ION BEAM BUFFER GAS COOLING BY A RF-QUADRUPOLE

E. Vassilakis, A. Schempp
Institut für Angewandte Physik, Johann Wolfgang Goethe-Universität,
60325 Frankfurt am Main, Germany

Abstract

Beams with high brilliances are required for many applications e.g. for exotic and radioactive beam application. One way of reducing the necessary acceptance resp. increasing the transmission of accelerators is beam cooling by the statistical collisions with a buffer gas and a decreasing of the emittance in a short transport section in front of the accelerator.

Our experimental setup is a combination of an RF-quadrupole and He-buffer gas on an Ar-beam.

1 INTRODUCTION

Usually ion beams are transported and accelerated in evacuated systems to protect scattering of the beam particals by residual gas atoms or molecules. While many studies have been done to improve the vacuum W. Paul has proven that ions can be captured in the resudual gas. New studies show that low pressure (buffer) gas can also be used to improve the quality of partical beams [1,2,3]. By collisions the buffer gas will take kinetic energy of the beam particals. Because the longitudinal kinetic component is much higher than the transverse one, the effect in beam direction is marginal but in the radial dimension significant.

In our expereiment we use an unmodulated rf-quadrupole so that the motion of beam particals is described by the Mathieu's equation

$$y''(s) + [a - 2q\cos(2s)]y(s) = 0 \qquad (1)$$

The magnitudes of oscillations is given by

$$E(s) = \sqrt{\varepsilon\beta(s)} \qquad (2)$$

where the beta funktion $\beta(s)$ represents the amplitude modu- lation [4]

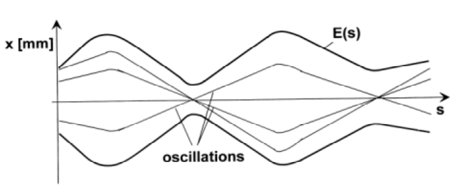


Fig. 1: The envelope of the oscillation.

As this socalled Betatron oszillation ω_{BETA} is determined by the initial beam conditions, application of a RF-quadrupole superimposes another oszillation ω_{RF} following the RF. Stable solutions of (1) will be found by approximation

$$q = \sqrt{8}\,\frac{\omega_{BETA}}{\omega_{RF}} \quad . \qquad (3)$$

The deviation will be less than 10 % [1].

Following Stokes law of viscous friction the damping of a partical with mass m, the mobility μ and electric charge z in a buffer gas modifies Mathieu's equation to

$$y''(s) + \frac{z}{\mu}\frac{y'}{m}[a - 2q\cos(2s)]y(s) = 0 \quad . \qquad (4)$$

Thus the region of stable solutions exstends over the conventional one.

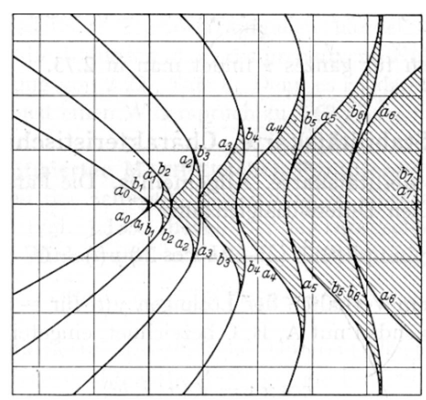


Fig. 2: Illustrated regions of bounded and unbounded solutions of Mathieu's eq. (Strutt's map). The indicated graphs represent the socalled characteristical curves which separate the regions of stable and unstable solutions. Stable solutions only exist in the hatched zone [5].

The emittance ε of a beam is one of its basic characteristics. It describes the distribution of beam particals in the phase space:

$$\varepsilon = \frac{1}{\pi^3}\iint di\, dp_i \qquad (i = x, y, z)\,. \qquad (5)$$

The brilliance B of a beam is defined as the ratio of the beam current I and the transverse emittance $\varepsilon_x \cdot \varepsilon_y$:

$$B = \frac{I}{\pi^2 \varepsilon_x \varepsilon_y} \quad \Rightarrow \quad \Delta B \sim \frac{1}{\varepsilon_x \varepsilon_y} \quad (I = const.) \qquad (6)$$

The factor π^2 transforms the emittance into an area.

Following the experiments done at REX ISOLDE and by R. B. Moore we analysed buffer gas cooling on an ion beam. But we deduced its influence on the emittance indirect from the measured beam current I into the Faraday cup [1-3].

2 EXPERIMENTAL SETUP

We have studied the buffer gas cooling in a RF-quadrupole with a length of 500 mm and 10 mm aperture. ^{4}He was used as buffer gas for the ^{40}Ar-beam. As ion source we utilise a Duoplasmatron. The frequency of the quadrupole has been varied from 1 MHz to 5 MHz with beam energies of 15, 25 and 80 eV/u. Thus, the ions were captured for 9 to 46, 7 to 36 and 4 to 20 periods. The pressure of the buffer gas was varied between $9*10^{-5}$ and $6*10^{-5}$ mbar. This selection of parameters follows simulations done by O. Engels with SIMION [6]. The beam current was measured at an apertur of 25 mm diameter and in a distance at 85 mm behind the electrodes. For analysation of inner and outer beam components I_I and I_O the Faraday cup was splitted in two concentric segments.

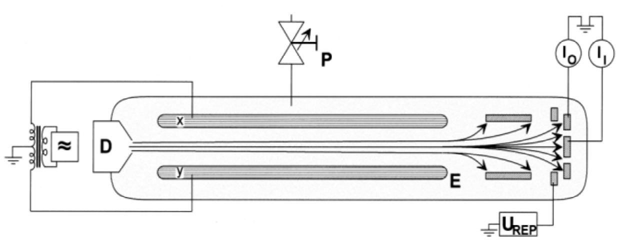


Fig. 3: Layout of the buffer gas cooling experiment. D: Duoplasmatron ion source, E: electrodes, P: buffer gas valve, U_{REP}: repeller voltage.

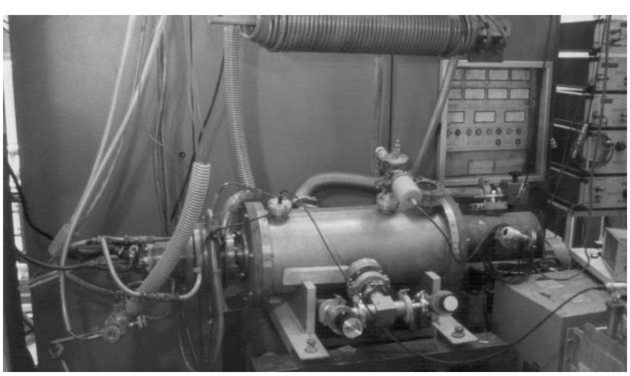


Fig. 4: Photograph of the experiment setup.

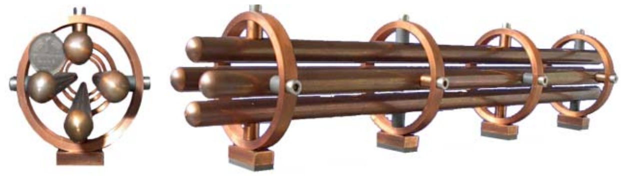


Fig. 5: View of the quadrupole.

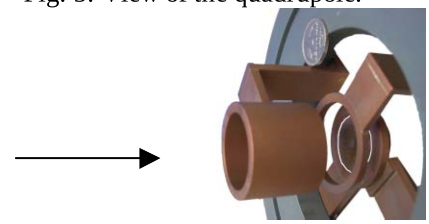


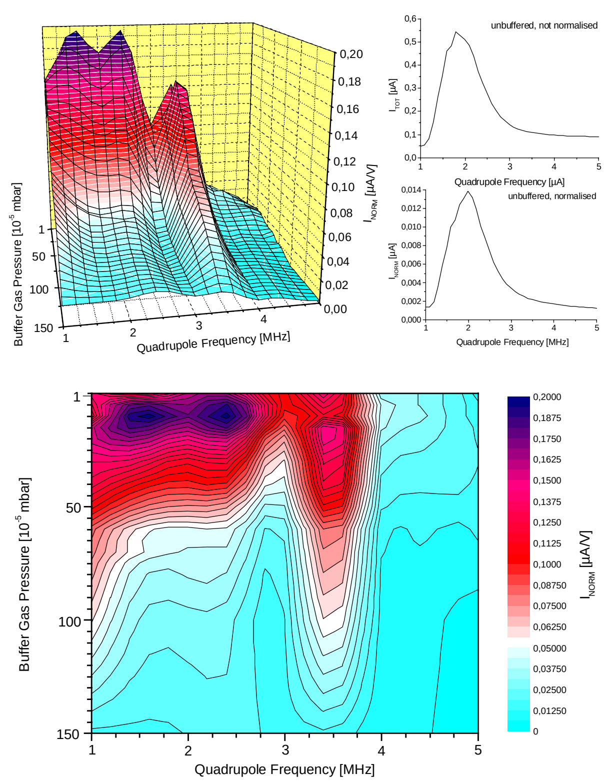
Fig. 6: Picture of the diagnostic elements.

3 RESULTS

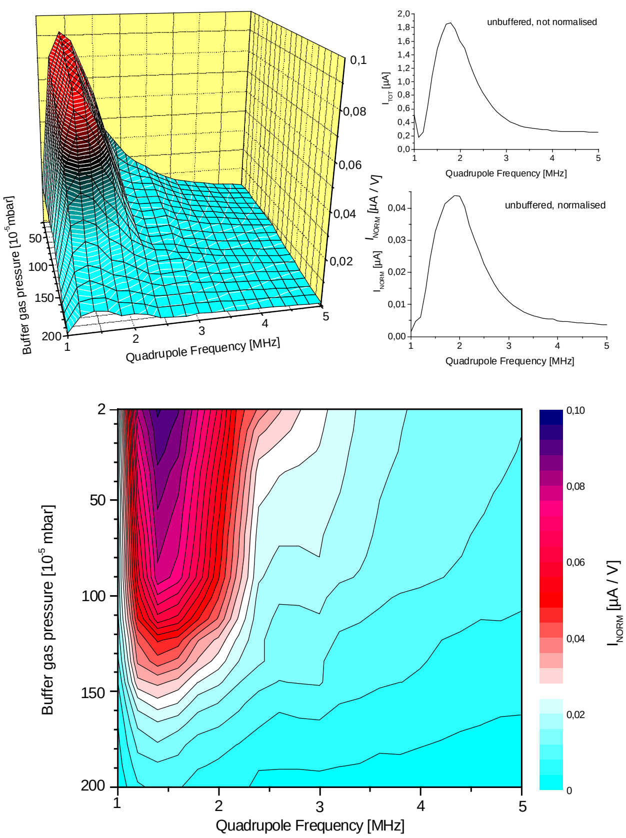
Comparison of the transported beam current of the cooled ion beam with the unbuffered shows several significant differences:

- the maximum current of the beams increases from 0,14 to 0,2 µA/V (15 eV/u) and from ~0,04 to 0,1µA/V (25 eV/u) but remains the same at 80 eV/u.

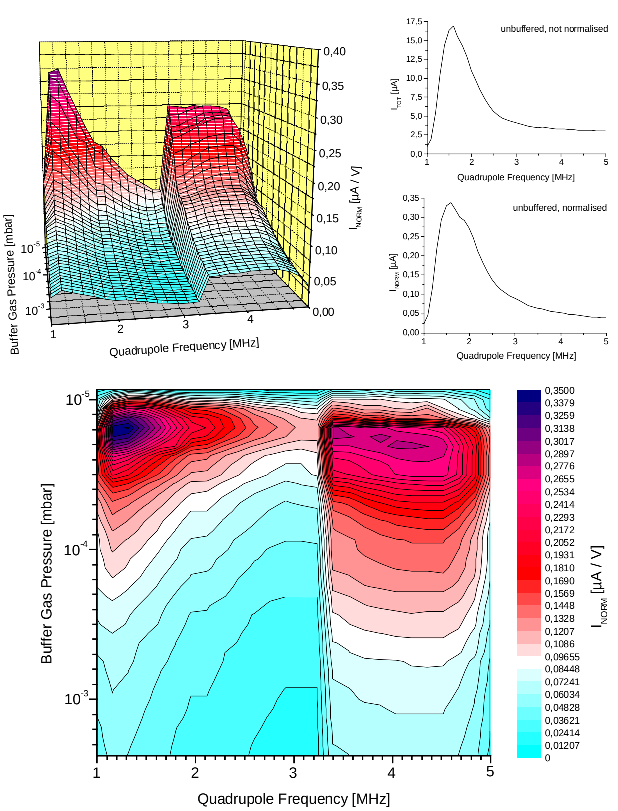
-after a maximum at ~1,8 to 2 MHz the current of the uncooled beam is monotonicly decreasing. However, a second maximum occurs at 3 to 4 resp. 3,2 to 5 MHz when using the 15 resp. 80 eV/u energy cooled beam (fig. 7a-c). The vertex of this local maxima is located in the range of $2*10^{-5}$ to $6*10^{-5}$ mbar.



7a: Plots of the 15 eV/u beam.



7b: Graphs of the 20 eV/u beam.



7c: Plots of the 80 eV/u beam.

Fig. 7a-c show the normalised transported ion beam current I_{NORM}. Beside the three dimensional graphs of the cooled beams for comparison the graphs of the unbuffered beams resp. not normalised ones are shown. The measured total beam current I_{TOT} is normalised to the frequency-dependent Quadrupole Voltage V_{QU}: $I_{NORM} = I_{TOT} / V_{QU}$.

The increase of the beam current at the fixed aperture of the Faraday cup shows the cooling effect:
As the Duoplasmatron provides a constant rate of ions and the sensitive area of the Faraday cup remains the same, following eq. (6) the denominator of the fraction thus the transverse emittance must have been reduced.

4 CONCLUSIONS

The experiment demonstrates that buffer gas cooling in combination with RF-focussing can increase the brillance of transported low energy ion beams.

More detailed measurements have to be done to determine the influence of the various parameters like beam energy, quadrupole frequency, buffer gas pressure, ratio of mass of the colliding particals and number of frequency periods.

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