Development of the design of the research module - model of a high-temperature surface with induction heating

A N Varava¹, A S Demidov¹, A V Zakharenkov¹, V D Loktionov¹, A T Komov¹ and A V Dedov¹

1 General Physics and Nuclear Fusion Department, National Research University “MPEI”, Russia, 11250 Moscow, Krasnokazarmennaya, 14

ZakharenkovAV@mpei.ru

Abstract. The paper describes a test bench for evaluating the cooling efficiency of a working area with a high energy density using a two-component dispersed coolant flow. The design of a pneumatic sprayer and the scheme of the working area cooled by a two-component dispersed flow are described. A description of the design of the new research module and a scheme for installing thermocouples on it is given. A method for measuring the temperature of the walls of the research module is proposed. Adjustment tests were performed at the operating parameters of the coolant $p_{\text{water}} = 2,5 \times 10^5$ Pa, $p_{\text{air}} = 2,0 \times 10^5$ Pa, $G_{\text{water}} = 0,048$ kg/c; $G_{\text{air}} = 1,7 \times 10^{-3}$ kg/c.

1. Introduction

A feature of modern technologies is an increase in the values of the densities of the transferred heat fluxes, both due to an increase in the level of heat fluxes and due to a decrease in the characteristic dimensions of heat transfer devices. The search for new methods for intensifying heat transfer is a characteristic feature of the structural elements and technologies being introduced today. In advanced energy technologies, the greatest heat flux densities occur in thermonuclear reactors and installations, in the development of which technological issues have now come to the fore. One of the effective ways to cool high-temperature surfaces can be the use of a dispersed gas-liquid flow as a heat carrier. This is especially important for cooling the internal elements of a thermonuclear reactor, such as a limiter, a diverter, and a blanket [1, 2].

2. Working setup and nozzle description

To study the possibilities of the dispersed cooling method, the department created an experimental setup “Dispersed cooling of a target”, which consists of three main systems:

- hydraulic circuit for cooling the working area;
- heating systems based on the IHS-20 high-frequency generator;
- systems for collecting and processing information National Instruments.

Fig.1 shows a schematic diagram and photographs of the assembled hydraulic circuit for cooling the working section with both a single-phase flow (distilled water) and a two-component dispersed flow of the coolant.

The cooling circuit works as follows. Distilled water is supplied to the working section 1 by a pump from a tank with distilled water. To control the flow rate, pressure and temperature of water and gas, digital flow meters 2 with the possibility of adjustment, pressure gauges 3, and thermocouples 4 of the K type are used. Solenoid valves 5 provide the supply of components to the atomizing device.
To clean and prepare the components from mechanical impurities, the filter 6 and the air preparation unit 7 are used. The required air pressure is provided by a compressor 8 or a gas cylinder. Depending on the operating parameters of the components at the outlet of the spraying device 9, a two-phase mixture of water and gas is formed with the distribution of water droplets in size and velocity. The dispersed flow enters the channel, where it cools the inner surface of the working section 1 of the high-frequency generator heated by the inductor 10, and then enters the storage tank 11. To prevent water from entering the gas main, the non-return valve 12 is used. The inductor 10, which ensures uniform heating of working section 1, is connected to the terminals of the high-frequency generator IHS-20 with a maximum electrical power consumption of 20 kW.

For the formation of a dispersed flow, a design of a pneumatic spraying device was developed. The spraying device includes a spray nozzle 1, an outer nozzle body 2, water supply units 3 and air 4, turbulators of the components of the dispersed flow 5, as well as fixing 6 and sealing 7 elements. A diagram of the manufactured device is shown in Fig. 2.

**Figure 1.** Cooling system schematic diagram: 1 - research module; 2 - flow meters; 3 - digital pressure gauges; 4 - temperature sensors; 5 - electromagnetic valve; 6 - mechanical filter; 7 - compressed air preparation device; 8 - compressor (gas cylinder); 9 - spraying device; 10 - inductor; 11 - storage tank; 12 - non return valve

**Figure 2.** Spraying device diagram: 1 - spray nozzle; 2 - outer casing of the nozzle; 3 - air supply unit; 4 - water supply unit; 5 - turbulators of dispersed flow components; 6 - fixing elements; 7 - connecting fittings; 8 - replaceable nozzles

The parameters of the dispersed flow formed by the spraying device are as follows:

- components used: water (distilled water), air (non-aggressive or inert gases: N₂, Ar);
- overpressure of components: \( p_{\text{water}} = (0.1 \div 5.0) \cdot 10^5 \text{ Pa} \), \( p_{\text{air}} = (0.1 \div 8.0) \cdot 10^5 \text{ Pa} \);
• volume flow rate of components: $Q_{\text{water}} = (0.65 \div 7.0) \cdot 10^{-4} \text{ m}^3/\text{s}$, $Q_{\text{air}} = (0.28 \div 2.2) \cdot 10^{-3} \text{ m}^3/\text{s}$;
• diameter of water droplets in the flow: $d = (10 \div 100)$ microns;
• angle of jet opening: $\alpha = (7 \div 13)^\circ$.

The collapsible design, replaceable nozzles, and a movable stem allow you to change the angle of the spray jet and the size of the droplets. The nozzle design is designed in such a way that the inner diameter of the cooled channel can vary in the range $16.0 \div 24.0$ mm.

3. Working section and thermocouple probe description

The working section is a two-layer cylindrical tube. The outer layer is made of nickel, a material that is easy to work with and has a high magnetic permeability. The inner layer is made of pseudo-tungsten-copper alloy, a material with a high coefficient of thermal conductivity. One of the main conditions for the choice of material for the working area was the equality of the values of the coefficients of linear expansion, which is carried out for these materials.

The outer nickel layer is a cylindrical tube with an outer diameter of 80 mm, an inner diameter of 52 mm and a length of 100 mm. The inner tungsten-copper layer is also a cylindrical tube with an outer diameter of 52 mm and an inner diameter of 18, with a wall thickness of 17 mm and a length of 98 mm. Drawings of the outer and inner layers with holes for thermocouples are shown in Figure 3.

![Figure 3. Drawings of the outer (upper) and inner (lower) layers](image)

The use of a two-layer working area is necessary to simplify the modeling of heat distribution in the working area. Since the induction heating method is used, internal heat sources appear in the single-layer working section, the distribution of which is difficult to predict. To get away from this, it was proposed to use a two-layer construction of the working area. The task of the outer layer is to transfer heat uniformly from the inductor to the inner layer of the working area. Then, for the inner layer, provided that the working section is thermally insulated, on the outer edge it is possible to achieve the boundary condition of the second kind.
In addition, the cylindrical working section, with a heated outer wall and a cooled inner wall, is a thermal lens, which makes it possible to increase the heat flux density on the inner surface of the working section in comparison with the heat flux density on its outer surface by several times.

To determine the temperature field in the working section, 10 type K thermocouples were installed, the location of which is also shown in Figure 3. To create holes with a depth of 30 and 60 mm with a hole diameter of 1.1 mm, an electric discharge superdrill was used.

To measure the local temperature values in the channel of the IM of the components of the dispersed flow, a thermocouple probe was designed and manufactured, consisting of four thermocouples with a diameter of 0.5 mm, mounted on a special frame, which makes it possible to simultaneously move these thermocouples along the length of the channel during the experiment. Moreover, the measuring junctions of the two extreme thermocouples were located at a distance of 1.5 mm from the inner surface of the cooled channel, the third thermocouple was located on its longitudinal axis. This probe, due to its design, is able to move smoothly along the axis of the cooling channel starting from the upper edge of the investigated module along the coolant flow by 88 mm, which makes it possible to measure the temperature of the cooling medium inside the channel. The design of the probe is shown in Figure 4.

4. Results of commissioning tests.
As a result of commissioning tests, the following parameters were measured: mass flow rate of the dispersed mixture components, working area inlet and outlet pressure and temperature, electric heating power, wall temperature along the target length.

Acknowledgments
The Russian Science Foundation 19-79-00271 financially supported the hydraulic circuit and the pneumatic nozzle, the design development and the creation of a new working section were carried out with the financial support of the Russian Science Foundation 21-79-10179.

References
[1] Lyublinski I.E., Mirnov S.V., Komov A.T. et al. J. of Physics: Conf. Series 2017 891(1) p. 012152
[2] Vertkov, A.V., Komov, A.T., Lyublinski, I.E. et al. Problems of Atomic Science and Technology. Series Thermonuclear Fusion 2018 41(1) p. 57–64