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Gas dynamics considerations in a non-invasive profile monitor for charged particle beams

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A B S T R A C T

A non-invasive, gas jet-based, beam profile monitor has been developed in the QUASAR Group at the Cockcroft Institute, UK. This allows on-line measurement of the 2-dimensional transverse profile of particle beams with negligible disturbance to either primary beam or accelerator vacuum. The monitor is suitable for use with beams across a wide range of energies and intensities. In this setup a nozzle-skimmer system shapes a thin supersonic gas jet into a curtain. However, the small dimensions of the gas inlet nozzle and subsequent skimmers were shown to be the cause of many operational problems. In this paper, the dynamics of gas jet formation transport and shaping is discussed before an image-processing based alignment technique is introduced. Furthermore, experimental results obtained with a 5 keV electron beam are discussed and the effects of gas stagnation pressure on the acquired beam are presented.

1. Introduction

Diagnostics systems are an essential part of any particle accelerator. They are used to measure the beam's properties and optimize the accelerator's performance. They can be found in any accelerator from high energy colliders for particle physics experiments to light sources, free electron lasers, exotic ion accelerators and smaller scale machines for fundamental studies and precision experiments. For real time beam monitoring, non-invasive methods have the advantage of least interference with the beam and thus affecting less the machine. A non-invasive beam monitor must have minimal interference with the particle beam, in order to preserve the quality of low intensity beams. It can also protect the diagnostics from high intensity beams and minimize the maintenance required as well as preserving the vacuum environment.

A candidate for non-destructive monitoring is a gas jet monitor where the particle beam interacts with a gas jet shaped into a curtain, causing ionization. The ions can be collected by means of an electric field and provide information on the beam. Due to the low gas jet pressure, the number of particles interacting with the gas is negligible compared to the number of particles in the beam. Thus, the monitor can be considered as non-invasive.

Two applications of a gas jet based beam profile monitor have been demonstrated by Hashimoto et al. [1–3]. The first case is an oxygen gas jet for profile measurements of an 8 MeV proton beam of the National Institute of Radiological Sciences (NIRS) in Chiba, Japan. Oxygen gas from a high pressure tank enters a vacuum chamber and after a skimming section the gas is focused by a non-homogeneous magnetic field of 1 T acting on the magnetic moment of the gas molecules before interacting with the proton beam. The interaction produces ions which are collected by an electric field and imaged on an MCP detector where the beam profile can be obtained. The second application is a nitrogen gas jet for the JPARC main ring (MR). It operates based on the same principle as the oxygen jet but without magnetic focusing. The nitrogen gas jet instead passes through one more collimator in order to obtain the desired characteristics. Both of these applications have demonstrated their functionality for high energy beams but they have not been applied on a low energy, low intensity beam for precision experiments in extreme high vacuum.

The monitor presented in this paper was designed to operate in an ultra-high vacuum environment in the order of 10^{-11} mbar and probe proton and antiproton beams ranging from 20 to 300 keV [4] [5]. These are the requirements for the profile monitor at the Ultra-

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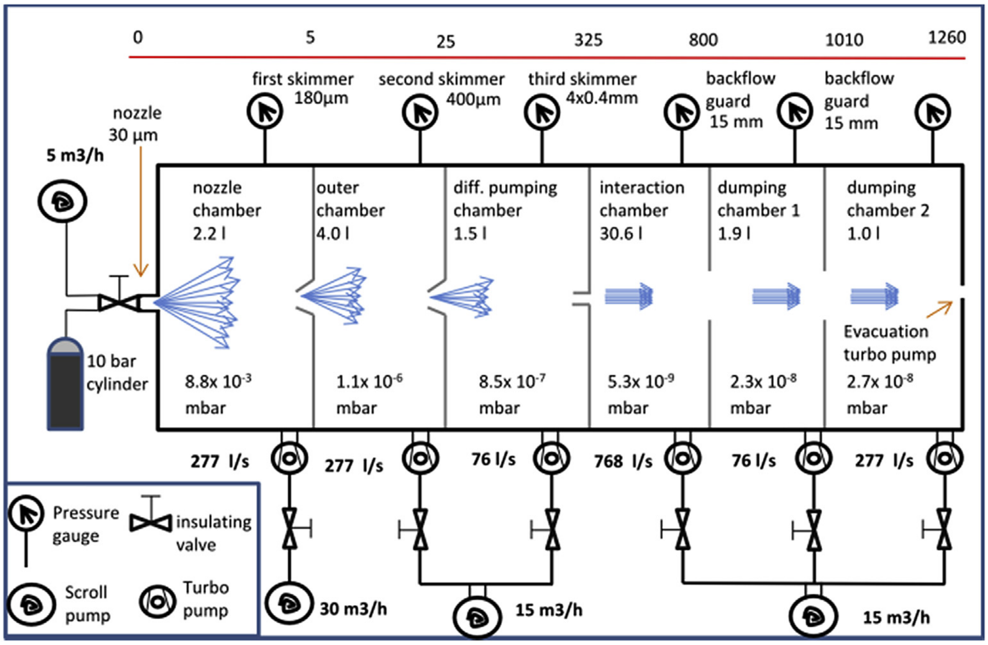

Fig. 1. Gas jet setup layout, including vacuum pumping system.

low energy Storage Ring (USR) at the Facility for Low-energy Antiproton and Ion Research (FLAIR) in Darmstadt [6]. According to these specifications, low energy beams with ultralow currents (1 nA or less), few particles ($<10^7$) and beam size varying from 2 cm to a few mm will require the development of new diagnostic devices. The beam monitor is based on the reaction microscope design, developed by the Ullrich group at MPIK for high precision atomic physics experiments [7]. In a reaction microscope, a neutral gas undergoes a supersonic expansion into the vacuum reaching Mach number 7 and an internal temperature of a few *K*. It is then skimmed and shaped into a pencil jet. Such a low temperature minimizes the thermal motion of the gas so that after the interaction with a beam and imaged on a position sensitive detector the cold ion trajectories can be traced backwards to the exact point of interaction.

For beam monitoring purposes the principle of operation remains the same but the skimmer shape is altered to produce a thin gas sheet. For the same purposes it has been estimated that confidence intervals of 5% in beam position determination can be accepted, corresponding to about 1500 ionization events and 4% precision on the determination of beam profile width. According to the design considerations of this beam profile monitor and the case of USR, acquisition times compatible with ms to µs imaging will be feasible [8].Although designed initially for the strict specifications of the USR, the monitor is flexible and can also operate in different vacuum environments and different beams. The interaction with the beam relies on ionization, a well-studied process with rich literature available for different gas species, primary beam types and energies. The reaction rate which determines the measured profile quality can then be controlled by the stagnation pressure or by using gas species with convenient cross sections, making the monitor easily adaptable to different applications. Beam monitors based on the ionization of the residual gas have been used in many facilities as a non-invasive method. The monitor reported here is based on the same ionization process with the difference of a higher reaction rate because of the gas jet's higher density.

The aim of this paper is to present the design details and the operating principle of the supersonic gas jet based beam profile monitor that was built and commissioned at Cockcroft Institute, UK [8]. The results of the first measurements with nitrogen gas are discussed as well as the alignment process. Of a particular interest is the performance of the monitor under different stagnation pressures.

2. Materials and methods

2.1. Design description

The test stand is composed of 4 main sections. Following the order of the jet as it travels these are: the nozzle chamber, differential pumping section, interaction chamber and dumping section. The layout with emphasis on pumping details is presented in Fig. 1

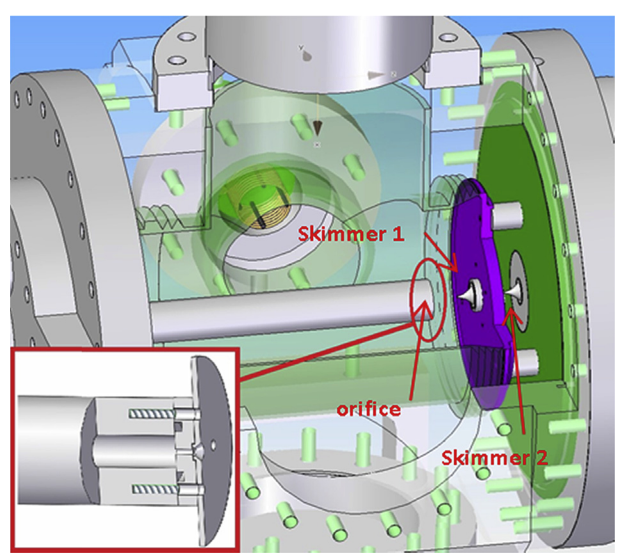

Fig. 2. Schematic CAD drawing of the nozzle chamber where the first two skimmers are highlighted.