Design of Transversal Phase Space Meter for Atomic Hydrogen Beam Source

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For optimization of polarized atomic beam sources apparatus it is important to have detailed information about characteristics of sources of hydrogen atoms, especially, taking into account present intensity limitations of polarized atomic beam sources. Usually, longitudinal velocity distribution of hydrogen atoms produced by RF dissociator is measured while transversal phase space of unpolarized atomic hydrogen beams was not measured up to now. In this work we report and discuss a design of transversal phase space meter for pulsed atomic hydrogen beam source. The meter design is based on “two slits” method which is well known from ion beam technique. Specific feature of the meter are movable sensitive detector of hydrogen atoms and molecules.

Keywords: Source of polarized hydrogen atoms; transversal phase space meter; mass-spectrometer.

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1. Introduction

Polarized atomic beams of hydrogen or deuterium atoms with thermal energy are produced by atomic beam sources (ABS) apparatus consisting from rf discharge dissociator of molecular hydrogen (deuterium), multipole separating magnets and high frequency transitions units (see Ref. 1 for details of the atomic beam method). Intensity of dc polarized atomic hydrogen beams produced by modern atomic beam (AB) apparatus reached level of $\sim 10^{17}$ at/cm² sec (see Ref. 2). In pulsed mode of operation polarized atomic hydrogen beam with peak intensity of $\sim 2 \cdot 10^{17}$ at/cm² sec has been obtained.³

Further increase of polarized atomic beam intensity is limited by several restricting processes including scattering of atoms in collisions with residual gas molecules

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and recombination of atomic hydrogen at higher pressure in a hydrogen rf discharge dissociator.

For atomic hydrogen beam cooled to 6K it had been found⁴ that focusing factor for the cold atomic hydrogen beam drops to low value of ~ 2 for high density of the initial unfocused atomic hydrogen beam. It was supposed that this effect is explained by intra-beam scattering of hydrogen atoms during their passage through multipole magnets.

It was suggested⁵ that observed saturation of intensity limitations of AB cooled to conventional temperature of ~ 80 K may be explained by the intra-beam scattering as well.

However, for most intense pulsed atomic hydrogen beam from INR RAS source it has been found^{3,6} that observed limitation of the pulsed atomic hydrogen beam intensity is connected with a beam-skimmer interaction. Shock-like “gas cloud” is arisen at a skimmer position due to the beam-skimmer interaction, and AB is attenuated due to scattering of atoms in collisions with the gas cloud particles. The model validation has been performed with measurements of radial size of hydrogen atoms source at test bench of a pulsed ABS at COSY Juelich.⁷ It was found that radial distribution of density of hydrogen atoms source has tails with size larger than diameter of a skimmer. This means that some hydrogen atoms trajectories of a free atomic beam start from region downstream the skimmer orifice indicating existence of “gas cloud” consisting from hydrogen atoms and molecules inside the skimmer. The gas cloud size (~ 10 mm) indicates that the gas cloud is situated close to the skimmer orifice.

Thus, the beam-skimmer interaction leads to change of effective size of atomic beam source and to change of divergences of atoms trajectories. This makes influence on focusing of atoms by multipole separating magnets and should be taken into account for design of ABS multipole magnets.

Most detailed information concerning initial characteristics of the atomic beam parameters such as the radial size and radial distribution of atoms density and divergence of the atoms trajectories can be obtained by measurements of transversal phase space of the AB downstream the skimmer. Design of the transversal phase space meter for the atomic beam will be discussed in chapter 2. Some expected results will be considered in chapter 3.

2. Design of the Transversal Phase Space Meter

Schematic diagram of the AB transversal phase space meter is shown in Fig. 1.

The meter design is based on “two slits” method which is well known from an ion beam technique. AB has cylindrical symmetry in standard ABS. So, it is sufficient to measure transversal phase space portrait (transversal emittance) of AB only in one direction: vertical or horizontal. For definiteness, we accept that in Fig. 1 the transversal emittance is measured in vertical direction.

Fig. 1. Schematic diagram of the AB transversal phase space meter.

The phase space meter consists from movable diaphragm with slit orifice (first slit) which cuts a stream from AB which is narrow (~ 0.5 mm) in vertical and wide (~ 30 mm) in horizontal direction. The first slit is moved by step motor drive in vertical direction. The first slit position determines vertical coordinate of the atoms stream which then is analysed by a mass-spectrometer with second movable slit installed in front of the mass spectrometer entrance. The mass-spectrometer is moved in vertical direction together with the second slit by another step motor drive. The hydrogen AB consists from mixture of hydrogen atoms and hydrogen molecules with small part of water molecules which are formed due to small flux admixture of oxygen to the dissociator gas flux to suppress hydrogen atoms recombination. The mass-spectrometer separates out signals corresponding to different particles of the AB. Neutral atoms and molecules of the AB are ionized in collisions with electrons generated by an electron gun and moving in direction along the second slit. Mass analyses of the ions extracted from the ionization region is performed by a magnetic or time-of-flight mass-analyser. A micro channel plate (MCP) is planned to be used as detector of the ions.

Displacement of the second slit — mass-spectrometer assembly in vertical direction for fixed position of the first slit allows to measure neutral particle density distribution in the stream cut out by the first slit and by this way distribution of atomic trajectories divergence in vertical direction.

3. Expected Results

Transversal phase space of AB downstream a skimmer is determined by geometric parameters of a source of atoms and a beam formation system as well as by mechanism of AB formation including beam-skimmer interaction.

For low hydrogen gas pressure in a dissociator bulb there will be effusion mode of gas flux escaping out a dissociator nozzle. In this case radial size of an atoms source will be equal to a nozzle radius. Divergence of AB downstream the skimmer

Fig. 2. Expected transversal phase space portraits of AB downstream a skimmer for different mode of AB formation (vertical axis: divergence in rad, horizontal axis: AB size in mm a) — effusion mode; b) — supersonic mode; c) — supersonic and beam-skimmer interaction mode.

will be determined by the nozzle and the skimmer diameters and distance between the nozzle and the skimmer. Figure 2a shows expected transversal phase space portrait for this case. The nozzle diameter was accepted to be 2 mm; the skimmer diameter — 6 mm, distance between the nozzle and the skimmer — 30 mm.

For supersonic mode of gas escaping out the dissociator nozzle a “freezing surface” becomes source of free atomic beam. In this case the source diameter becomes larger than the nozzle diameter and “freezing surface” locates between the nozzle and the skimmer. This leads to larger emittance in comparison with effusion mode as shown in Fig. 2b.

Beam-skimmer interaction should lead to formation of “gas cloud” at the skimmer orifice position and strong increase of the AB divergence due to scattering of AB particles on the gas cloud as shown in Fig. 2c.

Thus, strong difference in transversal phase space portraits is expected for different gas pressure in an ABS dissociator bulb. This allows to use results of AB transversal phase space measurements for analyses of mechanism of AB formation.

4. Conclusion

Measurements of transversal emittance of atomic hydrogen beam downstream a skimmer of ABS would produce valuable information which is necessary for design of optimal multipole magnet system. The AB emittance meter should help to resolve

the long-standing question about mechanism of AB formation and intensity limitation. This should give a guide line to further optimization of the ABS apparatus.

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