Russian Flight Hall Thrusters SPT-70 & SPT-100 After Cathode Change Start During 20-25 ms

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Abstract: There are represented the results of experimental research of start descriptions of flight Russian hall thrusters SPT-70 and SPT-100 produced by Fakel Experimental Design Bureau where flight incandescent start systems are changed by engineering models of non-incandescent start based on the neutralizer-cathodes NIC M1.05 and NIC M5.04 and ignition units developed and manufactured in Science & Technology Center of Space Power & Engines of National Aerospace University "KhAI". The comparison of these two thrusters modifications are represented. It is shown that start descriptions of Russian flight thrusters SPT-70 and SPT-100 with non-incandescent cathodes fit the requirements for spacecrafts orientation and stabilization control systems.

I. Introduction

The use domain of electric propulsion thrusters (EPT) is increasing each year. The time is now for necessary and reasonable EPT use in orientation and stabilization control systems (OSCS) of modern spacecrafts. The sufficient problem here is long start time of modern spacecrafts. Well known Russian Hall thrusters SPT-70 and SPT-100, for example, have the start time of 160…180 s, while the ignition time of OSCS thrusters must not be more than 1 s.

The cathodes are one of the most inertial units of the most of modern EPT. Moreover, cathodes make the limit of EPT life-time both for the number of ignitions and for the steady-state routine life-time. Cathodes also sufficiently influent on the power and gas sufficiency and other thruster's descriptions. So the choice of EPT cathode type is difficult and responsible multi-parameters task.

High emission gas discharge hollow cathodes (HEGHC) relating to plasma electron emitters class are the most advanced among the cathodes, which are developed now for EPT. These cathodes permit to obtain high emission current density (up to $10^6…10^7$ A/m^2 in the orifice) with low power consumption (10…25 W/A) and can operate in self-heating mode not only in steady-state routine but also in ignition routine, which has permitted to make on their base non-incandescent cathodes (NIC) without the start heater (incandesce).

It is known that NIC start-time in sufficiently lower then for incandescent ones[1].

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II. General Guidelines

A. Investigation Aim

The creation of flight samples of hall effect thrusters (HET) with fast non-incandescent start fitting to requirements for spacecrafts orientation and stabilization control systems is the final aim of this work, which is dedicated to experimental research of fast non-incandescent start of hall thrusters and is the further stage of Fakel EDB and KhAI joint works.

B. Main Engineering Descriptions of Investigation Object

Flight cathodes KE-5A and KN-3 were changed by engineering models of non-incandescent cathodes (NIC) M1.05 (discharge current 2.2 A) and NIC M5.04 (discharge current 4.5 A) produced in Science & Technology Center of Space Power & Engines of National Aerospace University "Kharkiv Aviation Institute", Ukraine (STC SPE KhAI) to improve the ignition descriptions of flight Hall thrusters SPT-70 and SPT-100 (Fakel Experimental Design Bureau, Russia).

The pictures of NIC M1.05 and NIC M5.04 engineering models (EM) are shown on the Figure 1. Their main technical parameters are represented in the table and on the Figure 2.

Description name and dimension	Parameters values			
	SPT-70		SPT-100	
	KE-5A	NIC M1.05	KN-3	NIC M5.04
1. Nominal discharge current, A	2.2	2.2	4.5	4.5
2. Xenon start mass flow, mg/s	0.25…0.35	0.1…0.2	0.35…0.50	0.1…0.2
3. Start power consumption, W	80…95	20…30	80…95	25…40
4. Start time, s	160	0.01…0.02	160	0.02…0.025

The discharge gap clamp and power supply of all the stages of discharge evolution in NIC during their start was provided by ignition unit (IU). IU operation is based on the direct voltage transformation into voltages, which are necessary for auxiliary discharge gap of hallow cathode, keeping the mode of glow discharge and arc discharge consequently.

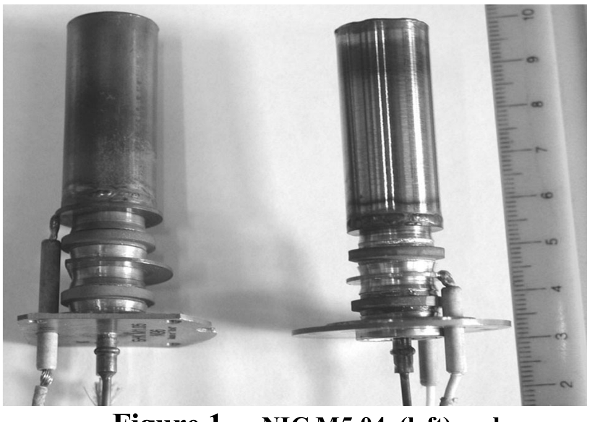

Figure 1. NIC M5.04 (left) and NIC M1.05 (right)

C. Measurements methods and tools

The tests and research of technical descriptions of hall thrusters took place on the Fakel EDB and STC SPE stands.

NIC were maintained on HET by technology interfaces in the position similar to standard cathodes.

Experimental research of HET with NIC were done in the following scail:

- pre-work up during not less then 30 min in HET nominal operation mode (I_p=2.2 A, U_p =300 V for SPT-70 and I_p=4.5 A, U_p =300 V for SPT-100);
- investigation of cathode xenon mass flow rate influence on HET stationary parameters in the range of 0.05-0.40 mg/s with nominal discharge current;
- investigation of discharge current influence on SPT-70 stationary parameters beginning form 2.20 A and decreasing with the step 0.20 A with cathode mass flow rate 0.15 mg/s and autonomous solenoids switch-on, solenoids current on all the modes was 2.20 A;
- determining the start descriptions of HET with NIC included the measurement of functional start time (time between IU switch-on and discharge current nominal value appearance) with different delays between cathode switch-on as well as the investigation of discharge voltage and current and voltages and currents in IU and NIC chains change in time. Time was measured by ignition voltage and discharge current oscilloscopy. Two beam

oscilloscope VC-5470 and fast processes automatic registration system were used for this purpose.

The sequence of HET with NIC start was as followed;

- xenon mass flow through the cathode and anode switch-on;
- discharge voltage switch-on;
- IU with feed voltage 27 V switch-on;
- IU operation keeping during 1…2 s, then IU switch-off.

D. Investigation results.

Stationary descriptions.

The influence of cathode xenon mass flow rate $\dot{m}_{к}$ on SPT-70 stationary parameters is searched in the range 0.05…0.40 mg/s with nominal discharge current I_p=2.2 A and voltage U_p=300 V during the operation with KE-5A standard cathode and EM NIC M1.05 and EM NIC M5.04. It is found that HET-70 thrust with NIC were 41.1…41.6 mN inside entire range of research parameters, which is some higher then nominal value 40 mN in operation with KE-5A. It is because of lower NIC power consumption comparatively with standard cathode. Some approximate description of cathode power consumption can be floating potential $U_{кз}$ value, which was measured as potential difference between cathode and "ground".

The dependences of $U_{кз}$ on $\dot{m}_{к}$ are shown on the Figure 2. One can see that NIC M1.05 and NIC M5.04 power consumption is by 5…8 W/A lower than for KE-5A. Optimum value of $\dot{m}_{к}$ for NIC M1.05 is 0.15 mg/s.

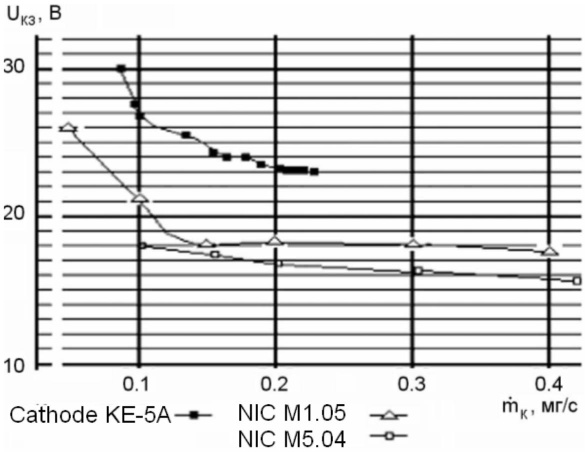

Figure 2. U_f **dependence on** $\dot{m}_{к}$

The influence of discharge current I_p on SPT-70 stationary parameters is searched. It is found that NIC M1.05 provides the stable thruster operation in the range of I_p =0.65…2.2 A with $\dot{m}_{к}$=0.15 mg/s. SPT-70 thrust was changing here from 7.5 mN to 41.2 mN.

Start descriptions

IU was switched-on for 1…2 s during the search of SPT-70 with NIC start descriptions and cathodes start was normal without the failure every time. Ignition descriptions investigations were in two modes: "cold" – NIC start from cold state when the delay between switches-on was not less than 1 hour, and 'hot' – NIC start from hot state with the delay not more than 6 s after HET stationary operation during not less than 15 min, or start of incandescent cathode heating to hot state by standard heater in nominal mode. The results of "hot" start are not represented here.

The most typical SPT-70 electric descriptions are show on the Figures 3…8: discharge voltage U_p and current I_p change in time during the functional ignition period as well as ignition voltage $U_п$ and current $I_п$ in ignition chains in cathodes. These descriptions measurement were done in millisecond range to provide the registration of all the stages of discharge evolution during the start, except the clamp (micro- or even maybe nanosecond range).

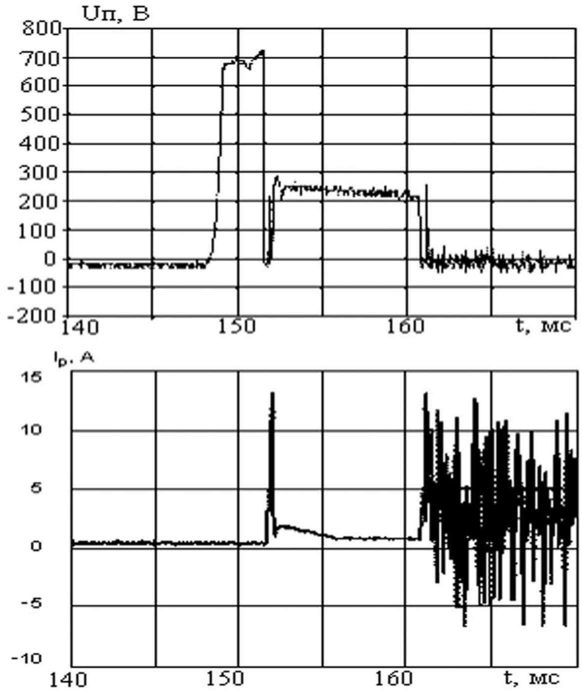

Figure 3. SPT-70 with NIC M1.05 "cold" start descriptions with $\dot{m}_{к}$**=0.15 mg/s**

“Cold” start

Three stages of discharge evolution during SPT-70 with NIC M1.05 “cold” start with $\dot{m}_{к}$=0.15 mg/s are well seen on the Figure 3: I stage with duration of 4 ms – high voltage mode of glow discharge keeping by IU clamp chain; II stage with duration 10 ms – normal glow discharge keeping by IU glow discharge keep chain and III stage – arc keeping by consequent IU chain. Thus thruster functional start time is 14 ms.

Figure 4 demonstrates that “cold” functional start of the same SPT-70 with the same NIC M1.05 with the same $\dot{m}_{к}$ is possible during 5 ms via two stages – I (5 ms) and III, missing II.

It is seen on the Figure 5 that with all the same non-changed conditions that in two cases before (Figures 3 and 5) “cold” functional start of CPT-70 is possible during 2 ms with pass on the II stage just after the clamp providing after shown 2 ms time passing to the last III arc stage of discharge evolution. The realization of one of these three different sceneries of “cold” start takes place occasionally and additional start researches with large statistic volume are necessary to make ignition process control possible.

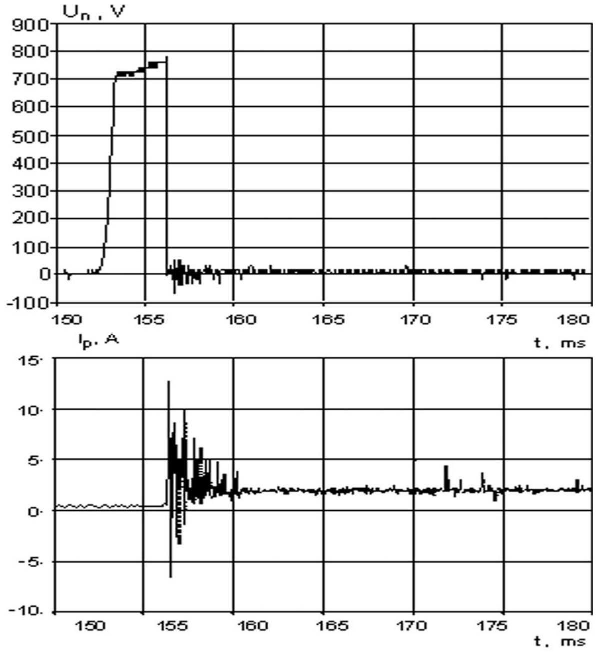

Figure 4. SPT-70 with NIC M1.05 “cold” start descriptions with $\dot{m}_{к}$=0.15 mg/s

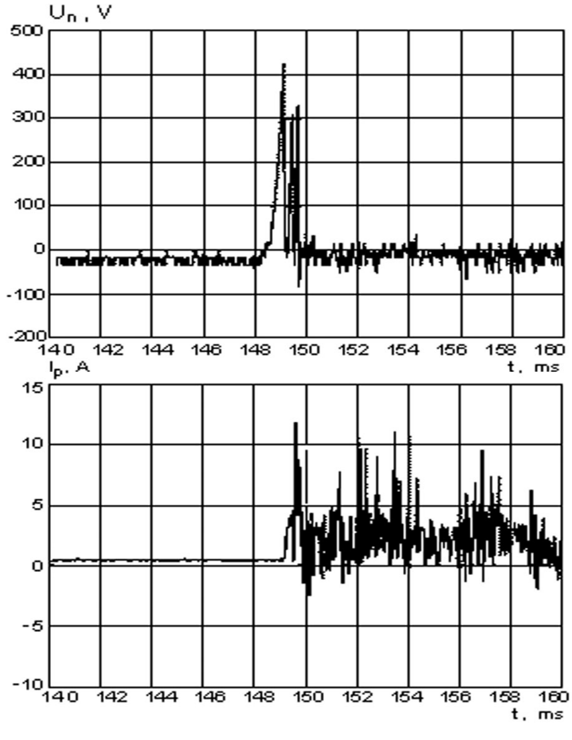

Figure 5. SPT-70 with NIC M1.05 “cold” start descriptions with $\dot{m}_{к}$=0.15 mg/s

III. Conclusion

Researches had shown that the change of incandescent cathodes by non-incandescent ones permits to decrease the functional start time of Russian flight hall thrusters SPT-70 & SPT-100 to 20-25 ms (by 4 orders) and start power consumption and start xenon mass flow – in 2…3 times. The power consumption of NIC M1.05 and M5.04 in steady-state routine inside CPT-70 and SPT-100 is also lower than ones of flight cathodes KE-5A and KN-3.

Thus, the use of NIC in flight CPT-70 and SPT-100 sufficiently changes their properties, firstly – ignition descriptions, which permits to increase their use domain on the spacecrafts OSCS.

References

1. Schatz M.F. Heatless Ignition of Inert Gas Ion Thruster Hollow Cathodes //18th International Electric Propulsion Conference, AIAA Papers, Alexandria, Virginia, Sept. 30 – Oct. 2, 1985. – IEPC-85-208.