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APPLICATION OF A HEAT HYDRAULIC ACCUMULATOR TO THERMAL STABILIZATION OF THE EVAPORATION ZONE OF A HEAT PIPE

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The use of a heat hydraulic accumulator (HHA) for thermal stabilization of the evaporation zone of a heat pipe (HP) has been proposed. The experimental setup for investigation of the heat pipe with a heat hydraulic accumulator has been described. Results of the experiments on this assembly have been presented. It has been shown that the installed heat hydraulic accumulator allows thermal stabilization of the evaporation zone of the heat pipe to a precision of 1^{o}C.

Introduction. Heat pipes as heat-transfer elements with a high thermal conductivity are widely used in thermal-regulation (temperature-control) systems of both space and ground use [1, 2]. They represent thin-walled pipes with a capillary structure on the interior surface filled with a liquid heat-transfer agent. The entire gas volume is occupied by the saturated vapor of the heat-transfer agent. In supplying heat to the evaporative part of a heat pipe, we have boiling of the heat-transfer agent and transportation of it in the gas phase to the condensation zone, where the vapor is condensed. Subsequently the vapor returns to the evaporation zone under the action of surface tension forces. The employment of the phase transition of the heat-transfer agent enables one to obtain comparatively high coefficients of thermal conductivity, for example, the ratio of the thermal conductivity of an ammonia heat pipe to the thermal conductivity of pure aluminum is about 1000.

However, heat pipes possess a certain feature. As the heat load supplied to them grows, the temperatures of the evaporation zone and the condensation zone increase, i.e., regular heat pipes are of little use in precision thermal stabilization of objects. Gas-regulated heat pipes also fail to ensure high-precision thermal stabilization of an object or they become too bulky precisely because of the explicitness of the regulation [3].

It has been proposed that heat hydraulic accumulators be used in two-pipe thermal-regulation systems for thermal stabilization of evaporative heat exchangers. A heat hydraulic accumulator is a vessel filled with the same working substance as the thermal-regulation system. To the heat hydraulic accumulator, one can supply (or remove from it) such a quantity of heat which is necessary for thermal stabilization of the heat hydraulic accumulator itself at a specified temperature level. The heat hydraulic accumulator is installed in the thermal-regulation loop and it determines the saturation pressure in it. It is precisely owing to the constant saturation pressure maintained in the loop that thermal stabilization of evaporative heat exchangers is ensured.

The present work seeks to experimentally check the capacity of a heat hydraulic accumulator to thermally stabilize the evaporative part of a heat pipe to a precision of 1^{o}C for different values of the heat load supplied to the heat pipe irrespective of heat-removal conditions.

Experimental Setup. A schematic diagram of the experimental setup is presented in Fig. 1.

The setup incorporates the heat pipe under study with a heat hydraulic accumulator. The heat pipe has axial trapezoidal grooves; its maximum heat-transfer power is 250 W at room temperature. The heat hydraulic accumulator is an ammonia-filled vessel of volume 0.5 liter with a thermally stabilizing jacket through which the heat-transfer agent from a thermostat is circulating. By changing the level of temperature maintained by the thermostat one can vary the temperature and accordingly the pressure in the heat pipe. In this system, the heat hydraulic accumulator (HHA) has the function of specifying the saturation pressure in the heat pipe, i.e., of regulating the temperature of the evaporation zone of the heat pipe. An electric heater H and a heat exchanger C are connected to the heat pipe in the evapo-

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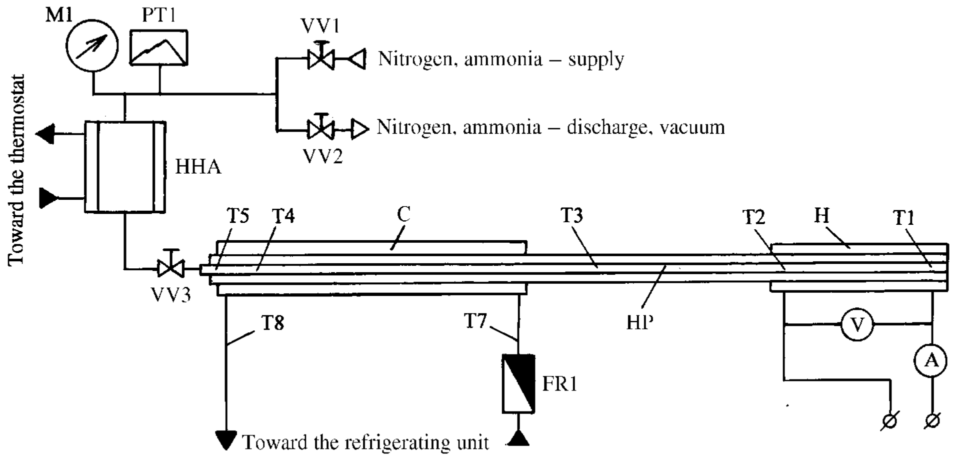

Fig. 1. Pneumatic hydraulic circuit of the experimental setup.

TABLE 1. Characteristics of the Measuring System

Parameter	Type of sensor	Error of the sensor δ_g, %	Method of recording	Error of recording δ_r, %	Total error δ, %
Temperature T1–T5	TM-334	1	LC-104+LC301	0.896	1.896
Pressure PT1	DDM-25	0.8	LC-102+LC301	0.046	0.846
Temperature T7–T8	IS-264	1	LC-104+LC301	0.896	1.896
Flow rate FM1	DR6-241	1.06	LC-451	0.334	1.394

ration zone and the condensation zone respectively. The cutoff valve (T100) VV3 is installed between the heat pipe and the heat hydraulic accumulator and it allows experiments in the heat pipe both without a heat hydraulic accumulator and with a heat hydraulic accumulator. Valves VV1 and VV2 are designed for connection to auxiliary bench systems with the aim of performing technological operations (check for strength and leak proofness, filling of the heat pipe and the heat hydraulic accumulator with ammonia, and others). To measure the temperatures in different zones of the heat pipe, on the surface of its casing we installed resistance thermometers (TM-344, 10 Ω) T1 and T2 in the evaporation zone, T3 in the adiabatic zone, and T4 and T5 in the condensation zone. The pressure in the heat hydraulic accumulator determining the saturation temperature of ammonia in the heat pipe is measured using the pressure transducer PT1 (DDM-25) and the manovacuummeter M1 (MVP-3A-UU2). The quantity of heat supplied to the evaporation zone is determined by measuring the voltage and the current in the circuit of the electric heater H. The quantity of heat removed in the condensation zone is determined from the results of measurements of the flow rate FR1 (flowmeter DR6-241) of the heat-transfer agent (antifreezing solution tosol A-40I) and the difference of temperatures T7 and T6 (resistance thermometers IS-264, 100 Ω) at the inlet and outlet of the heat-transfer agent from the heat exchanger C. The measuring system of the setup is based on the use on an LTC crate (Lcard Company) with LC-102H, -451, and -104 measurement modules with an LC-301 high-speed 12-digit analog-to-digital converter.

The control program is written in the LabView environment. We record all the parameters measured, display them on the monitor, and file and also withdraw and file the calculated values such as the supplied and removed power, the thermal conductivity of the heat pipe, and others.

Table 1 gives the metrological characteristics of the measurement system.

The total error of parametric measurement is determined from the formula [4]

$$\delta = \delta_g + \delta_r ,$$

where δ_g and δ_r are the relative errors of the primary gauge and the recording, %.

To determine the recording error we carried out metrological certification of the measuring channel. The values of the errors of the temperature sensors and the pressure transducer are taken from the ratings, while the error of the flowmeter is determined from the results of spillage.

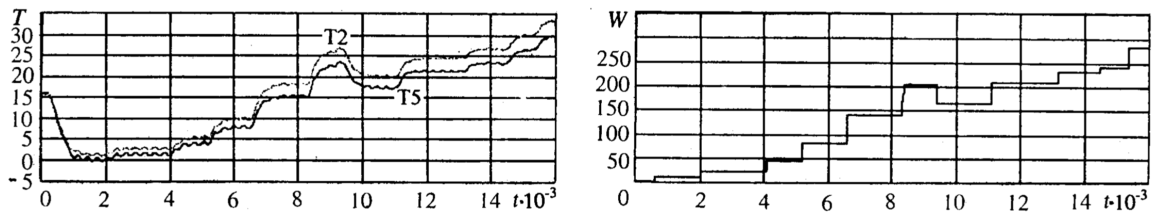

Fig. 2. Tests of the heat pipe without regulating elements: temperatures of the evaporation zone (T2) and the condensation zone (T5) and power supplied to the evaporation zone vs. time. *T*, ^{o}C; *W*, W; *t*, sec.

To diminish the influence of a random error on the result of a parametric measurement at the instant of one observation the control program carries out successively 100 measurements of each parameter and computes the average value, which is subsequently considered as the value of the parameter measured at a given instant of time.

Experimental Procedure. The experiment is arbitrarily subdivided into two stages. At the first stage, we investigate the operation of a regular heat pipe with axial grooves under variable heat load and heat-removal conditions [5]. The heat pipe filled with the required amount of ammonia is positioned so that its longitudinal axis is horizontal. On the heat pipe, we arrange a heater, a heat exchanger, and temperature sensors. Thereafter the heat pipe is insulated with polyethylene foam 10 mm thick. We test the heat pipe at different levels of supplied (removed) heat load at a constant temperature of the heat-transfer agent at the inlet to the heat exchanger C.

After the first stage of experiments in the pipe, we fill the heat hydraulic accumulator with ammonia so that its amount suffices to fill the entire heat-pipe volume and the heat hydraulic accumulator remains at least one-quarter full. The heat pipe and the heat hydraulic accumulator are filled with ammonia of special purity using special-purpose bench equipment. Thereafter we connect the heat hydraulic accumulator to the heat pipe via a VV3 valve as a result of which the heat pipe becomes totally filled with liquid ammonia. We set the temperature (accordingly the pressure) in the heat hydraulic accumulator and the heat pipe and carry out a cycle of experiments analogous to that performed for the pipe without a heat hydraulic accumulator. In addition to variation of the heat load in the heat pipe with a heat hydraulic accumulator, we carried out experiments on the possibility of specifying the temperature of the evaporation zone of the heat pipe upon change in the level of pressure in the heat hydraulic accumulator and checked the independence of the level of temperature of the evaporation zone from heat-removal conditions. The thermoregulator of the refrigerating machine was readjusted to different levels of temperature. The fluctuations of temperatures T7 and T8 are attributed to the automatic switch-on–switch-off of the refrigerating unit of the heat-removal loop.

Experimental Results and Their Analysis. Results of the experiments on the heat pipe without a heat hydraulic accumulator are given in Fig. 2. It is clear from the figure that with growth in the heat load transferred to the heat pipe we observe a growth in the temperatures of all the heat-pipe zones at constant temperatures of the heat-transfer agent; the increase in the temperature in the evaporation zone is linear, in practice, and it is about 0.125 ^{o}C/W.

Regular heat pipes are characterized by a drop in the temperature in all their zones upon a decrease in the temperature of the heat-transfer agent of the cooling loop (heat exchanger C), which is due to the increase in the heat transfer from ammonia to the heat-transfer agent and accordingly the decrease in the temperature and the saturation pressure of the heat-transfer agent inside the heat pipe. From the data obtained it is clear that it is not practical to employ a regular heat pipe for precision thermal stabilization under variable heat release and heat removal.

Figure 3 gives experimental plots obtained for the heat pipe with a heat hydraulic accumulator. From the figure it is clear that when the heat pipe with a heat hydraulic accumulator is employed the temperature of the evaporation zone of the heat pipe correlates with the saturation temperature specified by the heat hydraulic accumulator. The growth in temperature T2 (to 2000 sec) is attributed to the creation of superheating required for boiling of ammonia in the capillary structure of the heat pipe. The drop in temperature T2 (2000–4000 sec) is caused by the decrease in the pressure in the heat hydraulic accumulator when it reaches the steady-state regime, which is obvious from the behavior of the pressure in the heat hydraulic accumulator. Beginning at 4000 sec, temperature T2 remains constant, in practice (to a precision of 1^{o}C), despite the increase in the heat load from 37 to 160 W.

Upon stepwise change in the heat load, we observe a pressure fluctuation in the heat hydraulic accumulator which is associated with the displacement of ammonia from the heat pipe to the heat hydraulic accumulator. It is the

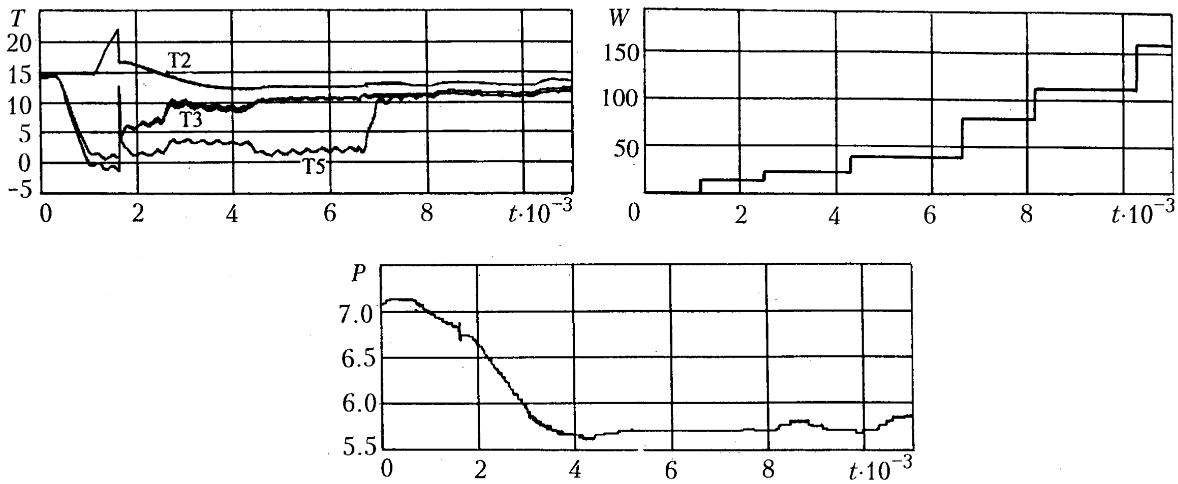

Fig. 3. Regulation of the temperature of the evaporation zone of the heat pipe (T2) using the heat hydraulic accumulator for a variable heat flux in the evaporation zone in the course of the experiment. *T*, ^{o}C; *W*, W; *P*, bar; *t*, sec.

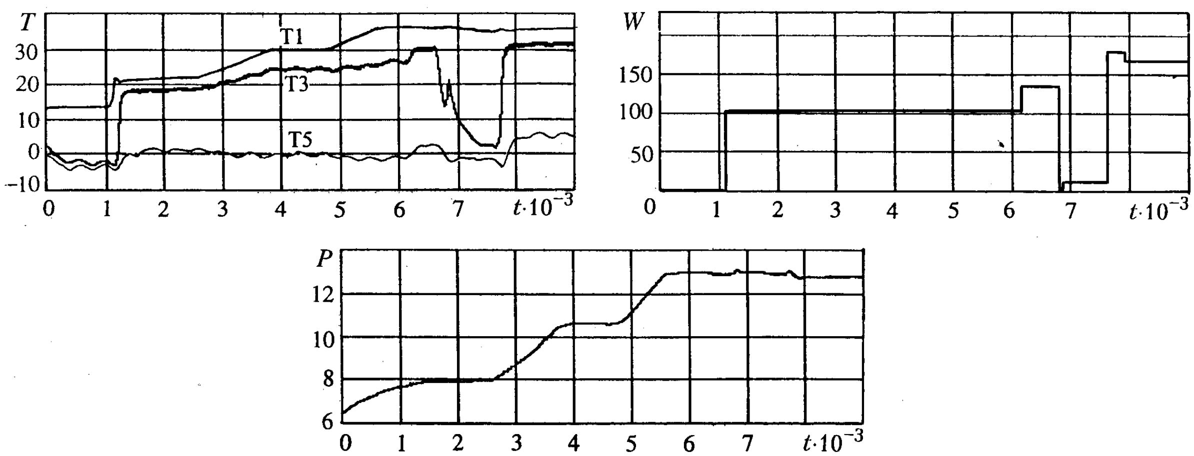

Fig. 4. Investigation of the possibility of specifying the temperature of the evaporation zone of the heat pipe with a heat hydraulic accumulator (T1) by changing the pressure in the heat hydraulic accumulator. *T*, ^{o}C; *W*, W; *P*, bar; *t*, sec.

pressure fluctuations in the heat hydraulic accumulator that cause a deviation of the temperature of the evaporation zone of the heat pipe from the specified value. For this design of the heat hydraulic accumulator the fluctuations decay in about 2000 sec but their low value and weak influence on the evaporation-zone temperature are worth noting.

From Fig. 3, it is also clear that when the heat loads are small the heat pipe is filled with liquid ammonia, which is supercooled in the condensation zone and the adiabatic zone; then, as the heat load increases, the part of the heat pipe submerged in liquid ammonia is reduced (we observe a growth in T3 at first) to the total clearing of the vapor channel (6600 sec). The heat hydraulic accumulator acts as the regulator of the phase-transition temperature not only in the evaporation zone but also in the condensation zone. Figure 4 demonstrates the possibility of specifying the temperature of the evaporation zone of the heat pipe by varying the temperature level of the heat hydraulic accumulator; it also gives data on the behavior of the temperature in the evaporation zone in the case of a stepwise growth and decrease in the transferred heat load. The interrelation between the temperature in the evaporation zone and the pressure level specified by the heat hydraulic accumulator is quite obvious.

In the time intervals 0–1500 sec, 2700–3700 sec, and 4800–5600 sec, the heat hydraulic accumulator reaches the steady-state regime (the thermostat is adjusted to a higher temperature level) for a constant heat load. The steady

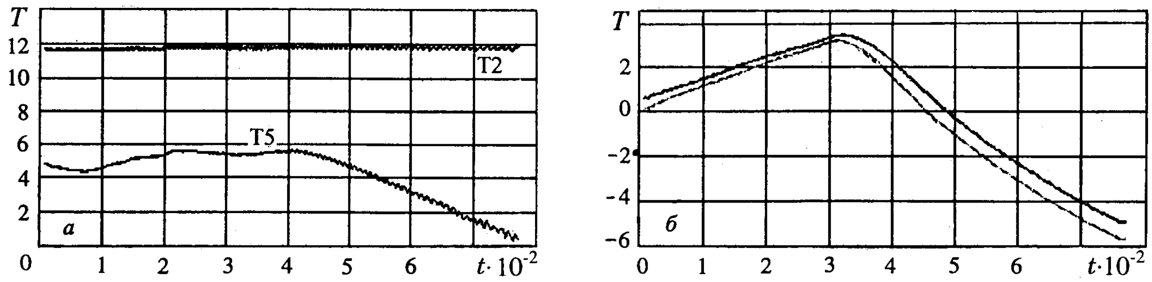

Fig. 5. Investigation of the influence of heat-removal conditions (T7 and T8) on the temperature of the evaporation zone (T2) of the heat pipe with a heat hydraulic accumulator. T, ^{o}C; t, sec.

states of the system heat pipe + heat hydraulic accumulator which are characterized by constancy of the temperatures along the heat-pipe length for a constant heat load are shown in the ranges 1500–2700 sec, 3700–4800 sec, and 5600–6200 sec. Figure 4 shows the interrelation between the level of pressure in the heat hydraulic accumulator and the temperature of the evaporation zone, which confirms the possibility of specifying the temperature level of the evaporation zone of the heat pipe.

In the range 6200–9100 sec, we carried out stepwise increase and throwing-off of the heat load supplied to the evaporation zone of the heat pipe. From the behavior of the temperatures it is clear that the evaporation-zone temperature remains constant, in practice ($\pm 1^{o}$C), with a change of 10 to 180 W in the heat load. This confirms the possibility of thermal stabilization of the evaporation zone of the heat pipe by variation of the heat load over wide ranges.

The investigations carried out point to the fact (Fig. 5) that in the presence of the heat load (more than 5 to 7 W) the temperature of the evaporation zone (a) is independent of the temperature of the heat-transfer agent at the inlet to heat exchanger C (b), suggesting that thermal stabilization of the evaporation zone is possible under variable heat-removal conditions.

CONCLUSIONS

As a result of the above work, we have shown the possibility of precision thermal stabilization of the evaporation zone of a heat pipe using a heat hydraulic accumulator with variation of the supplied heat load and heat-removal conditions over wide ranges. The heat hydraulic accumulator can be used for regulation of the temperature of the evaporation zone in the heat pipe under both ground conditions and microgravity conditions, where the serviceability of the heat hydraulic accumulator with capillary grids has been shown in a series of flying experiments with an ammonia thermal-regulation loop as part of the installation at the Mir space station.

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