STUDY OF ISOTHERMICITY OF Cu/WATER FLAT HEAT PIPE FOR THE SURFACE TEMPERATURE SOURCE

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Abstract

The paper presents the results of experimental investigation of temperature fields for Cu/water flat heat pipe-based device and characteristics of flat heat pipe (FHP) condenser at operating temperatures from 30 to 250 ^{0}C. The design of surface temperature source based on FHP principle and methodology of surface temperature determination with contact thermometer has described. The heat performance FHP prototype has studied with temperature control of vapor channel. The gravity-aided FHP was chosen as sample owing to its high uniform surface temperature.

The main metrological aim of surface temperature source is the isothermicity, which could be provided with the heat pipe condenser. The investigation results showed the good isothermicity for this apparatus.

KEYWORDS

Flat heat pipe, isothermicity, temperature fields, surface temperature, calibration.

INTRODUCTION

This paper introduces the heat pipe technology, which could be used as the good solution to metrological calibration purposes [1]. The traceable calibration of contact thermometers by comparison them with standard thermometers in thermostats [2] is not suitable approach because of the difference in conditions of calibrating and using. Calibration of surface temperature sources requires the evaluation of their main characteristics [1,3] also of establishing the correction factors for metrological calibration of contact temperature sensors [4]. The contact sensors calibration equipment needs to provide the defined and reproducible surface temperatures what is usually based on method of extrapolation precise temperature readings derived from temperature sensors inside the solids [5]. Transport processes in measured object, in temperature sensor and between the medium, sensors and environment result in thermal measurement errors. The FHP principle can provide the ideal thermal uniformity of surface/volume temperature profile due to the high isothermicity of flat condenser owing to the two-phase heat transfer processes [2]. The heat pipe usually works well in orientation when the heat input-down/heat output-up.

EXPERIMENTAL SETUP AND PROCEDURE

The goal of tests was the investigation of FHP-based apparatus performances and opportunity to apply it as surface temperature source in contact thermometry. The characteristic values (geometrical parameters and thermal properties) give important information for establishing errors and for application of measured objects surface. This process requires special test sample and apparatus with well known and reproducible calibration data.

Test sample. The using of sintered-wick gravity-aided vertical FHP improves the heat transfer characteristics of reference block. In this tested modification the capillary limit could be neglected and the good operation will be only limited by flood and boiling limits. The experimental test sample was produced (Tab.1) in order to determine the main parameters of FHP-based reference block. The condenser has been situated upper than evaporator in the tested sample. The water/copper FHP suits to the temperature range from 50 to 250 ^{0}C. Working fluid (10 and 20 ml) has circulated in FHP prototype.

Table 1. Main characteristics of test sample and of FHP-based reference block

d_e, mm	d, mm	t, mm	t_w ,mm	t_{wick},mm	t_v,mm
100	84	25	7	1	42 x2

Type	Gravity-aided FHP
Temperature operating range	30 – 250 ^{0}C
Working fluid	Water
Envelop material	Copper
Condenser	Flat, covered with capillary structure
Evaporator	Flat, covered with capillary structure
Capillary wick	Sintered cooper powder (δ = 2 mm)
Total height	25 mm
Transport zone height	25 mm
Maximum vapor pressure at 250 ^{0}C	36 atm
Fill charge, α	88 %
The temperature sensor shell	Inside the vapor channel, not covered with capillary structure
Condenser boundary conditions	Third kind (free air convection)
Evaporator boundary conditions	Second kind (uniform heating)

Testing methodology. The heat pipe evaporator in second part of experiments was heated by electric block controlled by sensitive PRT thermometers and PID temperature controller of thermal load. The control system has used the temperature readings from PRT thermometers inside the vapor channel (Fig.1.).

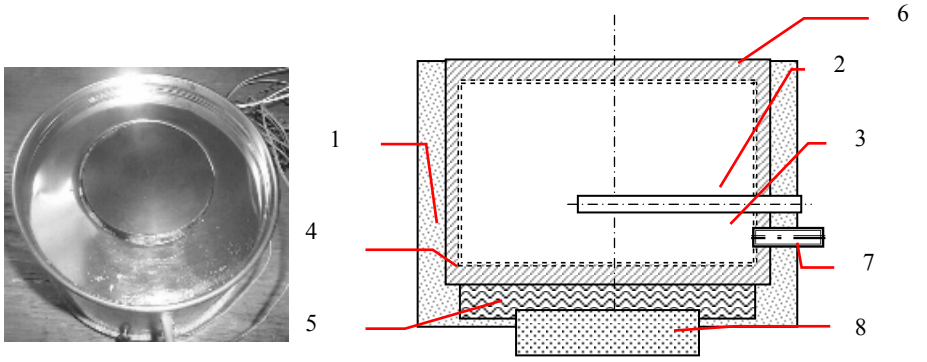

Fig. 1. a - Test sample of gravity-aided Cu/water powder wick FHP, b – sketch of FHP-based reference block: 1- thermal insulation, 2 – temperature sensitive element shell (for instrumentation), 3 – vapor channel, 4 – sintered copper wick, 5 – electrical heating element, 6 – external FHP condenser surface, 7 – filling line (sealed before operation), 8 – power supply input.

The low thermal conductivity thermal insulation with stainless steel sheath have surrounded transport zone. Electrical flat heater provided the uniform block heating. The temperature readings (100 readings per measuring point) in first part of experiments were done with contact temperature sensor TK5 (industrial surface mounted type).

EXPERIMENTS

The features of temperature regulation of the FHP-based reference block with signals from contact thermometers in vapor channel have been investigated. All tested samples (fig.2) had the same geometrical parameters and general characteristics.

A number of experiments were carried out with three different operating regimes: by self-stabilization of temperature in vapor channel (stabilization period τ = 60 minutes from 90 to 103 ^{0}C), by manual temperature adjustment and by automatic adjustment. The influence of various filling from 5 to 10 ml at presence/absence of non-condensable gas inside the FHP has been also investigated. The surface temperature was measured by superficial industrial contact probe (model INTEKO-TK5) with accuracy of ± 0.3 ^{0}C for temperature range from 0 to 200 ^{0}C.

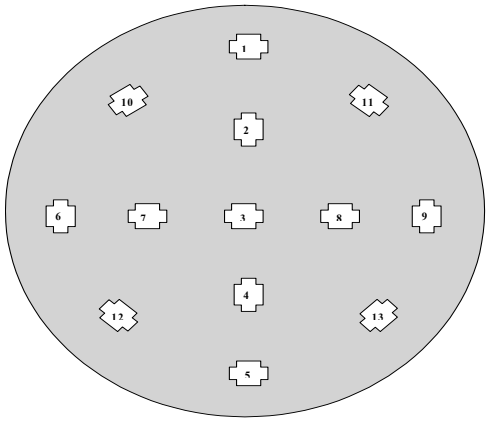

Fig. 2. Sketch of point's orientation along the radius

Points	1	2	3	4	5
X-axis,mm	0	0	0	0	0
Y-axis,mm	33,4	16,7	0	-16,7	- 33,4

The position of temperature sensing element in vapor channel was directly under the central measuring point 3. Temperature in the vapor channel was registered within ± 0.1 ^{0}C. The absolute surface temperatures on a surface were registered by contact temperature sensor and the temperature fluctuation in readings was from 0.001 to 0.01 ^{0}C. The period of temperature adjustment in the vapor channel was done. The thermal load provided with an electrical heater. The steady state mode from 20 до 100 ^{0}C has achieved in 15 minutes. The equipment used for the temperature control in vapor channel was:

- thermocouple chromel/alumel,
- temperature PID control with apparutus Sosna-02 (accuracy of adjustment ± 0.01 ^{0}C);
- temperature registration by multi-channel temperature monitored by device Sosna-03.

The contact sensor model IST-M16 with sensitivity in 0.001 ^{0}C is used for precise monitoring of surface temperature at a final stage of experiment.

Time of close contact the temperature probe to surface was from 40 to 60 seconds in a mode without temperature adjustment. The measurements were carried out for 13 points on a surface, starting from point 1. The temperature measurement data are given for five points located on a diameter of test sample surface. The temperature difference have been defined by data processing for every control point.The test sample temperature difference in was derived from complex measurements of temperature differences in vapor channel and along the heat pipe condenser surface as shown in figure 3.

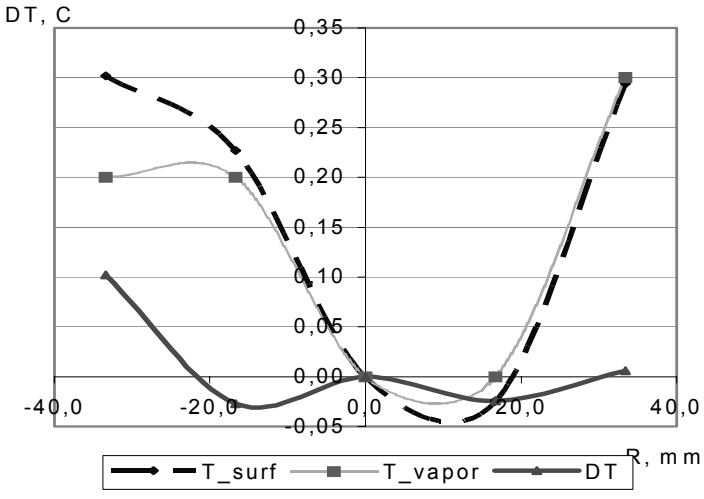

Fig. 3. Temperature measurment data received after measurements

The test sample non-isothermicity was defined as $\Delta T_{surf} = f(R)$ for non-adjustment thermal load for various temperature levels in vapor channel 36; 100; 150 ^{0}C. The results are given in figure 4.

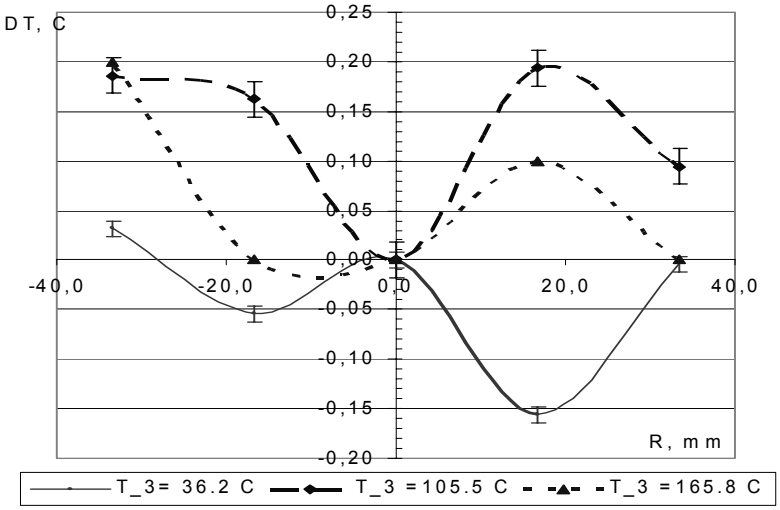

Fig. 4. Testing results of temperature distribution on FHP surface $\Delta T_{surf} = f(R)$ for various working vapor temperatures with non-adjustment of thermal load (T_{amb} = 23.8 ^{0}C)

Thermometer TMK-3 was used for temperature registration in cooper sample for conditions T_V = 36.2; 105.5; 165.8 ^{0}C (with accuracy in ±0.1 ^{0}C for temperature range from 0 to 200 ^{0}C). The period of every measurement on a surface was 90 seconds. The investigations for non-adjustment conditions have shown that the voltage deviations could reach the value 100±1.0 V during the 13 measurements 10 minutes.

From the received data follows that the temperature differences on a surface of a sample did not exceed the value 0.02 ^{0}C. Hence, it is possible to consider the received data as acceptable with taking into account the peculiarities of instrumentation, absence of the applied force control and some deviations of vapor temperature.

It was defined the influence of gas presence on surface non-isothermicity of FHP (fig.5).

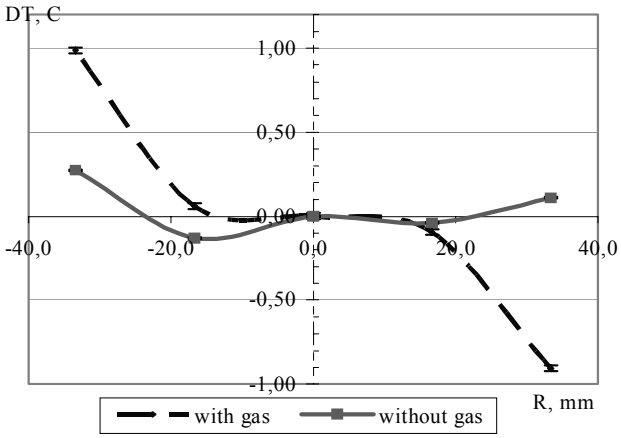

Fig. 5. Testing results of gas influence on surface temperature distribution along the diameter $\Delta T_{surf} = f(R)$ for manual temperature adjustement at T_v=105 ^{0}C, T_{amb} = 23.8 ^{0}C

The manual adjustment of thermal load was used for obtaining $\Delta T_{surf} = f(R)$ which was related to central point R_3 = 0. Temperature of a cooper test sample reached the 103.2 ^{0}C for 60 minutes. The 10 temperature measurements within 60 seconds in vapor channel were done by continuous readings for every temperature level. The parameters of manual adjustment in vapor channel were the following: the heating for 5 seconds and the holding at fixed temperatures for 20 seconds after 90 minutes of

temperature rising from 100 to 150 ^{0}C. Monitoring of surface temperatures was done by contact sensor IST-M16 (device resolution is 0.001 ^{0}C) with indicating of temperature standard deviations.

Investigations shows that the presence of little quantities of gas in FHP has led to increase of heat pipe non-isothermicity and the overall temperature difference has exceeded the value 2 ^{0}C on distance 66.8 mm.

The influence of working liquid amount on surface temperature non-isothermicity was investigated in manual-adjusted thermal load. The preliminary measurements have shown the variation in FHP performance is not significant between the filling with 10 ml and 20 ml therefore data received for 20 ml of water is not used. The research results are given in figure 6.

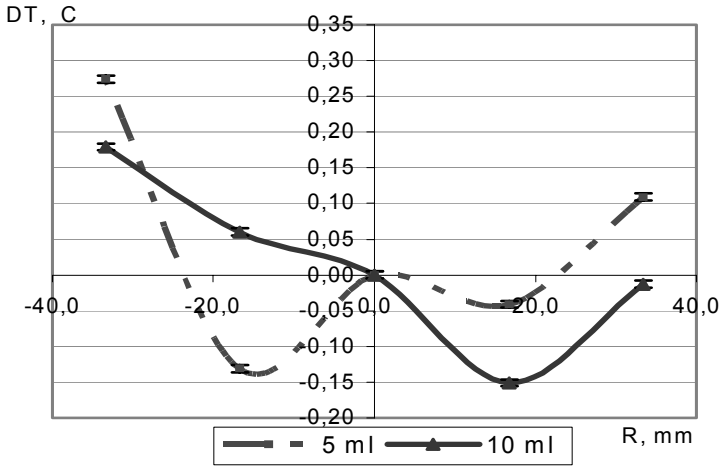

Fig. 6. The comparison of $\Delta T_{surf} = f(R)$ for next liquid charges: 5 ml, 10 ml; from start point $R_3 = 0$ with manual temperature adjustment at $T_v = 104$ ^{0}C and $T_{amb} = 23.8$ ^{0}C

The effect of time factor elimination and thermal inertia on received temperature fields were studied by determination of mean value from direct and return temperature readings for all control surface points. Thus the specimen after gas elimination and charged with 10 ml of water was chosen for testing under temperature conditions: $T_{amb} = 23.8$ ^{0}C, $T_V = 104.0$ ^{0}C. The mean values of $\Delta T_{surf} = f(R)$ were obtained with the purpose of neutralization of time influence during the all FHP temperature measurements (fig.7)

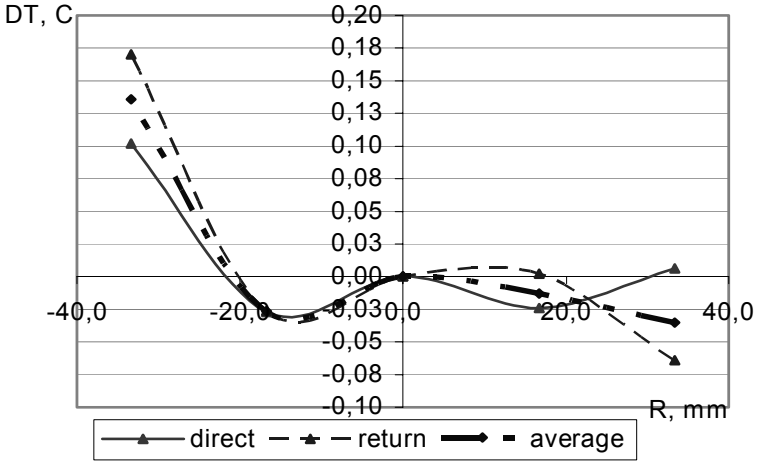

Fig. 7. The data comparison archived for temperature distribution $\Delta T_{surf} = f(R)$ of a surface FHP for manual-adjusting thermal load in degassed sample with 10 ml of water

As a result of investigation is shown the maximal temperature difference does not exceed the value 0.02 ^{0}C at manual FHP temperature control.

The tests results in automatic temperature control mode with Sosna-03 of temperature fields received from readings of high sensitive device ITS-M16 with sensitivity 0.001 ^{0}C. The results have shown in fig.8.

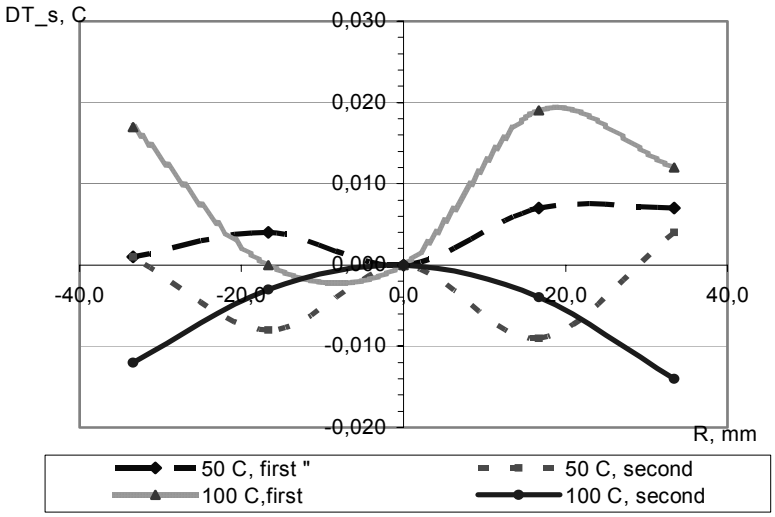

Fig. 8. The measurements of $\Delta T_{surf} = f(R)$ with center R_3=0 for automatic controlled temperature in vapor channel Cu-FHP at T_v = 50..100 ^{0}C

The experiment has shown the surface isothermicity under the automatic temperature adjustment was one time higher than that without temperature adjustment. The total temperature difference on a surface did not exceed the 0.025 ^{0}C for T_V =100.1 ^{0}C and 0.018 ^{0}C for T_V =30.2 ^{0}C.

Next series of experiments are carried out by definition of temperature profiles on the researched sample surface with use of non-contact precise thermometry technique. The thermal vision infrared camera (model IR-SnapShot^{TM} with accuracy ±2^{0}C within the temperature range -30..600 ^{0}C; resolution 0.1 ^{0}C) have been used for capturing of radiometric IR images of test sample surface (fig.9.)

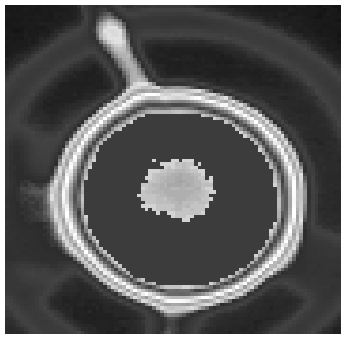

Fig. 9. Digital thermal image of sample surface of Cu/water FHP: ■ - Isotherm from 57.2 to 58.2 ^{0}C for undisturbed temperature profile

For exact definition of absolute temperature of test surface, it was necessary to correct the emissivity values of investigated metal surface. Under steady state boundary conditions T_{amb} = const the emissivity correction (from 0.96 to 0.98 for emissivity of cooper sample) could result in magnitude deviation ±0.5 ^{0}C from actual temperature.

TEST RESULTS

It was assumed the absence of significant temperature drop in FHP vapor channel. The measurements by contact temperature probe could lead to some deviations. The deviations in temperature readings often result from thermal contact resistances between the sensor and test sample.

The calibration uncertainty could be due to surface roughness, the deviations from exact vertical position of sensor and depends on temperature gradient in test sample, the material depending thermal conductivity and influence of different ambient parameters. It was previously investigated the direct temperature measurements lead to errors due to thermophysical characteristics, temperatures of material, technical futures of temperature sensors, roughness of condenser flat surface.

It is follows from metrology recommendations the FHP sample tests should be carried out under boundary conditions of free air convection. For each of 13 points the analysis of differential temperatures ΔT_{hp} was carried out by special algorithm. The FHP reached the steady state conditions less than 20 minutes even when the heat thermal loads were changed.

CONCLUSIONS

The prototype of FHP-based reference block was developed to provide the isothermicity of FHP condenser surface for metrological application. The test sample demonstrated the suitable operation within the temperature range from 30 to 250 ^{0}C and could be base for creation of surface temperature source. It was also investigated the disturbance in surface temperature fields of FHP condenser, which have resulted in partial errors for measurements with contact temperature sensor.The study has shown the high sensitive temperature-sensing element is required temperature monitoring and control in vapor channel.

For temperature measurements by contact sensor, which has resulted in measurements partial errors the disturbance of superficial temperature fields of FHP condenser is investigated.

The readings variation can be reduced with metal surface coating (for example, silver-plating).

The copper surface of FHP condenser coated with metal (fig. 10) with thickness δ = 80..120 μm could be sufficient for reducing the mechanical deformation, avoiding oxidation and improving the mechanical strength of FHP under high-pressure condition. That fact gives the more wider operating temperature range for water/cooper FHP. The temperature fields of surface temperature source and in FHP condenser can be monitored by contact and non-contact thermometry techniques.

Fig. 10. Surface temperature sources with different plating thickness for further investigations

Nomenclature

T – weight of FHP,mm
t_v – vapor chamber weight, mm
t_{wick} – wick weight,mm
t_w – wall FHP height, mm
D – external diameter, mm
d – internal vapor diameter of the FHP, mm
H – height, mm
H_a – transport zone height, mm
DT,ΔT – temperature difference, ^{0}C
T_s – surface temperature, ^{0}C
T_v – temperature in vapor chanel, ^{0}C
T_{amb} – ambient temperature, ^{0}C

α – fill charge, %
λ – themal conductivity, W/mK
δ – thickness, μm
PID – Proportional-Integral-Derivative
PRT – platinum resistance thermometer.

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