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Optimization of the vacuum system of the Atomic Beam Source.

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Оптимизация вакуумной системы источника поляризованных атомов

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Аннотация

Настоящая работа выполнена в рамках разработки источника поляризованных атомов водорода или дейтерия для ANKE спектрометра на накопительном кольце ускорителя COSY - Jülich.

Атомарный водород (дейтерий) поступает в источник через сопло диссоциатора и проходит через ряд камер с дифференциальной откачкой. Целью данной работы является оптимизация вакуумных условий в первой камере источника поляризованных атомов.

Одним из основных ограничений при увеличении интенсивности атомного пучка является скорость откачки рассеяных атомов и молекул в первой камере источника. Взаимодействие остаточного газа с атомарнам пучком разрушает направленный поток атомов и, в конечном итоге, приводит к уменьшению плотности внутренней мишени накопительного кольца. В работе были исследованы вакуумные условия при различных комбинациях вакуумных насосов и различных потоках инжектируемого газа. В результате найдена вакуумная схема, позволяющая поднять поток газа до 5 мбар·л/с с существенным улучшением вакуума в первой камере.

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Abstracts

This work is done in the frame of the development of the polarized atomic beam source (ABS), which is under construction for the ANKE spectrometer in COSY-Juelich accelerator and storage ring.

Hydrogen (deuterium) atomic beam emitted from the nozzle of the dissociator, goes through the number of chambers with the differential pumping. The optimization of the vacuum conditions in the first chamber of ABS is the aim of this work.

One of the main restriction on the increase of the atomic flow is impossibility to pump out the rest gas at the first stage of ABS. The interaction between the rest gas and the atomic beam destroys the beam and finally decreases the density of the polarized target in the ring. We investigated vacuum conditions of the first stage at different gas flows and different pumping schemes. As a result we found the pumping structure which essentially increases the possible hydrogen gas flow (up to 5 mbar l/s) with the appropriate vacuum conditions.

1. Introduction

The present work is done in the frame of the development of the polarized atomic beam source (ABS) [1-4], which is under construction for the ANKE spectrometer [5] in the COSY-Jülich accelerator and storage ring. The ABS will inject polarized hydrogen or deuterium atoms into a windowless gas-storage cell [6] positioned as an internal target in the circulating proton beam.

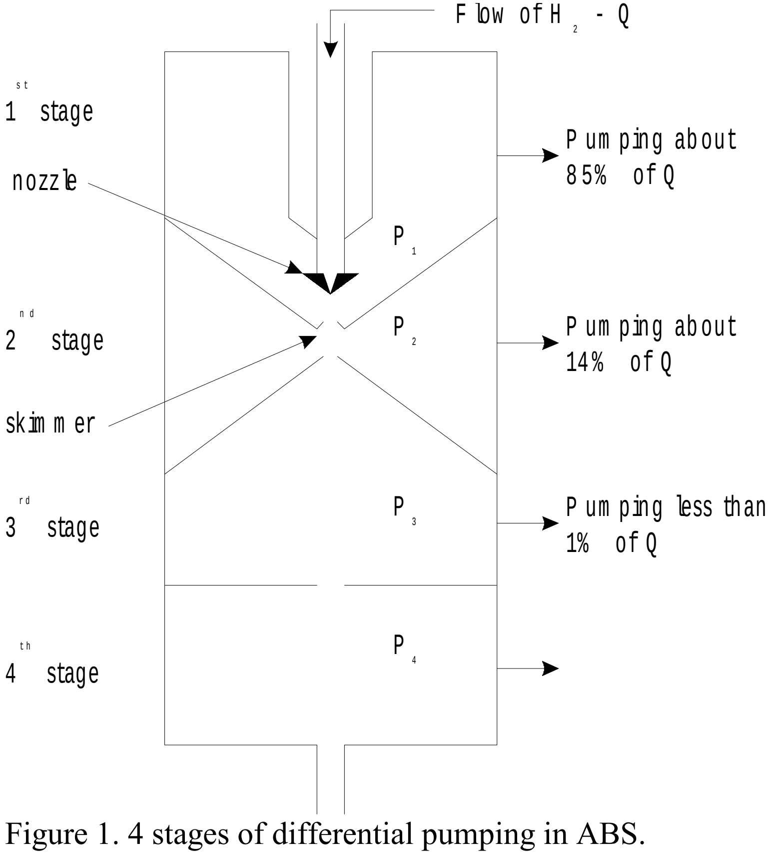

Figure 1. 4 stages of differential pumping in ABS.

Vacuum system of the ABS [7] consists of separate parts with the differential pumping (figure 1). The most essential part of the atomic beam (up to 85%) is pumped in the 1st stage of ABS. The improvement of the vacuum conditions here is the most important task. Interaction of the beam with the rest gas between the nozzle and skimmer can destroy the hydrogen beam. The qualitative dependence of the target density against the H_2 flow to the dissociator is shown on figure 2. The maximum of this dependence is defined by vacuum conditions in the 1st stage. We tried to increase the possible atomic flow by the improvement pumping conditions in the 1st stage.

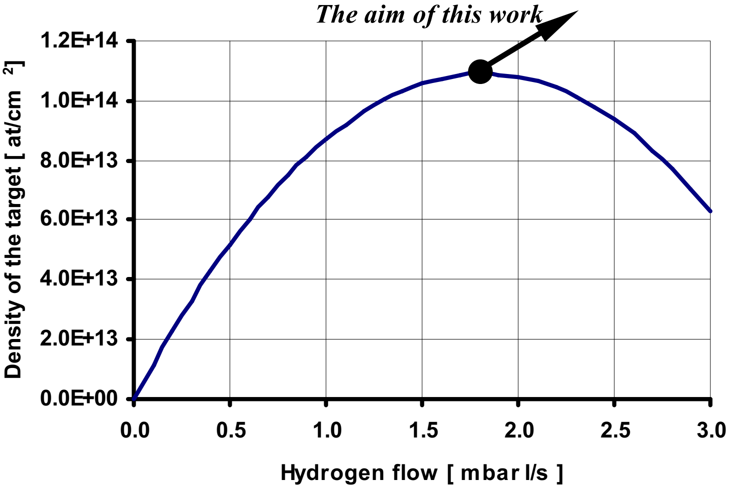

Figure 2. Qualitative picture of the target density as a function of the hydrogen flow through dissociator.

All vacuum elements in the system (vacuum pumps, vacuum gauges, valves etc.) are controlled by the computer. During the tests we made the prototypes of the elements of the slow control system and tested working algorithms for the vacuum elements.

2. Vacuum elements in the first stage.

Traditional structure for the high flow pumping systems with the use of Balzers [8] turbo pumps is shown on the figure 3. It comprises two identical pumping lines. In this work we worked basically with one of them, because second one gives only factor 2 in pumping speed.

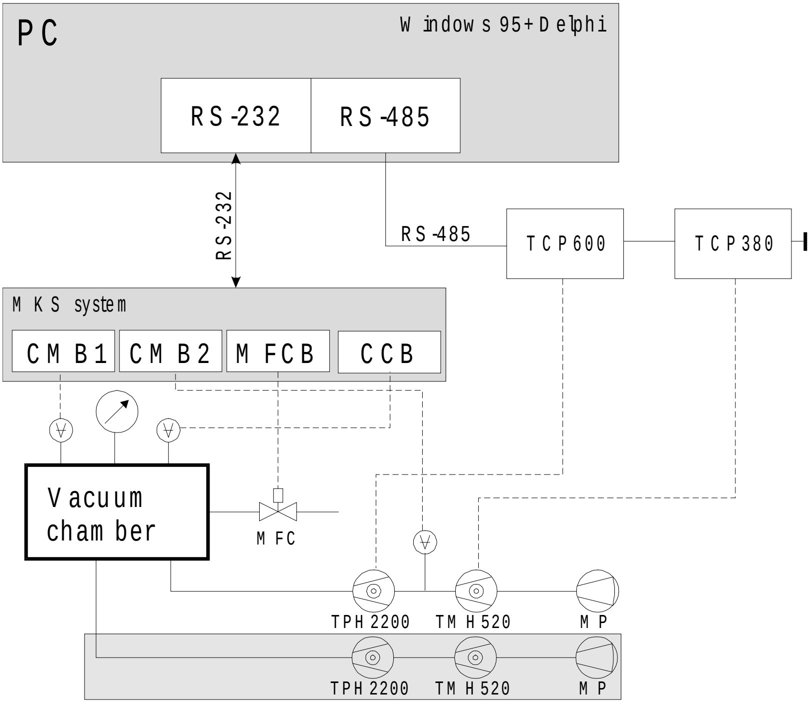

Figure 3. Block-scheme for the testing of the traditional vacuum scheme.

Three pumps TPH 2200, TMH 520 and membrane pump are connected serially. The big turbo-molecular pump TPH 2200 is connected to the vacuum chamber. Turbo-molecular drag pump TMH 520 is at the entrance of the TPH 2200. Outlet of TMH 520 is pumped by membrane pump. Vacuum in the chamber is measured by vacuum gauges with the cold cathode. Vacuum between TMH 2200 and TPH 520 is measured by capacitance vacuum gauges. For the creation of the gas flow (we have been working with H_2 and air) we used the "mass flow controller" (MFC) by MKS type 1259C - the same type which we are going to use for the dissociator gas supply system. The maximum possible flow is 8 mbar·l/s (about different units see Appendix A, B). All elements used in the system have interface and can be connected to the PC. Turbo pump controllers (power supplies) have RS-485 interface and through National Instruments PC board [9] send and receive information from PC. Vacuum gauges and mass-flow controller are connected to the MKS [10] crate with special modules (one module for every element) and MKS crate has RS-232 interface and gives us a possibility to have bilateral data exchange with 4 devices.

During the measurements we checked only two parameters connected with vacuum system:

- vacuum before every pump;
- rotation speed of the turbo pumps.

These two parameters we measured as a function of the hydrogen flow.

The measurements are shown in the figures 4,5. The indicator of the normal work of the pump are:

- linear dependence of the vacuum as function of the flow;
- independence of the rotation speed from the flow.

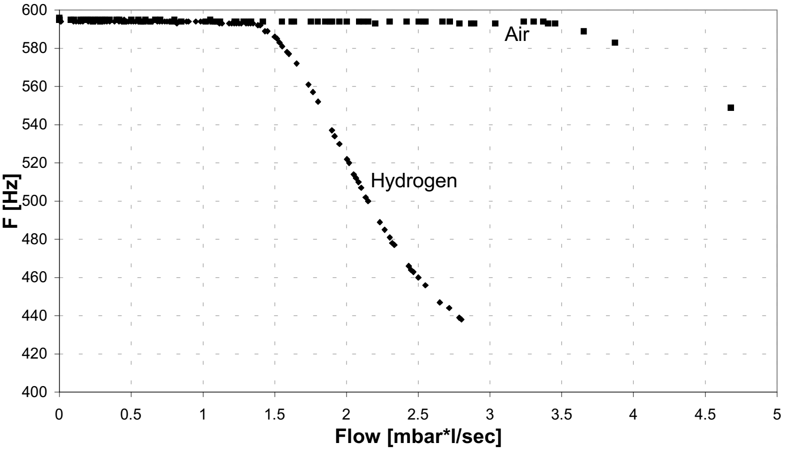

Figure 4. Rotation frequency for the turbo molecular pump TPH2200 against the flow of hydrogen and air.

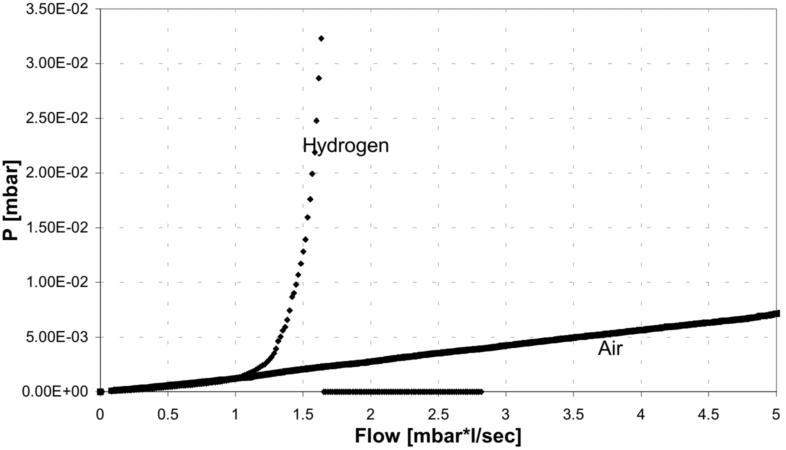

Figure 5. Vacuum in the chamber before turbo molecular pump TPH2200 against the flow of hydrogen and air.

The upper limit for the hydrogen flow is about 1.2 mbar·l/s (figures 4-5). At this point the vacuum in the chamber falls down and the rotation speed falls down too. This limit is not connected with the TPH 2200 because it should pump with the constant rotation speed up to 3 mbar·l/s in the chamber (technical data for TPH 2200). We have changes oa the rotation speed at 1.2 mbar·l/s. This restriction can have three reasons:

- during the tests we used for the TPH 2200 protection greed before pump. It restricts the pumping speed about 20%, but it increases the rotation speed. We saw simultaneous changes of the rotation speed and vacuum drop.
- restricted conductance of the chamber. But we have empty chamber now without any restrictions of the flow and this can decrease vacuum, not the rotation speed.
- we have insufficient outlet pumping of the TPH 2200. The high outlet pressure restricts the vacuum and rotation.

For understanding of the outlet pressure dependence of the TPH 2200 we measured pressure between TPH 2200 and TMH 520 as function of the flow (figure 6). We checked the rotation speed of the TMH 520 up to the maximum possible flow and did not find any changes. This is special turbo molecular drug pump which is especially used for the big gas flows up to 10 mbar·l/s. From 1.5 up to the 5 mbar·l/s pressure is the linear function of the flow. It means that the pump is in the working conditions. But at the flow 1.2 mbar·l/s we have pressure 0.1 mbar. Technical conditions for the outlet pressure TPH 2200 is 0.01 mbar. For the achieving of this pressure we should :

- either increase pumping speed of the second turbo pump,
- or decrease the outlet pressure of the TMH 520.

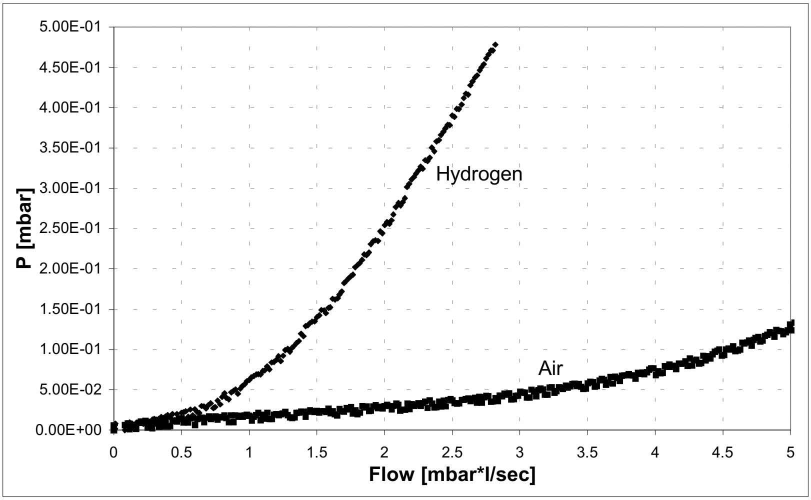

Figure 6. Pressure between TPH 2200 and TMH 520 against gas flow.

We do not want to use another type of the turbo pump in the second stage. In this case to increase the pumping speed we can use pumps in parallel. But we are working in linear regime and we will get pressure not better than 0.05 mbar. It is not sufficient for the normal work of TPH 2200. On the figure 6 we can see the compression ratio for the TMH 520. This is outlet pressure divided by the inlet pressure as a function of the flow. At the flow of 1.5 - 2.5 mbar·l/s the compression ratio is nearly constant and changing between 8 and 10.

On the outlet line of the TMH 520 we use the membrane pump with the minimum pressure 2-3 mbar (figure 7). Using the compression ratio 8-10 we shall never get the suitable outlet pressure for the TPH 2200.

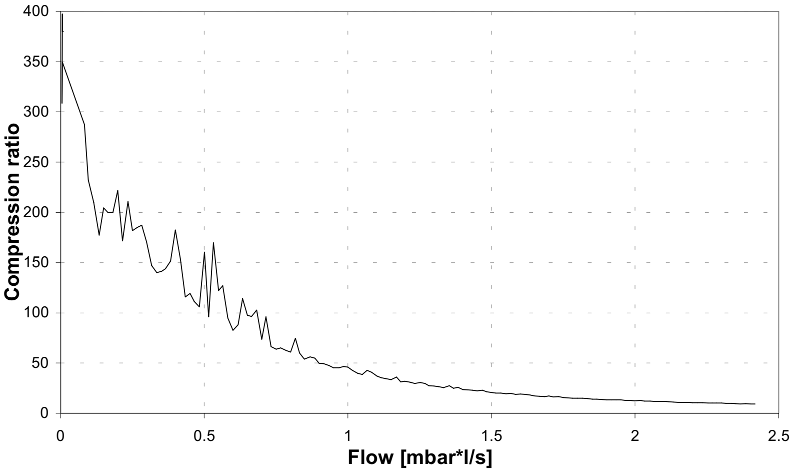

Figure 6. Compression ratio TMH 520 against the gas flow.

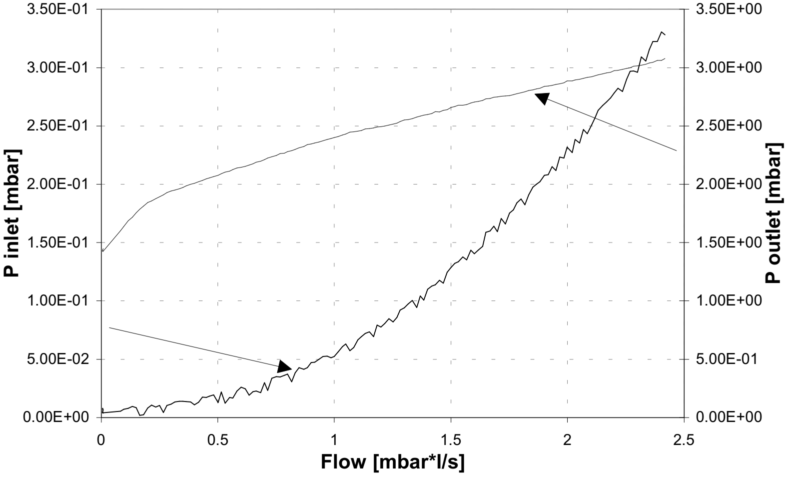

Figure 7. Inlet and outlet pressures for the TMH 520 against the flow.

In this case for the creation of an appropriate outlet pressure for the TPH 2200 we should use the additional stage of the pumping. For example two serially connected TMH 520.

3. Serially connected TMH 520.

The principle layout of the vacuum and the measurement scheme with the serial connection of TPH 2200 and two TMH 520 is shown on the figure 8.

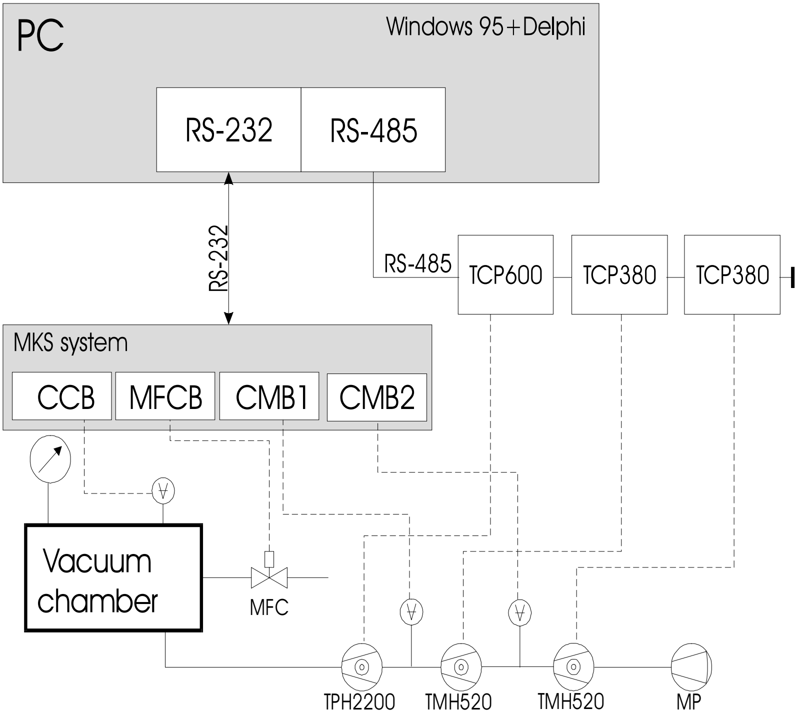

Figure 8. The principle layout of the vacuum and control system with three serially connected turbo pumps.

The control system is approximately the same (figure 3). We used the additional capacitance vacuum gauge between TMH 520.

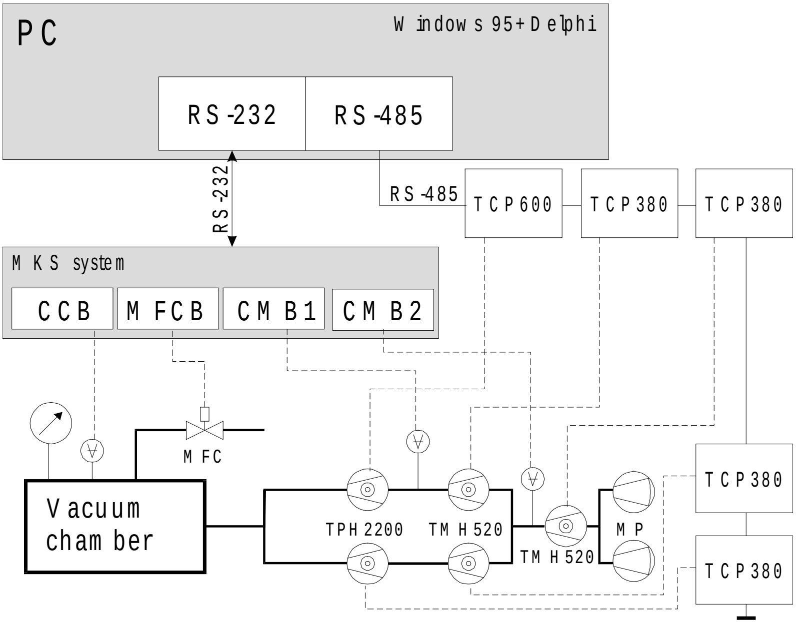

Figure 9. Final variant of the 1st stage vacuum system.

In the first stage of the ABS we planned to use two TPH2200 as primary turbo pumps. On the figure 9 we propose the 1st stage vacuum system with two TPH 2200 primary pumps, two TMH 520 secondary pumps, one common TMH 520 next turbo pump and two membrane pumps as a back up pumps. On the figure 10 the rotation frequency dependencies against the flow is plotted. 1st and 2nd line correspond to the one TPH 2200 in the 1st stage of ABS. They have correspondingly Q_{max1} and Q_{max2}. First line corresponds to the vacuum scheme with one TMH 520, the second - to the two serials connected TMH 520. Third line is the total scheme (figure 9) with 5 turbo pumps in the 1st stage. It has Q_{max3} maximum possible flow.

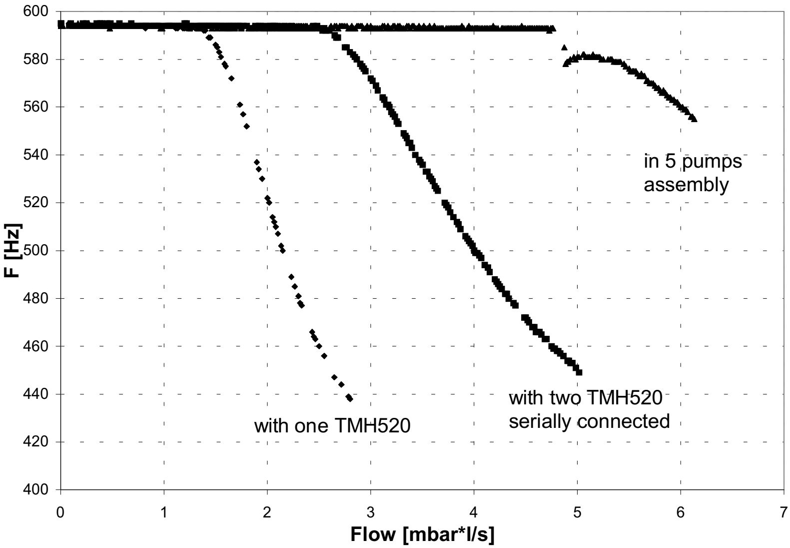

Figure 10. Rotation speed of the TPH 2200 against the gas flow for the different vacuum schemes.

Maximum possible flow for the different vacuum schemes is in the table 1. The conclusion is that the additional serially connected TMH 520 increases more than two times the possible gas flow to the first stage of ABS. Differences between $2Q_{max2}$ and Q_{max3} is negligible (4.9 mbar·l/s and 5 mbar·l/s) but on the scheme with 5 turbo pumps (figure 9) we used 3 secondary TMH520 against 4 on the figure 8.

Table 1.

Vacuum scheme	Q_{max}	total Q_{max}
TPH2200-TMH520-MP (Figure 3).	1.2	2.4
TPH2200-TMH520-TMH520-MP (Figure 8).	2.5	5.0
2TPH200-2TMH520-TMH520-2MP (Figure 9).	--	4.9

The pressure dependence against the gas flow is shown on the figure 11. In the linear pressure range as a function of the flow we can write:

$P_{1,4} = A_4 Q + B_4 \qquad 0 < Q < 2.4$ mbar l/s

$P_{1,5} = A_5 Q + B_5 \qquad 0 < Q < 5.0$ mbar l/s,

where $P_{1,4}$ is the pressure inside the vacuum chamber in the traditional configuration of the pumping system (Figure 3), $P_{1,5}$ is the pressure inside the chamber in the configuration of the pumping system proposed by authors.

4. Conclusion.

Systematical measurements on the base of the slow control system prototype gives us a possibility during the investigation of the traditional vacuum scheme for the first stage

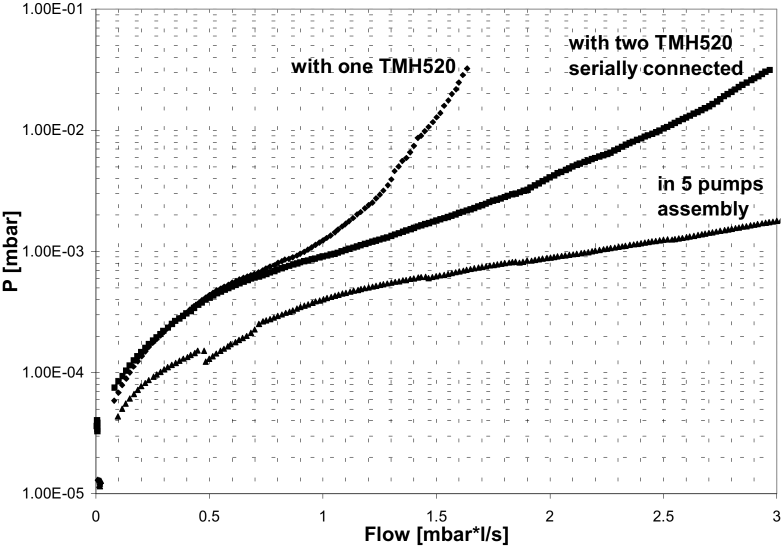

Figure 11. Vacuum in the chamber against the gas flow.

of ABS to find the most “narrow” pumping elements. One additional turbo molecular drug pump:

- more than two times improves vacuum in the first stage of ABS (at the same gas flow);
- about two times increases the dynamic range of the flow - from 2.4 mbar·l/s up to 5.0 mbar·l/s.

We hope that these features give us a possibility to increase the target density about two times.

Appendix A.

Pressure and gas flow measuring units.

Table A.1. Dependence of the different pressure measuring units.

	bar	mbar	Pa	atm	Torr
1 bar	**1**	**10^3**	**10^5**	**0.987**	**750**
1 mbar	**10^{-3}**	**1**	**10^2**	**0.987 10^{-3}**	**0.750**
1 Pa (N/m^2)	**10^{-5}**	**10^{-2}**	**1**	**0. $^{-5}$**	**0.750 10^{-2}**
1atm=760 Torr	**1.013**	**1.013 10^3**	**1.013 10^5**	**1**	**760**
1 Torr	**1.333 10^{-3}**	**1.333**	**133**	**1.316 10^{-3}**	**1**

Table A.2. Dependence of the flow measuring units.

	(mbar l)/s	sccm[1]	(Pa m^3)/s	atom/s
1 (mbar l)/s	**1**	**59.21**	**0.1**	**2.652 10^{19}**
1 sccm	**1.689 10^{-2}**	**1**	**1. $^{-3}$**	**4.479 10^{17}**
1 (Pa m^3)/s	**10**	**592.1**	**1**	**0.987 10^{-5}**
1 atom/s	**3.77 10^{-20}**	**2.233 10^{-18}**	**3.77 10^{-21}**	**1**

[1] 1 sccm = 1 standard cubic centimeter per minute = (1 atm cm^3)/min

Appendix B.

Different values used in the paper [11].

P_1 - inlet pressure [mbar],
P_2 - outlet pressure [mbar],
Q - gas flow [mbar l/s],
S - pumping rate, $S = Q / P_1$, [l/s],
C - compression ratio, $C = P_2 / P_1$.

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