

# NUMERICAL AND EXPERIMENTAL ESTIMATION OF HEAT CONDUCTIVITY FOR SPACE ANTENNA REFLECTOR MATERIAL

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**Abstract.** This article devoted for experimental method of contact heating thin carbon plates. Thermal tests provided non-stationary temperature field with gradient, which is co-directional plane reinforcement in sample. New plane reinforcement thermal conductivity data were obtained within temperature gap between 295 and 375 K. Modern thermal conductivity data could be applied for development projects of space precision antenna reflectors.

## 1. Introduction

Space communication, navigation and astronomy technology development is associated with the information expansion and frequency range increase. The higher is the radio signal frequency, the stricter are the requirements to the size and shape stability for space antenna reflectors (SAR) [1]. For example, in advanced systems permissible variation in SAR profile in proportion to the deployment diameter is estimated at  $5 \cdot 10^{-6}$  [2]. The best materials for SAR are polymer composite materials (CM) – carbon fiber reinforced plastics (CFRP) characterized by high specific strength and stiffness, and low linear thermal expansion coefficient. Thermal physical characteristics of CM should be specified in the SAR design process. Thermal conductivity in the direction perpendicular to the reinforcement plane has been sufficiently investigated, but the temperature gradients in this direction are small and the heat conductivity plays an insignificant role in their formation. Under non-uniform heating the temperature gradients have a much stronger dependence on the heat conductivity in the reinforcement plane.

In the conventional flat layer method the heat conductivity is determined in the perpendicular direction to the surface of a circular or rectangular specimen. Due to the small thickness of the reflector skin these results are of low practical value. The improved laser flash method in LFA 457 facility by NETZSCH [3] determines heat conductivity in the reinforcement plane, but it has not come into wide usage yet. To investigate CM heat conductivity in the longitudinal direction the method can be used which has been tested on long hollow CFRP rods and spacecraft cable elements [4-7].

**The aim of this paper** is to provide the design calculation for SAR with the input data on CM heat conductivity in the reinforcement plane.

## 2. Experiment

The thermal tests involved space antenna reflector elements in the form of thin-walled CM plates, 80 mm in length ( $l$ ), 18 mm in width ( $d$ ), 1.5 mm in wall thickness ( $\delta$ ). The specimens were non-uniformly heated along the length and uniformly heated along the width (Fig. 1).

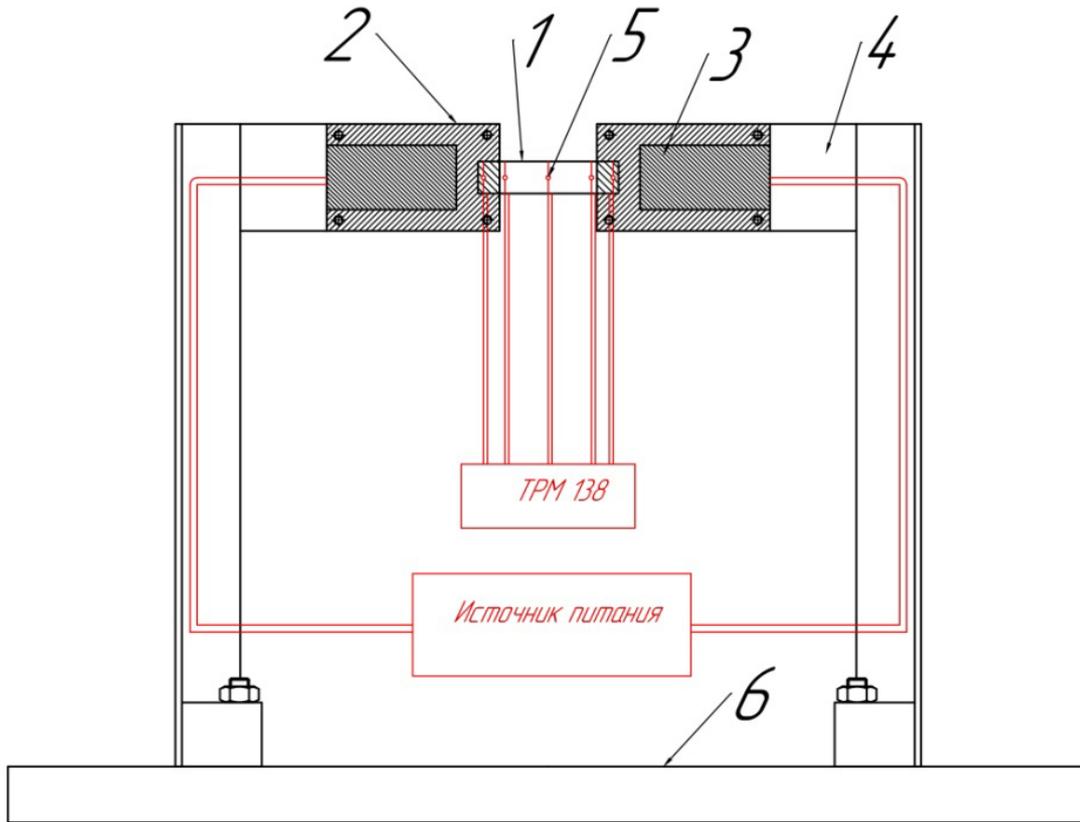


Fig. 1. Contact heating facility: 1 – specimen; 2 – copper plates; 3 – heating elements; 4 – frame; 5 – thermocouples; 6 – base.

Specimen 1 was fixed between the two heaters 2 of HSL-300 type. In order to align the temperature field along the specimen length and width, the heaters 3 were clamped between the copper plates 2. The movable frame 4 enabled testing specimens of up to 120 mm long. The heaters were powered by two adjustable power sources HY3000-2. The temperature of the specimen and the heaters was monitored with the thermocouples 5. Three K-type (chromel-alumel) thermocouples were positioned along the specimen's longitudinal axis: two along the edges and one in the centre. The thermal electrodes were fixed along the isothermal surface and were connected to the TPM-138 adapter unit to automatically log the experiment data.

The experiment prediction was performed on the unidirectional heat conductivity model for a thermally thin body:

$$C(T) \frac{\partial T(z, \tau)}{\partial \tau} = \frac{\partial}{\partial z} \left( \lambda_z(T) \frac{\partial T(z, \tau)}{\partial z} \right) + q_V(z, \tau); \quad (1)$$

$$\tau = 0, \quad T(z) = T_0(z) = T_f; \quad (2)$$

$$z = 0, \quad T(\tau) = T_1(\tau); \quad (3)$$

$$z = l, \quad T(\tau) = T_2(\tau) \quad (4)$$

where  $q_V(z, \tau) = 2(-\varepsilon(T)\sigma_0(T^4(z, \tau) - T_f^4) - \alpha_f(T)(T(z, \tau) - T_f)) / \delta$  stands for the volumetric heat source;  $C = c \rho$  – the volumetric heat capacity;  $c$  – the specific heat capacity;  $\rho$  – the density;  $\lambda_z$  – the thermal conductivity in the reinforcement plane;  $l$  and  $\delta$  – the plate length and width;  $\varepsilon$  – the plate surface emissivity factor;  $\tau$  – the time;  $T_1(\tau)$ ,  $T_2(\tau)$  – the temperatures on the plate edges;  $T_f$  – the environment temperature.

The calculations indicated that at  $\lambda_z$  equaling 1 – 6 W/(m·K) the distance from the heaters to the central thermocouple should be from 15 mm to 25 mm.

The experiment was conducted in a vacuum chamber to eliminate the natural convection effect. The typical results are presented in Fig.2.

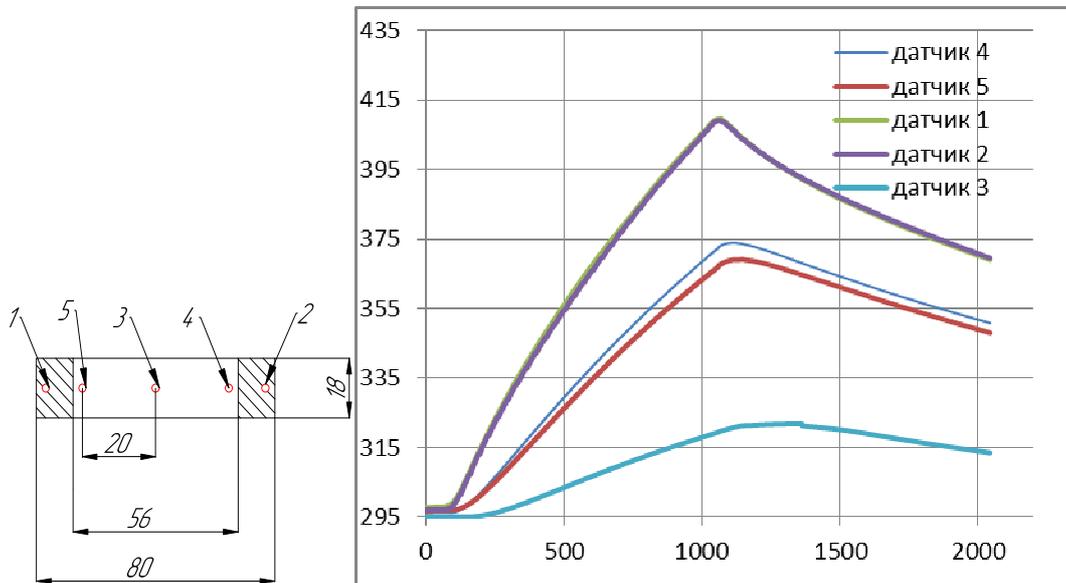


Fig. 2. Thermal testing of a CFRP specimen:  
a) thermocouples layout; b) testing thermographs

### 3. Experiment Data Processing And Results Analysis

The heat conductivity  $\lambda_z$  was determined with the help of software for heat conductivity inverse problem [5]. The input data were the experimental temperature values (Fig. 2). The emissivity coefficient was assumed to be  $\epsilon = 0.86$ . The target heat conductivity values  $\lambda_z$  varied from 8 to 3 W/(m·K). The calculation stop criterion was the maximally exact agreement of the experimental curve  $T(\tau)$  of the central sensor with the calculated curve at the preset value of  $\lambda_z$ . The minimal difference between the calculation and experiment thermographs was achieved at  $\lambda_z=3.3$  W/(m·K) and did not exceed 4 K (Fig. 3). The difference between the calculation and experimental temperatures can be caused by the imprecise setting of the emissivity coefficient  $\epsilon$  and errors in thermocouples positioning.

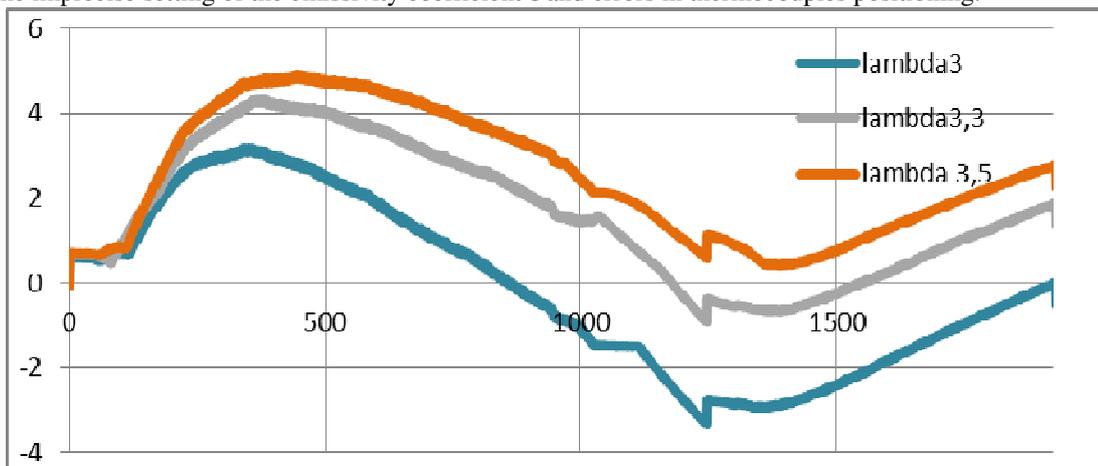


Fig.3. Error  $\Delta T$  between the calculated and experimental temperature of the central sensor at different values of  $\lambda_z$   
temperature

The results of calculated and experimental estimation of CFRP heat conductivity  $\lambda_z$  were used as input data for the design calculations of a high-precision SAR. It was assumed that the side surface of the reflector with the base 1000 mm in diameter and 50 mm structural depth was exposed to the solar radiation flux with 1368 W/m<sup>2</sup> density. The temperature gradient between the irradiated and shadow sides at  $\lambda_z = 3.3$  W/(m·K) constituted  $\Delta T = 88$  K, and the total displacement was  $\Delta = 0.17$  mm (Fig. 4, 5). In comparison,  $\Delta T$  and  $\Delta$  decrease by more than 30% at  $\lambda_z = 20$  W/(m·K) for equivalent simulation conditions.

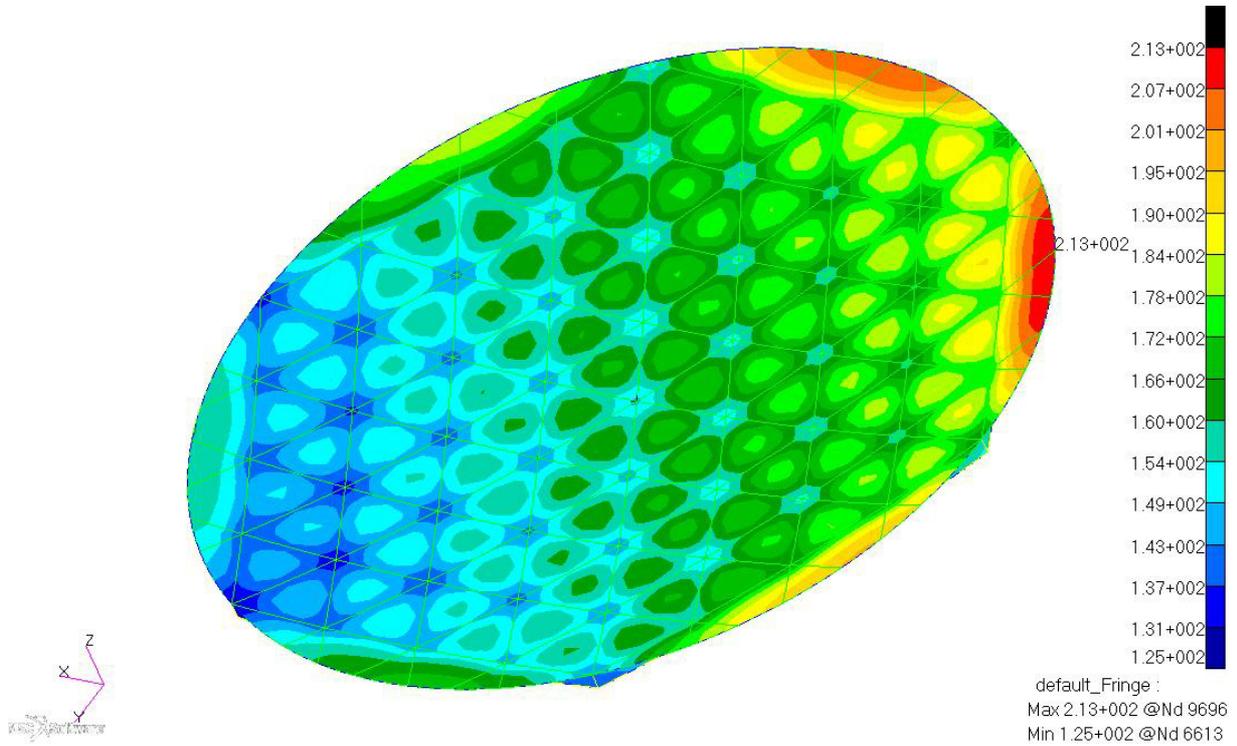


Fig. 4. Temperature distribution at  $\tau = 500$  sec,  $\lambda_z = 3.3$  W/(m·K)

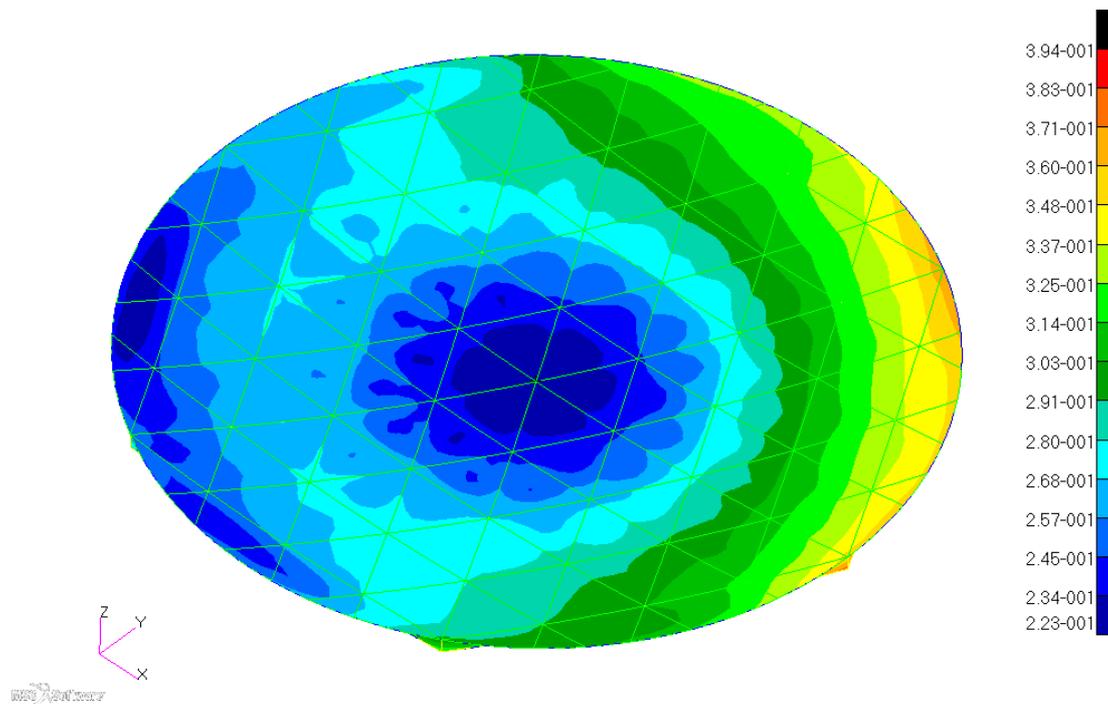


Fig. 5. Total displacement of reflecting surface at  $\tau = 500$  sec,  $\lambda_z = 3.3$  W/(m·K)

## 4. Conclusion

The method for numerical and experimental estimation of longitudinal heat conductivity in thin-walled CFRP plates was tested. It was determined that the heat conductivity in the reinforcement plane in (295 ... 375) K temperature range is  $\lambda_z=3.3\pm 0.2\text{W}/(\text{m}\cdot\text{K})$ . in order to improve the SAR design calculation accuracy it is feasible to conduct tests in a wider temperature range including low temperatures.

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## References

1. Lopatin A.V., Rutkovskaya M.A. The review of designs of modern transformed space antennas // Vestnik Sibirskogo gosudarstvennogo aerokosmicheskogo universiteta im. akad. M.F. Reshetneva. – 2007. – No 2. – pp. 51-57.
2. Fundamentals of identification and design of thermal processes and systems: Coursebook / O.M. Alifanov, P.N. Vabischevich, V.V. Mikhailov et al. – Moscow, Logos, 2001. – 400 p.
3. Anisotropic thermal conductivity of thin polycrystalline oxide samples / A. Tiwari, K. Boussois, B. Nait-Ali, D.S. Smith, P. Blanchart // AIP Advances. – 2013. – Vol. 3, Issue 11. – Art. 112129.
4. Reznik S.V., Denisov O.V. Setting and results of thermal tests of composite rod elements for space structures // Vestnik MGTU im. N.E. Baumana. Maschinostroenie. – 2008. – No 4. – pp. 81-89.
5. Thermal vacuum test of hollow rods for space structures / S.V. Reznik, O.V. Denisov, P.V. Prosuntsov, V.P. Timoshenko, A.V. Shulyakovskiy // Vse Materialy. Entsiklopedicheskij Spravochnik (All the Materials. Encyclopaedic Reference Book). – 2012. – No 7. – pp. 8-12.
6. Modeling and Identification of Heat Transfer Parameters in Rope Elements of Space Structures. I. Rationale of Experimental Conditions / S.V. Reznik, V.P. Timoshenko, P.V. Prosuntsov, D.S. Minakov // Thermal Processes in Engineering. – 2013. – Vol. 5, No. 5. – pp. 235-239.
7. Modeling and Identification of Heat Transfer Parameters in Rope Elements of Space Structures. II. Rationale of Experimental Conditions / S.V. Reznik, V.P. Timoshenko, P.V. Prosuntsov, D.S. Minakov // Thermal Processes in Engineering. – 2014. – Vol. 6, No 8. – pp. 378-383.