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DESIGN CHARACTERISTICS AND TEST RESULTS FOR SOME CONDUCTION PUMPS

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The details of some dc conduction pumps designed by the authors together with the pump characteristics and some operational and test data are reported. The design details of a 15 000 A acyclic generator are also given. It is suggested that under laboratory conditions the operation of low-capacity dc helical pumps fed by rectifiers may be more advantageous.

Electromagnetic pumps are widely used for the transport of liquid metals in heat exchangers. Much attention is being given to the development of simple and reliable pumps capable of performing under high-temperature conditions.

A dc conduction pump with a capacity of 7×10^3 cm^3/sec has been developed for pumping liquid Na or NaK alloy at operating temperatures of 850-1050° K. The current input to the pump is 10 000 A at a voltage of 0.6 V. The major components of this pump are as follows: a magnetic circuit made of St. 3 steel, a double-turn copper exciting winding of 80×80 mm^2 cross section, a working section located in the gap of the magnetic circuit and connected in series with the exciting winding, a return conductor designed to compensate the armature reaction.

Tests on numerous conduction pumps have shown that the component that most often fails, even at relatively low liquid-metal temperatures, is the working section of the pump, the area where the conductors meet the wall of the duct being especially vulnerable.

The working section of the pump described is shown in Fig. 1. The duct 1 is made of a tube 63×1.5 mm in diameter flattened to a 16×82 mm^2 section along a 360 mm length. The tube consists of Kh18N9T steel. The nickel electrodes 3, 4 are argon arc-welded into openings cut in the sides of the tube. The electrodes are in direct contact with the liquid metal. As a result, the electrical resistance in the working section of the duct is reduced to a minimum.

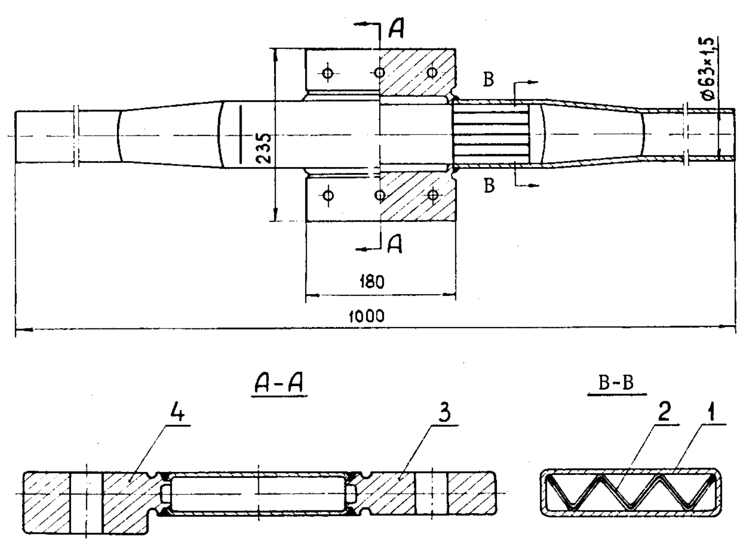

Fig. 1. Working section of pump.

The part of the tube wall that conducts the current is ground to a thickness of 0.7 mm. At the weld spots the thickness of the conductor is approximately equal to that of the tube wall, which assures a reliable joint between the two materials.

To reduce the leakage currents in the liquid metal outside the magnetic field longitudinal baffle plates 2 are installed in the duct at the entrance and exit of the working section. The baffle plates consist of two zigzag plates each 0.4 mm thick (material: Kh18N9T steel) with a 0.5-mm thick mica layer inbetween. The mica layer is hermetically sealed between the plates by welding. The use of these plates reduces the required input current and significantly increases the efficiency of the pump.

To prevent oxidation of the copper parts, the pump is enclosed in a hermetically sealed chamber with an inert-gas atmosphere of $(0.3\text{-}0.4) \times 10^5$ N/m^2 gauge pressure. Bellows are used to seal the working section and the exciting winding where they leave the chamber. These seals also compensate for the thermal expansion. The relatively large electrical resistance of the bellows and the low voltage at which the pump operates practically exclude the possibility of leakage currents through the chamber.

The electrical resistance of the "dry" pump was measured before filling the pump with liquid metal, and was found to be 144.7×10^{-6} ohms. The resistance of the exciting winding together with the return conductor was found to be 3.76×10^{-6} ohms.

NaK alloy was used for the test. The operation of the pump was found satisfactory in the temperature range 770 to 970° K. The upper temperature limit was set in this case by the heater capacity.

The pump characteristics obtained from these tests are shown in Figs. 2 and 3. The experimental data are in good correspondence with the calculated values.

The experiments showed that the developed pump design satisfies expectations, the working section with welded nickel electrodes performs reliably.

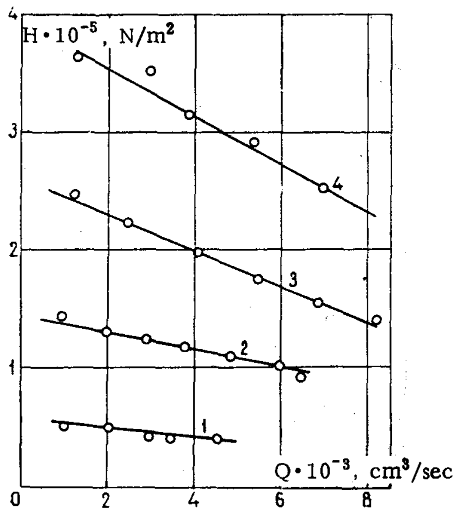

Fig. 2. Pressure as a function of flow at various input currents: 1) 4000 A, 2) 6000 A, 3) 8000 A, 4) 10 000 A.

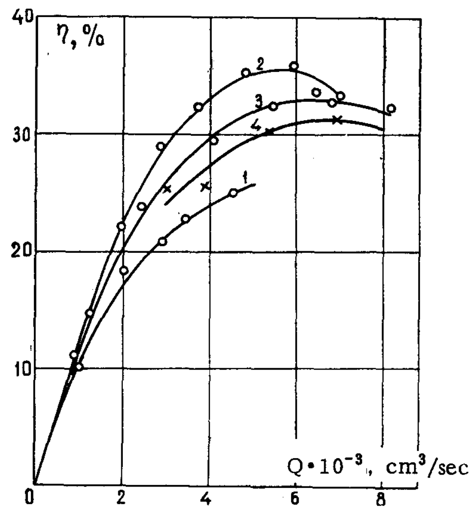

Fig. 3. Efficiency as a function of flow at various input currents: 1) 4000 A, 2) 6000 A, 3) 8000 A, 4) 10 000 A.

To obtain flow capacities up to 400 cm^3/sec a conduction pump was developed whose working section was made, together with the electrodes, from 25-mm thick plate. The current input under operating conditions was 3000 to 5000 A. As in the previous case, the pump was placed in a hermetically sealed chamber with an inert-gas atmosphere. The components of the magnetic circuit were made of St. 3 steel, the 45×50 mm^2 cross section exciting winding was made of copper and had four turns. The working section of the pump was made of Kh25T steel.

The manufacture of the working section began with drilling a longitudinal hole, the future duct for the liquid metal, through the end face of the metal plate. This was followed by a preliminary machining: turning in the duct region and milling of the plane faces. In this process, the required thickness of the current-conducting duct wall was established. To obtain an elliptical duct section the duct was flattened to dimensions of 6×32 mm^2. This operation was followed by final machining. The shape of the workpiece before the flattening operation is shown in Fig. 4. The absence of soldered and welded electrodes reduces the electrical resistance of the primary circuit and increases the reliability of the pump.

First, the pump was mounted in such a manner that the conductors were located in a vertical plane. Such an arrangement, however, induced a significant pulsation in the output due to the gases which, to some extent, are always present in the liquid metal and accumulate in its upper layers. After being turned through a 90° turn, i.e., into a horizontal-electrode position, the pump worked satisfactorily and continuously at a temperature of 870° K.

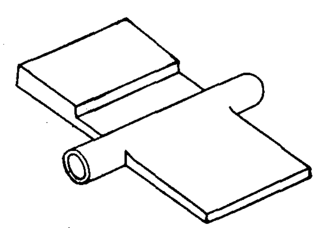

Fig. 4. Working section of pump with 400 cm^2/sec capacity before flattening operation.

The pumps described were supplied during the experiments by transducers of the ND 10 000/5000 and ANG 5000/2500 type. These units are, however, quite large, occupying an area many time greater than that required for the pumps themselves. To supply these pumps under normal operating conditions, an 11-kilowatt acyclic generator was therefore developed. This generator is shown schematically in Fig. 5.

The magnetic circuit of the generator consists of the following components: upper yoke 1, core 2, casing 7, and lower yoke 5. The construction material of these components is St. 3 steel. The exciting winding 6 is wound around the core. The hollow cylindrical rotor 8 is made of copper and is located in the annular gap around the core. The rotor is isolated from the shaft 4 and the casing by means of textolite sleeves. The width of the nonmagnetic gap is 4 mm, the thickness of the rotor wall 2.5 mm. The induction field strength in the rotor is 1.35 Wb/m^2.

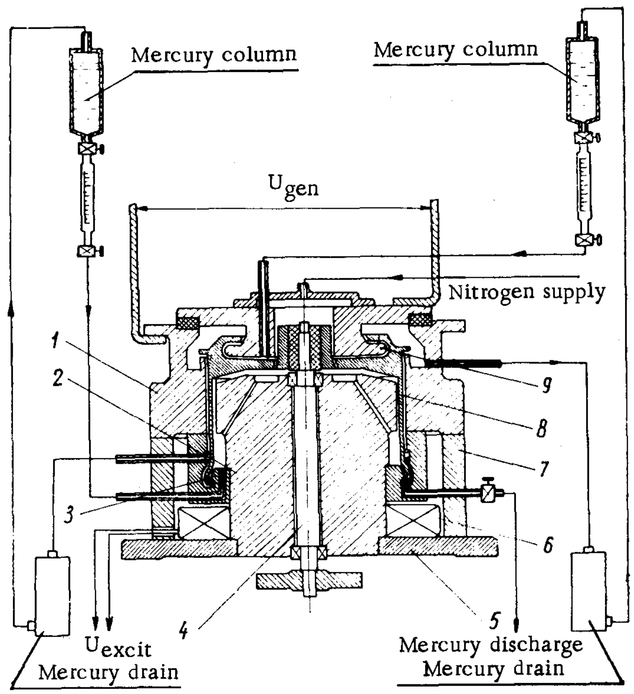

Fig. 5. Acyclic generator.

The generator is equipped with two water-cooled liquid-metal brushes 3, 9. During the preliminary tests, double-distilled mercury was used as the liquid metal medium. To avoid the formation of amalgam, the copper surfaces were coated with a thin layer of nickel. However, this method of coating was found to be unsatisfactory and was subsequently replaced by chromium plating.

Because of the high operating temperatures, intensive oxidation of the mercury was observed. Hence, in the final generator design all joints and the shaft were fitted with reliable seals and the interior of the generator was filled with nitrogen at a gauge pressure of (0.1 to 0.5) × 10^5 N/m^2. Furthermore, to remove oxide-contaminated mercury from the brushes a special circulating system was developed.

The experiments have shown that at speeds not greater than 1500 rpm the mercury occupies a stable position. An analysis of the experimental data gave the following generator characteristics: n = 1500 rpm, μ = 0.7 V, I = 15 000 A, η = 76%. Final conclusions regarding the reliability of the present design, however, must await the completion of long-term tests.

At low pumping rates the use of dc electromagnetic pumps with helical ducts becomes more advantageous. In the case of multiturn helical ducts, these pumps can be operated at relatively low currents (100 to 200 A) supplied by relatively small rectifiers.

The characteristics of a pump of this type with a rated output of 2 cm^3/sec liquid metal at temperatures up to 800°K are shown in Figs. 6 and 7. The test results correspond to operation with an InGaSn alloy at a temperature of 300° K. This pump is presently in operation pumping the same alloy through a small radiation loop. It has now been operating successfully for more than 1000 hours.

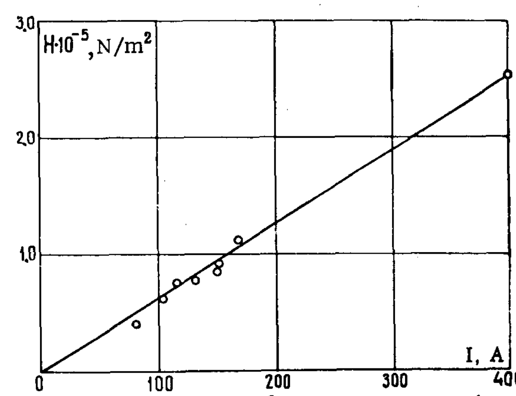

Fig. 6. Dependence of pressure on current in working section of pump at zero flow and constant exciting current.

The working section of this pump and the current conductors are monolithic. The unit consists of two coaxial shells made of Kh18N9T steel. A helical duct for the liquid metal (4 × 4 mm^2 cross section) is formed on the internal shell. The wall thickness of this duct is 0.5 mm, the number of turns, 15. Since the pump was designed to pump InGaSn alloy, which does not wet the surface well, the internal surface of the duct in the working section of the pump was coated with a special tinning.

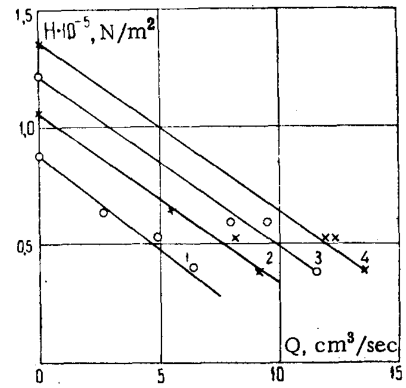

Fig. 7. Pressure as a function of flow at various currents in the working section and constant exciting current: 1) 140 A; 2) 170 A; 3) 195 A; 4) 215 A.

The pump has an independent exciting system, which permits continuous pressure regulation by varying the magnetic flux. The exciting current is 1 A. The exciting winding consists of a segmented coil made of 0.83 mm heat-resistant PNSDK wire. In case of necessity, the individual segments can be connected in parallel during the warmup period and fed from a conventional ac supply. Under these conditions, warmup is realized by the eddy currents induced in the magnetic system and in the walls of the working section.

To prevent cooling of the liquid metal at low flow rates, an additional 200-watt nickel-chromium heating element is mounted on the top flange of the pump.

The simplicity of design and high reliability make this pump very suitable for laboratory conditions.

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