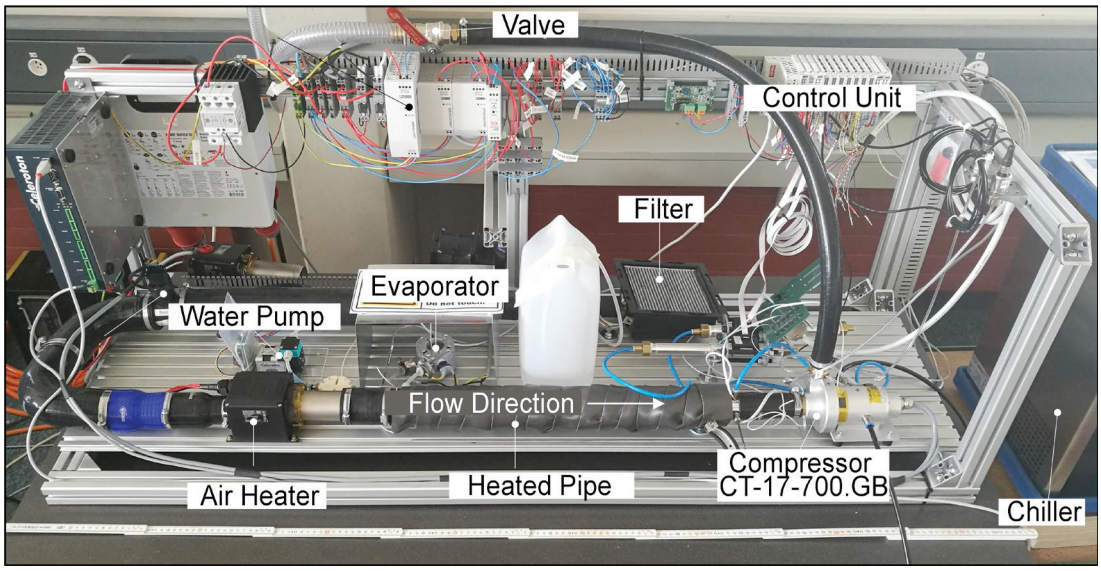
If condensate is formed, the water droplets could damage the gas bearing and other components of the turbo compressor and lead to corrosion. Experimental and theoretical investigations have shown that a critical accumulation of condensation can occur if the compressor's cooling water

TURBO COMPRESSORS FOR BUSES, CARS AND SHIPS

The company Celeroton has developed integrated compressor electronics for an inverter with the designation CC-550-7500. This is commercially distributed and is used, among other things, in the hydrogen-powered version of the „Businova“ bus of the French company SAFRA. The fuel cell, which supplies the electricity for the bus‘s electric motor and contains Celeroton electronics, is made by the French company Symbio FCell.

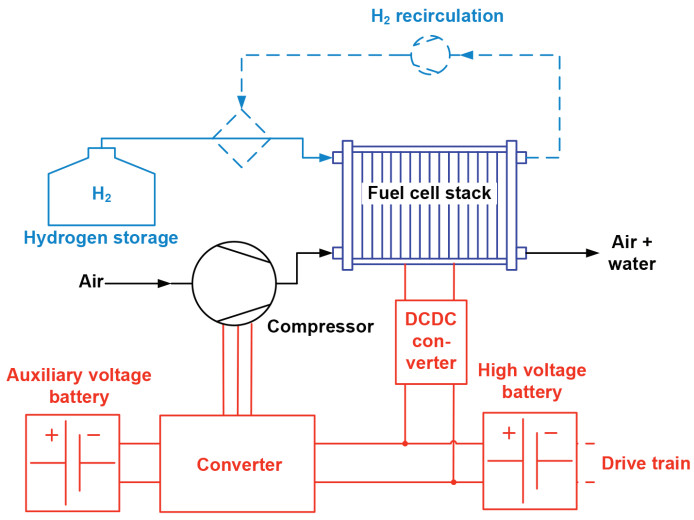
Celeroton is working with industry on other projects: For example, the company has contributed the compressor for a fuel range extender developed by Swiss Hydrogen. A turbo-compressor from Celeroton powers a fuel cell that has been driving the electric motor of a passenger ship in La Rochelle, France, since 2017.

In addition to applications in fuel cell systems, the turbo compressors are used for transporting inert and noble gases and for cleaning optical lenses. BV



Engineers used this test stand to investigate possible impairments of the compressor by condensate. Photo: Celeroton

circuit reacts too slowly, i.e. the cooling water does not heat up fast enough to prevent condensation. Condensation can be avoided with suitable countermeasures: Possible countermeasures include specifications for the design of the compressor cooling system, heating and start-up processes in the compressor and/or fuel cell system, as well as design modifications and parameters for the compressors themselves.



In a fuel cell system for automotive applications, a large number of components are installed in addition to the actual fuel cell stack. To achieve the highest possible overall efficiency, it is important that the parasitic loads of the compressor and conversion losses can be kept as low as possible. Graphic: Celeroton

Compact Electric Motors for Serial Production

Until two years ago, Celeroton was perceived as a prototype and engineering company for turbo compressors. «We are now developing into a manufacturing SME that builds turbo compressors with associated control electronics in series,» says Managing Director Bartholet. As a result, more and more production-related issues are coming to the fore, such as optimized engine topology. The central question is how the stator of the electric motor that drives the turbo compressor should be wound or specifically, how the individual coils of the winding are to be arranged.

Among other things, the results should make it possible to build the powerful turbo compressors with 12 kW even more compact, also in industrial serial production. In order to successfully master such design problems, Celeroton has built up the corresponding knowhow in-house for the construction of electrical machines.

Commercial Vehicle-Fleets of Companies

Celeroton is well positioned to supply an important component for fuel cell vehicles. However, what share hydrogen technology will play in future mobility cannot be reliably predicted at the moment. The technology must become even more cost-effective, and a network of hydrogen filling stations must be developed. Celeroton is counting on a breakthrough of the technology in light and heavy commercial vehicles, because these often belong to a fleet that can be refueled at a central location.

In a current project the company from Volketswil is working with another company that wants to a fleet of small trucks with hydrogen to be in use starting in 2021. Ideally, the project will become a model that will convince other companies of the advantages of the technology.

- **Information** can be obtained from Dr. Stefan Oberholzer (stefan.oberholzer[at]bfe.admin.ch), head of the SFOE research program Hydrogen and Fuel Cells.

- Further **technical papers** on research, pilot, demonstration and flagship projects in the field of hydrogen and fuel cells can be found at www.bfe.admin.ch/ec-h2.

Author: Dr. Benedikt Vogel, on behalf of the Swiss Federal Office of Energy (SFOE)
Version: November 2020