MEASUREMENTS OF RADIAL SIZE OF A HYDROGEN ATOMS SOURCE

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Radial size of a hydrogen atoms source has been measured with an iris diaphragm and a quadrupole mass-spectrometer. The hydrogen atoms were produced by a pulsed rf discharge dissociator of a polarized atomic hydrogen source. It was found that the hydrogen atoms source size is larger than the dissociator nozzle diameter (2.5 mm). Gaussian characteristic radius of the hydrogen atoms source is increased with increase of a gas flux. Radial distribution of the source density has tails with size larger than the skimmer diameter (6 mm). Origination of the tails is discussed.

1. Introduction

Intensity of polarized atomic hydrogen beams obtained with atomic beam sources (ABS) and density of atoms in the beams is determined by acceptance of sextupole magnets and emittance of source of unpolarized hydrogen atoms. Emittance is proportional to radial size of the hydrogen atoms source. So, the source radial size is important characteristic which is determined by a dissociator nozzle geometry and by properties of hydrogen flux escaping the nozzle.

For calculation of atoms trajectories and design of optimal configuration of ABS's sextupole magnet system it is accepted usually that radius of hydrogen atoms source is equal to a dissociator nozzle radius. However, for a typical flux from a dissociator of 1 mbar l/s a mean free path for hydrogen atoms in gaseous flux coming through the nozzle is significantly less than the nozzle diameter, and the nozzle cannot be considered as a source of a collision free atomic hydrogen beam. Density of atomic hydrogen is reduced during expansion of gas into vacuum, collisions between atoms in the expanded gas become rare, and the expanded hydrogen jet becomes by a source of a collisions-free atomic hydrogen beam. Radial size of the source depends on hydrogen gas density in the dissociator, cross-section for collisions between hydrogen atoms and molecules, angular divergence and other parameters of the gaseous expanding jet.

In this paper we describe a simple method for measurements of the hydrogen atoms source and present results of the measurements.

2. Experimental setup

The measurements were performed at IKP Jülich ABS test bench. The ABS includes a pulsed rf discharge hydrogen dissociator which operates with repetition rate of 1 Hz, pulse duration of 10-30 ms and power of RF discharge up to 2 kW [1]. Atomic hydrogen was cooled to temperature around of 70 K passing through aluminum alloy accommodator. The dissociator nozzle diameter was 2.5 mm. A skimmer had orifice diameter of 6 mm. The distance between the nozzle and the skimmer was 30 mm. Molecular hydrogen was supplied by a pulsed electromagnetic valve. Smaller amount of molecular oxygen was added by a separate gas valve. Time delays between the gas valves trigger pulses and rf discharge pulse were adjusted to optimize the atomic hydrogen beam intensity.

The hydrogen atoms radial size measurements were made with an iris diaphragm and a QMS. The experimental setup is shown schematically in Figure 1.

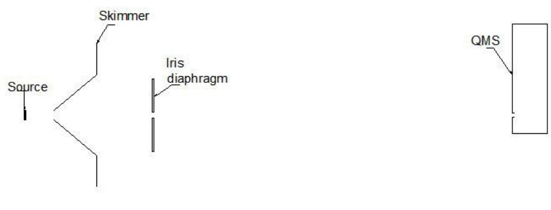

Figure 1. Schematic diagram of apparatus for measurements of radial size of a source of hydrogen atoms.

The iris diaphragm was installed in sextupole magnets vacuum chamber 7 cm downstream the skimmer orifice. The sextupole magnets were removed from the vacuum chamber during the measurements.

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The diaphragm diameter was changed by motor drive from 1.5 mm to 25 mm. The QMS was installed in separate vacuum chamber with differential vacuum pumping. Distance between the iris diaphragm and the QMS was 80 cm. The QMS "sees" the hydrogen atoms starting from the source area within radius:

$$R_s = (1 + L_1/L_2)\, R_d, \qquad (1)$$

where R_d is the iris diaphragm radius, L_1 is distance between the source and the diaphragm, L_2 is the distance between the diaphragm and the QMS.

Integrated radial distribution for the atoms source density can be obtained recording the QMS signal vs the iris diaphragm radius and taking into account formula (1).

3. Results

Typical results of the measurements are shown in Figure 2.

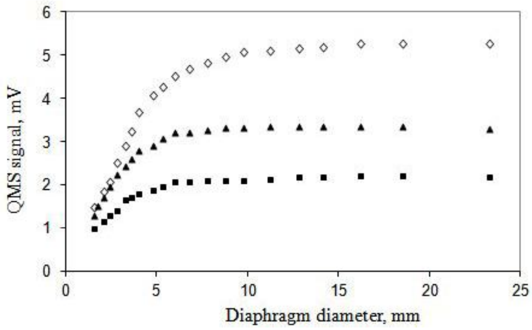

Figure 2. The QMS signal (H–atoms) vs the iris diaphragm diameter. ▪ - number of hydrogen molecules injected into the dissociator tube per pulse is $1.5{\cdot}10^{17}$ mol/pulse, ▲ - $N_{H2} = 3{\cdot}10^{17}$ mol/pulse, ◇ - $N_{H2} = 5{\cdot}10^{17}$ mol/pulse.

QMS signal for atomic hydrogen is shown in the Figure 2 vs the iris diaphragm diameter. The data were taken for different hydrogen gas flux from the dissociator. The gas flux was recorded in number of hydrogen molecules injected into the dissociator tube per pulse which was calculated using recorded pressure change in the dissociator vacuum chamber.

Comparison of the data for $N_{H2} = 5{\cdot}10^{17}$ mol/pulse (corrected in accordance with formula (1)) with expected QMS signal vs radius is shown in Figure 3. The dashed curve show expected dependency for case when the hydrogen atoms source has radius of 1.25 mm (equal to the dissociator nozzle radius) and the long-dashed line is for the source radius of 3 mm (homogeneous source density distribution was assumed).

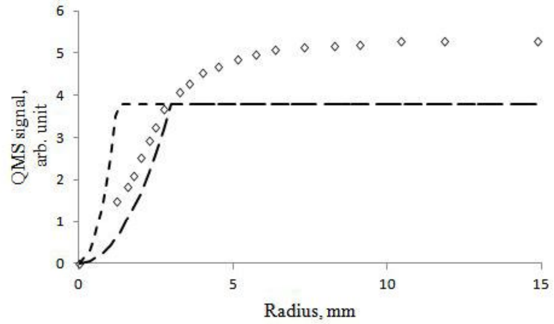

Figure 3. Comparison of the experimental data (◇ - $N_{H2} = 5{\cdot}10^{17}$ mol/pulse) with curves for expected QMS signal vs radius at source position. The curves show expected QMS signal for homogeneous source density distribution and for radius of the source equal to the dissociator nozzle radius - 1.25 mm (dashed line) and to the skimmer radius – 3 mm (long-dashed line).

It follows from the Figure 3 that the distribution has tail with radius larger than the skimmer radius. This means that significant part of atoms trajectories (about 28 % for gas flux of $5{\cdot}10^{17}$ mol/pulse) started to the QMS from points downstream the skimmer. We'll discuss the physical reasons for the tail formation in a chapter 4 of the paper.

From Figure 3 it follows also that the atoms source density distribution is not homogeneous. Gaussian distribution better agrees with experimental data for smaller gas flux as shown in Figure 4. Characteristic radius of the Gaussian distribution is 1.74 mm for $N_{H2} = 1.5{\cdot}10^{17}$ mol/pulse and 1.79 mm for $N_{H2} = 3{\cdot}10^{17}$ mol/pulse.

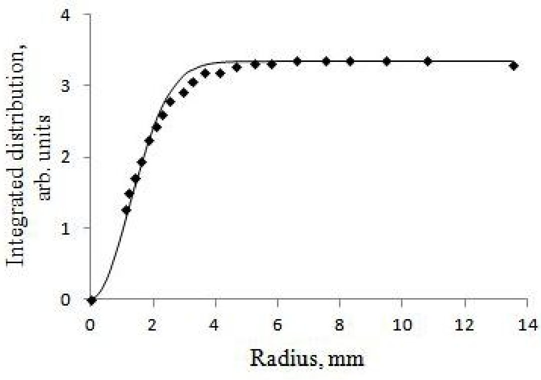

Figure 4. Integrated distribution of the hydrogen atoms source density. ◆- experimental data for $N_{H2} = 3{\cdot}10^{17}$ mol/pulse. Solid curve is the fit assuming Gaussian radial density distribution with characteristic radius of 1.79 mm.

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Some discrepancy (~ 3 %) between the experimental data and the Gaussian fit curve exists at radius of around 3-5 mm. For larger gas flux $N_{H2} = 5{\cdot}10^{17}$ mol/pulse the disagreement sharply increases to ~ 10 % as shown in Figure 5.

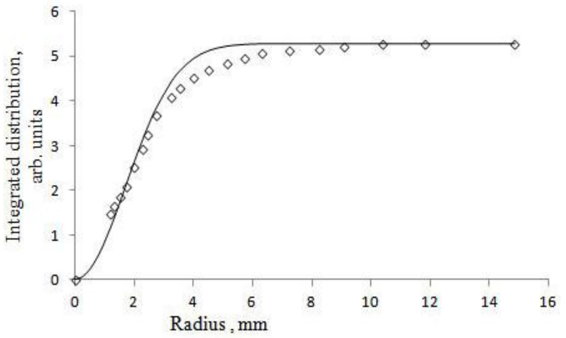

Figure 5. Integrated distribution of the hydrogen atoms source density. ◇ experimental data for $N_{H2} = 5{\cdot}10^{17}$ mol/pulse. Solid curve is the fit using Gaussian radial density distribution with characteristic radius of 2.4 mm.

Better agreement with experimental distribution has been obtained with two-Gaussian fit. One of the two Gaussian distributions was "cut" at the skimmer radius. The results of the fit are shown in Figure 6.

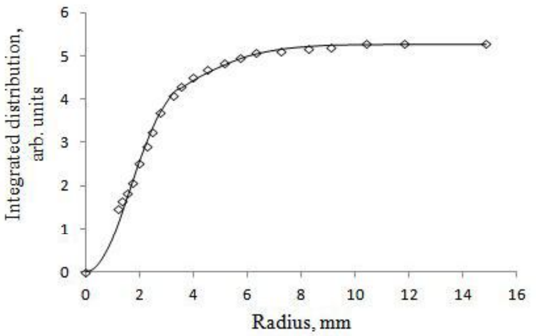

Figure 6. Integrated radial distribution of the hydrogen atoms density. ◇ - experimental data for $N_{H2} = 5{\cdot}10^{17}$ mol/pulse. Solid curve – fit assuming two-Gaussian radial density distribution with characteristic radiuses of $R_1 = 1.9$ mm, $R_2 = 4.2$ mm.

The respective fit curves for the source radial density distribution are shown in Figure 7.

4. Discussion

The measurements reveal increase of radial size of the hydrogen atoms source with increase of gas flux from the dissociator. Characteristic radius of Gaussian fit increases from 1.74 mm for gas flux of $N_{H2} = 1.5{\cdot}10^{17}$ mol/pulse to 1.9 mm for $N_{H2} = 5{\cdot}10^{17}$ mol/pulse. The source radius is larger than the nozzle radius of 1.25 mm and smaller than the skimmer orifice radius (3 mm). The source radial size increase is connected

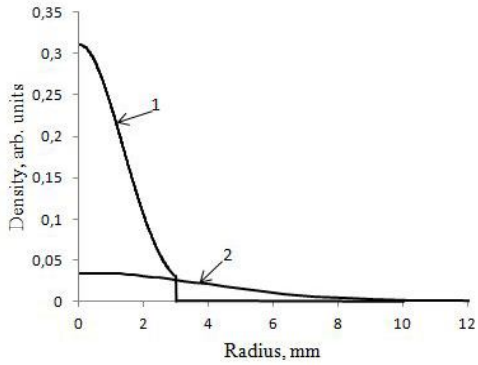

Figure 7. Radial hydrogen atoms density distribution correspondent to the two - Gaussian fit shown in Figure 6. The experimental data were fitted by sum of two Gaussian curves. Curve (1) was cut at the skimmer radius (3 mm).

with two processes. One of them is increase of radius of expanded jet at point where collisions become rare ("freezing surface") with increase of gas flux. This process can lead to limitation of atomic hydrogen beam intensity if the hydrogen atoms source effective radius becomes larger than the skimmer orifice radius ("screening effect") [2]. However, in our study the characteristic source radius is still smaller than the skimmer orifice radius (3 mm) and the recorded data show that "screening effect" does not limit significantly the atomic hydrogen beam intensity in the present ABS setup.

Another process is formation of the tail in the density distribution with radial size larger than the skimmer radius. We see two possible mechanisms for the tail formation: one could be intra-beam scattering downstream the skimmer and another - formation of a dense gaseous "cloud" inside the skimmer [3, 4]. Experimental data for the source density radial distribution shown in Figures 6, 7 correspond better to the second mechanism of the gaseous "cloud" formation inside the skimmer. In this mechanism radial distributions shown in Figure 7 have clear interpretation: the distribution (1) corresponds to the primary atomic hydrogen beam starting from the dissociator while the distribution (2) corresponds to the gaseous 'cloud' formed inside the skimmer. The primary atomic hydrogen beam is cut by the skimmer with radius of 3 mm. The fit agrees well with the experimental data as shown in Figure 6.

If the intra-beam scattering is responsible for the tails origination it should lead to formation of a smooth

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radial source distribution. However, the one-Gaussian fit does not agree well with experimental data as shown in Figure 5.

5. Conclusions

Radial distribution of hydrogen atoms source density has been measured with iris diaphragm and QMS. The measurements show increase of radial size of the source vs gas flux. Characteristic radius of one-Gaussian fit increases from 1.74 mm for gas flux of $N_{H2} = 1.5{\cdot}10^{17}$ mol/pulse to 1.9 mm for $N_{H2} = 5{\cdot}10^{17}$ mol/pulse. For large gas flux of $N_{H2} = 5{\cdot}10^{17}$ mol/pulse formation of tail in the distribution with diameter exceeding the skimmer orifice diameter has been found. Two-Gaussian distribution fit agrees well with the experimental data for this case of large gas flux. Possible mechanism of the tail origination is formation of a gas “cloud” inside the skimmer. The “cloud” becomes by a source of hydrogen atoms with diameter larger than the skimmer diameter.

Thus, the measurements of radial size of a hydrogen atoms source give useful information for design and optimization of ABS apparatus and for study of mechanism of formation of atomic hydrogen beams.

References

1. R. Gebel, O. Felden and R. Maier. Proc. of 12th International Workshop on Polarized Sources Targets and Polarimeters. PSTP 2007, BNL, USA. AIP Conf. Proc. **980**. 2008. P. 231.
2. D.K. Toporkov. Nucl. Instr. And Meth. In Phys. Research. **A536**. 2005. P. 255.
3. A.S. Belov, L.P. Netchaeva and A.V. Turbabin. Rev. Sci. Instrum. **77**. 2006. P. 03A522.
4. A.S. Belov. Proc. of 12th International Workshop on Polarized Sources Targets and Polarimeters. PSTP 2007, BNL, USA. AIP Conf. Proc. **980**. 2008. P. 209.

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