Heat resistance of heat-retention lagging materials' optical measurement method for orbital spaceship "Buran"

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Optical characteristics' analysis of one type of the heat-retention lagging for orbital spaceship "Buran" has been conducted. Reflection ρ_λ, spectral ratios were measured in the range of wave-length λ=0,3-1,1 micrometers by the temperature of 20°-1000 °C.

The success of many space programs depends on achievements in creation of the effective thermal heat protection system of reusable orbital spaceship [1]. The development of high-temperature resistant protective constructions is the necessary stage of "Buran's" program. Separate parts of spaceship lagging are heating to 1600 °C while letdown from orbit because of aerodynamic braking in superstandard layer. Solar radiation is a heating source of spaceship in cosmos. Lagging is being under special conditions of outer space with -269 °C in shadow. Solar ray stream reaches its maximum value q=1.4 kVt/m^2 because of absence of atmosphere absorption. Therefore temperature of spaceship surface on orbit reaches from -150 °C to +150 °C [2]. Thus materials the lagging is made of should have corresponding optical characteristics for effective over-radiation of heat received by the lagging. Also they should be heat-resistant in a process of reusing not less then 100 cycles.

Research conducted in our work on temperature dependence of optical characteristics (reflection spectral ratio ρ_λ, absorption spectral ratio α_λ, spectral hemispheric emissivity factor ε_λ, solar radiation absorption ratio α_S) of thermal-insulation tile which are used for reusable space vehicle shell revetment. These tiles are heat-shielding constructions of two types: "with black" anti-erosive covering (EVCH-4M1Y-3 and kernel from TZMK-10 material on the basis of super-thin clean quartz fiber) and "with white" anti-erosive covering (EVS-6 with the same kernel). Such types of lagging are installing on external surface of orbital spaceship depending on its temperature zone. Consequently tiles with EVCH-4M1Y-3 covering is used for "Buran's" underbody thermal protection while letdown from orbit, in view of the fact that temperature their reach from 700 °C to 1250 °C. EVS-6 type tiles are preventing top from solar radiation overheat while orbital flight.

Reflection spectral ratio ρ_λ measuring, was held on the plant (fig. 1) that consists of: spectrophotometer (1), high-temperature sphere photometer HTSP (integrating sphere) (7) with temperature controlling device (5), receiver (9) with unit power (10). Monochromatic light beam from spectrophotometer through focusing system (diaphragm (2), lens (3), and turning mirror (11)) is directed on the sample (4) that is in sphere (7) or on the sphere wall. Scattered radiation is integrated by photometer and received by receiver. Signal from receiver feeding voltmeter (8). Temperature in working cavity HTSP is controlled by thermopair (6) connected with high-accuracy temperature regulator HTR3.

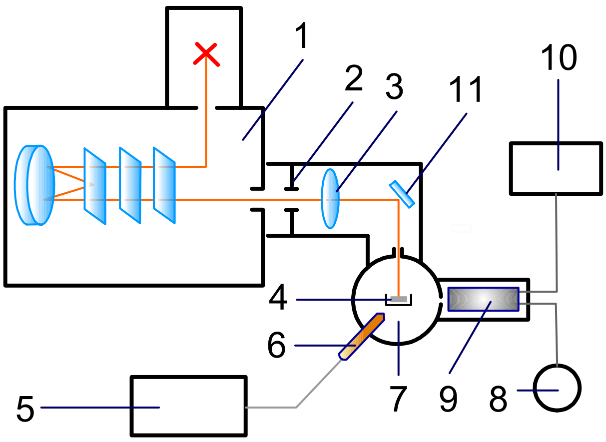

Fig. 1 *Experimental plant scheme.*

Basic part of the plant is HTSP, which scheme is presented on fig. 2, HTSP consists of three spheres (3), (4), (6); (3) and (4) form thermostatic cavity (5), sphere (6) is covered with thick coating inside (2.5-3 mm) MgO and playing role of integral photometer. Heating elements (11) are placed on the sphere (6) outside. Monochromatic beam is directed to photometer (9) on sample (1). Sample can be turned on necessary angle that is counted out on limb (10). For optical elements and receiver protection from air heat flow out of photometer working cavity quartz plates are used – polished (2) and mat (8). Light guide (7). Temperature is set and maintained in whole measuring process accurate to ±0.5 C.

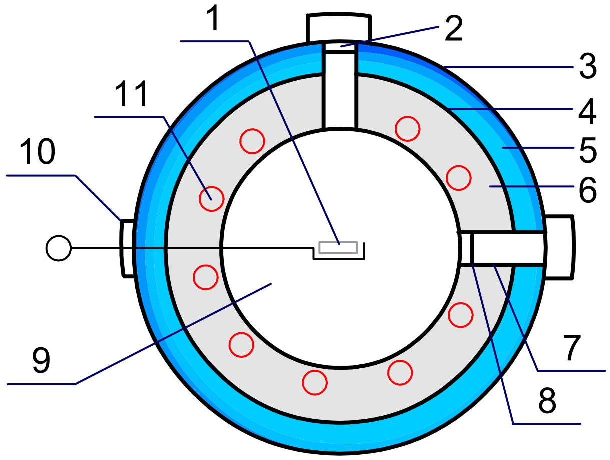

Fig. 2 *HTSF construction scheme.*

Tiles spectral ratios ρ_λ were measured in high-temperature sphere photometer on the sample under direct radiation depending on beam angle of incidence for wave length interval λ=0,3-1,1 mkm and temperature range T=20-300 °C. Sample heating to high temperatures 400-1000 °C was carried out in electric furnace. Sample sustaining during every fixed temperature lasts for 20-30 min. After measurement under high temperature samples sustained not less then 12 hours under 20 °C, afterward again their optical characteristics were measured. Such sample sustaining under normal temperature necessary for structure transformation caused by heat and has reversible nature. Fibrous material heating causes their structure transformation that stipulates corresponding changes in their light-spectrum of reflection and absorption. While cooling part of this structure transformations disappear and they can be subsumed under reversible. If material spectral ratios α_λ after cooling from heated condition completely coincide with spectral curves α_λ before heating, so structural transformations should be subsumed under completely reversible. In case that α_λ values of heated and cooled samples are coincide then structural transformation are completely nonreversible.

Thus, spectrophotometric research of cooled and heated samples allows determine reversibility of structural transformations, which occur under different heating temperature, in other words determine materials heat resistance. Since lagging thickness is "optically endless" that is their transmission ratio τ_λ=0, then α_λ=1-ρ_λ.

In the process of research conducted, determined that value α_λ in λ=0,3-1,1 mkm range and T=20-1000 C range of EVCH-4M1Y-3 tiles after cooling from heated state completely coincide with – α_λ of this sample before heating. In other words for EVCH-4M1Y-3 type tiles full reversibility of optical characteristics in researched temperature range 20-1000 °C is observed.

EVS-6 type tiles up to 300 °C temperature in the greater part of spectral range evince reversible optical characteristics. Higher then 400 °C temperature some their nonreversibility is observed, especially under 900-1000 °C. Consequently tiles heat resistance temperature with EVCH-4M1Y-3 coating exceeds 1000 °C, while EVS-6 – 300 °C.

Such conclusions confirm spectrophotometric research conducted by us for several cycles of heating-cooling that in addition proves possibility of their reusability.

EVCH-4M1Y-3 tiles optical characteristics research proved that in λ=0,3-1,1 mkm range and T=20-1000 °C range is close to gray body. EVS-6 tiles have characteristics of gray body in λ=0,5-1,1 mkm range. This gave opportunity to determine important parameter - total emissivity ε. Then under 900 °C heating temperature for EVCH-4M1Y-3 tiles ε=0,89 and for EVS-6 tiles ε=0,11. This characteristic is important for determination of thermal radiation stream and body thermal equilibrium conditions. And have especially big sense then researching spaceship heat exchange conditions.

One of characteristics that determine material solar radiation tolerance is integral solar radiation absorption coefficient α_S. This characteristic is important for determination of thermal radiation stream and body thermal equilibrium conditions. And have especially big sense then researching spaceship heat exchange conditions while orbital flight.

In this research for EVCH-4M1Y-3 tiles determined α_S=0,9-0,91. EVS-6 tiles have small value α_S=0,11-0,17. Also it restricts heating temperature from solar radiation of spaceship's upper side which is turned to the Sun while orbital flight.

In assignment on projection of "Buran's" thermal protection is given that for EVCH-4M1Y-3 tiles $\varepsilon\approx$0,8-0,92, and for EVS-6 tiles $\alpha_S\leq$0,32 [2]. Evidently from research conducted these requirements for tiles are fully satisfied. These conclusions received from detailed optical characteristics, namely: absorption and reflection spectral ratios.

Research results can be used in projecting thermal heat protection elements for reusable spaceships.

References

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[2] L.P. Voinov ; "Thermal Designing of the BURAN Orbital Spaceship" *from book* Aerospace Systems, (Moscow) Publishing House of Moscow Aviation Institute: 115-122 (1997)