Research Article

Experimental studies into the dependences of the axial lead coolant circulation pump performance on the pump straightening device parameters*

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Abstract

The paper presents the results of experimental studies into the dependences of the axial pump performance (delivery rate, head, efficiency) in lead coolant on the parameters of the straightening device (SD) installed downstream of the impeller (the SD inlet flow angle and the number of the SD blades with a variable impeller speed change).

The studies were performed as applied to the operating conditions of small and medium plants with lead cooled fast neutron reactors with horizontal steam generators (BRS GPG). The designs of such plants are being matured at Nizhny Novgorod State Technical University (NNSTU).

The experiments were conducted on the FT-4 NGTU test bench at the lead coolant temperatures in a range of 440 to 500 °C. The number of the test blades was five and eight, and the SD inlet flow angle was 22, 24, 28, and 32°. The tests were also performed without an SD (with the SD dismantled). The shaft speed of the NSO-01 NGTU pump, with changeable SDs installed into its rotating assembly, was varied in a range of 600 to 1100 rev/min with a step of 100 rev/min. The SD sleeve diameter was 82 mm, the SD blade diameter and height were 213 mm and 80 mm respectively, and the maximum lead coolant flow rate during the studies was up to ~ 1650 t/h. The NSO-01 NGTU pump performance was determined with four changeable straightening devices and with no SD, the pump shaft speed being 600 to 1100 rev/min, as the circulation circuit hydraulic resistance changed owing to the movement of the wedge in the valve installed in it. The tests were performed with the impeller designed and supplied by NNSTU ($D = 213$ mm, $d_{sl} = 82$ mm, the blade number is four, and the blade angle is 28°).

The obtained results are recommended for use to design axial heavy liquid metal coolant pumps.

Keywords

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Introduction

There is currently no experience of building and operating axial pumps for the design of heavy liquid metal cooled plants (Beznosov et al. 2006). The standard structural design of an axial pump comprises a straightening device the purpose of which is to convert some of the velocity of the flow leaving the impeller and entering the pump discharge end and to stabilize the flow characteristics. The straightening device (SD) with non-rotating blades is installed downstream of the rotating pump impeller. The operating efficiency of the SD depends both on its geometry (number of blades, flow angle, blade profile, etc.) and on the characteristics of the coolant wall layer force interaction and the blade material that contacts the coolant (wettability, roughness, etc.) (Pfleiderer 1960, Karelin 1975, Lomakin 1966, Budov 1986, Mikhaylov and Malyushenko 1977, Rozhdestvenskiy 1977).

The experimentally found dependences of the axial pump performance on the design parameters of straightening devices in the lead coolant under the reactor circuit conditions make it possible to develop, on a justified basis, the best possible geometry of the wetted pump parts in the preset ranges of the shaft speed values.

Methods were justified at the earlier stages of the activities performed at the FT-4 NGTU test facility at NNSTU (Beznosov et al. 2014, 2014a, 2014b, 2015a, 2015b, 2017a, 2017b) for carrying out experiments aiming to elaborate recommendations on the pump main circulation circuit designs as applied to fast lead cooled reactor plants with horizontal steam generators (BRS GPG); the designs for such reactor plants are being matured at present at NNSTU (Beznosov et al. 2009, 2012, 2013, 2016, Beznosov and Bokova 2012, Handbook on Thermohydraulic Analysis 1987, Drozdov et al. 2009, Dragunov et al. 2015, Chechyotkin 1971).

Experimental procedures

Essentially, the tests consisted in determining the performance (delivery rate, head, efficiency) of the axial pump installed in the lead coolant circulation circuit with various SD designs differing in the number of blades and the SD inlet flow angle with a stepped variation of the pump shaft speed, the impeller geometry being fixed.

The SD of the respective design (Fig. 1) is installed into the rotating assembly of an NSO-01 circulation pump of the FT-4 test facility lead coolant circuit. The test temperature of the lead coolant was 440 – 500 °C.

The pump performance was determined for each version of the SD design installed into the pump's rotating assembly with the pump shaft speed varied in the limits of 600 to 1100 rev/min in steps of 100 rev/min. The hydraulic resistance of the lead coolant circulation circuit was varied by changing the control valve wedge. The maximum test delivery rate of the lead coolant reached 1650 t/h.

All of the SD components were made of 12Kh18N10T steel. All SD versions had the sleeve diameter of 82 mm,

Figure 1. Versions of the SD design.

and the maximum diameter of the downstream blade circumcircle was 213 mm.

The pre-estimated outlet angle of the absolute impeller outlet flow velocity component in the nominal mode was in the limits of 26 to 28°. The SD versions manufactured for the tests had blades enabling the flow to enter the space between blades at the angles of 22, 24 and 28° (eight blades) and 32° (five blades). A part was also manufactured (a spacer consisting of a shell and flanges) to be used as the chamber substituting the SD but having no blades.

Protective oxide films formed and were maintained on the surfaces of the blades and other SD components by monitored regulation of the oxygen thermodynamic activity a in lead. This dimensionless parameter was kept in the range $a \in [1 \times 10^{-4}, 1 \times 10^{-3}]$ with the use of the FT-4 facility's standard regulation system by capturing bubbles of a gaseous mixture of argon with hydrogen or oxygen and introducing these into the coolant flow with the lead jets falling onto the free surface [15] from the test facility's circulation pump constant-head tube. The accuracy of regulation in the above limits was maintained through the performance of the lead oxygen thermodynamic activity sensor designed and supplied by IPPE with a 10% permissible relative EMF deviation from the rated value. The following test facility parameters were measured and recorded in each mode:

- NSO-01 pump shaft speed;
- pump inlet and outlet coolant pressure;
- circulation circuit coolant delivery rate;
- pumped lead coolant temperature;
- pump motor power;
- thermodynamic activity of oxygen in lead coolant.

Studies were performed in all modes with fixed control valve wedge positions in the circulation circuit (fully up, 30% down, 60% down, 90% down) with the respective variation of the circulation route hydraulic resistance.

Key results

The dependence of the pump delivery rate and head on the SD inlet flow angle and the number of blades has been established. The results of measuring the pump delivery rate for serially installed SDs with the flow angles of 22, 24, 28, and 32° and with the dismantled SD have shown

(Fig. 2) that the pump delivery rate does not practically change if the shaft speed is fixed, that is, the pump rate is conservative to the tested SD design versions.

The pump delivery rate was somewhat higher with a smaller number of the SD blades. This can be explained by the fact that the reduced number of blades led to a smaller hydraulic loss in the SD. A certain increase in the pump delivery rate, as compared with eight-blade SDs, was recorded in the wet end tests for a pump design with no SD. It should be noted that the five-blade design had a greater inlet flow angle (32°) and the blade profile was slightly different from other versions.

The pump head with fixed shaft speed values and the SD inlet flow angles of 22, 24 and 28° changes insignificantly (in the limits of a few percent) and somewhat greater with an inlet flow angle of 32°, which can be caused by a larger difference in the designs than in previous versions. The differences in the test results for various SD designs were expected to be much greater. Such results were recorded in the tests of all SD versions with all pump shaft speeds varying in the limits of 600 to 1100 rev/min. The potential cause for the obtained results is the presence of a certain factor in the pump wet end that is decisive (except the shaft speed) and levels down the potential differences in the pump head in the testing of versions. A less probable explanation is that the tests were performed with substantially non-optimal values of the SD inlet flow angles. A steadily improved pump performance was observed across the test range (Table 1) with no SD in the tested wet end. This result runs counter to literature data on water transferring axial pumps [2]. Potential explanations for the result include the presence of a constant-head tube in the pump discharge structure,
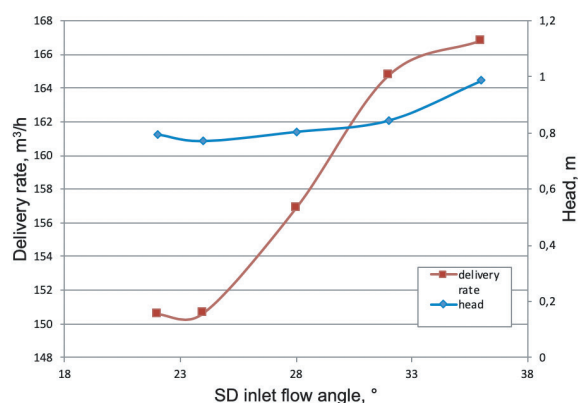
a difference in the physical characteristics of the fluids pumped, and their interaction with the structure surfaces.

Dependence of the pump performance with different pump SD deigns

The nature of the pump delivery rate dependence on the shaft speed (Fig. 3) is the same for all tested pump SD versions, beginning with $n = 700$ rev/min. A major difference in the dependence characteristics with $n = 600$ rev/min is defined by the NSO-01 NGTU pump design having a hole in the lower part of the constant-head tube.

The nature of the pump head dependence on the shaft speed (Fig. 4) is the same for all tested pump SD versions in the limits of 600 to 1100 rev/min. This result requires further studies to determine the best pump SD design.

The nature of the pump efficiency dependence on the shaft speed (Fig. 5) is practically the same for all tested pump SD versions in the limits of 700 to 1100 rev/min. A certain increase in the pump efficiency is recorded starting with $n=700$ rev/min and up to ~ 900 rev/min with a subsequent decrease of $\sim 10\%$. A relatively small efficiency in the testing of pump models (approximately not more than 18%) can be explained by scale and other factors.
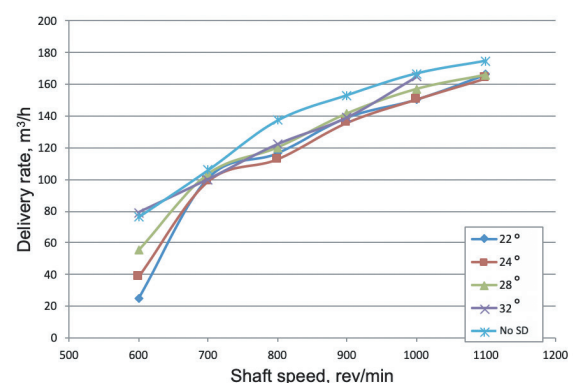
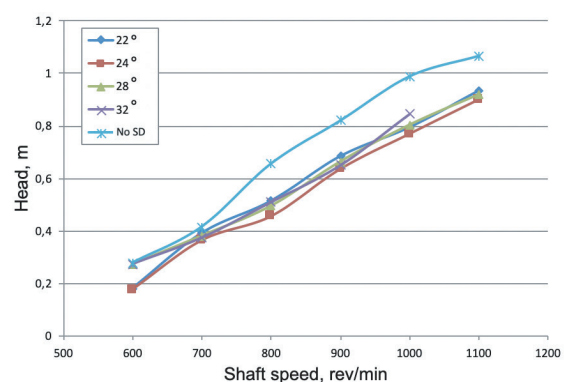**Figure 3.** Delivery rate as a function of the pump shaft for different SD designs.

Figure 4. Pump head as a function of the shaft speed for different SD designs.

Figure 2. Pump head and delivery rate as a function of the SD inlet flow angle with an invariable pump shaft speed of n = 1000 rev/min.

Table 1. Pump performance with $n = 1000$ rev/min.

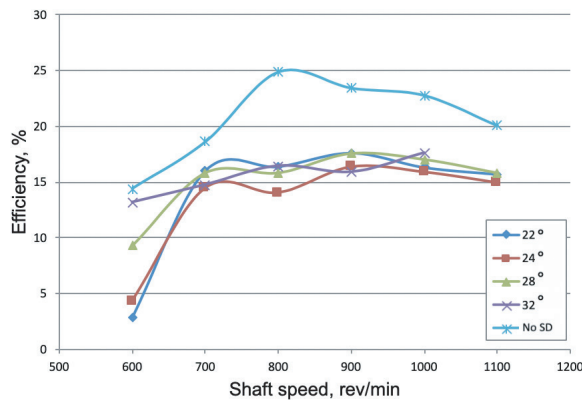| Angle, °	Head, m of lead column	Delivery rate, t/h	Efficiency, %
22	0.795	150.5709	16.34
24	0.771	150.6349	15.89
28	0.804	156.882	17.00
32	0.845	164.7588	17.63
No SD	0.988	166.8293	22.78

Figure 5. Pump efficiency as a function of the shaft speed for different SD designs.

Conclusion

The results of experimental studies into the dependence of the axial lead coolant pump performance (head, delivery rate, efficiency) at a temperature of 440 to 500 °C, the maximum delivery rate being up to 1650 t/h, on the parameters of the pump straightening devices with five and eight blades, and with the SD inlet flow angle of 22, 24, 28 and 32°, the shaft speed being in the limits of 600 to 1100 rev/min, are recommended for use to design axial pumps for heavy liquid metal cooled reactor plants. Special attention shall be given to the experimental check of the requirement to install the outlet straightening device and to its design.

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