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Super high-speed electric motor with amorphous magnetic circuit for the hydrogen fuel cell air supply system☆

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ABSTRACT

Hydrogen fuel cells are one of the important directions of development of the global energy. Hydrogen fuel cells are being actively implemented in the aviation systems, for example in Airbus A320. Boeing and Airbus announced creation of an auxiliary power unit fuel cell with capacity up to 200 kW in 2017–2018. In the automotive industry hydrogen fuel cells are also widely used. But the efficient use of hydrogen fuel cells is not possible without establishment of effective systems related to their operation.

Therefore, our article proposes a new topology of high-speed motor for compressor of the hydrogen fuel cell. An original solution to raise the energy efficiency of high-speed motor presented in our article, the novelty of which is the use of amorphous alloys. Research of the new design methods of computer modeling in Ansys Maxwell was conducted; optimal geometric dimensions of the high-speed motor with two-pole and four-pole magnetic system were obtained in this article. In the modeling losses on eddy currents in permanent magnets and iron of the rotor for two-pole and four-pole magnetic systems were taken into account. All the theoretical results have been experimentally verified. For this purpose the layout of the high-speed motor with the perforated winding was created. Design of the experimental model is also described in this article. The high-speed motor testing and analysis of test data take a special place in this article. In the experimental tests was found that the efficiency of our topology is 92.8% and the power density of our high-speed motor is 0.21 kg/kW with air cooling. These experimental tests prove the effectiveness of our topology compared to the known world analogues. Also in the article was proven that the use of our topology allows minimizing the mass of a hydrogen fuel cell with improved energy efficiency. This is especially important for the aerospace applications and automotive industry.

Introduction

Hydrogen energetics and hydrogen fuel cells (HFC) are one of the priority directions of the centralized and decentralized energetics development. All over the world various projects for the creation and use of HFC are actively developing; companies for the production of stationary HFCs are created in industry [1–3]. HFC are actively implemented in aviation systems, for example in the Airbus A320. Boeing and Airbus

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Nomenclature

A/mm^2	Amperes per square millimeter
B_r	Residual flux density of the permanent magnets
Co	Cobalt
H_c	Coercive force of the permanent magnets
E	Efficiency
HSM	High-speed motor
HFC	Hydrogen fuel cells
Hz	Hertz
A/m	Amperes per meter
kW	Kilowatt
kg/kW	Kilograms per kilowatt
MPD	Magnetic potential difference
mm	Millimeters
mm^2	Square millimeters
m.m.f.	Magnetomotive force
MPa	Megapascal
rpm	Rotations per minute
T	Tesla
V	Volt
W	Watt
W/kg	Watts per kilogram
W/m^3	Watts per cubic meter
$	Dollar
^0C	Celsius degree

announced the creation of an auxiliary power unit based on a fuel cell capacity up to 200 kW in 2017–2018. In the automotive industry HFC are also widely used. That is, hydrogen energetics forms fast-growing high-technological market with a significant economic potential in the recent years. This is due to the several advantages of HFC, such as an environmental friendliness, a high efficiency (E) and a high energy density stored in HFC.

HFC is typically treated as a separate element in the literature. But real HFC is a complex system consisting of the several subsystems: hydrogen supply system; air supply system; refrigerating system; humidification system; statistical converter and control system, Fig. 1 [4,5].

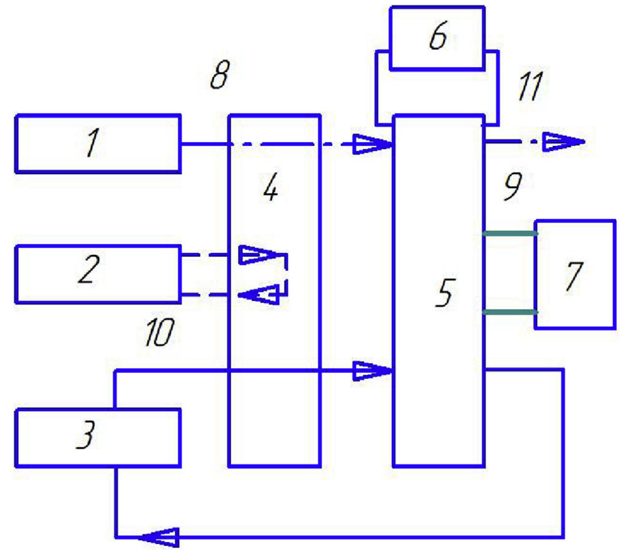

Fig. 1 – Structural scheme of the HFC. 1– hydrogen chamber; 2– water tank; 3– compressor with HSM; 4– moisturizer; 5– hydrogen cell; 6– statistical converter; 7– refrigerating system; 8– hydrogen movement; 9– refrigeration; 11– electric current; 10– air movement.

HSM for the HFC

It should be noted that a high efficiency of HFC was achieved in general, but the effectiveness and E of HFC are reduced because of energy consumption and low efficiency of the related systems.

In Ref. [4] it is shown, that one of the elements that reduces effectiveness of HFC is an air compressor and its electric drive - a key component of the air supply system of HFC. In case of heavy load, it consumes up to 20% of a generated power. Moreover, efficiency of the compressor is determined by efficiency of its electric drive.

That's why a lot of publications devoted to the development of the highly efficient electric drives for HFC [4–12]. In Ref. [4] a high-speed motor (HSM) with permanent magnets power of 500 W, with an E of 92% and a power factor of 0.9 for HFC with capacity of 3 kW is described. That is, the HSM consumes 603 W and it is 21% of the HFC power. In Ref. [6] two types of HSM are described: asynchronous and synchronous with permanent magnets. Power of both engines is 6 kW at a rotor speed of 120 000 rpm. Both engines are designed for the use in HFC. In Ref. [7] HSM with permanent magnets with a power of 12 kW and a rotor speed of 120 000 rpm is described. In Ref. [8] HSMs power of 580 W and a rotor speed of 250 000 rpm for HFC are characterized. This HSM is used in HFC with a capacity of 10 kW. As can be seen from the results of [8] at a given power of HSM the air supply system of the HFC maintains an excess oxygen factor of 2 and a pressure of 1.4 bars. Overall, the achieved consumption of HSM in relation to the power of HFC is much better than the consumption that described in Ref. [5]. But the author of [8] does not explore all operation modes of the HFC and HSM, while in the overload operation modes can take place a considerable increase of the power consumption of HSM.

The creation of HSM with the same power and rotation speed is described in Refs. [9–12]. From analysis of the works [5–12] it is possible to form an overall appearance of the future HSM for HFC: a synchronous motor with permanent magnets, power of from 0.5 kW to 6 kW and rotor speed of from 120000 rpm to 250000 rpm.

As can be seen from the given HSM analysis, its significantly influences on the energy efficiency of HFC, so achievement of the maximum efficiency of HSM with the minimum weight and size overall dimensions is a relevant and important scientific task.

Since a rotor speed of HSM for HFC is considerable, then the problem of providing a high E at a design stage is a high

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