

Abstract

Cryogenic Hydrogen Cooling Concept for Sustainable Air Mobility

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This paper presents an innovative cooling concept for hydrogen-based air mobility propulsion systems. The system architecture is based on cooling an electrical motor by cryogenic hydrogen as sketched in Fig. 1. The nominal motor power is 300 [kW] at rotational speeds of maximum 2,500 rpm and compact design to fit into a lightweight airframe.

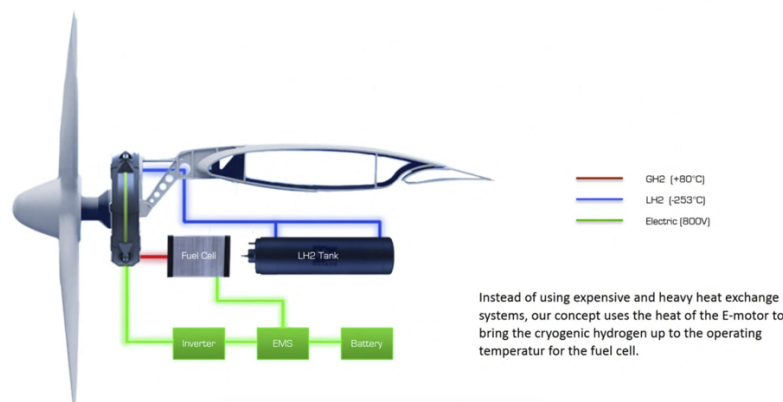


Fig.1: System layout of an electrical propulsion system cooled by cryogenic hydrogen.

Based on analytical pre-studies and a Model-Based Systems Engineering (MBSE) design approach, the relevant design steps including simulation, experimental testing and setup of the model functions will be described.

The focus will be set on the experimental findings of cryogenic hydrogen fluid flow with thermal heat exchange [1]. Here, the thermodynamic and fluid dynamic behavior of hydrogen flowing through an electrically heated hollow conductor, acting as a cooling agent to maintain specified temperature and pressure ranges, will be highlighted. The test data evaluation revealed a strong dependency of the cooling power from the hydrogen mass flow at pressure levels above 4 [bar]. The hydrogen is assumed gaseous, but cryogenic, with no phase transition within the motor system.

During the experimental testing, two types of hollow conductors were subjected to constant current, varying mass flows, and pressures. Two test series were conducted: the first analyzed a straight hollow conductor, while the second focused on a coiled hollow conductor. Uniform boundary conditions were maintained to ensure comparability, using consistent measurement points.

The overall system behavior is represented by an innovative Model-Based Systems Engineering approach [2] sketched in Fig. 2.

By defining model functions representing the physical system behavior, a virtual model of the propulsion system has been set up to pre-test the system behavior and give evidence for scaling laws.

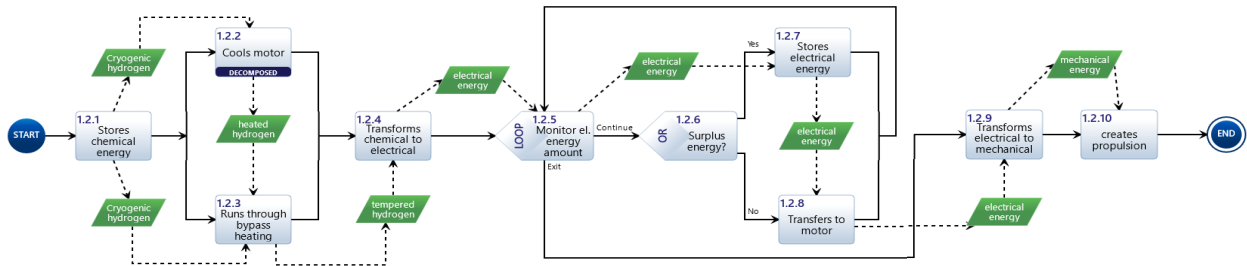


Fig.2: Model-Based Systems Engineering approach for the hydrogen-cooled power train.

Here, the correlations and interdependencies of the energy flow rates between the sub-systems of the powertrain will be analyzed in detail. The model functions are based on analytical pre-calculations, experimental findings and simplified relations from thermodynamics and fluid mechanics.

Further, the quasi-static system behavior will be used to design a control loop for the propulsion system, representing the system dynamics when the aircraft is accelerating or decelerating. The response time of the hydrogen cooling system is very short, consequently the control loop shall be designed based on previously trained scenarios and fallback setting in case of a cooling system malfunction. This reinforcement learning framework, supported by the digital twin of the cooling system, provides a remarkable adaptability in optimizing mass flow rates according to varying thermal loads. This approach can outperform conventional control methods by dynamically managing complex nonlinear interactions within the system, thereby achieving enhanced energy efficiency and stable thermal regulation.

Finally, the validation of the virtual model of the propulsion system is carried out using test data from a representative model of the motor.

[1] Baeten, A., Barm, S., Fackler, M., Majic, N., Reitenberger, J., Guenther, T., Lohr, C., Sause, M., Trauth, A. and Weihrich, R. (2023a), *Concept study of a lightweight high performance axial flux motor cooled with cryogenic hydrogen: SAMPE North America, Seattle, Washington, United States.*

[2] Barm, S., Reitenberger, J., Bersiner, P., Baeten, A., Baeten, S., Fackler, M., Koerner, T. and Oblinger, C. (2024), "Design of a Cryogenic Airborne Hydrogen Cooling System for Electric Propulsion", in *AIAA SCITECH 2024 Forum, Orlando, FL*, American Institute of Aeronautics and Astronautics, Reston, Virginia.

Biography

André Baeten



PhD in Mechanical Engineering, Technical University of Aachen (RWTH); 10 years R&D engineer flight physics at Airbus Military Air Systems, Munich; 2 years systems engineer air defense systems (MEADS) at MBDA, Munich; since 2009 Professor of lightweight construction and composite technology at Augsburg Technical University of Applied Sciences; scientific director of the Technology Transfer Center Hydrogen Technology, Lightweight Construction, and Digital Technologies