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Experimental studies into the dependences of the axial lead coolant pump performance on the impeller cascade parameters

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Abstract

The paper presents results of experimental studies into the dependences of the axial lead coolant pump performance (delivery, head, efficiency) on the impeller cascade parameters, including the number of blades, the cascade blade angle and the cascade solidity. The studies were conducted as applied to conditions of small and medium sized plants based on lead cooled fast neutron reactors with horizontal steam generators. The designs of such plants are now in the process of elaboration at Nizhny Novgorod State Technical University (NNSTU). The studies were conducted at NNSTU's FT-4 test facility at a lead coolant temperature of 440–500 °C. In the process of investigations, the number of blades in the form of flat plates was 3, 4, 6 and 8, the cascade blade angle was in a range of 9–43°, and the cascade solidity (0.6–1.2) was changed by changing the blade section chord length. The shaft speed of the NNSTU's NSO-01 pump, onto which changeable impellers were installed, was changed in steps of 100 rev/min in an interval of 600–1100 rev/min. The blade diameter was about 200mm, and the maximum lead coolant flow rate in the course of the tests reached ∼2000 t/h. The performance of 27 impellers was investigated. It is recommended that the investigation results should be used in design of axial HLMC pumps.

Keywords: Heavy liquid metal coolant; Fast neutron reactor facility; RCP; Pump impeller; Pump head; Axial pump; Lead coolant; Pump delivery.

Introduction

There is currently no experience of developing and operating axial pumps for heavy liquid metal cooled (HLMC) systems under design.

The performance of such pumps depends on the circulating heads about the pump impeller blades through the cascade. Along with the blade section shape, the key cascade parameters are α (blade angle), Z (number of impeller blades), and l/t (cascade solidity) [1,2]. Experimental determination of the optimal values for these parameters in the lead coolant in the reactor circuit environment will make it possible to provide for a feasible design of the optimal impeller geometry in the given shaft speed ranges. The optimal geometry of the impeller cascades will make it possible to ensure the required pump performance (delivery, head, efficiency). A more representative comparison of the investigation result requires invariability of the pump blade section geometry and delivery/discharge rates, including the guide vanes [2].

More representative studies require full-scale conditions of the coolant contact with the surfaces of the pump wet end materials (adhesion work, roughness, etc.) which affect their force interaction.

In accordance with these requirements, experimental investigations are conducted at NNSTU's FT-4 test facility [3] to study the dependences of the NSO-01 changeable-impeller axial pump performance on the cascade parameters. The final objective of the investigations is to develop recommendations for the reactor coolant pump designs as applied to small and medium sized plants based on lead-cooled fast-neutron reac-

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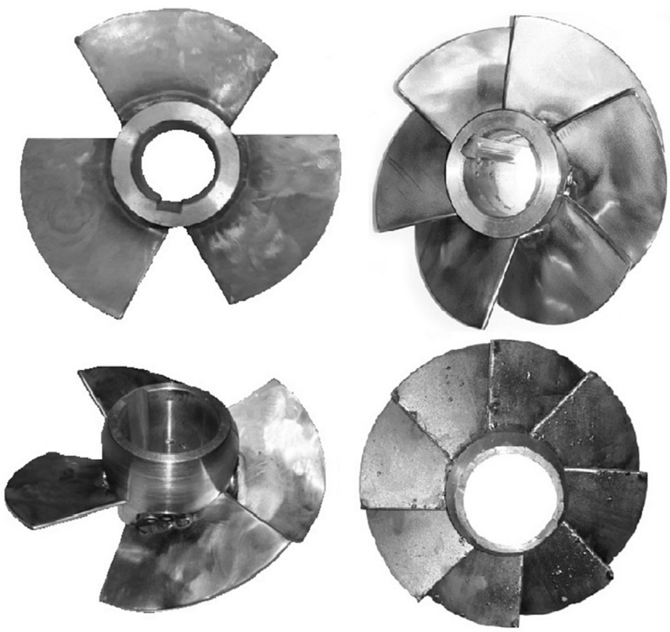

Fig. 1. Photographs of impellers.

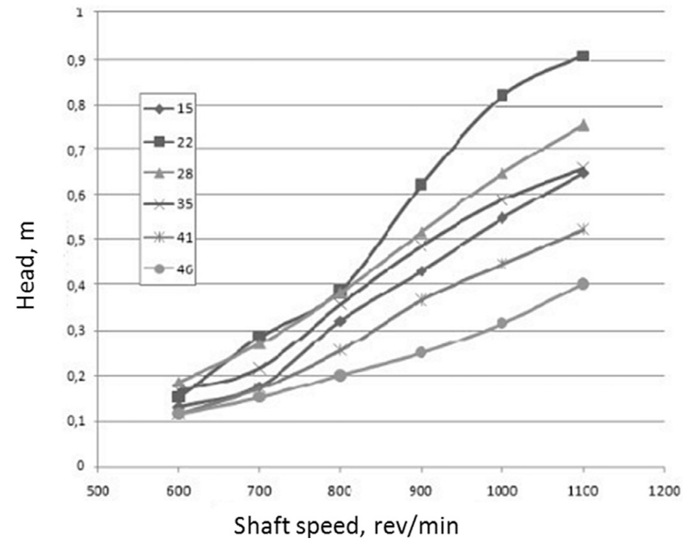

Fig. 2. Pump performance as a function of shaft speed.

tors with horizontal steam generators; the designs for such reactor plants are being elaborated now at NNSTU [4,5].

Experimental procedure

The purpose of the investigations was to determine the performance (delivery, head, efficiency) of a pump installed in a circulation circuit with a lead coolant, depending on the cascade parameters, including the blade angle (α), the number of blades (Z) and the cascade solidity (l/t), during a stepped variation of the pump shaft speed (n). Further studies are expected to follow for the experimental determination of the optimal guide vane performance [6].

Impellers with different cascade designs were installed onto the NSO-01 circulation pump shaft in the lead coolant circuit of the FT-4 test facility. The lead coolant test temperature was 440–500 °C. Dependences for 27 impeller designs with flat blades were determined with the speed in the event of each impeller design being 600–1100 rev/min. The hydraulic resistance of the circulation circuit was varied by repositioning the governor valve wedge. The maximum lead coolant flow rate in the investigation process reached ~2000 t/h.

Identically shaped blades (flat plates of 09H18N10T steel) (see Fig. 1) were installed onto the impellers of the diameter $D1 = 200$ mm.

The number of the blades installed onto the impellers was 3, 4, 6 and 8; and the blade angles were 9°, 15°, 22°, 32°, 38°, 41° and 46°. Variability of the cascade solidity was achieved by changing the blade chord length (0.8–1.2) with a change in the area of each blade S_b: for 100% – the area $S_b = 0.0079\,m^2$; for 80% – $S_b = 0.0063\,m^2$; for 120% – $S_b = 0.0079\,m^2$ (the chord length was changed only for two wet ends with four blades and the blade angle of 28°) [7,8].

The pump shaft speed was changed in steps of 100 rev/min.

Protective oxide coatings were formed on the impeller blade surfaces and maintained by controlled regulation of the thermodynamic activity of oxygen (a) in the lead. This dimensionless parameter was kept in the range of $a = 10^{-4}$–10^{-3} by the FT-4 facility's standard regulation system through capturing and introducing into the coolant bubbles of a gaseous argon mixture with hydrogen or oxygen with the use of lead jets falling onto its free surface from the facility's circulation pump constant-head tube. The accuracy of regulation in the above range was achieved through the performance of an IPPE-designed thermodynamic activity sensor with a 10% limit on the permissible relative EMF deviation from the rated value. The following parameters of the test facility were varied and fixed in each mode: the NSO-01 pump shaft speed; pump outlet and inlet pressure; pumped coolant temperature; pump motor power; pump shaft torque; thermodynamic activity of oxygen in the lead coolant [9–11].

Studies were conducted in all modes with three governor valve wedge positions (fully up, 30% down, 60% down) with the respective hydraulic resistance of the circulation path. To compare the results, four impellers with profiled blades were manufactured, and similar studies were conducted on the pump performance dependences. As estimated by the authors, the error in the herein presented findings will amount to ± (20–30)% of the obtained values [12–14].

Key results

Dependence of the pump performance on the changeable impeller speed

It has been found that an increase in the impeller speed in a range of 600–1000 rev/min with the gate valve being fully opened (independent of the blade number, the blade angle and the cascade solidity), leads to a monotonous increase in the pump delivery and head (Fig. 2). Such dependence indicates