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THE INCREASE OF THERMOCONDUCTIVITY OF MATERIALS IN THE FIELD OF CENTRIFUGAL ACCELERATIONS AND FORCES

Lepeshkin A.R.* and Bychkov N.G.
*Author for correspondence
Central Institute of Aviation Motors,
Moscow, 111116, aviamotornaja, 2
Russia,
E-mail: lepeshkin.ar@gmail.com

ABSTRACT

The investigation of the thermal conductivity in a materials under influence of the centrifugal accelerations and forces is a new work which is important for aerospace engineering. The material thermal conductivity of the blades and disks used in the calculation of the thermal state of parts of the turbine rotor. In the investigation the developed method of investigation of thermal conductivity of materials in the field of centrifugal acceleration and forces has been used. A device with a heat conductor to determine the thermophysics characteristics on the spin rig using the vacuum chamber in conditions of centrifugal acceleration and forces has been developed. The results of the investigations of unsteady heat-conductor in the field of centrifugal forces and accelerations are given. From the analysis of the results of experimental investigations it may be stated that the thermal conductivity of the heat-conductor increases significantly with an increase of a rotation frequency compared to the steady state without rotation. In the studied phenomenon of thermal conductivity the two components are present: the action of the centrifugal acceleration and centrifugal tensile load. The second component is a small value (10-20%) on the basis of obtained experimental data on the influence of stretching. Thus, this increase of the thermal conductivity significantly associated with an increase of an electronic conductivity (electron transport) of the metal due to heat-carriers (having mass) - free electrons under the influence of centrifugal accelerations taking into account Wiedemann-Franz law.

The obtained results are of practical importance for the assessment of the thermal state of the rotating parts of aircraft engines and other energy turbomachines.

INTRODUCTION

The material thermoconductivity of the blades and disks used in the calculation of the thermal state of parts of the turbine rotor. The thermoconductivity was obtained in stationary conditions of gravity. It is considered that the effect of centrifugal force and acceleration does not change the thermoconductivity of the material. However, experiments [1] conducted by the authors show this statement is not true. The turbine blades operate at extreme centrifugal accelerations of 40000...100000 m/s^2 and we can expect significant thermoconductivity change in these conditions. In addition to acceleration the tension centrifugal force acts on rotary parts. The influence of compressive forces on the thermoconductivity of GaSb compounds was investigated in [2]. When the pressure rises to 250 ... 350 MPa the thermoconductivity increased by 15 ... 20% of these compounds [2]. The investigations of the thermoconductivity of materials at tension have not been conducted.

The information on electronic phenomena in metals are given in [3, 4]. The russian scientists Mandelstam L.I. and Papaleksi N.D. established this phenomenon by experimentally in 1913. In their experiment the variable potential difference across the ends of the wire coils arises at rotating and the phone made the sound attached to the ends of the coil wire. This experiment has been enhanced in 1916 by the American scientist Tolman R.C. In his experiment the coil had been rotating rapidly and then it braked abruptly. In this case, the electrical current pulse was recorded by a ballistic galvanometer. This pulse is associated with the inertial motion of free charges (electrons have mass) in a thin copper wire of the coil. The electrons continue to flow during abrupt braking of conductor.

These experiments also confirmed that the acceleration effect on the electron phenomena in metals under braking. However from these experiments had not been done conclusions and assumptions about the influence of electronic effects on the thermal processes in the short wires and rotary parts.

NOMENCLATURE

t	[°C]	Temperature

V	[°C/ s]	heating rate
τ	[s]	Heating time
P	[MPa]	Tensile load
υ	[m/s]	Rotation speed
a	[m/s^2]	Centrifugal acceleration

EXPERIMENTAL METHOD OF INVESTIGATIONS

In given work we investigated the thermal conductivity of the material in the field of accelerations and centrifugal stretching forces during tests on the spin rig (Fig. 1). The method of the investigations and device are developed and presented in work [1]. The device contains: 1 - fastened insulated conductor, 2 - small heat source - electric heater on the flat disk (Fig. 2). The insulated radial conductor is a copel wire (length l = 55 mm, diameter 0.5 mm) and electric heater with length of 10 mm (Fig. 2). Thermocouples welded to the ends of the heat-conductor. The investigations were conducted in a vacuum chamber on the spin rig equipped by electromotor with use of an automatic control system of rotation frequence.

Monitoring of a thermal state of the heat-conductor (placed on a rotating disk with a heater) provided of computer measurement system. The processing of the results was provided by the developed program. The wires of the electric heater and thermocouples of the heat-conductor were joined to mercury current collector. The stabilized power supply is used for the electric heater.

When considering a general rectangular three-dimensional heat-generating solid, three main external boundary conditions types can be considered, namely heat transfer to the surroundings in a singular Cartesian direction with adiabatic conditions for other directional external surface sets, orthogonal bi-directional heat transfer to the surroundings with the other external direction being adiabatic, and a case with tri-directional heat transfer to the surroundings as represented in Figure 1.

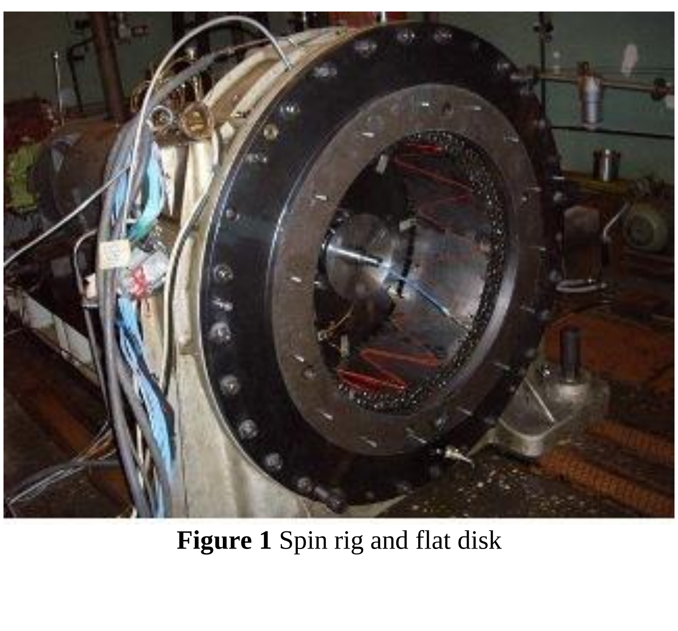

Figure 1 Spin rig and flat disk

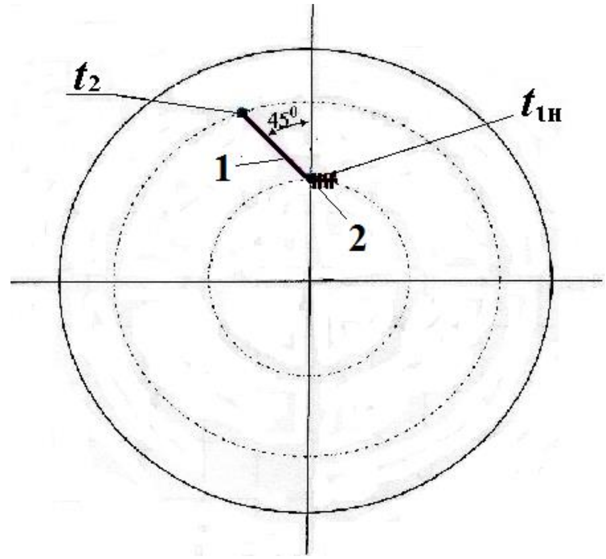

Figure 2 Device on the flat disk

EXPERIMENTAL RESULTS AND DISCUSSION

The investigations of the thermal conductivity on view of centrifugal accelerations and forces were conducted in accordance with the developed method. In the first investigation the basic thermocouple indications were recorded during the work time of the heater under conditions of the vacuum chamber without rotation. The subsequent investigations in the vacuum chamber using the thermocouple indications were recorded at each rotation frequency during the work time of the heater. The results of the investigations of an unsteady heat of the radial heat-conductor in Fig. 3.

It is known that the thermal conductivity of a material is a function of the heating rate. The processing of experimental heating curves (Fig. 3) in view of this functional dependence was carried out. As a result the heating rate curves were obtained in Fig. 4.

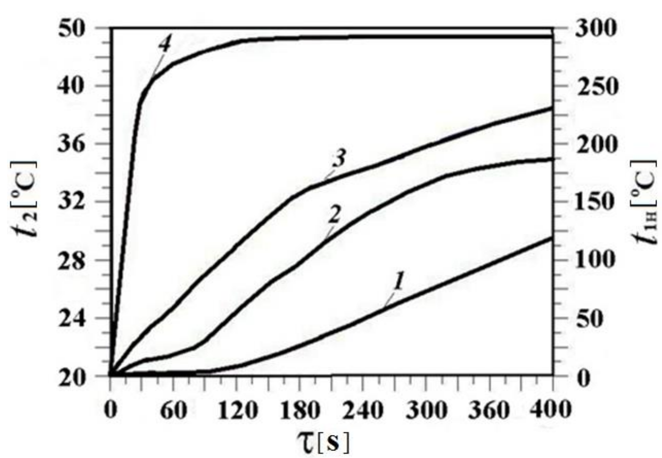

Figure 3 Temperatures on the end of the heat-conductor t2 depending on the heating time τ at different speeds υ: 1 – 0 r.p.m. (υ =0 m/s), 2 - 2500 r.p.m. (υ = 25 m/s) , 3 - 5000 r.p.m. (υ =50 m/s), 4 - temperature of the electric heater

Analysis of the curves in Fig. 4 shows that the centrifugal accelerations and forces significantly affect on the thermal conductivity of a material of the heat-conductor and the relationships of maximum heating rates: $V_{m,1}/V_{m,0}$ = 2.5, $V_{m,2}/V_{m,0}$ = 3.0.

Thus, the heating rate and, therefore, the thermal conductivity increases, respectively, 2.5 and 3.0 times with the increasing of rotation frequency (speed υ, centrifugal acceleration a) to 2500 r.p.m. (25 m/s, 25000 m/s^2) and 5000 r.p.m. (50 m/s, 50000 m/s^2).

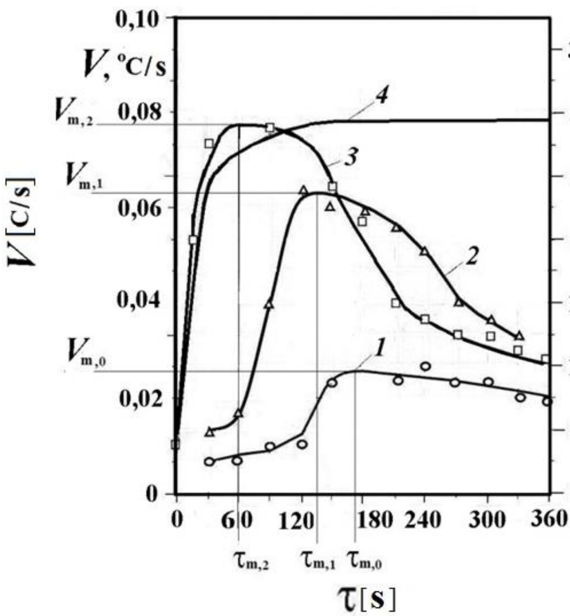

Figure 4 Heating rates on the end of the heat-conductor depends on the heating time τ at different speeds: 1 – 0 r.p.m. (υ =0 m/s), 2 - 2500 r.p.m. (υ =25 m/s), 3 - 5000 r.p.m. (υ =50 m/s), 4 - temperature of the electric heater

RESULTS OF INVESTIGATION OF THERMOCONDUCTIVITY OF MATERIALS IN THE FIELD OF FORCES

The investigations on the influence of centrifugal acceleration and forces on thermal conductivity showed a significant increase of thermal conductivity of the material of heat-conductors with increasing of rotation frequence up to 5000 r.p.m. The tensile stresses in the heat conductor were reached 100-200 MPa at acceleration 50000 m/s^2. The two factors: stretching force and acceleration were during the experiment. It is necessary to identify the influence of each factor on the thermal conductivity.

A special method developed and used to estimate the effect of tensile stress on the thermal conductivity of material. A device for the experimental determination of the thermal conductivity by loading of materials by tensile force is an axial loading device with grips that have thermal insulations (Fig. 5). It should be provided the minimum loss of heat flow through the grips of heat conductor.

The copel heat conductor is l = 55 mm and diameter of 0.5 mm. The electric heater length of 10 mm is placed at the beginning of the heat-conductor. The two chromel-alumel thermocouples 0.2 mm in diameter were welded to the upper and lower ends of the heat-conductor. The insulated heat conductor for investigation with thermocouples and electric heater was placed between the upper and lower grips of device. The calibration weight was joined through the lower grip to the lower end of the heat conductor. A stabilized power supply was used for the electric heater. The monitoring of a temperature state of the heat conductor was performed using a chromel-alumel thermocouples and computer system.

Figure 5 The device for loading of the heat conductor by tensile load

The investigation of the significance of structural factors of mechanical loading of the metal grid (phonon conductivity) by tensile force on the thermal conductivity was carried out using developed method. The change of temperature rates of unloaded heat-conductor at the end of the heater and at a distance of 55 mm from it were recorded on the first stage after the heater. Then the heater was turned off and the assembled structure within 3 hours was cooled to normal temperature. In the second step the 1 kg weight (tensile load is P = 50 MPa) was joined to heat-conductor and the heater turned on and indications of thermocouples were recorded on the stretched heat conductor. Then the cooling had been appling for the three-hours.

The temperature measurement cycles of the heat-conductor were repeated for different weights (tensile loads from 50 to 200 MPa). The mode of measurements was repeated three times for each load level. The analysis of the results shows that the thermal conductivity of the copel heat-conductor (sample) varies up to 10-20% causing tensile stress there in. Thus, the centrifugal acceleration is significant for the two factors (the centrifugal acceleration and force) which affects on the thermal conductivity at increasing of a rotation frequence.

CONCLUSION

In the investigations has been used the developed method of evaluation of thermal conductivity of materials in the field of centrifugal accelerations and forces. A device with a heat conductor has been developed to determine the thermophysics characteristics on the spin rig using the vacuum chamber in conditions of centrifugal acceleration and forces. The results of the investigations of unsteady heating of the heat-conductor are given in the field of centrifugal forces and accelerations. From the analysis of the results of experimental investigations it can be stated that the thermal conductivity of the heat-conductor increases by 2 and 3 times with an increase of a rotation frequency compared to the steady state without rotation. In the studied phenomenon of thermal conductivity the two components are present: the action of the centrifugal acceleration and centrifugal tensile load. The second component is 10-20 % according to obtained experimental data on the influence of stretching. Thus, this increasing of the thermal conductivity significantly associated with an increasing of an electronic conductivity of the metal due to heat-carriers (having mass) - free electrons under the influence of centrifugal accelerations. The obtained results have of practical importance for the estimation of the thermal state of the rotating parts of aircraft engines and other energy turbomachines.

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