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Lumped Ultra-High Vacuum Pumps Based on Non-Evaporable Getters

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Abstract—Lumped vacuum pumps based on non-evaporable getters are widely used in vacuum systems of charged particle accelerators. This type of pump will be used in the 4+ generation synchrotron at the Siberian Ring Source of Photons shared resource center. Prototypes of getter pumps with hydrogen pumping speeds of 300, 600, 900, and 1300 L/s are being manufactured and tested at the Budker Institute of Nuclear Physics. The designs of pumps are described, along with results from their tests.

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INTRODUCTION

The Siberian Ring Source of Photons shared resource center is unique in having a 4+ source for the generation of synchrotron radiation with an energy of 3 GeV and a record beam emittance of around 75 pm rad. The source is being created as part of the national project "Science and Universities" and the program "Academgorodok 2.0" in the science city of Koltsovo, Novosibirsk oblast. To obtain an ultrahigh vacuum, it is necessary to use both magnetic discharge pumps and vacuum pumps based on non-evaporable getters (NEG) [1].

Work on creating magnetic discharge pumps with strong (up to 0.3 T) magnetic fields [2] resumed at the Budker Institute of Nuclear Physics in 2020. Unfortunately, the disadvantage associated with the maximum vacuum of the pump itself (minimum pressure, 10^{-9} Torr) has yet to be eliminated. It was therefore decided to use a triode type of magnetic discharge pumps, since they have higher pumping speeds for inert gases than diode pumps. The development of the first single-potential uncooled triode magnetic discharge pumps in the Soviet Union and Russia is now in the final stage.

However, magnetic discharge pumps are themselves indispensable for having a high pumping rate for hydrogen, which is the dominant gas in an ultrahigh vacuum. Using compact pumps based on non-evaporable getters solves this problem perfectly.

Materials in getter pumps bind gas via chemisorption, so they must be reactive toward such residual gases normally found in a vacuum as H_2, CO, and CO_2.

Getters are generally classified into two distinct families: non-evaporable and evaporable.

NEGs are made from such reactive metals as titanium, zirconium, vanadium, and alloys of them. They usually take the form of pressed or sintered powders [3]. Due to their chemical reactivity, the surfaces of getter powders are easily passivated by some monolayers of oxides and carbides during the manufacturing process. This avoids further reaction with atmospheric gases and protects the material when exposed to air. After being placed in a vacuum, the passivation layer must be removed to clean the getter surface for further chemisorption. This is done by a type of heat treatment called activation, in which chemically bound atoms of oxygen, carbon, and nitrogen diffuse from the surface into the volume of the getter. The efficiency of diffusion depends strongly on the composition and microstructure of the getter. The temperature and duration of activation can therefore vary considerably from one getter alloy to another.

Non-evaporable getters are mainly used in cases where the sputtering of metals in a vacuum is undesirable, or there is no surface for deposition of a metal film.

A key feature of NEGs is their high pumping speed per unit volume. As a direct consequence of this feature, NEG-based pumps normally have compact housing and can be installed in small or limited-area systems. NEG pumps are also particularly effective at pumping out hydrogen, the main residual gas in typical ultrahigh vacuum systems. Additional features are low weight, no vibration (no moving parts), marginal power consumption, no maintenance, and negligible

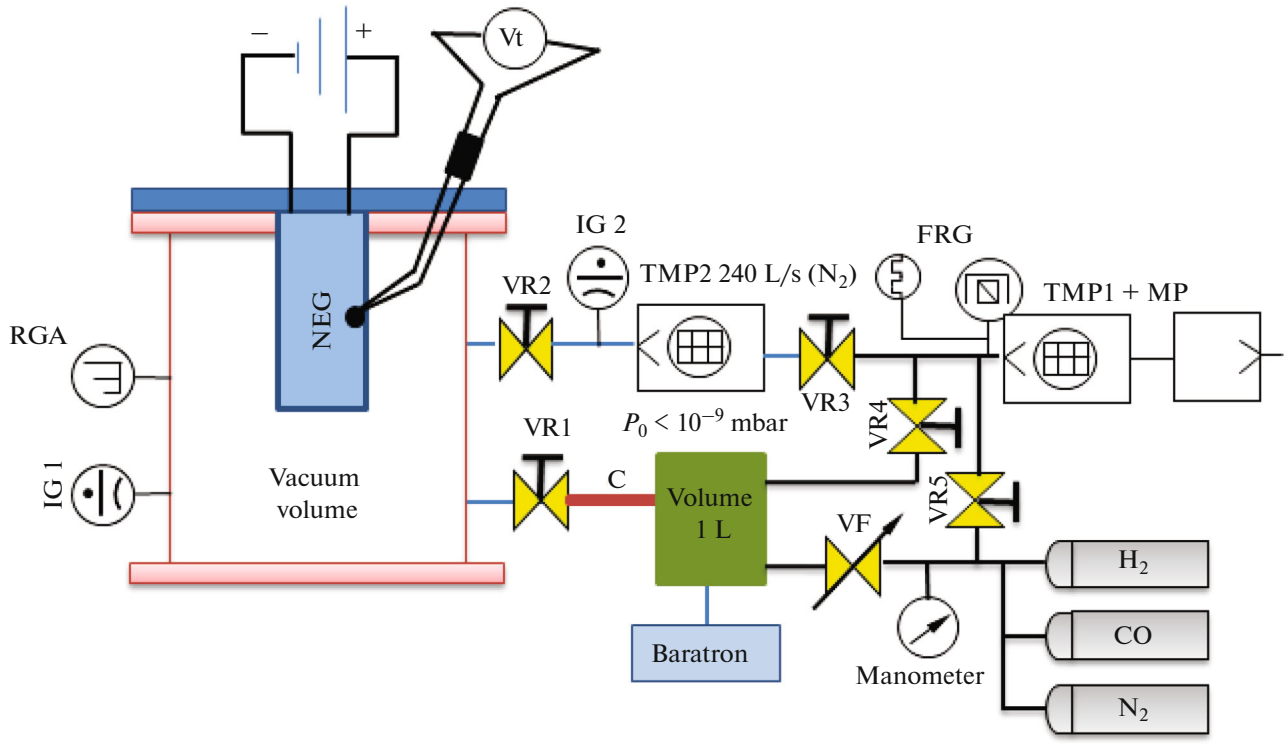

Fig. 1. Simplified scheme of the vacuum stand. RGA is a mass spectrometer; IG1-2 is a hot cathode pressure sensor; FRG is a wide range sensor; getter is the pump being tested; C is a capillary channel with molecular conductivity; TMP1+MP is a turbomolecular pumping station; TMP2 is a turbomolecular pump; the Baratron is a capacitive pressure sensor; the manometer is a arrow deformation pressure gauge; VF is a slotted leak; VR1, VR2, VR4, and VR5 are all-metal angle valves; and VR3 is the emergency electric valve.

influence of the magnetic field (magnetic permeability of the getters most commonly used is <1.001).

The main disadvantage of all getters is their selectivity in the sorption of gases, i.e., such chemically passive gases as inert gases (argon, neon) and simple hydrocarbons (methane) that do not react with the getter material, since a chemical reaction is impossible [4].

EXPERIMENTAL SETUP AND MEASURING TECHNIQUE

The activation and gas absorption characteristics of the getter pumps were measured on a specialized experimental setup (Fig. 1). The system was preliminarily evacuated by a station with a turbomolecular pump (TMP1) and an oil-free membranous pump (MP). High-vacuum pumping was done with turbomolecular pump TMP2. Emergency electric valve VR3 was installed to prevent the atmosphere from breaking through from the TMP1 + MP side. The fore and high vacuums were measured at the pumping station by a Pfieffer PKR 251 wide-range pressure sensor consisting of a Pirani sensor and a cold cathode pressure sensor.

Gas was let into the system through needle flow valve VF and capillary C (the molecular conductivity with respect to hydrogen was 2.8×10^{-3} L/s). The injection system was evacuated by the turbomolecular station through vacuum valves VR4 and VR5. An arrow pressure gauge and a Baratron capacitive pressure sensor were used to control the pressure of the injected gas.

The pressure in the system was measured by hot cathode pressure sensor IG1. The partial pressures of gases were measured using an RGA quadrupole mass spectrometer from SRS (Stanford, United States). Hot cathode pressure sensor IG2 was needed to control the flow of gas pumped out by turbomolecular pump TPM2.

Prior to our experiments, the stand was heated to temperatures of 220–240°C in order to reduce desorption from the chamber walls. We also measured he effective pumping speed of turbomolecular pump TMP2, the molecular conductivity of the capillary, and the coefficients of sensitivity of the pressure sensors with hot cathodes for each gas (H_2, CO, and Ar). Table 1 gives these values for each gas. All vacuum meters were calibrated each time they were opened to the atmosphere. Valve VR1 was closed at the start of the experiments. It was then opened, and the injected gas began to flow into the test chamber through the

Table 1. Molecular conductivity of the capillary channel, effective pumping speed, and coefficient of sensitivity of hot cathode pressure sensors for different gases

	Molecular conductivity C, L/s	Effective pumping speed S_{eff}, L/s	Coefficient of sensitivity K_{IG1}	Coefficient of sensitivity K_{IG2}
Hydrogen	2.8×10^{-3}	28	2.3	2.3
CO	7.6×10^{-4}	8.4	1	1
Argon	6.36×10^{-4}	7	0.77	0.74

Table 2. Basic parameters of getter pumps

Prototype	Max activation temperature, °C	Number of columns, pcs	NEG surface, cm^2	Getter weight, g	Porosity, %	Flange type
NEG300	650	1	300	60	30	Du 40
NEG600		2	600	120		Du 63
NEG1000		4	1200	240		Du 100
NEG1200		6	1600	360		Du 100

capillary. The flow of gas into the test chamber is determined by the expression

$$Q_{total} = C(P_{in} - P_{out}), \quad (1)$$

where C is a channel with calibrated conductivity L/s; P_{in} and P_{out} are the pressures at the inlet and outlet of the capillary C (Torr).

Pumping speed S_{NEG} of the getter during gas injection can be determined as

$$S_{NEG} = \frac{C(P_{in} - P_{out})}{K(P_{IG1after} - P_{IG1before})} - S_{TMP}, \quad (2)$$

where S_{NEG} is the pumping speed of the NEG pump. S_{TMP} is the pumping speed of the turbomolecular pump: 32 L/s for hydrogen and 8.9 L/s for carbon monoxide. C is the molecular conductivity of the capillary channel (L/s); $P_{IG1down}$ is the pressure of pressure sensor *IG1* downstream of the gas inlet (Torr); P_{IG1up} is the pressure of pressure sensor *IG1* upstream of the gas inlet (Torr); and K is the coefficient of sensitivity.

Sorption capacity was defined as the number of molecules upon whose absorption the pumping speed falls to 10% of the initial level:

$$\text{Doze} = \int_0^t (Q_{total} - Q_{TMP})\,dt, \quad (3)$$

where Q_{total} is the total gas flow (L Torr/s); Q_{TMP} is the flow of gas pumped out by the turbomolecular pump (L Torr/s); and t is the period of measuring.

The flow of gas pumped out by the turbomolecular pump can be determined as

$$Q_{TMP} = S_{TMP}K(\Delta P_{IG1} - \Delta P_{IG2}), \quad (4)$$

where

$$\Delta P_{IG1} = P_{IG1after} - P_{IG1before},$$
$$\Delta P_{IG2} = P_{IG2after} - P_{IG2before}. \quad (5)$$

$P_{IG1down}$ is the pressure at sensor *IG1* downstream of the gas inlet (Torr); P_{IG1up} is the pressure of sensor IG1 upstream of the gas inlet (Torr); $P_{IG2down}$ is the pressure at sensor IG2 downstream of the gas inlet (Torr); and P_{IG2up} is the pressure of pressure sensor IG2 upstream of the gas inlet (Torr).

VACUUM PUMP PROTOTYPES

AO Polema has for many years produced non-evaporable getters in large quantities for the nuclear power and oil and gas industries [5]. The first vacuum pumps based on Ti–Zr–Al getters manufactured by AO Polema were made from tablets 13 ± 0.5 mm in diameter and 3 ± 0.5 mm thick, with 60% porosity. More detailed results can be found in [6, 7].

The main parameters of the pumps are presented in Table 2. The pumps are made of getter discs. Each disc has an outer diameter of 25 mm and is 1.6 mm thick. The porosity is 30%, and the inner diameter is 8 mm to accommodate the heater. The chemical composition of the non-evaporable getter is Ti–Zr–Al. The discs are installed in series in a row with gaps of 1.5 mm. There are 30 pcs in each column. The height (from the flange to the end face of the getter pump) is no more than 130 mm. The temperature is controlled with a K-type thermocouple. One protective screen is used outside to reduce the heater's power by half. The getter pumps are on flanged connections of the Conflat type. Images of getter pumps are shown in Fig. 2.

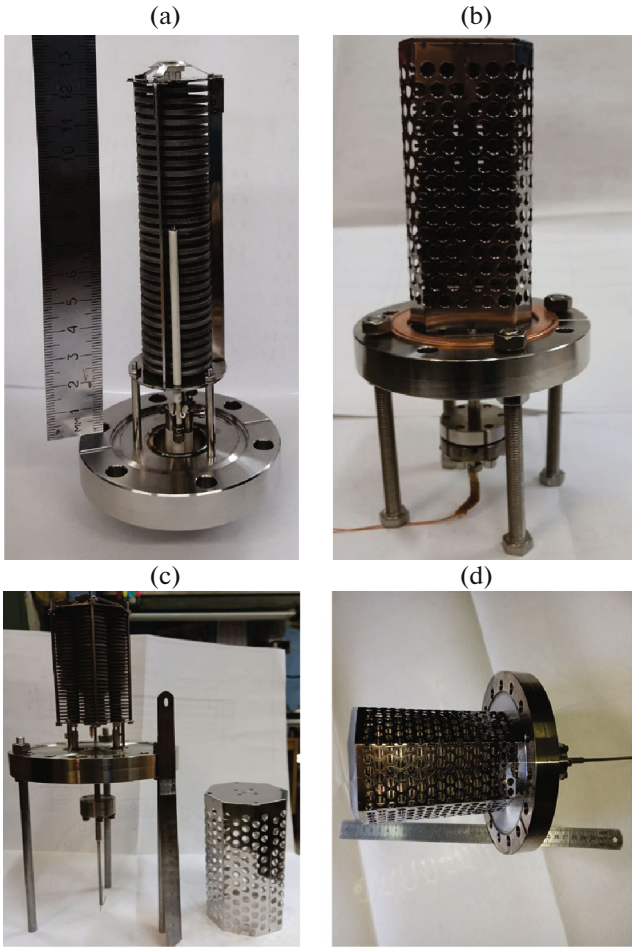

Fig. 2. Images of getter pumps: (a) NEG300, (b) NEG600, (c) NEG1000, and (d) NEG1200.

RESULTS AND DISCUSSION

Prior to measurements, the entire stand was heated to a temperature of 230°C over 24 h to reduce the background vacuum. After cooling to room temperature, the getter was activated for 20 h at the maximum temperature (650°C), and then passivated in air for at least 3 h.

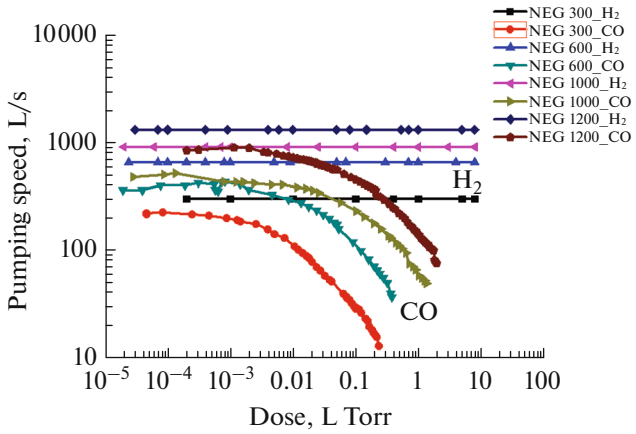

Fig. 3. Sorption capacity of getters for hydrogen and carbon monoxide.

Measurements of the pumping speed for hydrogen and the sorption capacity for carbon monoxide were made after the getters were activated at temperatures of 350 to 650°C every 50°C, but after each getter pump was cooled to room temperature. The hydrogen sorption capacity was estimated at around several thousand L Torr, so this hydrogen sorption capacity is enough after the getter is passivated by oxides. Excessive saturation of the getter with hydrogen also results in destruction and cracking of the getter.

Figure 3 shows the sorption capacity for hydrogen and carbon monoxide for each getter pump as a function of the temperature of activation.

Figure 4 shows pumping speeds for hydrogen and carbon monoxide at different temperatures of activation for four getter pumps.

For purposes of comparison, Table 3 also presents results for getter pumps manufactured by the Budker Institute of Nuclear Physics (INP SB RAS) and the

Table 3. Experimental results for getter pumps manufactured by the Budker Institute of Nuclear Physics and parameters of pumps manufactured by SAES Getters

	NEG pump	Max pumping speed for H_2, L/s	Max pumping speed for CO, L/s	Sorption capacity for CO, L Torr	Activation power 650°C, W	Activation power 550°C, W	Ratio of the speed for pumping H_2 to the getter area
INP SB RAS	300	300	220	0.24	124	78	1.0
	600	650	450	0.38	273	160	1.08
	1000	900	500	1.4	270	180	0.83
	1300	1300	850	2.0	370	255	0.81
SAES Getters	CapaciTorr 200	200	125	0.6	–	58	0.84
	CapaciTorr 1000	1000	600	4	–	190	0.88

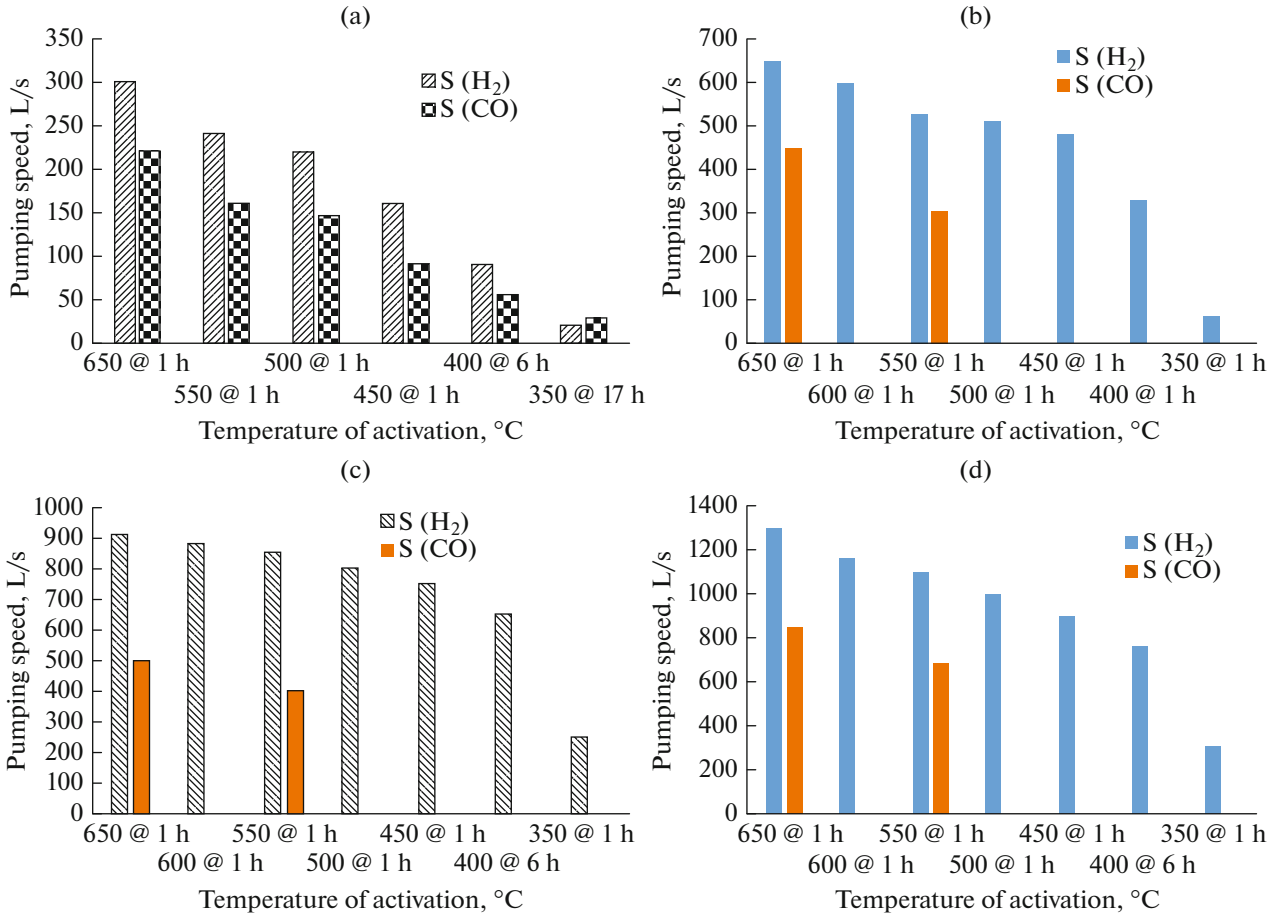

Fig. 4. Pumping speed of getter pumps for hydrogen and CO at different temperature of activations.

parameters of getter pumps manufactured by SAES Getters [8].

CONCLUSIONS

Prototypes of vacuum pumps based on non-evaporable getters with pumping speeds of 300, 600, 900, and 1300 L/s for hydrogen were manufactured and tested. These pumps correspond to foreign counterparts in terms of such characteristics as temperature of activation, pumping speed, and sorption capacity. Getters manufactured by AO Polema can be used in both accelerator technology and plasma installations.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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