The Device for Electric Propulsion Lateral Thrust Vector Components Measurement

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Abstract: At present on electric propulsion testing it is needed to measure not only thrust level but also thrust vector direction. This is caused by the requirement to mount thrusters on the spacecraft in such a manner, that their operation would not lead to the appearance of parasitic moments acting on the spacecraft. The thrust measuring device (TMD), purposed for measurement of electric propulsion lateral thrust components, was developed at Keldysh Research Centre. The device is based on the torsion balance scheme. The optical system based on the laser indicator is used as measuring tool. Tests of TMD revealed that in the range of lateral forces up to 1 mN it has a linear calibration characteristic. The paper presents the scheme of the device, the principle of its operation, including balancing, calibration and measuring procedures. Thrust vector direction measurement data for different Hall-effect thrusters at the power from 0.5 to 1 kW are presented.

I. Introduction

THE complexity in measuring of EP thrust vector lateral components is associated with extremely small values of magnitudes to be measured. For kilowatt-class thrusters with the thrust 10 to 200 mN and the mass 1 to 10 kg it is required to measure thrust vector lateral components values from 0.1 to 1 mN. Nevertheless, thrust measuring devices that are capable to measure the EP thrust vector direction, were developed in some organizations[1-4].

For determination of the thrust vector direction two types of TMD are used: on a basis of pendular suspension or torsion balance. The TMD based on pendular suspension (see, e.g., Ref. 4), are distinguished by small dimensions, that allow to use them in ordinary cylindrical small-size vacuum chambers, where thrusters are tested. The TMD based on the torsion-balance scheme[2] have much larger sizes that demands larger vacuum chambers for their use. However, the torsion balance can provide a rather high sensitivity of the extremely small magnitudes of the thrust lateral components measurement, produced by the thruster. Torsion balance is more simple and easy to use.

In this connection in SSC Keldysh Research Centre the choice in favour of the TMD based on the torsion balance scheme was made. A simple design of such type TMD was developed. In this TMD for lateral forces measuring the optical system based on the laser indicator was used.

II. TMD description

The TMD scheme is shown in Fig. 1. The weigh beam of torsion balance is mounted on the vacuum chamber axis. The flexible in twisting suspension is joined with the central section of the weigh beam. The thruster is positioned on the front end of the weigh beam and the counterweight - on the back. The thruster is installed on the moving mounting flange, fitted with the mirror. Outside the weigh beam of TMD a laser indicator is placed.

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For the ray to pass through the back flange the latter is made of quartz glass. A special drive allows rotating the suspension around its vertical axis to set the TMD "zero". Mating of the suspension and the weigh beam is realized through the bracket, within which rays of the laser indicator pass. There is a mounting flange adjustment assembly in the TMD design. Communication lines (gas and electric), linking the fixed and moving sections of the TMD, are supplied to the weigh beam to provide thruster and TMD operation.

A direct technique for lateral forces measurement is used. When mirror with the weigh beam end shift the reflected ray moves under lateral force effect. Reflected ray location is registered with the use of scale bar, installed opposite the back flange. The light spot deviation from the initial position characterizes the magnitude of the thrust vector lateral component. After the one component of the thrust vector measurement its other component is measured with a rotation of the thruster through the angle 90°. The amount of each thrust vector lateral components is derived from a difference between TMD indications in the course of thruster operation and immediately after operation that allows getting out of so-called "zero drift" effect.

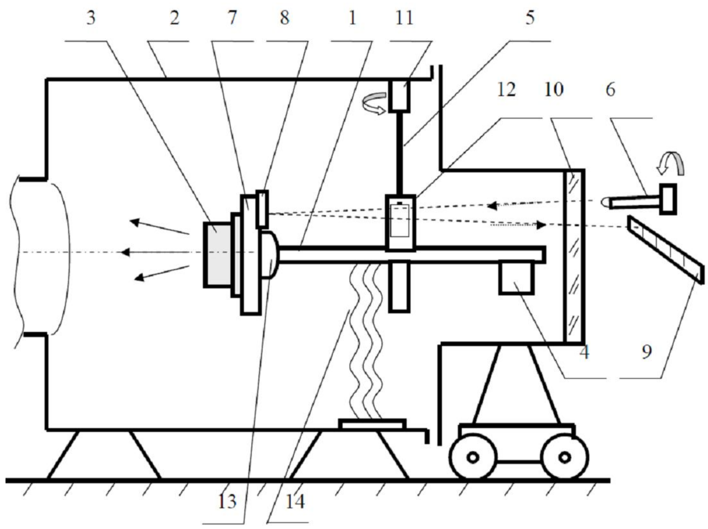

Figure 1. The TMD scheme.
1 – weigh beam, 2 – vacuum chamber, 3 – thruster, 4 – counterweight, 5 – flexible suspension, 6 – laser indicator with adjustment device, 7 – thruster mounting flange, 8 – mirror, 9 – scale bar, 10 – back flange of vacuum chamber, 11 – electric drive, 12 – bracket, 13 – adjustment assembly of the mounting flange, 14 – flexible communication lines (gas and electric).

A high measurement accuracy of the TMD requires an adjustment of mounting flange relative to the axis of the weigh beam suspension. With an inexact installation of the angular position of the mounting flange relative to the suspension a parasitic lateral force will be supplied to the TMD weigh beam after the thruster ignition that would lead to an error of the thrust vector lateral components measurement.

The principle of the thruster adjustment on the TMD is shown in Fig. 2. The ray from the laser indicator passes through a narrow vertical slit in the bracket and falls on the mirror, installed on the moving mounting flange. Further, the ray, reflected from the mirror, falls on the scale bar. The slit in the bracket is placed along the axis of the suspension. The adjustment involves the fulfillment of the following conditions:

- the ray leaving the laser indicator is to pass through the vertical slit in the bracket,
- the ray leaving the laser indicator is to fall on the centre of the mirror,
- the ray leaving the laser indicator is to be located at the same plane as reflected and falling rays.

The adjustment assembly, installed on the mounting flange serves to rotate the mounting flange relative to the weigh beam. Position of the laser indicator is controlled by the adjustment device.

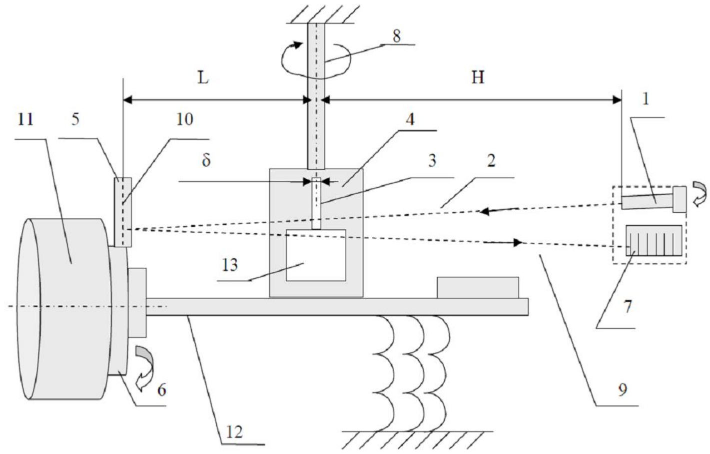

Figure 2. The adjustment scheme for the mounting flange with the thruster.
1 – laser indicator with the adjustment device, 2 – laser indicator ray, 3 – narrow vertical slit, 4 – bracket, 5 – mirror, 6 – mounting flange with the adjustment assembly,7 – scale bar, 8 – flexible suspension, 9 – ray reflected from the mirror, 10 – vertical indicator of the mirror, 11 – thruster, 12 – weigh beam, 13 – window for the passage of the reflected ray through the bracket.

To provide a high accuracy of the thrust vector lateral components measurement, the slit width, δ, in the TMD bracket was made approximately three orders less than the length of the weigh beam part, L, from the mounting flange to the bracket.

The maximum displacement of the light spot relative to the axis of the suspension, Z, that determines the adjustment error is defined by the expression: $Z = S \times L / (L + H) + \delta / 2$, where S is the value of the light spot displacement from the vertical plane on the scale bar, going through the laser indicator, H is the distance from the suspension axis to the laser indicator.

Substitution the data, relevant to the developed TMD, in this expression, results in the maximum error of the thruster angular mounting on the TMD approximately ± 1.5 angular minutes. It should be noted that the adjustment device, due to the arrangement of the laser indicator is outside the vacuum chamber, allows to check the accuracy of the thruster mounting on the TMD in the prestart adjustment of the TMD as well as during thruster testing. Such an operation may be required, for example, due to the thermal deformation of the TMD weigh beam under the impact of heat fluxes going from the running thruster.

An additional device was incorporated in the TMD configuration to examine the absence of the effect of the thruster vector principal component on the measurement of its lateral components. The device enables to load the TMD with a force, equal to the thrust vector principal component in magnitude and direction, and to check the absence of this effect on TMD indications. If TMD indications variate by the loading, this testifies to the appearance of the principal thrust component leads to the measurement error of the lateral components. In this case an additional adjustment of the TMD is realized.

III. Test results

The TMD tests showed that in the range of forces up to 1 mN the TMD calibration characteristic is linear (Fig. 3), that allows to use the direct technique for the lateral forces measurement, i.e., to determine magnitudes of lateral forces from an deviation of the light spot on the TMD scale bar. The measurement sensitivity of the lateral force was ~ 20 mm/mN.

When TMD was being created it was recognized, that the presence of the communication lines has a significant influence on the sensitivity of the lateral force measurement that is evidenced by the dependencies of the light spot deviation on the measuring scale on the lateral force in the presence and absence of communication lines, given in Fig. 4. These results show that at the stage of such TMD development, most attention should be focused on a stiffness decrease of the communication lines, but not the suspension. At the same time as shown by Fig. 4 the presence of the communication lines leads to violating of the calibrating characteristic linearity at forces exceeding ~ 1 mN.

Through the use of given TMD the thrust vector direction of different Hall-effect thrusters with the power ~ 0.5…1 kW, the mass ~ 2…3 kg, and the thrust ~ 20…40 mN was measured. The measurements revealed that the thrust vector deviation of the thrusters from the nominal one is less than 45 angular minutes. The measurement error of the thrust vector lateral components, produced by the 1 kW thruster, is at level ± 10….15 angular minutes. It was founded as well, that for the majority of the conducted measurements, the deviations of the thrust vector were observed

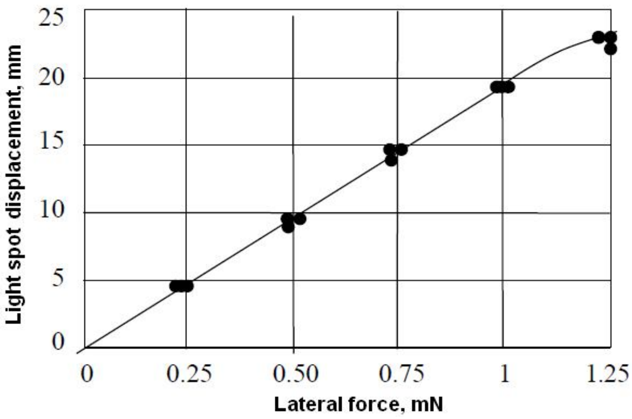

Figure 3. The displacement of the light spot on the measuring scale as a function of the lateral force.

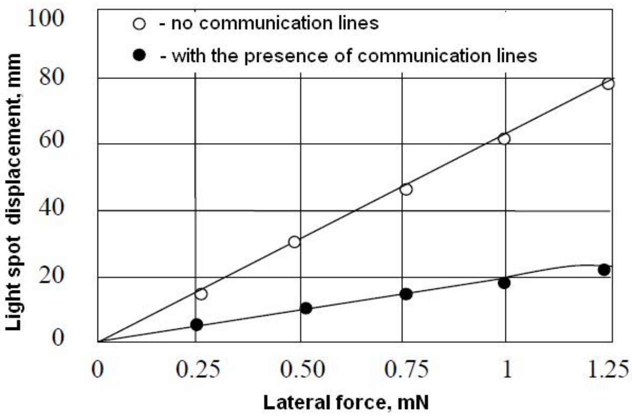

Figure 4. The displacement of the light spot on the measuring scale as a function of the lateral force with the presence and the absence of communication lines.

predominantly in the direction opposite the Hall thruster operating cathode.

The performed experiments demonstrated that the simple TMD developed may be successfully used for the EP thrust vector lateral components measurement.

IV. Conclusion

The device for the measurement EP thrust vector lateral components on the basis of torsion balance was developed. The device tests demonstrated the linearity of its calibration characteristic in the range of lateral forces up to 1 mN. The measurement error of the thrust vector lateral components, produced by the 1 kW thruster, is at level ± 10….15 angular minutes.

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