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HYSYS – System Components for Hybridized Fuel Cell Vehicles

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1 Project Overview

Fuel Cell Electric Vehicles (FCEV) are considered to contribute largely to a future sustainable mobility. FCEVs as well as other electrified vehicles use electrical drive train components which have still to be improved to be ready for the mass market at low cost. Principal functionality of FC vehicles under all day conditions has already been demonstrated with a relevant number of prototype cars from a large number of car manufacturers, also in projects funded by the EU (like CUTE/ECTOS). Nevertheless, FC-vehicles, FC-stacks and -systems do not yet meet all requirements for mass market introduction. Several components for FC-hybrid vehicles have to be improved to meet all necessary requirements for mass production. The overall goal of the project HySYS is the improvement of fuel cell system and electric drive train systems for fuel cell hybrid vehicles and ICE hybrid vehicles with a clear focus on fuel cell hybrid vehicles. To achieve this goal several key components for FC vehicles have been developed and being tested on the test bench. Work in HySYS is focused on electrical turbochargers for air supply, low cost humidifiers, hydrogen sensors for automotive use, effective low cost hydrogen supply line, high efficient, high power density drive train and high power Li-Ion batteries. All final tests will be done in two validator vehicles which are built up in the project by Daimler or modified by CRF. The project has been started in December 2005 and will end in November 2010. All system components have been specified, developed, produced and tested on the test bench. Most of them are currently being integrated in the two validator vehicles.

2 Project Objectives

Electrified vehicles, such as Fuel Cell Electric Vehicles (FCEV), Battery Electric Vehicles (BEV) and Plug-in Hybrid Electric Vehicles (PHEV) are considered to be the most promising candidates for a future sustainable mobility. The ICE-hybrid vehicle offers an opportunity to have another viable technical solution for sustainable transport available with a high number of vehicles on the market much earlier. All those technologies use electrical drive train components which have still to be improved to be ready for the mass market at low cost. Due to their superior efficiency when compared to hybridized ICE vehicles and the significant larger driving range as well as short refueling times when compared to BEVs, FCEVs are expected to be the preferred technology if the technological and economic barriers are overcome. Therefore, the HySYS project focuses on FC systems. However, components that can be used in other electrified vehicles are also considered and synergies with those have a high priority. Nevertheless, FC-vehicles, FC-stacks and -systems do not yet meet all requirements for mass market introduction. Several components for FC-hybrid vehicles have to be improved to meet all necessary requirements for mass production. Due to the large operation experience with FC-vehicles, the car industry is able to develop all necessary requirements and specifications together with suppliers and research institutes.

The overall goal of the project HySYS is the improvement of fuel cell system and electric drive train systems for fuel cell hybrid vehicles and ICE hybrid vehicles with a clear focus on fuel cell vehicles. Therefore, the system component work has the highest priority. Nevertheless, the evaluation of the results in real vehicles is essential. While the primary market for FC vehicles is the passenger car market, in this project the fuel cell system components, system architecture, operating strategies and package designs developed are implemented using a commercial delivery van platform in the minibus version. It is assured that all learnings and improvements can be used also for passenger cars.

In summary the objectives are as follows:

- Specifications for hybridized Fuel Cell Vehicles and Hybrid Electric Vehicles
- Identification of synergies between components of different vehicle architectures
- Low cost automotive electrical turbochargers for air supply with high efficiency and high dynamics
- Low cost humidifiers with high packaging density
- Low cost hydrogen sensors for automotive use
- Effective low cost hydrogen supply line
- High efficient, high power density drive train
- Low cost high power Li-Ion batteries
- Enhanced FC-drive train efficiency
- Two FC-vehicles to validate the achieved results and visualize the progress

3 Project Results

3.1 Fuel cell system components

For the air supply the concept of an electrical turbo charger (ETC) has been chosen. After the assembly of the 3rd generation ETC “HYSYS 02” the prototype was tested on a test bench. A maximum aerodynamic efficiency of 73% and the maximum total efficiency of 63% of the ETC were realised. This optimized ETC built up in a single housing fulfils the ETC functionalities and interfaces requirements for the air supply module of the HySYS FC-System at the test bench (see Figure 1). Furthermore significant reduction of noise has been achieved.

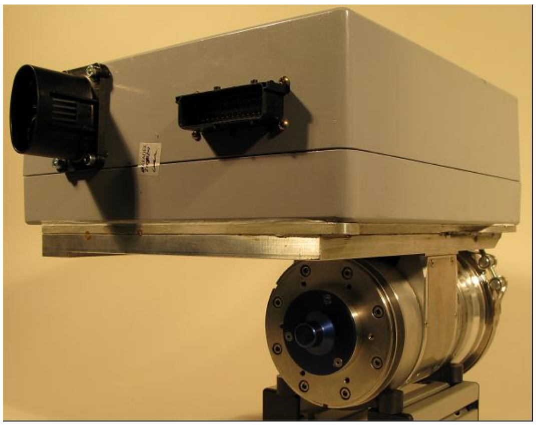

Figure 1: Final prototype ETC 3rd generation HYSYS02.

Figure 2: Detail of the air humidifier.

On the air humidifaction, the consortium developed a gas-to-gas humidifier. The chosen membrane materials combined with the best investigated solution for hollow fibre coatings have been realised and tested on an accelerated test procedure with promising results in small scale component level. For the first full scale humidifier module a new construction of the cartridge was realised to support the FC-system packaging and interface requirements. Two prototypes have already passed the assembling phase using the casting box and thereafter the testing procedure at the component test bench. A section of the humidifier module containing the full size hollow fibre cartridge is shown in Figure 2.

For hydrogen humidification the 3rd generation fuel recirculation pump prototype (HRP) is finalised as a compact single housing component including all its power electronics and cooling. The HRP and the hydrogen water separator prototype based on gravimetric separation principle have been tested by the developed hydrogen humidification line controls strategy at the hydrogen line test bench under simulated FC-System environment conditions.

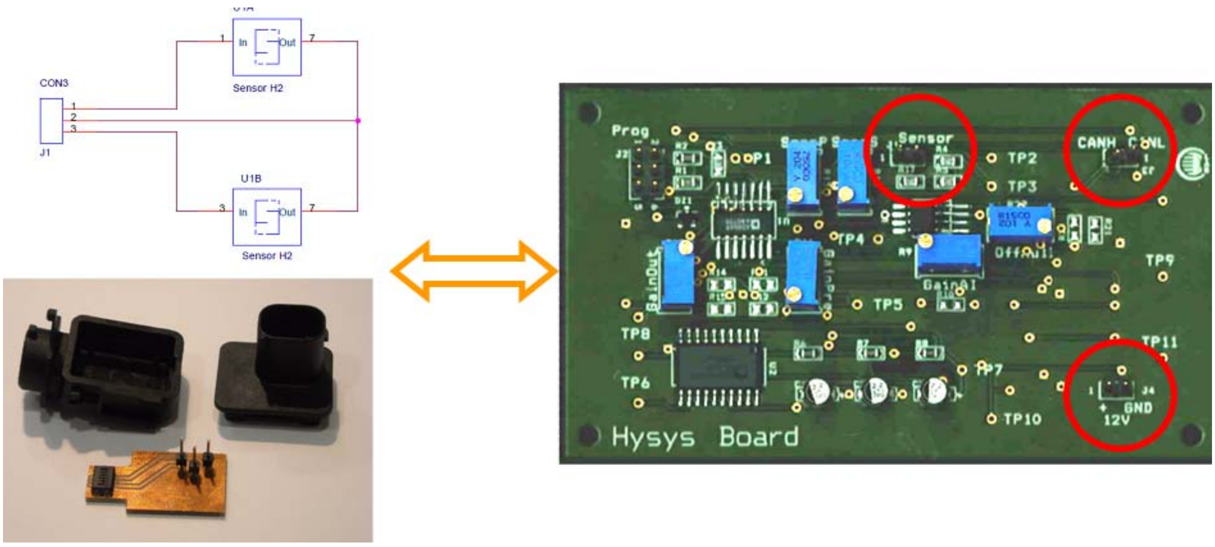

Figure 3: Integrated sensor prototype. The left part is the H_2-sensing element, which includes two silicon chips.

A hydrogen sensor development is investigated by a new manufacturing approach for automotive application. The first sensors are built and the first samples of the electronic system design for the hydrogen sensor are finished. It has been realised in parallel to the development of the H2-sensitive elements. The signal treatment and interface electronics of the hydrogen sensor system are finalised with an integrated sensor and circuit design shown in Figure 3.

Within the work on the Hydrogen supply architecture the line was enhanced by the hydrogen metering device prototype (HMD) that have been designed, built and validated even by live time tests. A photograph of the new hydrogen metering device prototype is shown in Figure 4.

At the time a 3rd final generation prototype is built up, delivered, already implemented and successfully tested at two different system environments for the two validator vehicles (Merecedes Sprinter and Fiat Panda). The 3rd generation prototype is already integrated at the hydrogen module and successfully tested at the Daimler FC system and achieved the full specified performance for the real FC-system testing (80 kW Daimler validator) as well as the performance at the simulated system environment with lower power (Fiat validator).

Figure 4: The prototype of 3rd generation hydrogen metering device integrated in the FC-System.

3.2 Electric drive system components

For the electric motor and power electronics, two different approaches have been followed, one for the Daimler validator and the other for the Fiat vehicle. Figure 5 shows torque and power for the e-motor developed for the Fiat vehicle.

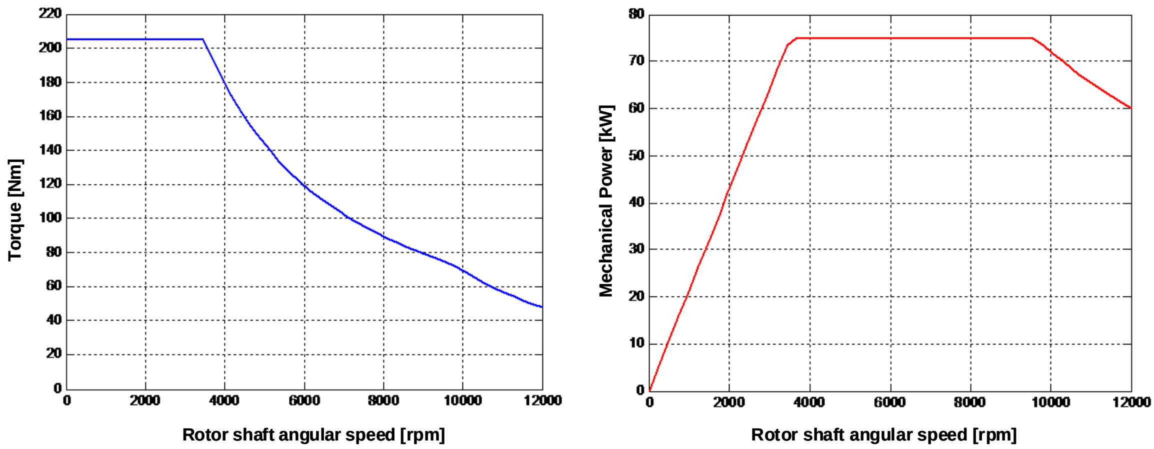

Figure 5: Traction e-drive: measured max transient torque and mechanical power vs. speed.

The developed traction e-drive has been compared with the Fiat state of the art solution (the direct inverter induction e-machine based traction e-drive applied in the HyTran IP Fiat Panda Hydrogen full performance FC vehicle validator): in terms of performance, an increase of torque close to 30% and of mechanical power of around 25% have been reached. In terms of efficiency, an advantage of absolute losses reduction of a factor close to 2 on the overall max values has been obtained. The e-motor and power electronics for the Daimler vehicle has also been finalized and tested on the test bench. Figure 6 shows the e-machine on the test bench.

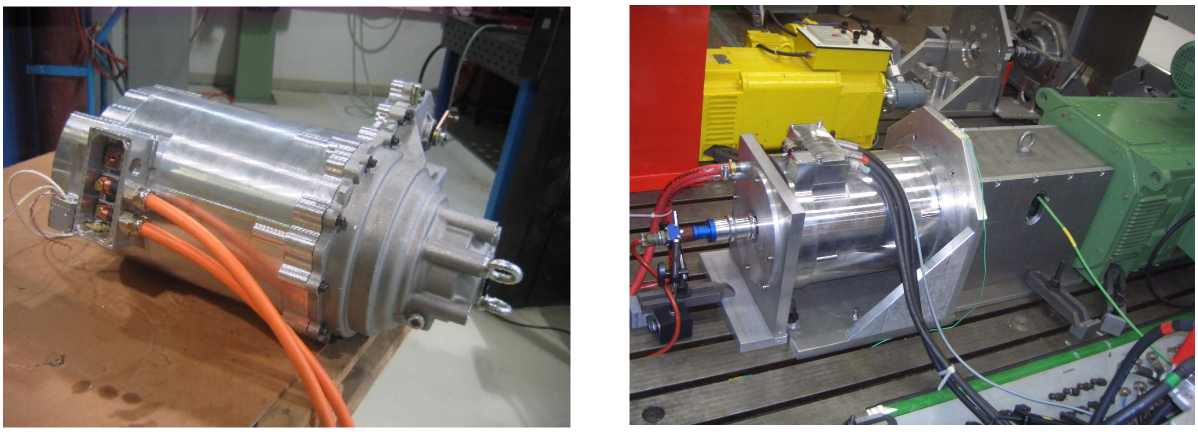

Figure 6: E-machine for Daimler validator with gear box and on test bench.

On the battery side the 80 cells Li-Ion Battery Systems (BS) on bench set up has been completed and the tests are going to be performed according to the defined charge-discharge profile (see figure 7)

Figure 7: **80 cells BS and BS test cooling network.**

3.3 Fuel cell system performance and vehicle integration

The tests carried out with the fuel cell system were mainly focused on the achievement of maturity of the fuel cell system for vehicle integration. Figure 8 shows a comparison of the efficiency of the measured HySYS fuel cell system and the efficiency curve for a fuel cell system from “WELL-TO-WHEELS ANALYSIS OF FUTURE AUTOMOTIVE FUELS AND POWERTRAINS IN THE EUROPEAN CONTEXT” (Version 2c, March 2007). This curve reflects the high expectations from 2003 (the FC-System efficiency curve from 2007 is identical to the version from 2003) on FC-System efficiency. The calculation of efficiency of the HySYS fuel cell system is based on the Faraday fuel consumption due the high accuracy of stack current measurement. The comparison shows that the HySYS FC-systems meets the expectations of improvement foreseen in 2003. The shown efficiency curves are quite similar in the range to 50% net power and almost identical in the range above 50% net power.

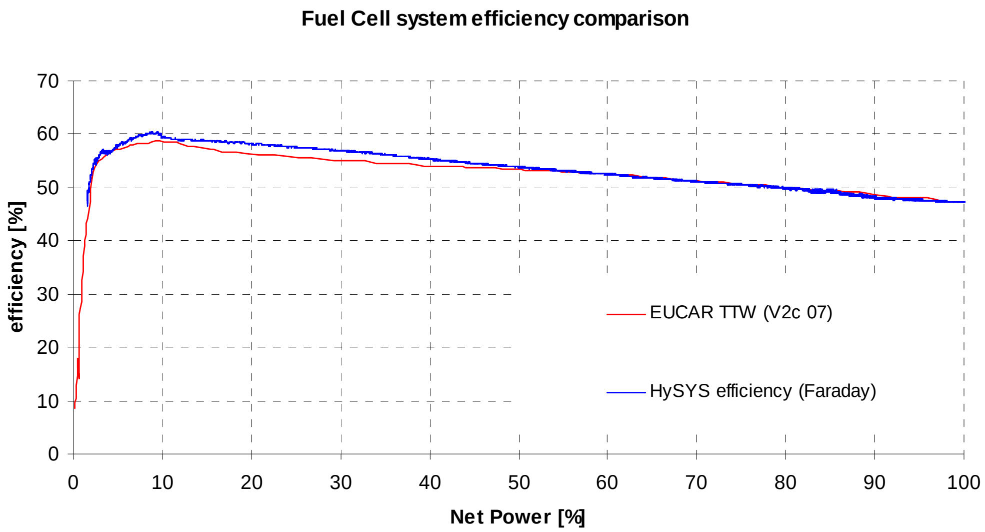

Figure 8: **Fuel cell system efficiency comparison (HySYS and fuel cell system efficiency curve from EUCAR WTW study).**

The integration of the fuel cell system and all other components is currently ongoing. The vehicles will be available for tests in summer 2010.

Project partners

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