NEON CRYOVACUUM SYSTEM FOR ENDURANCE TESTS OF ELECTROJET PROPULSION SYSTEMS

A.B. Batracov, Yu.N. Volkov, Yu.F. Lonin, A.G. Ponomarev

NSC “Kharkov Institute of Physics and Technology” Kharkov, Ukraine

E-mail: lonin@kipt.kharkov.ua

In article Cryovacuum Oil-free system designed to operate in the pressure range (10^5 ... $4{\cdot}10^{-5}$) Pa is described. Pumps and cryopanels included in a vicious cycle of manufacture and storage of liquid neon. The vacuum system is designed IPENMA National Scientific Center KhIPT for endurance tests of electrojet propulsion systems (EPS). In work the cryovacuum system for EPS at which a working body are xenon or to a lesser extent, argon is presented. In work the cryovacuum system for EPS at which a working body are xenon or to a lesser extent, argon is presented. To explore new developments such engines especially for endurance tests (up to 1000 hours of continuous operation) necessary to create a clean oil-free vacuum ($2{\cdot}10^{-2}$ Pa). It is provided with neon Cryovacuum systems that can remove the heat load of up to 10 W/cm^2. It is shown that at condensation more than 1.5 g/cm^2 of xenon don't occur changes in the speed of pumping of neon pumping-out elements, i.e. at the cryopanel area near 1m^2 carrying out resource tests of EPS is possible.

PACS: 52.30.g, 50.80.vp

INTRODUCTION

Rapid advancement of space rocket technologies in the sixties of the past century has promoted the development of plasma electrojet propulsions (EJP). At first, EJP, providing a small thrust for a long time have permitted a precise correction of the spacecraft flight trajectory parameters and the spatial orientation. The family of EJP includes plasma engines (PE), electrochemical engines (ECE) and electric-ion engines (EIE) [1-4].

The currently EJP are characterized by higher performances as compared to previous models. The EJP operating parameters are:

- Electric-ion engines (EIE) – velocity of jet ≈ 20...50 km/s, thrust ≈ 20...250 mN, efficiency ≈ 60...80%;
- Plasma engines (PE) – velocity of jet ≈ 10...50 km/s, thrust ≈ 10...500 mN, efficiency ≈ 45...60%

with a high endurance of ~ 10000 to 30000 h.

The modern electric jet engines, using plasma (ionized gas) as an actuating medium, permit to achieve a significantly higher thrust (velocity of jet) with a low propellant consumption that allows them to run for a long time.

EJP with such high performances can serve as cruise engines during flights for deep space orbits where the tractive resistance is almost absent [5].

The cryogenic pumping system is designed to produce oil-free vacuum pressure in the range $1{\cdot}10^{-5}$ Pa and modeling space. For cooling agents liquid neon and liquid nitrogen were applied. Cryovacuum system is designed for pumping high-ionized beams, inter alia, terrestrial life tests EJP [6, 7].

1. EXPERIMENTAL EQUIPMENT AND TECHNIQUES

The diagram of the vacuum assembly, with an inside cryovacuum panel, is presented in Fig. 1. The assembly is enclosed within the cylindrical chamber of 0.82 m^3 volume. Cryogenic pumps 12, 17 and cryopanel 2, being used with liquid neon, are connected into the closed cycle of liquefaction and storage (not shown). The main components of the cycle are: compressor of 150 atm pressure, gasholder, high-pressure cylinders, cleaning units and neon liquefier. The liquefier produces 5.9 dm^3/h. A closed cycle permits to exclude the neon losses and to reduce the running costs. Nitrogen-neon cryopump 12 is used as a forpump. Inside the chamber is a neon cryopanels bleeder type 2. It is made of copper, and has a surface area of 0.9 m^2. Nitrogen shield 5 (conductivity of 0.5) protects the cryopanel from the heat and gas flows. Initially the high-energy beams are cooled at the end nitrogen shield.

Plasma source 8 is installed at the opposite end flange. It is provided with a gas input system designed for measuring and controlling gas flows in the wide range**.** Besides this system feeds gas (Xe in our case) to EJP. Neon adsorption pump 17, designed for evacuation of Ne, H^2 and He, is fastened to the chamber bottom via the sucker provided with a valve.

2. EXPERIMENTAL PROCEDURE

To control the residual atmosphere composition a mass-spectrometer is used. The shield and cryopanel temperatures are measured with copper-constantan thermocouples. The forpump functions in the following way. The mechanical forpump AVZ-20 starts the liquid nitrogen squeezing via the nitrogen shield under pressure lower than the air pressure, then valve 10 opens to the vacuum chamber. The air concentrates on the shield, flows down it and comes into the liquid condensate receiver. When the pressure of $(5.5\dots7){\cdot}10^4$ Pa is reached neon is feed into the squeezing unit. On this element the air condensation takes place too. Under pressure of $(1.2\dots1.3){\cdot}10^4$ Pa the valve, connecting the pump with the condensate receiver, is cut off. In this case the evacuation of the chamber continues up to the pressure of $5{\cdot}10^{-2}$ Pa for 30…32 min with a liquid neon consumption of 3.5 to 3.8 dm^3.

If the nitrogen and neon squeezing are starting simultaneously the evacuation continues 24…26 min with neon consumption of 3.8…4.0 dm^3. If the nitrogen squeezing is carried out under pressure simultaneously with neon squeezing then the evacuation duration is 21…23 min with neon consumption of 4.2…4.4 dm^3.

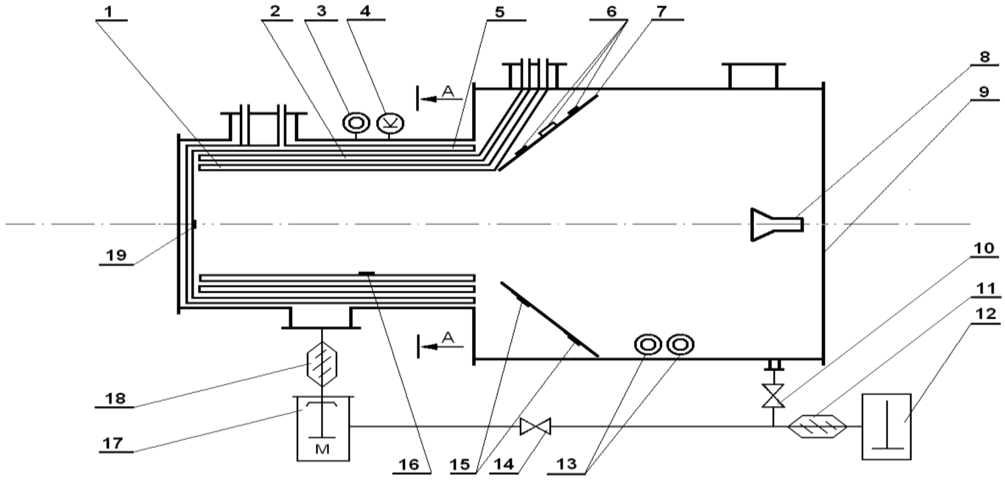

Fig. 1. Diagram of EJP testing:
1, 5 – nitrogen shield; 2 – neon cryopanel; 3, 4, 13 – vacuum sensing devices;
6, 15, 16, 19 – temperature sensors; 7 – uncooled shield; 8 – EJP; 9 – case; 10, 14 – valve;
11, 18 – liquid nitrogen trap; 12 – mechanical forevacuum pump; 17 – neon adsorption pump

Spectrum №	Total pressure	Xe	H_2	He	Ne	N_2	O_2	H_2O	C_nH_n
1	$2 \cdot 10^{-4}$	-	13	4	4	70	3	2	4
2	$1.2 \cdot 10^{-4}$	1	11	3	2	75	2	2	4

The for pump is cut off from the pressure chamber when the maximum pressure is reached. Then the cooling of the nitrogen shields in the pressure chamber begins and simultaneously the adsorption pump comes into operation. In 5…10 min the liquid neon squeezing through the cryovacuum panel is starting. The cryogenic system provides in the chamber the pressure of (1…2)·10^{-5} Pa in the no-load mode.

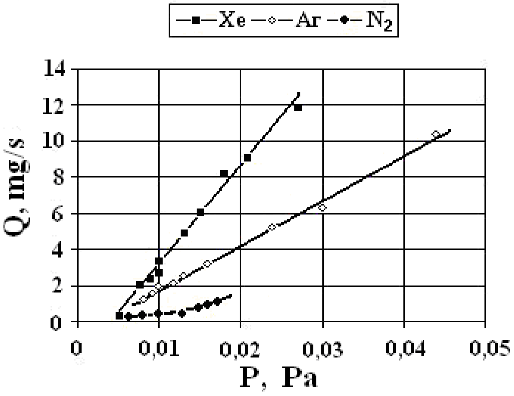

Fig. 2. Consumption characteristics of the system operating with a cold gas inflow

Table presents the residual atmosphere composition. Spectrum № 1 has been taken before the Xe inflow upon the adsorption pump being working and with the cold neon cryopanel. Spectrum №2 has been taken in 0.5 after Xe inflow cut off when the adsorption pump was not operating. In that case the total pressure is almost twice lower than in the no-load mode. Besides, the H_2, He, Ne percentage decreases that evidences on the presence of a mechanism of cryogenic capture by the Xe layers being condensed. A similar process is observed during the Ar and Kr condensation. More than 70% of nitrogen evidence on the probable presence of an insignificant cold microleak in the nitrogen shield. Also, a weak leakage through the current leads or coolant leads is possible.

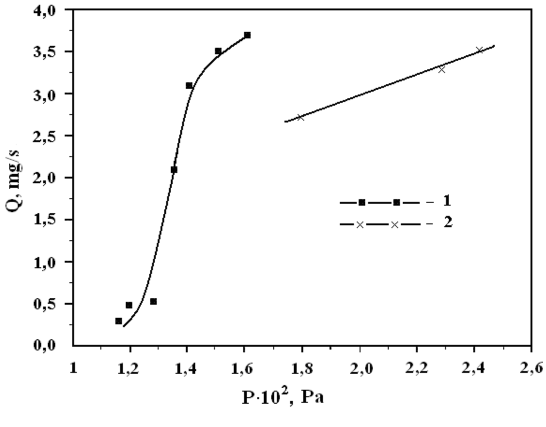

Fig. 3. Consumption characteristic in the case of xenon pumping out by the inside cryopanel:
1 – “cold” consumption; 2 – xenon consumption while EJP running

In that case the microleaks have no influence neither on the maximum vacuum in the no-load mode nor, especially, on the vacuum with Xe and Ar inflow. The presence of 10% of H_2 is caused by the residual atmosphere and is related with the hydrocarbon decomposition on the filaments of lamps.

Hydrocarbons are presented in the spectrum but their overall number does not exceed 2…4% and is determined by the presence of rubber seals at the flanges and stop valve. The pumping speed of the system was measured experimentally. The xe, a, n_2 and air inflow was carried out during 600 s.

There was not difference in the pumping speed for nitrogen and air and subsequently the accumulation of noncondensable air components h_2, ne and he was observed. The results are shown in the plots of Figs. 2 and 3. When EJP is operating with the xe consumption of 2.7…3.5 mg/s the pressure in the chamber is not worse than $2\cdot10^{-2}$ Pa that corresponds to the requirements for ejp tests.

CONCLUSIONS

The present study demonstrates that the cryovacuum systems using the liquid neon are capable to evacuate effectively Xe, Ar, Kr in the steady-state regime including these with a high-energy jet formation. Also it is shown that the possibility of the inside location of pumping-out elements permits to increase significantly the evacuation rate. The location of cryopanels in the large chamber gives an opportunity for the pumping surface area increase and proportional upgrade of the EJP consumption characteristics. This effect is an urgent condition for tests of rocket engines with high performances and significant working parameters.

REFERENCES

1. *Physics and application of plasma accelerators* / Proceedings of the II All-Union Conference ed. by A.I. Morozov, Minsk: “Nauka i Tekhnika”, 1974, p. 400 (in Russian).

2. S.D. Grishin, L.V. Leskov, N.P. Kozlov. *Electrical propulsions.* 1975, p. 271.

3. A.I. Morozov. *Basic physics of space electrojet propulsions. Elements of EJP flight dynamics*. M.: “Atomizdat”, 1978, v. 1, p. 328 (in Russian).

4. S.D. Grishin, L.V. Leskov. *Electrical propulsions.* M.: “Mashinostroeyniye” (in Russian).

5. *A Critical History of Electric Propulsion: The First 50 Years (1906-1956)* / Edgar Y. Choueiri in Journal of Propulsion and Power. 2004, v. 20, № 2, p. 193-203.

6. B.P. Batrakov, Yu.N. Volkov, V.A. Kravchenko, V.M. Leonov, V.G. Farafonov, S.L. Chepel. Cryogenic neon gas-dynamic installation // *Voprosy Atomnoj Nauki i Tekhniki. Seriya “Obshchaya i yadernaya Fizika”.* 1984, № 1(26), p. 42-46 (in Russian).

7. V.M. Murashko, A.A. Nesterenko, V.I. Savenko, L.P. Timkin, Yu.N. Volkov, V.A. Kravchenko. Neon cryovacuum system for testing and operation of 10 kW plasma accelerators. All-Union Conference on the plasma accelerators and ion injectors // *Abstracts*. Kharkov, 1989, p. 274- 275.

Article received 10.01.2014

НЕОНОВАЯ КРИОВАКУУМНАЯ СИСТЕМА ДЛЯ РЕСУРСНЫХ ИСПЫТАНИЙ ЭЛЕКТРОРЕАКТИВНЫХ ДВИГАТЕЛЕЙ

А.Б. Батраков, Ю.Н. Волков, Ю.Ф. Лонин, А.Г. Пономарев

Описана безмаслянная криовакуумная система, предназначенная для работы в диапазоне давлений ($10^5…4\cdot10^{-5}$) Па. Насосы и криопанели включены в замкнутый цикл получения и хранения жидкого неона. Вакуумная система разработана ИПЭНМУ ННЦ ХФТИ для проведения ресурсных испытаний электрореактивных двигательных установок (ЭРДУ). Представлена криовакуумная система для стационарных плазменых двигателей (СПД), у которых рабочим телом являются ксенон и, в меньшей степени, аргон. Для исследования новых разработок таких двигателей, в особенности для ресурсных испытаний, необходимо создание чистого безмаслянного вакуума ($2\cdot10^{-2}$ Па), что обеспечивается неоновыми криовакуумными системами, которые могут снять тепловую нагрузку до 10 Ватт/см^2. Показано, что при конденсации ксенона более 1,5 г/см^2 не происходит изменения в скорости откачки неоновых откачивающих элементов, т.е. при площади криопанели около 1 м^2 возможно проведение ресурсных испытаний СПД.

НЕОНОВА КРІОВАКУМНА СИСТЕМА РЕСУРСНИХ ВИПРОБУВАНЬ ЕЛЕКТРОРЕАКТИВНИХ ДВИГУНІВ

О.Б. Батраков, Ю.М. Волков, Ю.Ф. Лонін, А.Г. Пономарьов

Описано безмасляну кріовакуумну систему, яка призначена для роботи в діапазоні тиску ($10^5…4\cdot10^{-5}$) Па. Помпи і кріопанелі включені до складу замкненого циклу отримання та зберігання рідинного неону. Вакуумну систему розроблено в ІПЕНМП ННЦ ХФТІ для проведення ресурсних випробувань електрореактивних двигунів (ЕРД). Представлено кріовакуумну систему для випробування стаціонарних плазмових двигунів (СПД), в яких робочою речовиною є ксенон або, в меншій мірі, аргон. Для дослідження нових розробок таких двигунів, особливо для проведення ресурсних випробувань, необхідне створення безмасляного вакууму ($2\cdot10^{-2}$ Па), що забезпечується неоновими кріовакуумними системами, які можуть зняти теплове навантаження до 10 Ватт/см^2. Показано, що при конденсації ксенону більш 1,5 г/см^2 не робить змін у швидкості відкачування неонових відкачних елементів, тобто при площі кріопанелі 1 м^2 можливе проведення ресурсних випробувань СПД .