

Results of Tests of High-Current Cathode for High-Power Hall Thruster

IEPC-2011-197

*Presented at the 32nd International Electric Propulsion Conference,
Wiesbaden • Germany
September 11 – 15, 2011*

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Abstract: In the article the results of development of high-current cathode (up to 50 A) for high-power Hall thrusters are given. The description of test-bench facility: vacuum system, power supply system, storage and Xenon feed system, measuring system.

I. Introduction

At present one of the most used in space plasma thrusters is Hall thruster (HT), presented in Stationary Plasma Thruster (SPT) and Anode Layer Thruster (TAL). These thrusters are well enough researched. A variety of companies (such as EDB “Fakel”, Busec, SNECMA) created families of thrusters which overlap the powers from hundreds of watts to tens of kilowatts. For example, Hall thruster SPT-290 with power 50 kW, created in the USSR in the middle 80th in EDB “Fakel” is known. In the European Union under the program HIPER the HT intended for 50 kW regime is created. These Hall thrusters have efficiency about 70% at nominal operating currents 50-60 A. Design operating life is defined in 2000 hours, what determines the possibility of such thruster using for interplanetary missions.

However, the question of development of the cathode for such thruster remained open up till now. In the STC SPE at KhAI there is great experience in creating high-current cathodes for space and ground application. Therefore, the cathode with a nominal operating current of 50 A was created. The studies of its characteristics and preliminary short-term life tests were carried out

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II. General Guidelines

A. Small step back into history

Currently it is not a secret that in the USSR there were a lot of programs related to the necessity to use plasma thruster such as SPT and EDB “Fakel” in Kaliningrad was engaged in development and manufacture of it. The scientific support for these programs was carried out by numerous research organizations, including KhAI, which was assigned to the development, research and testing of new types of cathode-neutralizers for the whole family of SPT. For the serial cathodes EDB “Fakel” applied emitters on basis of zonal fused LaB_6 produced in the Institute of Problems of Materials (Kiev, Ukraine). With a sufficiently high work function (2.7 eV at 1400-1500 °C) and low resistance to poisoning these emitters have the only benefit: they allow long-term storage under atmospheric conditions.

Accumulated experience at KhAI in researching the emissive materials let us offer the use of impregnated emitters with tungsten barium aluminate composition. The work function of emitters varied in range 2.1-2.2 eV in significant decrease of operating temperature 1400-1200 °C. On the basis of this emission material the cathodes with working currents in range from 1.5 to 70 A were developed. However, for space applications they were not used because of the collapse of the Soviet Union.

In the independent Ukraine the works in improvement of emission materials were continued. Different compositions and fabrication method were researched. The main results are shown in Fig. 1, for comparison there is also data for other types of emitters. New types of emitters have tungsten matrix with impregnation by Ba Sc oxides. Developed materials have full resistance to atmospheric influence, high resistance to poisoning, are capable to work with current densities 100 A/cm² in bombardment by ions with energies 10-12 eV and temperature 900-1100 °C [1].

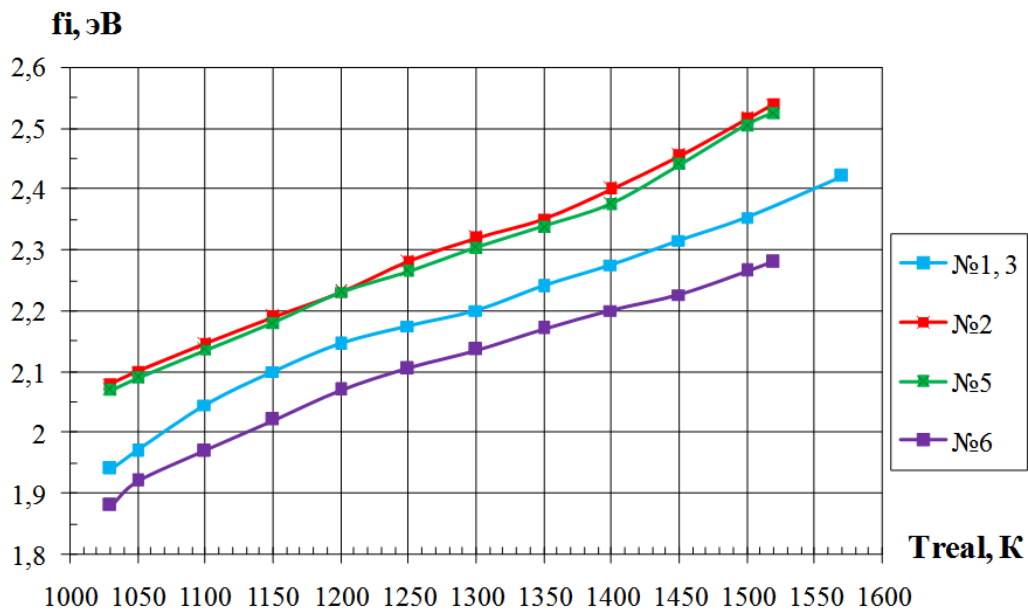


Figure 1. Low work function vs temperature #2,5 BaO, #1,3 BaO-Al₂O₃, BaO-ScO based impregnate emitters.

Developed materials were successfully used in series of high-current cathodes for ground application. In fig. 2, 3a, 3b the cathodes which work in nominal currents 500 A and 2000 A are shown. As a working gas both the grade 5 Xe (99.999) and commercially pure Ar (99.8) were used. In the second case the running time 1000 hours was done. The tests have shown the absence of changing of emissive properties both in vacuum testing and in use in atmospheric conditions. Further tests were not carried out because of high financial costs. Thus the high resistance of emitters to poisoning was confirmed.

The results of these studies, as well as experience gained in the development of the cathodes with a nominal operating current up to 20 A were used as the basis for development of cathodes with current up to 60 A.

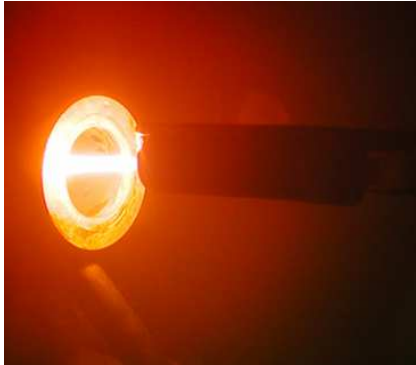


Figure 2. 500 A cathode Xe working



a)



b)

Figure 3. 2000A cathode installed in vacuum chamber a) and its working b).

B. Test equipment

To study of the cathode, a test bench equipment STC SPE at KhAI. Scheme and characteristics of the vacuum system are shown in Fig. 4. Wiring lay-out of cathodes and its installation on the cathode flange are shown on Fig. 5. In addition to measurements of electrical parameters the test bench was supplement with spectral measurements and probe diagnostics. However, at present study, this diagnostics wasn't used.

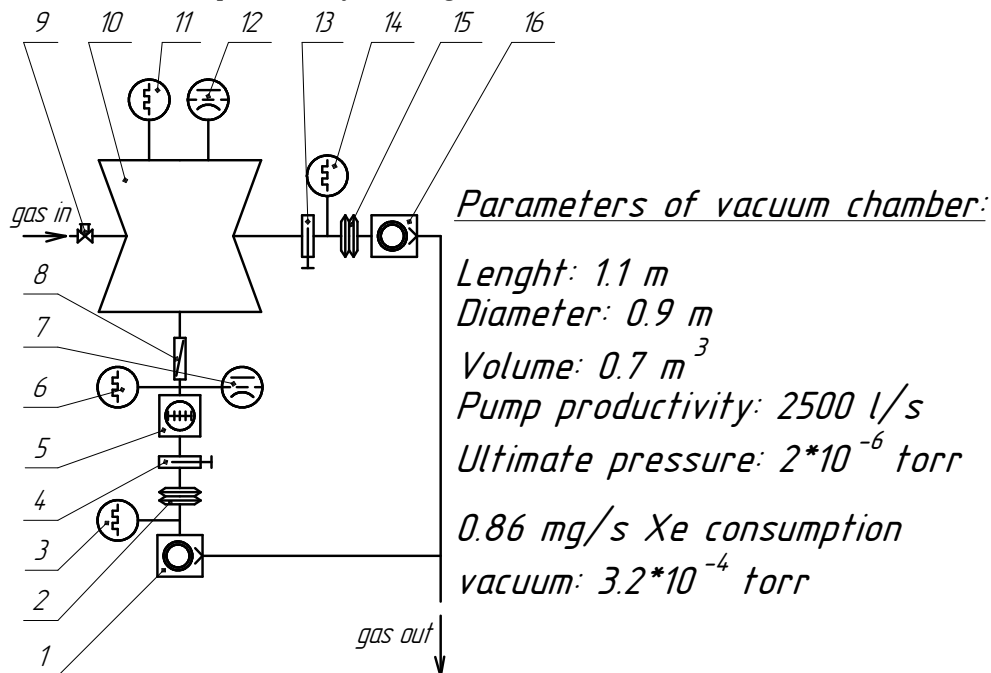


Figure 4. Hydraulic circuit and parameters of vacuum facility:

1, 16 – forepumps; 2, 15 – bellows; 3, 6, 11, 14 - thermocouple vacuum manometers; 4, 13 – vacuum valves; 5 – turbo-molecular pump; 7, 12 – ionization vacuum manometers; 8 – slide gate; 9 – inlet flap; 10 – vacuum chamber.

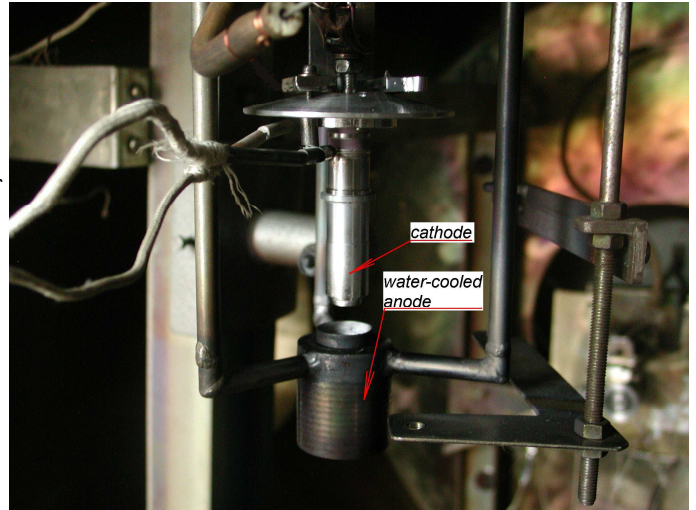
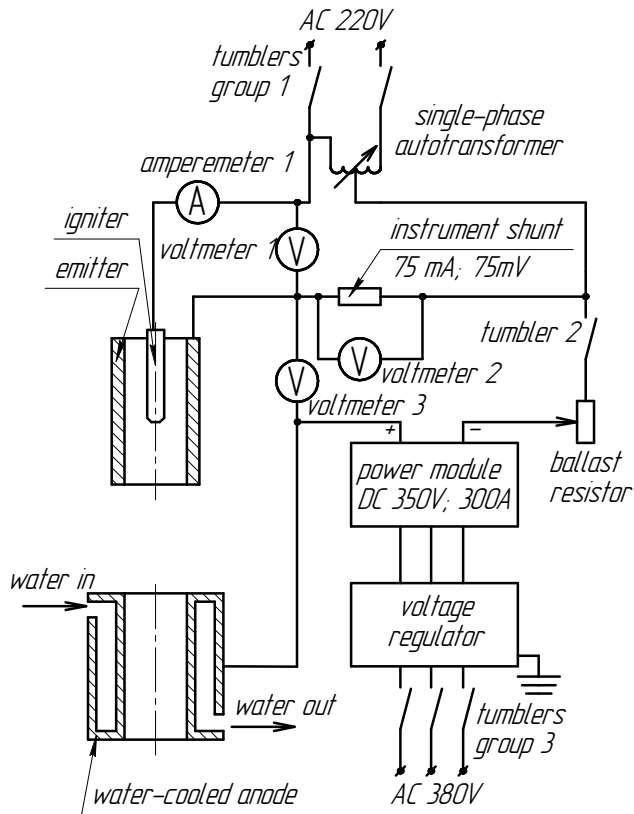


Figure 5. Wiring lay-out of cathodes and its installation on the cathodes flange.

C. Test results

Traditionally, in KhAI tests were carried out with heater-less cathodes. Initially for determination the limiting operation currents the cathode design stably worked at 20-25 A was tested. For reducing heat loads this model was equipped with a radiator mounted on the slice of metal-ceramic unit. Two cathodes were tested at operating currents up to 45 A and mass flow rates 0.75 and 0.97 mg/sec Xe (99.999). The analysis of results showed that the temperature of the metal-ceramic unit remained within acceptable limits (approximately 600 ° C), but the temperature of diaphragm remained high (1600 ± 10 °C).

The optimization of thermal scheme of the cathode by numerical methods showed that achievement of significant change of the temperature fields is practically very difficult task (see Fig. 6 and Table 1.) Therefore, to achieve the required operation parameters the inverse scheme of cathode ignition was applied.

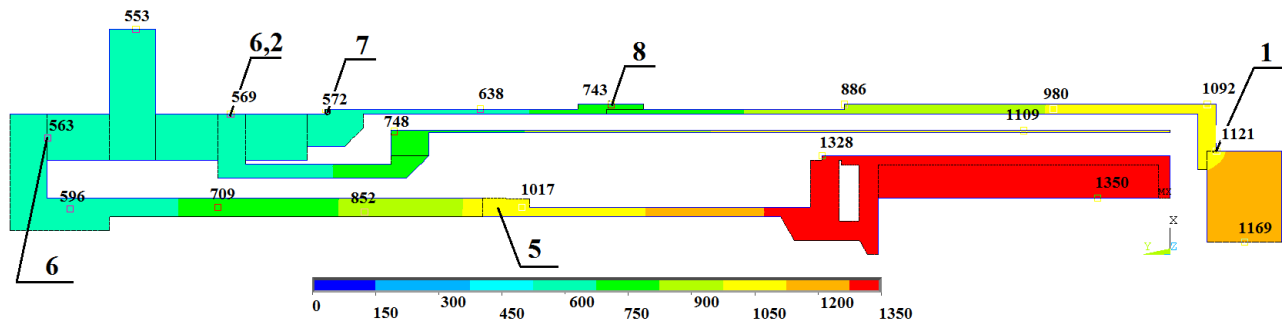


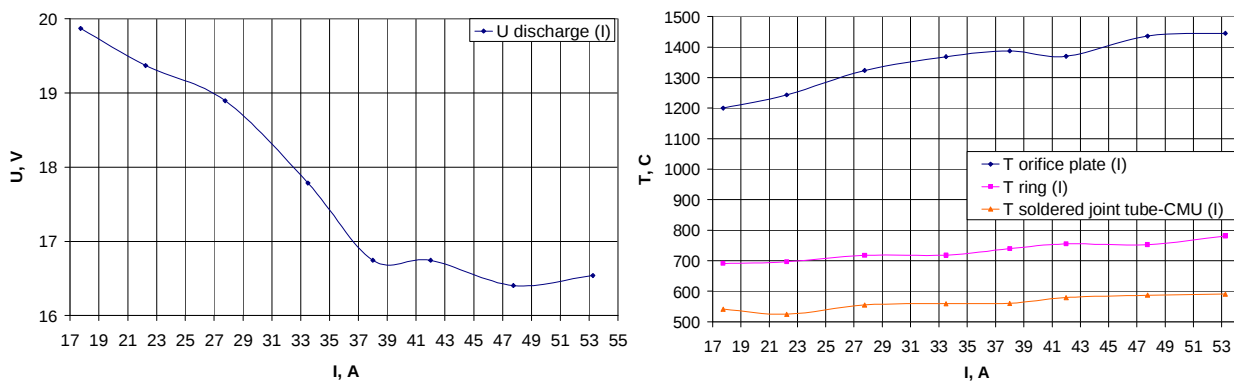
Figure 6. The results of thermal computation for 50 M1 catode modification.

Table 1. Results of cathode HHC50M1 optimization.

№ Point	T, °C	Change of T after optimization, °C	№ Point	T, °C	Change of T after optimization, °C
1	1116	Reduced on 5 °C	6,2	436	Reduced on 133 °C
5	907	Reduced on 110 °C	7	450	Reduced on 123 °C
6	417	Reduced on 147 °C	8	726	Reduced on 17 °C

In this type of heater-less cathodes emitter and diaphragm have the same potential. This lets significantly facilitate the cooling of the cathode emitter and simplify its structure.

The test results of HHC-50M3 are shown in Fig. 7. The cathode was tested at mass flow rate of Xe (99.999) 0.86 mg/s in the range of currents from 17 A to 55 A. There were possible short-term (up to 15 min) increase of the current up to 60 A. At the nominal current 50 A the temperature at the place of metal-ceramic soldering did not exceed 580 ± 5 °C without a radiator in a free suspension, the diaphragm temperature didn't rise above 1450 ± 7 °C. All critical points of construction had reserve at 150-200 °C in factor of safety. The cathode kept operability without changing its characteristics and the visible damages of the diaphragm after 200 hours of testing at 25 runs.

**Figure 7. Voltage and cathode temperature vs current for HHC-50M3.**

After optimization of the thermal scheme of the cathode M3 for further tests two cathodes HHC-50M4 and HHC-50M4bis were made. For guarantee the planned life-time the most thermally loaded elements of the cathodes were made of W-Re and Mo-Re zone melting alloys. In addition in the cathode 4bis the new emission material (BaO ScO system) with low work function which is lower on 0.1-0.3 eV than it is shown on Fig. 1, and high resistance to poisoning was used.

Test results are presented on the Fig. 8. Both constructions stably worked in the range of currents 10-60 A in mass flow rates 0.3-0.9 mg/s. Cathode 4bis (Fig. 9) had the opportunity to work in long-time mode up to 120 A. The temperature of the cathode M4 diaphragm did not significantly differ from the model M3 and was 1420 ± 7 °C. At the same time, operating temperature of diaphragm of model M4bis was significantly lower (1305 ± 5 °C). Both models were tested during 200 hours in 25 starts and showed stable performance.

The main characteristics of the cathode-HHC-M50M4 are presented in Table 2.

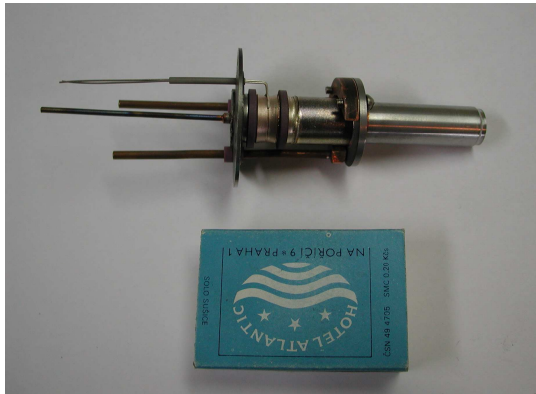


Figure 9. Photo of M4bis cathode modification.

Table 2. Characteristics of the cathode HHC-M50M4.

	Parameter	Level	Notes
1	Working current, A	15-55	Long duration conditions
2	Near SHC potential, V	15-26	Dependent on current
3	Mass flow rate, mg/sec	0.3-0.9	Dependent on current
4	Working gas	Xe	Purity 99.999 %
5	Ignition tension, V	700	Not more
6	Start time, sec	30	
7	Life time, hours	200 /10000	tested / prognosis
8	Ignition time	0.1	
9	Size, diam.(flange) / length, mm	14(38) /125	
10	Mass, grams	72	

To estimate the rate of Ba loss the spectral diagnostics and single probe were used. Fig. 10 shows the temperature distribution and plasma concentration over the radius of the cathode plume at a distance 4 mm from the diaphragm. In this section the cathode plasma spectrum was measured (Fig. 11).

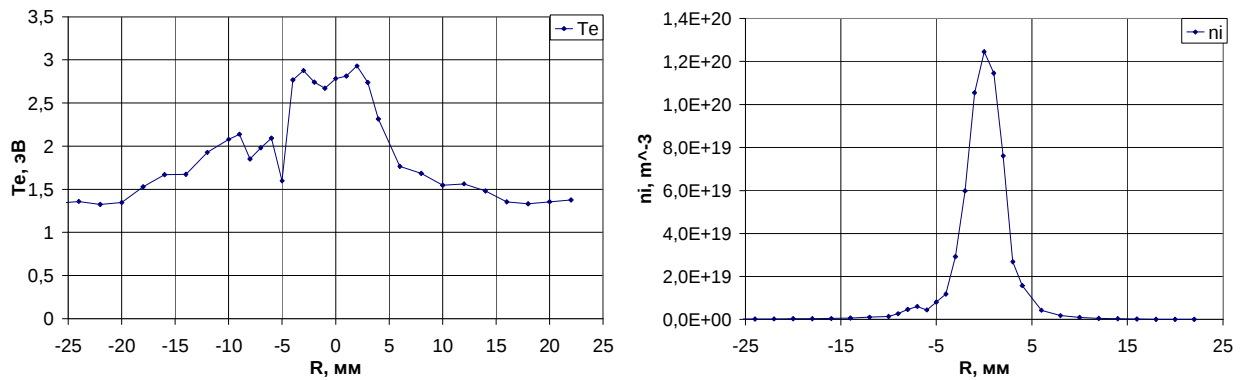


Figure 10. Temperature and electron concentration vs cathode plasma flux radius.

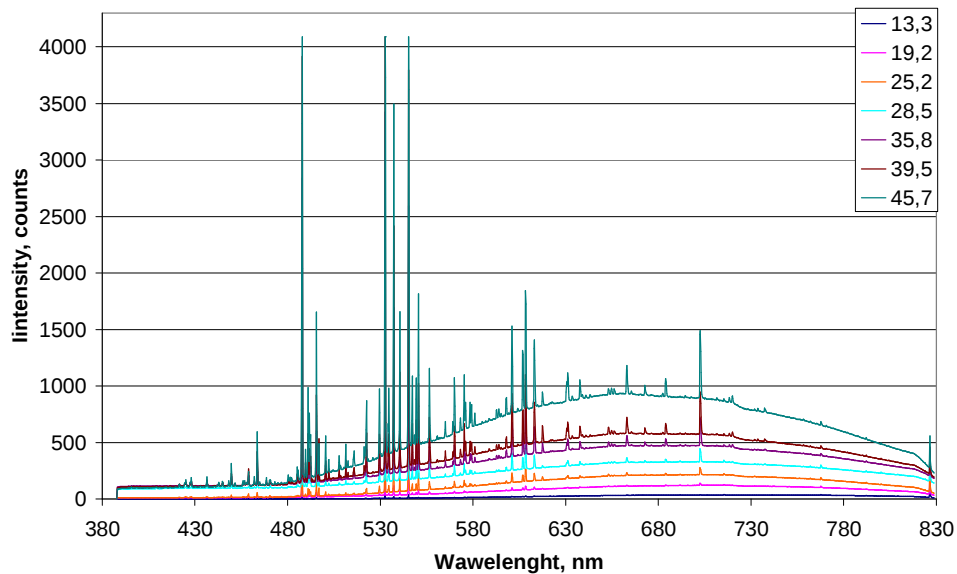


Figure 11. Spectral behaviour vs discharge current.

By the results of these measurements the relative erosion of Ba was calculated, as shown in Fig. 12.

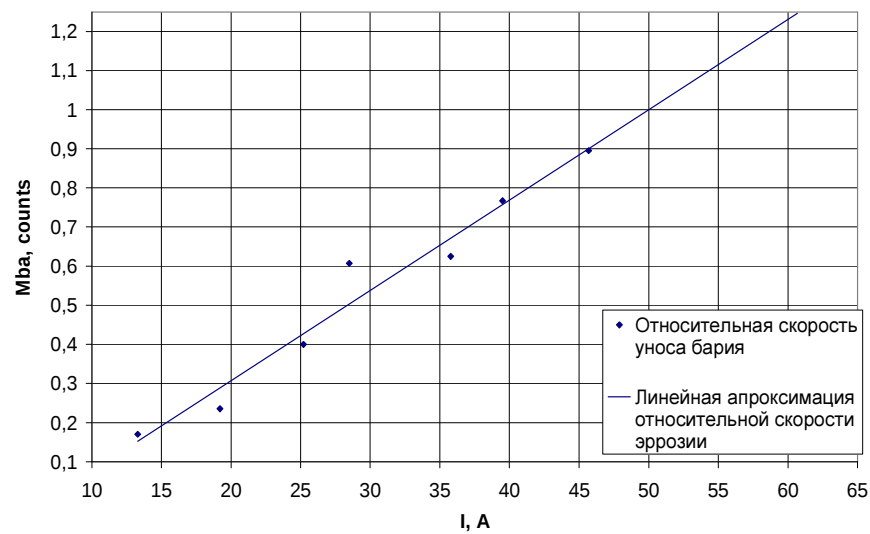


Figure 12. Relative speed of barium ablation depending on a discharge current.

III. Conclusion

After different numerical computations, constructive decisions and notices, researches of operating parameters of series of high-current heater-less cathodes in KhAI the HHC-M50M4 was developed. The cathode efficiently operates in the range 15-50 amperes.

Acknowledgments

Authors would like to express thanks to their young followers and students to Parahin G. and Zuev Z., also to Titov M. for valuable suggestions and help in translation of technical part of the article.

References

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