Ion Thruster ESKA 8 for North-South Stationkeeping of Synchronous Satellites

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It has been demonstrated by numerous experiments, endurance, and space flight tests that the electron bombardment ion thruster (Kaufman thruster) will be well suited for North-South stationkeeping of synchronous satellites. Based on the extensive experiences with the two ion thrusters, ESKA 18 and ESKA 28, a third one with 8 cm beam diameter called ESKA 8 was operated successfully for about 1000 hr. The measured ion-beam currents range from 50 to 235 ma, and the thrust from 4 to 15 mN at a specific impulse of 3160 sec. The most important experimental results obtained in the vacuum facility with 5-m length and 2-m diam are shown in diagrams. The measured performance data of ESKA 8 are compared with those of the other European thrusters.

I. Introduction

THE mercury electron bombardment ion thruster ESKA 8 was operated in the range of 4–15 mN at a specific impulse of about 3100 sec with an ion beam current from 50 to 235 ma. These parameters are well suited for N-S stationkeeping. It seems to be much better to have a somewhat higher thrust level than about 5 mN to decrease the duty cycle from 6 to about 4–5 hr/day so that the thruster life time need not exceed 1 yr.

II. Mercury Ion Thruster ESKA 8

Based on the experiences with the two ion thrusters ESKA 18 and ESKA 28, a third one with 8 cm beam diam called ESKA 8 was operated successfully for about 1000 hr. This laboratory test model differs somewhat from the thrusters ESKA 18 and ESKA 28 in the main hollow cathode assembly and in the grid system. Figure 1 shows a drawing of the thruster ESKA 8. The thruster body length and diameter are 80 and

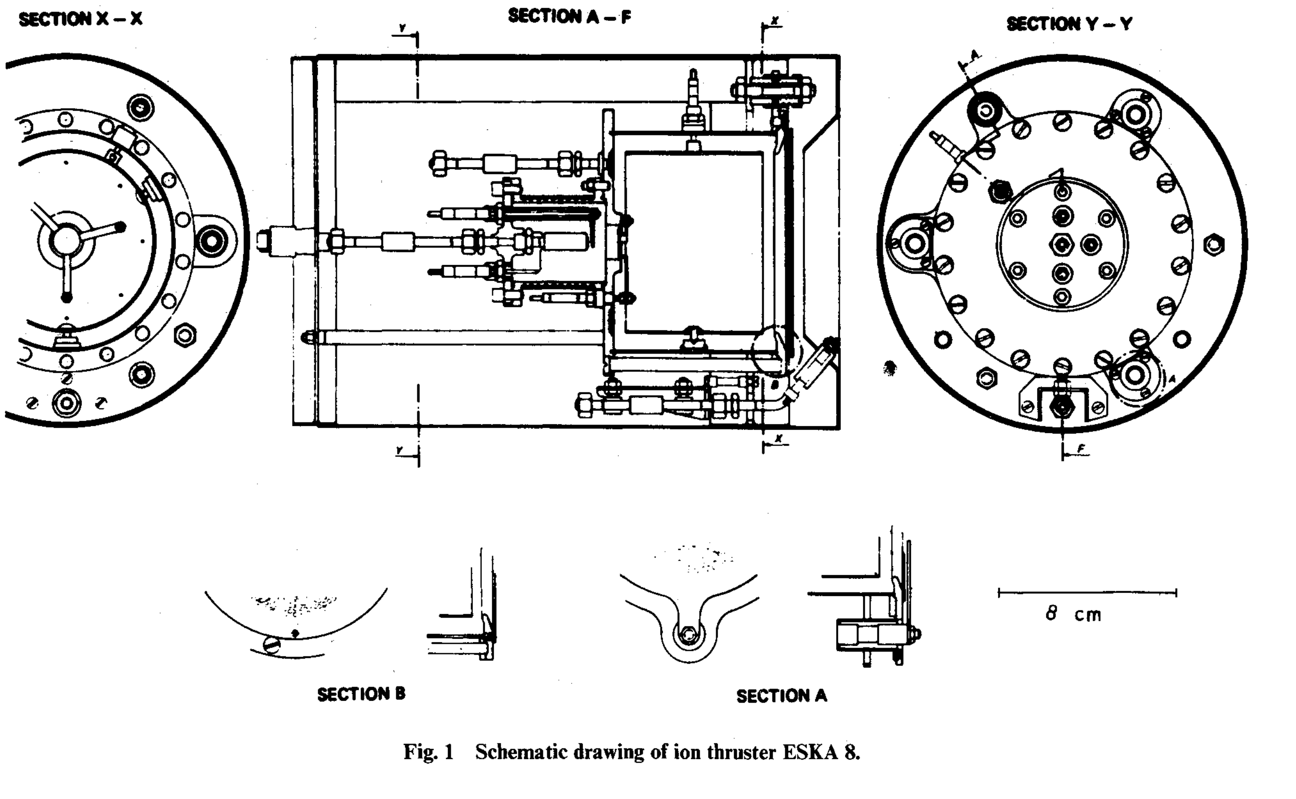

Fig. 1 Schematic drawing of ion thruster ESKA 8.

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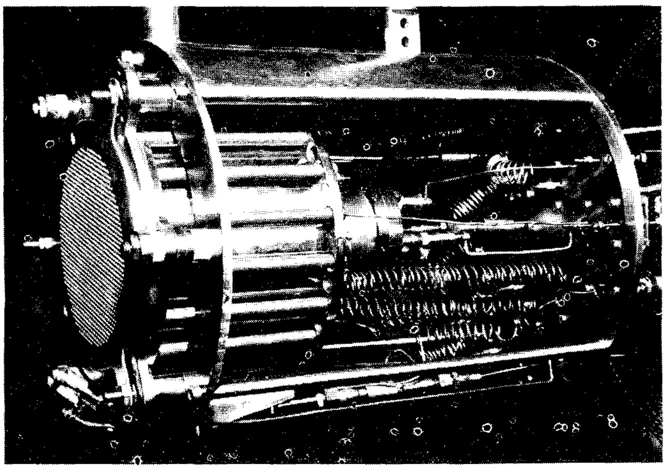

Fig. 2 Ion thruster ESKA 8 mounted at the prechamber flange of the vacuum facility with its ground screen removed.

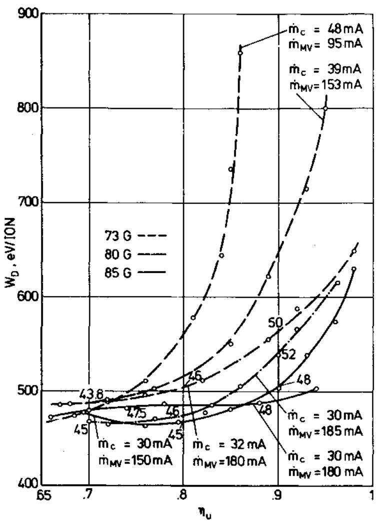

Fig. 4 Discharge loss w_D vs propellant utilization η_u for magnetic inductions of 73 gauss ---; 80 gauss —·—; and 85 gauss—— and different propellant flow rates and flow rate ratios. The other values are the discharge voltages.

100 mm, respectively. The anode i.d. is 80 mm and the thruster diameter is 170 mm. The hole diameter in the flat grids is 1.8 mm in the screen and 1.6 mm in the accelerator grid with an open area of 61% and a gap of 1 mm. The main hollow cathode is mounted inside a titanium cylinder of 36 mm i.d. and 44 mm length. The thruster has three vaporizers, two for propellant feeding into the discharge chamber and one for the neutralizer. Figure 2 shows the thruster ESKA 8 mounted at the prechamber flange of the vacuum facility (5 m length and 2 m diameter). The thruster ESKA 8 was operated with a set of permanent magnets arranged around the discharge chamber to produce an inhomogeneous magnetic field between the two pole pieces. The magnetic induction was changed by variation of the bar magnets between 12 and 18, corresponding to a magnetic induction from 73 to about 110 gauss. The magnetic induction was measured at a distance 10 mm from the screen pole piece.

III. Optimization of the Magnetic Induction for Different Propellant Flow Rates

All steady-state operation was at an anode potential between 800 and 1500 v and an accelerator grid potential of −800–−900 v. The total acceleration voltage of 1600 to 2400 v was high enough to produce ion-beam currents between 50 and 235 ma with drain currents between 0.3 and 0.5% of the ion-beam current. The discharge voltages ranged from 30 to 50 v with discharge currents between 0.7 and 4 a. Two vaporizers one for the main hollow-cathode and the other for feeding the mercury vapor directly into the outer region of the discharge chamber were used. All the data were obtained in the usual mode of straight-through flow from one end of the discharge chamber to the screen grid on the other end. There were two sets of measurements made. In the first case the mercury vapor was fed only through the main hollow-cathode and, in the other case, the two vaporizers were used. The main hollow-cathode vaporizer was electronically controlled by feed back of the ion-beam current. Mercury flows were limited on the low end by inability to sustain a discharge and at the high end by electrical breakdowns between the screen and the accelerator grids.

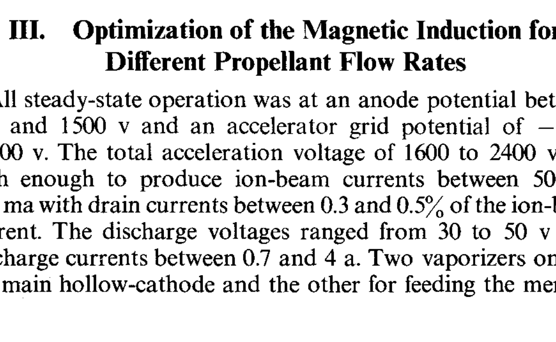

Fig. 3 Ion-beam current I_B vs discharge power P_D for a magnetic induction of 97 gauss and different propellant flow rates and flow rate ratios.

The measurements were performed in a wide range of propellant flow rates and flow rate ratios. In Fig. 3 the measured ion-beam currents vs the discharge powers are plotted for a magnetic induction of 97 gauss and for different mass flow rates. At the left side of each curve the discharge could just be sustained. With propellant flow through the main hollow-cathode only the ion-beam currents are much smaller than with two propellant flows. The largest ion-beam currents were obtained in those cases where the propellant flow rate $\dot m_c$ through the main hollow-cathode was as small as possible and the mass flow rate $\dot m_{MV}$ fed close to the anode had its largest values of about 200 ma. The curves in Fig. 3 must be seen together with those of Fig. 4. There the discharge loss vs the propellant utilization is shown for different magnetic inductions and propellant flow rates and flow rates ratios. With propellant flow through the main hollow-cathode only the discharge losses are larger than 780 ev/ion and the best propellant utilization is 82% at about 1500 ev/ion. With two propellant flows we have a much better situation (Fig. 4). The curves for larger propellant flow rates through the hollow-cathode than fed near the anode give smaller propellant utilization. The best results were obtained in those cases where the propellant flow rate close to the anode is much larger than through the main hollow-cathode. The smaller the propellant flow rate through the main hollow-cathode is, the smaller is the discharge loss. The mass flow rate through the hollow-cathode has a lower limit to sustain the main discharge. The physical interpretation is quite simple. When the flow rate through the hollow-cathode has its lowest possible value so that the discharge can just be sustained and the main propellant flow close to the anode is in a suitable range relative to the cathode flow rate then the ion-beam current has its highest and the discharge loss its lowest value. In this case the primary electrons give a relatively homogeneous discharge over the whole chamber diameter by collisions with the propellant atoms. In all other cases the discharge is more concentrated to the center of the

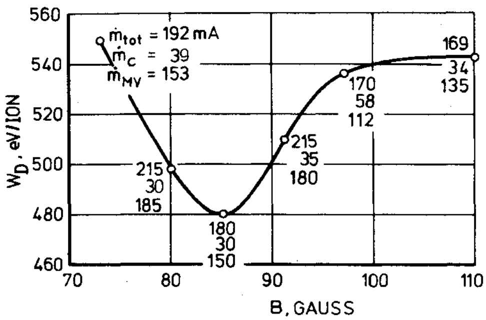

Fig. 5 Discharge loss w_D vs magnetic induction B for total propellant flow rates from $\dot{m}_{tot}$ = 169–215 ma.

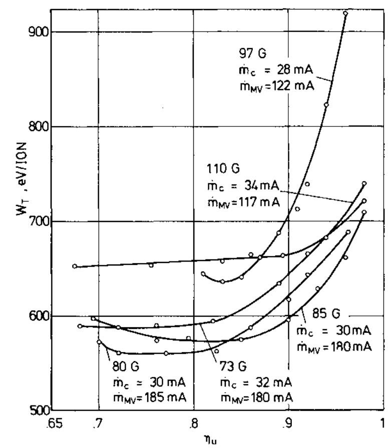

Fig. 6 Total thruster loss w_T vs propellant utilization η_u for five magnetic inductions and propellant flow rates.

discharge chamber, because the primary electrons lose their energies in the mercury vapor around the main hollow-cathode which has a higher density at a higher cathode mass flow rate.

From Fig. 4 we can see that the optimum magnetic induction for the thruster ESKA 8 is 85 gauss. Figure 5 shows the discharge losses vs the magnetic induction for nearly the same total mass flow rates of 169 to 215 ma at a propellant utilization of 85%. In Fig. 6 the specific total thruster loss is plotted vs the propellant utilization for different magnetic inductions and propellant flow rates.

For a magnetic induction of 85 gauss (14 bar magnets) we obtained the lowest total thruster losses in the range of 575–595 ev/ion at propellant utilizations from 85% to 90% and for a total propellant flow rate of $\dot{m}_{tot}$ = 210 ma equivalent.

IV. Discussion and Conclusions

The measured curves show good performance data for the bombardment ion thruster ESKA 8. This thruster was in operation for about 1000 hr with interruptions similar to those of the daily duty cycles in space applications. The conditions under which the thruster was operated were much harder than in a normal endurance test because we used a stainless steel target within the vacuum chamber and because the thruster was operated up to the highest possible input power.

Similar curves as shown in Fig. 4 were obtained with a 10 and a 20 cm bombardment thruster with different discharge chamber lengths at a discharge voltage of 40 v by Kaufman.[1] The wide range of measurements are particularly significant for throttled operation of a fixed configuration thruster, because many missions require operation at less than maximum thrust.[2] The comparison of the thruster ESKA 8 with the other European ion thrusters in discussion for N-S stationkeeping and with our two other ion thrusters ESKA 18 and ESKA 28 is shown in Table 1.

The electron bombardment ion thruster ESKA 8 shows performance parameters well suited for N-S stationkeeping applications. Electrical input power, thrust, and specific impulse can be well adapted to special satellite masses and missions.

References

[1] Kaufman, H. R., "Ion-Thruster Propellant Utilization," *Journal of Spacecraft and Rockets*, Vol. 9, No. 7, July 1972, pp. 511–517.

[2] Wilbur, P. J., "Experimental Investigation of a Throttlable 15 cm Hollow Cathode Ion Thruster," CR-121038, Dec. 1972, NASA.

Table 1 Performance characteristics of European ion thrusters

Thruster	Diam cm	Thruster power w	Thrust mN	Specific impulse sec	Propellant utilization	Ion-beam current density ma cm^{-2}	Thruster power/thrust w/mN
T4	10	230	10	3060	0.88	2.2	23
(throttled)	10	175	7	3060	0.87	1.4	25
CL 8	8	114	5	3060	0.87	1.65	23
SEP	7	117	4	4600	0.87	2.6	29
RIT 10 S	10	253.5	10	3965	0.842	2.2	25.35
ESKA 8	8	288	12.9	3160	0.90	4.0	22.3
CNES	7	104	1.5	6800	0.99	...	69
ESKA 18	18	1072	47.5	3860	0.85	2.4	22.6
ESKA 28	28	3455	143	3860	0.85	2.9	24.2