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# THERMOVISION STUDY OF TEMPERATURE FIELDS AND RADIATION CHARACTERISTICS OF ELECTRIC THRUSTER T-100 SURFACES

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## Abstract

A method is developed for investigation of temperature fiields on the surface of heterogeneous objects using thermovision equipment and the computer processing of images. Radiative characteristics of the T-100 thruster anode unit were determined experimentally. Temperature filds on its face were measured during stationary operation of the thruster in a vacuum chamber.

## Introduction

The development of electric plasma thrusters comprises investigation of their thermal conditions. Features of the design of the electric thruster, properties of emplozed materials and number of other factors affect the thermal conditions of the operating thruster. In turn, the thermal conditions influence on operating parameters of the thruster, its lifetime and the possibility to use it on and to adapt it for a specific spacecraft. That is why the investigation of the thermal conditions is an important and integral part of work on the development of high-effective electric thrusters.

The electric thruster with closed electron drift T-100 investigated in this work and developed at NIITP has a complicated configuration and various materials are used in it. This impedes calculatiion of temperature fields and settlement of boundary conditions. Experimental measurements of temperatures over the thruster using conventional transducers, such as thermocouples and resistance thermometers, cannot give a correct thermal pattern, as such as transducers cannot be plased everywhere; besides, they themselves can affect on the thermal conditions of the thruster and properties of the materials. This especially concerns the edges of high-temperature structural elements whose temperature should retain within ranges admissible for the materials employed.

## Technique for Thermovision Measurements

In this work, the temperature fields on the surfaces of the electric thruster operating in a vacuum chamber are investigated by means of infrared thermography. The thermovision diagnostics is an expeditions ans very informative means and can significantly speed up development of new thrusters. Howerer, the non-contact measurement of the temperature of complicated-configuration objects is impeded because of unever distribution of the radiating factors over their surface. That is why the radiative characteristics of a T-100-type electric thruster were investigated at the initial stage of this work on NIITP's thermovacuum test facility

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in the infared spectral region. For this purpose, the anode unit of the electric thruster was thermostatted in a muffle furnace and then the image of the isothermic object was taken.

In this work, a thermovision system was used for thermovisual diagnostics based on the IR imager "AGA 780SW" manufactured by the Swedish company AGEMA. The system consist of an IR scanner, monitoring unit, computer interface and IBM PC. The IR scanner employs a photodetector (InSb) cooled down to the temperature of liquid nitrogen. Installation of various diaphragms and filters and remote focusing of the image are envisaged. The operating spectral region of the IR imager ranges from 2 to 5.5 mm, the temperature resolution at the maximum sensitivity is 0.1 °C; The spatial resolution depends on the tipe IR lers, the maximally possible on being of 0.5 mrad. The electronic videosignal comes from the IR scanner to the monitoring unit where the quality of the thermal image is controlled and sinsitivity and displacement ranges are established that are required to provide proper operation of the computer interface. The interface plate onto which the signal comes from the monitoring unit is installed in the computer. It provides analog-to-digital conversion of the thermal image and its programmed entry into the memory and disk. The thermal image is processed in the computer with the help of interactive program complex "TERMO" that also allows obtaining exported files which can be processed with standard graphic packages.

The digital videosignal B to be prossed by program can be represented as follows:

$B = \tau \varepsilon I_w + \tau (1 - \varepsilon) I_a + B_o$ (for the object), or

$B_k = \tau I_w + B$ (for the control point with $\varepsilon = 1$ at the object's temperature).

Here, $\tau$ is the transmission factor of medium and intermediate optics; $\varepsilon$ is the object emissivity, and $\varepsilon J_w$ - the flyx emitted by the object; $(1 - \varepsilon) I_a$ - the external radiation flux reflected by the object.

The constant component Bo depends both on $I_o$ ($I_o$ - the constant component correlated with self-radiation of background and optical path elements) and on electron biases of videosignal. It is determined at a calibration of thermovision system by the model of perfectly block body through selection of coefficients a, b, c, $B_o$ for a standard curve of the following type:

$$B = a/(C \exp(\frac{b}{T}) - 1) + B_o$$

using method of least squares.

The distribution of $\varepsilon$ over the object surface is found by way of modification of original thermoimage $B$ ( x, y) according to the expression:

$\varepsilon = ( (B - B_o)/(B_k - B_o) - I_a/)/(1 - I_a/I_w)$.

This transformation was realized with use of graphical package SURFER. The processing results are given for most non-uniform engine end face in Fig. 1 and 2.The distribution of $\varepsilon$ in the form of modular surface is shown in Fig. 1, in Fig. 2 - in the form of lines superposed on an object videoimage for exact space conjunction of measurement results. The object videoimage input into computer was realized with the help of complex of technical vision fulfilled on the basis of matrix photoelectric converter. The scaling of thermovision and videomages was made in the program complex TERMO, for registration off isolines with an videomage the graphiical program package ALDUS FOTOSTYLER was used.

Experimental investigations and their results

Experimental investigations have revealed that on the end face anode unit the emisivity varies within the limits 0.6 to 1, being a most non-uniform in the disharge chamber region. On side and back unit surfaces the emissivity lays with in the limits 0.2-0.4. The knowledge of the emissivity distribution allowed the determination of temperature distribution over a surface of an operating engine.

The perfomance of thermovision measurements in vacuum chamber conditions and availability of external heat fluxes of various type has a set of peculirities. Firsty, this is, as a rule, a great length of optical path which necessitates the application of infra-red optics with high spatical resolution. Secondly, the measurements are conducted at a limited transmission of an optical path (availability of IR-windows and auscilliary mirrors) and in the presence of compliated background conditions. The additional difficulties arise in case of a non-inform surface of the experimental object. In this case, the exact account must be taken of its local optical characteristics. For this purpose, the geometrically-identical thermal images of an operating engine and its isothermic state are to be available.However, the minimum distange one could observe an engine mounted in the chamber measured about 6 m which is much more than for isotermic measurements. This required the use of the more powerful IR objective with 3.5 grad field of view and spatial resolution not worse than $0.5 \cdot 10^{-3}$ rad. An engine by itself was rotated $180^{\circ}$ as compared with the mounted one in the chamber in the process of measurements of $\varepsilon$. Furthermore, in this work, the two auxilliary elements were introduced to the optical configuration: the inlet infra-red window made out of $CaF_2$ and arranged in one of vacuum chamber flanges adapted to this case, and the flat mirror made out of alloy AMr-6 and fastened inside the vacuum chamber. The thermovision scanner with the remote guidance device were located outside the chamber.

The use of new elements in the scheme of the experiment has required an amplitude calibration of thermovision optic path, that was conducted in the range of thruster operating temperatures to increase the precision. For conducting a calibration, the model of perfecty black body with an operating range to 1200 c, aperture of 20 mm and $\varepsilon = 0.99$ was used. This model was arranged in the vacuum chamber near the thruster anode unit in the field of view of thermovisor. The power supply to a heater of perfectly blask body model was realized from a controllable autotransformer having a galvanic decaipling from a power network. The measurement of the emitting cavity temperature was carried out with ZA-thermocouples.

The measurement of the thruster surface temperature was conducted for stationary mode of item operation, the temperature fields were recorded during about 4 hours after its start. The pressure in the vacuum chamber was about $9 \cdot 10^{-5}$ mm Hg for xenon.The operating performance acting on the thruster temperature has taken the values:

- discharge voltage - 298 V
- discharge current - 4.35 A
- xenon flow though anode - 4.1 mg/s
- xenon flow though catode - 0.4 mg/s.

The magnetic coils are powered from an independent power source with current I = 4.12 A and U = 12 V. At the indicated parameters a thruster exerts a thrust F ~ 8 g.

The plasma influennce was checked in this work experimentally. For this purpose, two consencutive thermal images of a thruster were recorded in an interval between which the

plasma was turned off, and a temperature level on the anode unit surface had not time to change. An identity of these thermal images has confirmed that there is no plasma direct action on a signal reciived by the thermovisor.

A computer videosignal $B$ (x, y) is correlated to self-radiation of the object I (x, y) in the following manner: $I$ (x, y) = $B$ (x, y) - $Bo$. The object radiation may be, on the other hand, presented in the form:

$$I(x, y) = \varepsilon(x, y)) \cdot \tau \cdot I_w(x, y) + ((1 - \varepsilon(x, y)) \cdot I_a ,$$

where $\tau$ - the optic path transmission factor, $I_a$ - the background heat flux depending of ambient temperature, $I_w$ - the radiation flux that would be radiated by perfectly black body at the object temperature.Since a calibration in this work was conducted for the same optic path as the experiment was, $\tau = 1$. By way of various angular adjustments of infra-red scanner it was experimentally checked that the transmission factor is constant against field of view.

For the range of thruster operating temperatures $I_w >> I_a$ and at the measured $\varepsilon(x, y)$, one may believe that

$$\varepsilon(x, y) \cdot I_w(x, y) >> (1 - \varepsilon(x, y)) \cdot I_a$$

Then, for the experiments performed, one may consider:

$$I_w(x, y) = (B(x, y) - B_o)/\varepsilon(x, y)$$

This expression means that the file of the non-calibrated object image $B$ (x , y) which was obtained in the experiment is to be mathematically modified prior to comversion to temperature: subtract a constant component, bring it with the file $\varepsilon$ (x, y) into coincidence, divide one file by another term by term. Matchematical operations with the unage files fuulfilled in this work in program paskage SURFER, in doing so, the preliminary processing (improvement of spatial and amplitude resolution, coincedence of images, formation of export files) was realized in program complex TERMO. The obtained distribution $I_w$ (x, y) was converted to a temperature fild in accord with the expression:

$T(x, y) = b/\ln((1 + a/I_w(x, y))/c)$, where a, b, c - the constants of a calibration curve, calculated for the experiment carried out.

The infra-red images of an operating thruster and the same thruster in isothermic state are given in Fig. 3. As is seen, the optic characteristics of the object are essentially non-inform, and their local account is necessary in principle. On the image of an operating thruster, one can see at once the earlier unknown effect of azimuthal assymmetry of temperature in the region of the region of the discharge chamber caused, apparently, by asymmetry of cathode unit arrangement. In Fig. 4 show are the measurement results of surface temperature for a thruster operating in a stationary mode in the form of isothermic lines applied to its videoimage. It is evident that the temperatures are level with 700C in the most hot zones of the discharge chamber. The temperature asymmetry in the discharge chamber comprises about 80C. The minimum temperature level on the end face is of the order of 330 C. It should be noted that theh optic characteristics of thruster specimens with various operating times are somewhat differ - with growth of a number of worked hours the emissivites increase. These variations $\varepsilon$ were investigated at the first stage of the work. The error in the surface temperature determination due to the emissivity time variations comprises a magnitude of the 10 grad order.

## Conclusion

By this means, in consequence of the thermovision measurement technique use in experimental investigations carried out in the vacuum chamber conditions, obtained were the numerical data on temperature levels in various surface zones of the anode unit of on electrojet thruster. Besides, one can manage to discover such enough fine effects as the azimuthal asymmetry of temperature field. The experiments have corroborated that ET plasma is transparent in the IR region, which permits a use of technique of this work for investigation of non-stationary processes when a thruster is going into a heat mode. Apart from investigation of temperature fiels in the standard modes of ET operation, thermovision measurements may serve as an effective means for diagnostics when optimizing thruster parameters, at the control of its manufacture quality, finishing developmeent works at the thruster adaptation to a spacecraft, at study of operation non-standard modes and influence of modifications introduced to a thruster design.

## References

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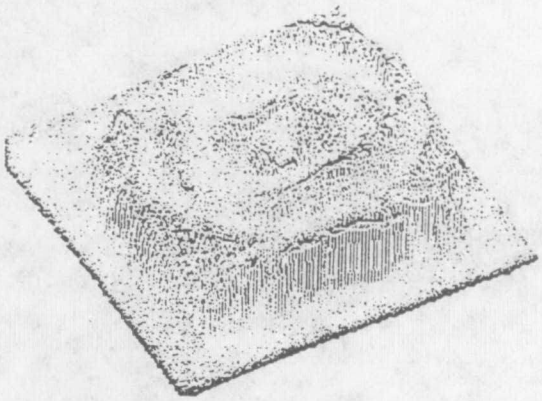

Fig.1
Emissivity distribution over an anod unit surface of electrojet thruster

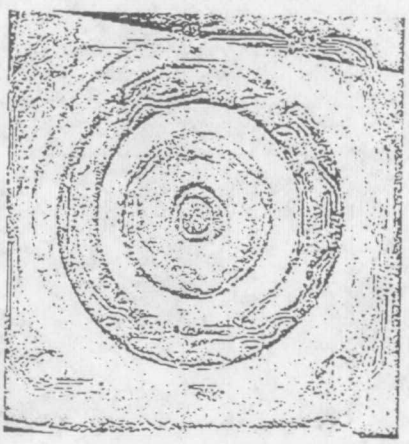

Fig.2
Emissivity distribution brought into coincidence with the videoimage of anod unit of electrojet thruster

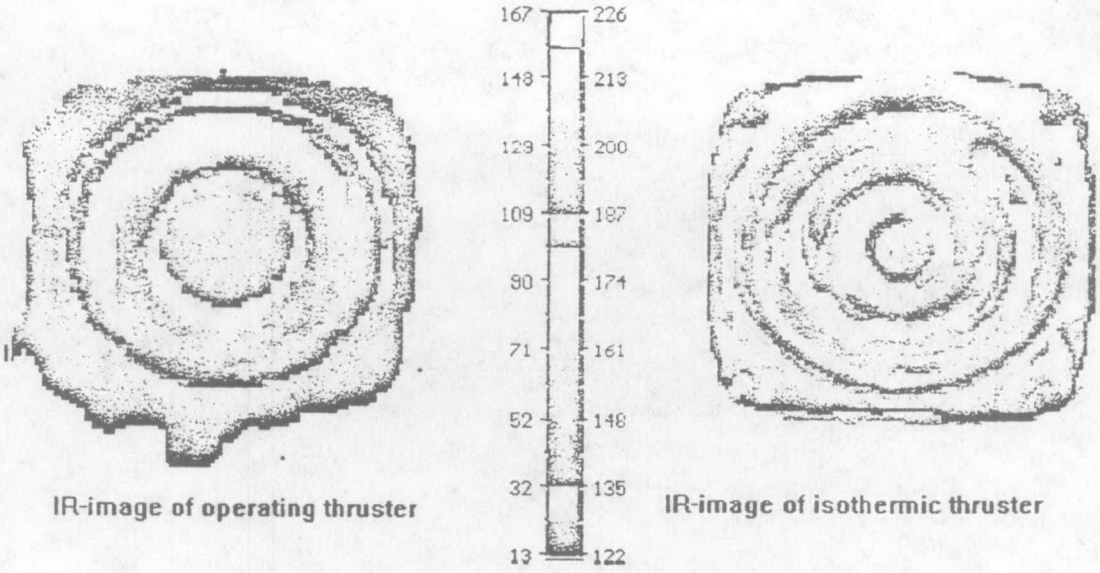


Fig.3
Infra-red images of operating and isothermic thrusters

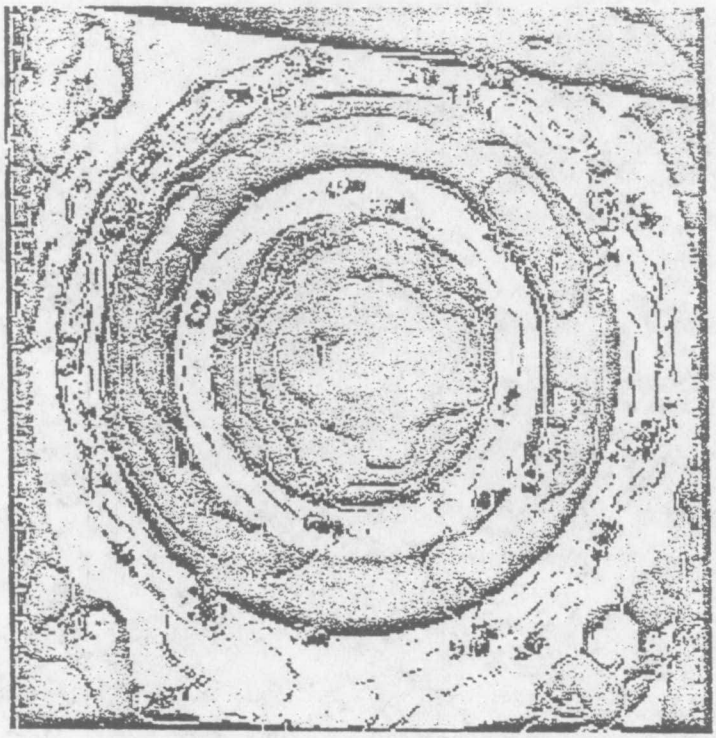

Fig.4

Temperatures of operating thruster brought into coincidence with the videoimage of anod unit.