EXPERIMENTAL RESEARCH RESULTS FOR AGAT CONTROL MEASUREMENT SYSTEMS AT AN ENVIRONMENTAL TEMPERATURE OF UP TO 350ºC

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Abstract

This paper presents experimental researches of Agat control measurement systems at an environmental temperature of up to 350 ºC with a system of compulsory air cooling.

1. Introduction

Measurements of mechanical stress of blades of turbines of modern aero-engines in various modes of their activity run into a problem of the activity of control measurement systems (CMSs) at high temperatures. In places of possible installation of CMSs, the ambient temperature can be in limits of 250–350ºC, and the temperature range of activity of commercial electronic systems is in a range of minus (40–20)ºC to (70–80)ºC; therefore, their application without special measures of a heat-shielding is impossible. Application of integrated microcircuits of military execution allows expanding this range from −50ºC to 125 ºC; however, the use of this element base requires special documents and substantiations of their application; in addition, these systems are usually much more expensive. Analysis of the market of SMMs for activity at heats has shown that, for example, German company Manner [1] offers telemetering systems that can operate at +150ºC without cooling. In the same place, an example of a telemetry system for activity is presented at a temperature of 280ºC with obligatory cooling. However, these systems are very expensive; for example, the price of a Manner system with 40 channels for activity at a temperature of 300ºC is on the order of 300 000 USD.

The high price of the Manner telemetry system is connected with completing products, i.e., the microcircuit and other elements allowing operating at temperatures of up to 170–200ºC, much more expensive usual microcircuits that operate at temperatures of up to 80–100ºC. So, for example, a usual tool amplifier costs 10-12 USD and operates at a temperature of 200ºC (for example, an INA129-HT operational amplifier) costs with delivery and a customs clearance up to 150 USD, i.e., it is 10-15 times more expensive.

2. Experimental and discussion

Overall objective of the present activity is an experimental study of the temperature operational mode of Agat CMSs with a system of compulsory cooling at an ambient temperature of 350ºC. The exterior view and characteristics are stated in detail in [2, 3]. For carrying out
experimental researches, we have chosen an Agat-222 CMS which allows creating a simple thermo casing in the form of a cylinder. The exterior view of an Agat-222 CMS and the design of the thermo casing are presented in Figs. 1 and 2. The thermo isolation was made of sheet asbestos with a thickness of 5 and 10 mm. Temperature sensors are located in two places on the external surface of the Agate-222 CMS. Entrance and output apertures with a diameter of 6 mm were made in the system of air cooling for an air flow under different pressure of compressed air: 670 L/min for 1 atm, 1000 L/min for 2 atm, and 1350 L/min for 3 atm.

Fig. 1. Image of an Agat-222 CMS.  
Fig. 2. Design of a thermo case for an Agat-222 CMS.

The experimental study of temperature operational modes of the Agat CMS was conducted under a cooling-air pressure of 1 to 3 atm and its temperature of 6–12°C, which depended on the ambient temperature at this time of the year: from December 17 to December 21, 2012. For imitation of an ambient temperature of 350°C, a SNOL-3,5 electrical chamber was used, which allows reproducing temperatures in the chamber of up to 350°C, automatically adjusting and maintaining the set temperature.

Figure 3 shows a photo of a SNOL-3,5 electrical chamber with the mounted Agat-222 CMS, to which a regular system of air cooling from a compressor station of the enterprise is made.

Fig. 3. Photo of a SNOL-3,5 electrical chamber with the mounted Agat-222 CMS.
Figure 4 shows graphs of the temperature of the external surface of the Agat-222 CMS under varying cooling-air pressure, a thermo case with 1st layer of asbestos with a thickness of 5 mm. At first, temperature sensing on body of the Agat-222 CMS was conducted in a live condition and at an ambient temperature of 18°C, a curve on drawing R\textsubscript{n}. It is evident from the graph that the temperature of the external surface of the Agat-222 CMS almost linearly increased to 40°C in the first 60 min of supervision; later, a delay of growth of temperature to a level of 43–45°C was observed throughout supervision of 150 min, which suggests that thermal equilibrium takes place.

![Graph of temperature vs. time](image)

**Fig. 4.** Graphs of the temperature of the external surface of the Agat-222 CMS under varying cooling-air pressure. The heat insulation layer of asbestos is 5 mm.

After that, the temperature in the electrical chamber was established at 350°C and the following experiments were conducted:

1. The actuated Agat-222 CMS, in which the reference temperature of its external surface was 28°C, was placed in the electro chamber. On a drawing - R\textsubscript{n+k} (Fig. 4), it is visible that the external case temperature achieved made 90°C in 40 min of supervision, which suggests that the maximum operating time of the Agat-222 CMS without cooling is no more than 30–40 min.

2. On graphs of 1 and 2 atm in Fig. 4, the sensing of the temperature of the external surface of the Agat-222 CMS depending on a cooling-air pressure of 1 and 2 atm is shown; the temperature of the cooling air at this time of the year was 10–12°C.

Experiment has shown that, under a cooling-air pressure of 1 atm, the equilibrium temperature inside the Agat-222 CMS was about 90–95°C under a cooling-air pressure of 2 atm. The equilibrium temperature inside the Agat-222 CMS was about 65°C; the time of establishment of the equilibrium temperature was 20 min longer than under a cooling-air pressure of 1 atm.

Figure 5 shows graphs of the temperature of the external surface of the Agat-222 CMS under
varying cooling-air pressure for the thermo case with two layers of asbestos with a total thickness of 10 mm.

**Fig. 5.** Graphs of the temperature of the external surface of the Agat-222 CMS under varying cooling-air pressure.

Graphs of 1, 2, and 3 atm in Fig. 5 show the temperature of the external surface of the Agat-222 CMS depending on a cooling-air pressure of 1, 2, and 3 atm; the thermo insulation layer has a thickness of 10 mm; the temperature of the cooling air at this time of the year was 10–12°C.

Experiment has shown that under a cooling-air pressure of 1 atm, the equilibrium temperature inside the Agat-222 CMS was about 75°C. Under a cooling-air pressure of 2 atm, the equilibrium temperature inside the Agat-222 CMS was established at about 50°C, and the time of establishment of the equilibrium temperature was 10 min longer than under a cooling-air pressure
of 1 atm. Under a cooling-air pressure of 3 atm, the equilibrium temperature inside the Agat-222 CMS was established at about 32°C, and the time of establishment of the equilibrium temperature was 8-10 min longer than under a cooling-air pressure of 2 atm.

Figure 5 shows, for comparison, a curve of the temperature of the body of the Agat-222 CMS with one insulation layer with a thickness of 5 mm and a cooling-air pressure of 2 atm. Comparison of these curves suggests that the equilibrium temperature of the Agat-222 CMS's body under a cooling-air pressure of 2 atm with one insulation layer is also about 62–65°C instead of 48–50°C in the case of double isolation.

Figure 6 shows graphs of the temperature of the external surface of the Agat-222 CMS under a cooling-air pressure of 3 atm with one and two layers of heat insulation.

![Graph](image)

**Fig. 6.** Graphs of the temperature of the external surface of the Agat-222 CMS under a cooling-air pressure of 3 atm.

Experiment has shown that under a pressure of 3 atm and its temperature of 10–12°C, the equilibrium temperature of the Agat-222 CMS's body was established at about +45°C. If the thickness of the thermal insulation increases 2 times, the equilibrium temperature is on the order of 30–32°C. The air flow in both cases was 1347–1400 L/min.

Computer modeling of thermal processes of the Agat-222 CMS was conducted with the use of environment pdetool programs Matlab, where a regional problem of heat conductivity was determined on the basis of known distribution of temperature at time $t$ and described by the parabolic equation
\[
\rho c \frac{\partial T}{\partial t} - \text{div}(k \cdot \text{grad}(T)) = Q + h \cdot (T_{\text{ext}} - T),
\]

where \( \rho \) is the density of environment, \( c \) is the specific heat of environment, \( k \) is the heat conductivity of environment, \( T \) is the temperature of the border of the settlement area, \( Q \) is the amount of heat received from internal sources, \( h \) is the factor of convective or conductive heat exchange of the settlement area and the environment, \( T_{\text{ext}} \) is the ambient temperature at infinite removal from the settlement area.

Convergence of results of the computer modeling with experimental data was within 5-8\% of an error.

3. Conclusions

(1) The conducted experimental study has confirmed the possibility of using available Agat-222 CMSs with usual delivered elements operating at temperatures of up to +80ºC under condition of obligatory air cooling under a cooling-air pressure of 2–3 atm. Thus, the temperature of the body of the Agat-222 CMS will be as follows:
- for the insulation layer with a thickness of 5 mm: 65 to 45°C;
- for the insulation layer with a thickness of 10 mm: 50 to 32°C.

(2) Convergence of results of the computer modeling with experimental data was within 5–8\% of an error.

(3) Cost of the Agat-222 CMS operating at an ambient temperature of up to 300ºC is 2.5–3 times lower than the products offered by the German company Manner.

References

[1] www.sensortelemetrie.de
