Analysis of hydraulic resistance in a rotating junction of the cooling system of an active phased array antenna of a circular view

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Abstract. A hydraulic rotating transition is used to ensure the supply of coolant to the fuel elements when the antenna system is fully rotated. One of the main actuators of the antenna liquid cooling system is the hydraulic rotating transition. The SolidWorks Flow Simulation software package simulates the change in hydraulic resistance in a hydraulic rotating transition in various modes of operation. The process of transferring the coolant through a hydraulic rotating transition to the antenna, with full rotation, taking into account the influence of the geometric shape of the channels on the fluid flow, was modeled. The maximum values of resistances are analyzed in different operating modes. The dependence of hydraulic resistance on the quality of surface treatment of parts is given. The value of the hydraulic resistance in different modes of operation of the hydraulic rotating transition (HRT) is less than the value allowed to ensure the circulation of the working fluid in the cooling system. Based on the data obtained, an assessment of the feasibility of using the design of a hydraulic rotating transition for an active phased antenna array of a circular view at the design stage is made.

1. Introduction
An active phased antenna array (hereinafter referred to as APAA) includes elements of electronic equipment, which are based on a transceiver module (hereinafter referred to as TM) with a monolithic integrated circuit (hereinafter MIC) (Fig. 1). As part of MIC, the efficiency of solid-state microwave amplifiers reaches a power of about 25%, which means 75% of the input power is released into heat. The heat load arising from the MIC on the TM body reaches 100 W / cm², and therefore it is not rational to use air cooling, this will lead to an increase in the size and weight of the APAA. A more promising solution for heat removal is a combined liquid and evaporative cooling system. The cooling system designed for the TM uses heat pipes operating on the basis of the evaporative effect, where Freon-113 with a boiling point of 480° C acts as a working fluid. Heat pipes are led out to a common radiator, from which heat is removed by the central liquid cooling system of the antenna, in which the working fluid is "OZH 65 LENA" [1-4].
When designing an APAA cooling system, it becomes necessary to supply and intake coolant into a rotating antenna with the lowest hydraulic resistance. To do this, a hydraulic rotating transition (hereinafter HRT) is installed in the supporting-rotary device (hereinafter referred to as the SRD).

One of the topical areas of research is the assessment of hydraulic resistance arising in the HRT [5-9]. During the development of the HRT design, an analysis of the groundwork for the development of cooling systems for full-revolving APAA was made [10]. On the basis of the analysis, a design in which the HRT is placed as part of the design of the supporting-rotary device, where a rotating contact device (RCD) is located in the central part, which provides signal and power transmission to the APAA (Figure 2) was adopted.

**Figure 1.** 3D model of the TM structure.

**Figure 2.** Placement of the HRT in the supporting-rotary device, RCD is not dissected. 1 - hose for fluid supply to the heat exchanger, 2 - hose for fluid intake from the heat exchanger, 3 - hose for fluid supply to APAA, 4 - hose for fluid intake from APAA.
The general view of the HRT structure is shown in Fig. 3. Structurally, the HRT consists of a movable and stationary body parts made of steel 14X17H2. The HRT has two angular contact bearings fixed on the base and at the upper flange, capable of providing a nominal rotation of 20 rp/m and taking a load of no more than 100 kg [11].

Reinforced O-rings are used to ensure tightness during full-circle rotation at a speed of 20 rp/m.

**Figure 3.** General view of the HRT structure, where 1 is the stationary part of the HRT, 2 is the moving part of the HRT, 3 is an angular contact bearing, 4 is a reinforced sealing ring.

In the liquid cooling system, designed for the radar complex, the calculated operating pressure at the inlet to the HRT is equal to 301325 Pa [12]. To ensure the volume of the flowing liquid in the APAA sufficient to remove heat from the TM radiator, the maximum hydraulic resistance at the HRT is not more than 10,000 Pa [13-15].

For the operation of the HRT as part of the radar complex, we will accept the following requirements:

1. Use of coolant “OZH 65 LENA”
2. Rotation of APAA at a speed of 3 to 20 rp/m
3. Hydraulic resistance in the hot water heater is not more than 10,000 Pa
4. Working pressure in the cooling system is 301325 Pa.

Fig. 4 shows the circulation of the coolant, where P1 is the flow of liquid from the heat exchanger to the HRT, P2 - from the HRT to the APAA, P3 - from the AFPAA to the HRT, P4 - from the HRT to the heat exchanger.

**Figure 4.** Three-dimensional model of the HRT depicting the circulation of the coolant.
2. Results of the research

As an example, Figure 5 shows the model of the HRT in the initial position of rotation and when turning by 40°. The flow of the coolant “OZH 65 LENA” with a working pressure of 301325 Pa is simulated along the HRT channels with a working pressure of 301325 Pa, and a speed of rotation of the HRT from 3 to 20 rp/m. Modeling of the angle of rotation of the HRT was carried out in the range from 0° to 180°, where the position of 180° is the maximum distance from the feed channels to the liquid intake. In fig. 5 (a) the fluid supply and intake channels are coaxial (zero position), which ensures minimal hydraulic resistance. In fig. 5 (b) the rotation of the HRT is 40°, in contrast to the zero position, the fluid flow encounters an obstacle in the form of a perpendicularly located channel wall, resulting in an increase in pressure and hydraulic resistance. Fig. 6 shows the graphs of the dependence of the hydraulic resistance on (a) the angle of rotation and (b) the speed of rotation of the HRT. The geometry of the channels was determined experimentally during the simulation and the most optimal design was used in the calculations, where the main task is to provide hydraulic resistance up to 10,000 Pa. The plotting took place on the basis of the simulated results.

Figure 5. Modeling in the software module SolidWorks Flow Simulation HRT a) in the initial position and b) when rotated by 40°.
Figure 6. Dependence of the hydraulic resistance a) on the angle of rotation and b) on the speed of rotation of the HRT.

The roughness of the surface treatment of the coolant supply and intake channels also affects the fluid flow resistance. Fig. 7 shows the dependence of the hydraulic resistance relative to the roughness of the surfaces of the coolant supply channels. The values on the graph are given for the angle of rotation of the HWRT at 180°. Since when turning by 180°, the maximum path of interaction of the liquid with the surface is involved.
In the process of modeling the supply of coolant through the HRT, the influence of the geometric shape of the channels on the hydraulic resistance was analyzed. The hydraulic resistance essentially depends on the head loss in the local resistances, in which the velocity vector changes direction. The largest value of the loss is recorded at the inlet to the HRT due to a change in the flow movement caused by the perpendicular position of the channel relative to the inlet. Part of the energy of the fluid flow is spent on the redistribution of velocities, changing the direction of the flow and vortex formation.

As can be seen from the given graphs, the hydraulic resistance does not go beyond the maximum value of 10,000 Pa, which means that the designed HRT meets the requirements for providing pressure in the cooling system to remove heat from the TM radiator. The greatest value of hydraulic resistance 8734 Pa is achieved at a speed of rotation of the APAA of 20 rp/m. The most preferable quality of surface treatment of parts of the channels, based on manufacturability, will be Ra 0.8, which will provide optimal fluid resistance on the walls, which is explained by the beginning of the curve in the graph in Figure 7.

3. Discussion and conclusion
This study makes it possible to assess the hydraulic resistance in the HRT at the design stage and, depending on the results obtained, make adjustments at the stage of the HRT development. When designing the HRT, the influence of local resistances on the change in the flow direction was taken into account, as a result of which the most optimal shape of the channels was experimentally determined.

It was found that the hydraulic resistance in various operating modes of the hydraulic rotating transition does not go beyond the specified requirements, which fully corresponds to the thermal balance of the APAA operation as part of the radar complex. The dependence is revealed that the quality of surface treatment of parts of a hydraulic rotating transition is directly proportional to an increase in hydraulic resistance.

At present, technological preparation of production for the manufacture of HRT and design of a stand for testing and confirming the calculated data are being carried out.

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