Development of sputter ion pump with strong magnetic field for obtaining of ultra-high vacuum

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INTRODUCTION

The new synchrotron source SRS SKIF (Novosibirsk) requires ultra-high vacuum condition for obtaining of long lifetime stable 3 GeV electron beam with extremal low emittance at level 75 pm*rad. In recent years, combined pumps consist of non-evaporable getters and sputter ion pumps in one vessel start to be more and more popular. At this combination a mass-dimension characteristics are improved and ultimate pressure decreases considerably.

Usually pumping speed of conventional sputter ion pumps reaches its maximum value at pressure range from 1E-7 Torr to 1E-6 Torr. The paper describes a developing of compact sputter ion pump optimized for application in combination with non-evaporable getter pump at ultra-high vacuum condition. The main idea is an increasing of magnetic field and a decreasing of Penning cell size to increase pumping speed and shift its maximum to low pressure range.

The modified triode type of the sputter ion pump is planned to be used in SRS SKIF because its pumping speed for noble gases is higher than for diode type.

THEORETICAL CALCULATION

The pumping speed of one cell can be determined as:

a) Bz ≤ B ≤ 2Bz

$$S = 1{,}56 \cdot 10^{9} \cdot \left(1 - \frac{1{,}5 \cdot 10^{6} \cdot P}{1 + 4 \cdot 10^{6} \cdot P}\right) \cdot P^{0{,}2} \cdot h \cdot d^{2} \cdot Bz \cdot (B - Bz)$$

where S – pumping speed of one cell for nitrogen [l/s];
P – pressure [Torr];
h – height of anode cell [m];
d – diameter of anode cell [m];
B – magnetic field [T];
Bz – threshold magnetic field [T] corresponding to discharge switching on: $Bz = \frac{6 \cdot 10^{-4}}{d}$

b) 2Bz ≤ B ≤ Bmax

$$S = 3{,}9 \cdot 10^{10} \cdot \left(1 - \frac{1{,}5 \cdot 10^{6} \cdot P}{1 + 4 \cdot 10^{6} \cdot P}\right) \cdot P^{0{,}2} \cdot h \cdot d^{2} \cdot B^{2}$$

where Bmax – magnetic field [T] when pumping speed is a maximum and is equal as $Bmax = \frac{15{,}26 \cdot 10^{-6} \cdot \sqrt{Ua}}{d \cdot P^{0{,}05}}$
Ua – high voltage in V

c) B ≥ Bmax

$$S = 9{,}1 \cdot 10^{-2} \cdot \left(1 - \frac{1{,}5 \cdot 10^{6} \cdot P}{1 + 4 \cdot 10^{6} \cdot P}\right) \cdot P^{0{,}1} \cdot Ua \cdot h \cdot (1 - \frac{1{,}05 \cdot 10^{7} \cdot ((B - Bmax) \cdot d \cdot P)^{1/2}}{Ua})$$

The total pumping speed of whole pump can be found as:

$$Sn = S \cdot N$$

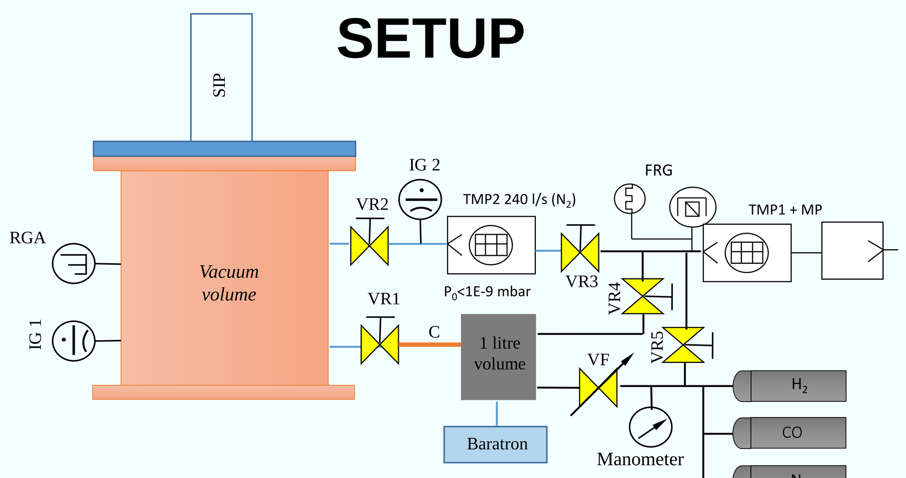
where Sn – total pumping speed of pump for nitrogen in l/s;
N – quantity of cells.

But it is necessary to remember about gap between anode and cathodes. The molecular conductivity of this gap can reduced the pumping speed and so effective pumping speed is equal as

$$S_{eff} = \sqrt{Sn \cdot U} \cdot th(\sqrt{\frac{Sn}{U}})$$

where Seff – effective pumping speed of pump for nitrogen [l/s];
U – total molecular conductivity of both gaps between anode and cathodes [l/s].

SETUP



– Dry diaphragm pump
– Turbomolecular pump
– Mechanical deformational manometer

IG 1-2 – hot cathode gauges
RGA – residual gas analyzer
VR 1-5 – all-metal angle valves
VF – leak valve
C – capillary with known molecular conductivity
FRG – full range gauge

EXPERIMENTAL METHOD

The method is based on the measurement of pressure drop on a vacuum element with known conductivity (Dynamic Flow Method).

$$S_{eff} = \frac{C \cdot P_{bar}}{K \cdot (P_{IG1\,after} - P_{IG1\,before})}$$

Where Seff – effective pumping speed of pump at nitrogen [l/s];
C – molecular conductivity of capillary [l/s];
$P_{IG1\ after}$ – pressure after gas flow by IG1 [Torr];
$P_{IG1\ before}$ – pressure before gas flow by IG1 [Torr];
Pbar – pressure measured by Baratron [Torr]
K – sensitivity coefficient

DESCRIPTION OF SPUTTER ION PUMPS

The main parameters of pumps are presented in Table 1. The pump body and the anode cells is made of stainless steel. The cathodes are made of titanium. All tested pumps are diode type.

Table 1. The main parameters of sputter ion pumps.

Name of manufacture	Diameter, mm	Height, mm	Gap between anode and each cathode, mm	Cell quantity, pcs	Magnetic field, T	High voltage, kV	Type
BINP #1	12	14	4	36	0,12	5,0	Diode
BINP #2	12	14	4	36	0,28	5,0	
Катод	16	20	???	32	0,11	5,0	
BINP #3	7,6	14	4	95	0,12	3,0 / 5,0 / 7,0	
BINP #4	7,6	14	4	95	0,28	3,0 / 5,0 / 7,0	

THE EXPERIMENTAL RESULTS

The measurements were carried out at high voltage of 5 kV and pressure range from 1E-9 Torr to 1E-4 Torr. The most perspective pump with cells diameter 8mm was measured at voltages 3 kV and 7 kV also.

The pumping speed and discharge current versus pressure for tested vacuum pumps with cells diameter more than 10 mm are shown on Figures 1 and 2 .

The pumping speed and the discharge current versus pressure in tested vacuum pump with cells diameter 8 mm are presented on Figures 3 and 4 .

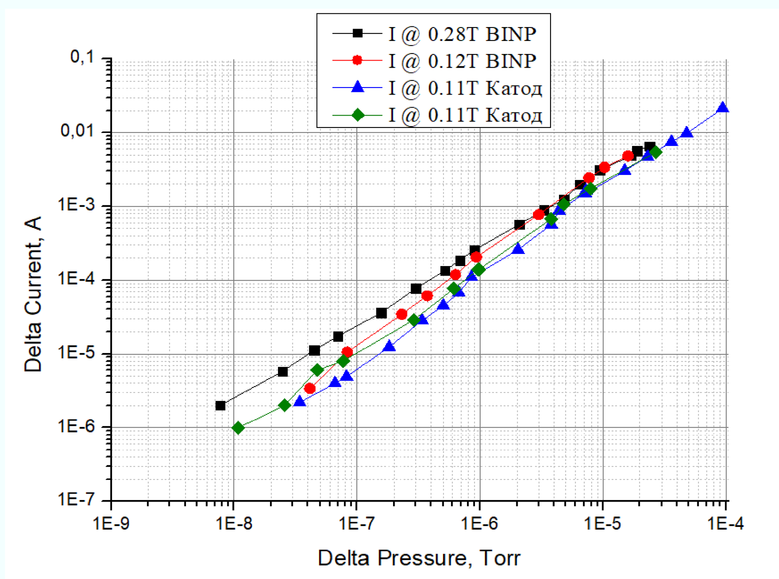


Fig. 1. The discharge current vs pressure

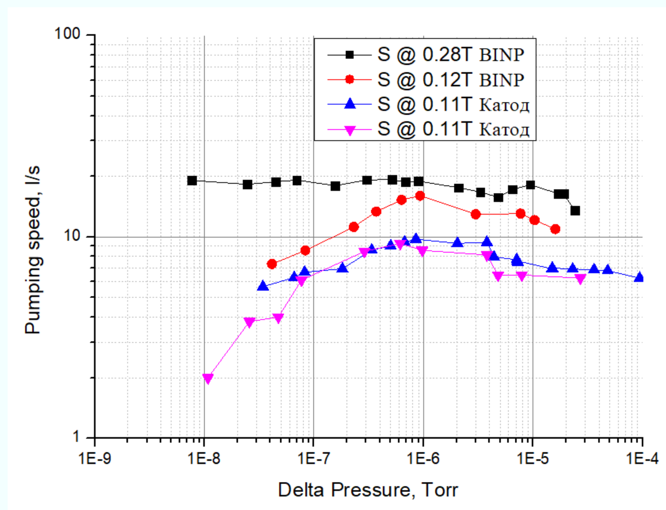


Fig. 2. The pumping speed vs pressure

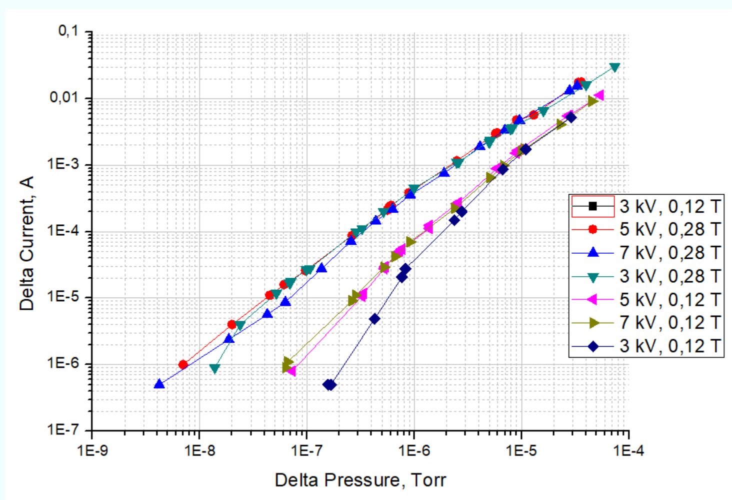


Fig. 3. The discharge current vs pressure (cell diameter of 8 mm)

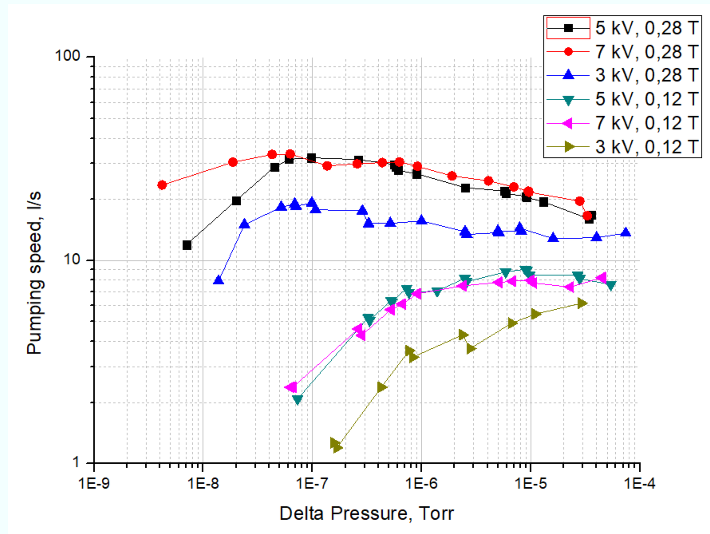


Fig. 4. The pumping speed vs pressure (cell diameter of 8 mm)

Name of manufacture	Cell pumping speed, l/s	Total pumping speed, l/s	Effective pumping speed, l/s	Specific pumping speed, l/s/cm^3	Effective pumping speed, l/s
	Calculation				Measurement
BINP #1	0,4	14,5	14	0,18	16
BINP #2	1,1	40	21	0,7	19
Катод	0,9	27	??	0,22	10
BINP #3 (at 5 kV)	0,16	15	11	0,25	9,0
BINP #4 (at 5 kV)	1,0	95,0	30	1,056	29,0

CONCLUSION

- The several sputter ion pumps with the different magnetic fields and height and diameter of cells were tested in pressure range from 1E-9 to 1E-4 Torr.
- It presents the theoretical calculations and the experimental results of pumping speed which agree between themselves very well.
- The pump with cells diameter 8 mm and the magnetic field 0,28 T looks very perspective
- It is expected that specific pumping speed 1,6 l/s/cm^3 for nitrogen can be obtained by choice of cell geometrical sizes and gap between anode and cathodes.

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