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NUCLEAR POWER PLANTS

Evaluating the Thermodynamic Efficiency of Hydrogen Cycles at Wet-Steam Nuclear Power Stations

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Abstract—Various schematic solutions for implementing a hydrogen cycle on the basis of thermal and nuclear power stations are discussed. Different approaches to construction of cooling systems for the combustion chambers used in hydrogen-oxygen steam generators are described. An example of solution is given in which the combustion chamber is cooled by steam, which is the most efficient one in the thermodynamic respect. Results from an assessment of the thermodynamic efficiency of hydrogen cycles organized on the basis of the power unit of a wet-steam nuclear power station equipped with a K-1000-60/1500 turbine are presented. The thermodynamic efficiency of different schematic and parametric versions of implementing a hydrogen cycle, including those with a satellite turbine operating on displaced steam, is carried out. It is shown that the use of satellite turbines allows the power output and efficiency of the power unit of a wet-steam nuclear power station to be upgraded in a reliable and effective manner.

Keywords: nuclear power engineering, hydrogen power engineering, thermodynamic efficiency, wet-steam cycle, hydrogen cycle, hydrogen, oxygen, satellite turbine, hydrogen-oxygen steam generator, combustion chamber

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Much attention is now paid both in Russia and abroad to matters concerned with using the energy generated at nuclear power stations (NPSs) for producing environmentally clean hydrogen fuel, which has good prospects for its use in the future. Research works are carried out with a view to determine how competitive and advisable the production of hydrogen at NPSs equipped with different types of reactors is [1, 2]. In addition, matters concerned with the possibility of generating peak electric energy at NPSs by storing energy in the form of hydrogen fuel for its subsequent use in the hours of maximum electric load in power systems are solved. To this end, it is proposed to connect a dedicated hydrogen-oxygen steam turbine jointly with a hydrogen-oxygen steam generator furnished with a water-cooled combustion chamber.

In accordance with the principles of thermodynamics, use of water as cooling medium is inefficient because part of the energy generated during the combustion of hydrogen in oxygen will be spent for the phase transition. At the same time, with such method of steam generation, this turbine can operate independently of the NPS power unit. In [3, 4], a version was additionally considered involving the use of a hydrogen-oxygen steam generator furnished with a steam-cooled combustion chamber jointly with a connected turbine unit and hydrogen-assisted steam reheating. This solution can be used both for generating additional peak electric energy in the connected turbine and for achieving better efficiency and higher power capacity of the main cycle due to additional hydrogen-assisted superheating. In [5], a somewhat different approach to implementing a hydrogen cycle is proposed, according to which the combustion chamber is also cooled by steam. But in that case, self-ignition of the hydrogen-oxygen mixture occurs due to a high temperature of more than 450°C. If the temperature of mixture is insufficient for its self-ignition, a special igniting catalyst is used. The schematic solutions suggested in [3–5] can be used for additional hydrogen-assisted superheating of steam in the cycles of both thermal and nuclear power stations in order to improve their efficiency.

The Program for development of the Russian power industry stipulates intense commissioning of NPS capacities in the country's power systems. At the same time, nonuniformity of electric load curves generates the need to search for justified ways of organizing base-load operating conditions for the newly commissioned power units, as well as for the operating NPSs. Along with construction of pumped-storage power stations, development and use of hydrogen cycles implemented on the basis of wet-steam NPSs can be an efficient solution of this problem. By generating high-temperature hydrogen steam and using it for increasing the working parameters of wet-steam cycle, it is possible to obtain, apart from better efficiency of the cycle, additional peak power in the hours