ACCELERATION SYSTEM OF BEAM BRIGHTNESS BOOSTER

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Abstract

The brightness and intensity of a circulating proton beam can now be increased up to the space charge limit by means of charge exchange injection or by electron cooling, but cannot be increased above this limit. Significantly higher brightness can be produced through charge exchange injection with space charge compensation [1]. The brightness of the space charge compensated beam is limited at low level by the development of electron-proton (e-p) instability. Fortunately, e-p instability can be self-stabilized at a high beam density. By development of surface plasma sources (SPS) with cesiation and RFQ, an H- beam injector was prepared with intensity ~0.1 A. Now we are ready to produce a "superintense" circulating beam with intensity and brightness far above the space charge limit. A beam brightness booster (BBB) for significant increase of accumulated beam brightness is discussed. An accelerating system with a space charge compensation is proposed and described. The superintense beam production can be simplified through the development of a nonlinear, nearly integrable focusing system with broad spread of betatron tune and a broadband feedback system for e-p instability suppression [2].

INTRODUCTION

Charge Exchange Injection (CEI) was developed to increase a circulating beam's intensity and brightness above injected beam parameters by multiturn injection of beam into the same transverse phase space areas (Non **liuvillian** injection) [3,4,5]. At that time, the intensity of the H^- beam from the plasma source was below 5 mA, with a normalized emittance of ~1 π mm mrad. The intensity of the H^- beam from charge exchange sources went up to 15 mA, but the brightness B of this H^- beam was ~100 times less than the brightness of a primary proton beam because only 2% of proton beam was converted into H^- ions. In this situation, increase of the circulating beam's brightness by up to 100 times was necessary to reach the brightness of the primary proton beam, which can be used for one or several turn injection. The intensity and brightness of H^- ion beams was increased by orders of magnitude by the admixture of a trace of cesium into gas discharges (cesiation effect) [6]. After development of surface plasma source (SPS) with cesiation, H^- beam intensity was increased up to 0.1 A with emittance ~0.2 π mm mrad, [7,8] and the brightness of the injecting beam became close to the space charge limit of a real accelerator such as the Fermilab booster [9]. With such a beam, it is impossible to further increase circulating beam brightness, but CEI is routinely used for rising the circulating beam intensity for many orders by injection into different parts of the transverse phase space (painting in the transverse phase space) [5,9,10]. Further increasing circulating beam brightness is possible by using multiturn CEI with space charge compensation by particles with opposite charge (electrons or negative ions) [1,11,12]

Unfortunately, such a possibility is complicated by strong transverse two beam instability, which is driven by beam interaction with accumulated compensating particles in the circulating beam.

The strong instability with fast loss of bunched beam was discovered in 1965 at a small scale proton storage ring (PSR) during the development of charge exchange injection, and was stabilized by feedback [3, 4, 5, 12, 13]. This instability was explained in [4] as an inversed variant of the strong transverse instability of a circulating electron beam caused by interaction with compensated ions (beam- ion instability) predicted in 1965 by B. Chirikov [14]. An analogue of this instability, electron proton (e-p) instability, was observed experimentally with very low threshold at the same time during accumulation of a coasting beam [1, 5, 11-13]. The e-p instability of the coasting beam was in a good agreement with theory [14,15].

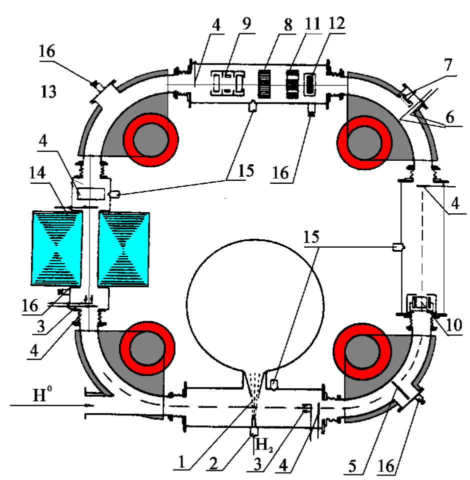

Figure 1: Schematic of a storage ring with diagnostics and control.

1-striping gas target; 2-gas pulser; 3-Faraday Cup; 4-Quartz screen; 5, 6-moving targets; 7-ion collectors; 8-current monitor; 9-Beam Position Monitor; 10-Quadrupol pick ups; 11-magnetic BPM; 12-beam loss monitor; 13-detector of secondary particles density; 14-inductor core; 15-gas pulses; 16-gas leaks.

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A superintense circulating beam with intensity far above the space charge limit was produced at BINP in the simple race track [5,12,13,16] shown in Fig.1.

H^0 beam with a current of up to 8 mA and energy 1 MeV, produced by stripping of an H^- beam, is injected by CEI with electron stripping in the supersonic hydrogen jet into race track with a bending radius of 42 cm, magnetic field 3.5 kG, index n=0.2-0.7, straight sections 106 cm, aperture 4x6 cm^2, revolution frequency -1.86 MHz. An inductive core was used to compensate for the ionization energy loss of ~200 eV per turn, which produced some effects of ionization cooling [3].

A superintense proton beam with intensity ~1 A corresponding to calculated vertical betatron tune shift ΔQ=0.85x6 =5.1 with Q=0.85 was accumulated with e-p instability self-stabilization by fast accumulation of high circulated beam current and accumulation of plasma from residual gas ionization.

This self- stabilization of the transverse e-p instability in the PSR is explained by increasing the beam density and increasing the rate of secondary particle generation above a threshold level with a fast decrease of the unstable wavelength λ below the transverse beam size *a*. (i.e. the sum of beam density n_b and ion density n_i are above a threshold level):

$$(n_b + n_i) > \beta^2 / 2\pi r_e a^2 \; ; \; (r_e = e^2/mc^2).$$

In high current proton rings it is possible to reach this "Island of stability" by fast, concentrated charge exchange injection without painting and enhanced generation of secondary plasma, as was demonstrated in the small scale PSR at the BINP [5, 12, 13, 16]. Beam brightness lost through proton scattering and ionization loss straggling can be compensated for by improved ionization cooling with beam focusing the target by solenoid lenses as shown in Fig. 2.

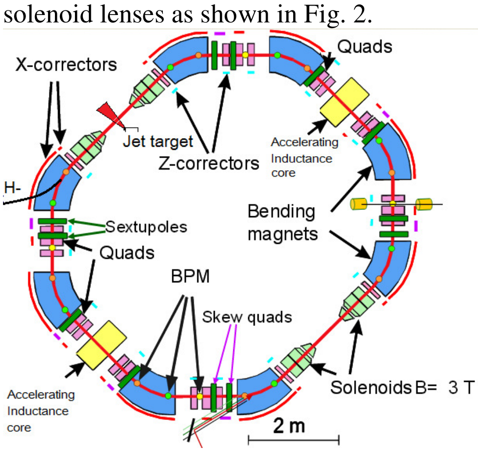

Figure 2: As a prototype of BBB magnetic system can be used a magnetic system of VEPP 2000 round beams collider in BINP with a strong solenoidal focusing of the beams at colliding points.

The broad betatron tune and corresponding Landau damping are important for increasing the threshold of e-p instability [14,15]. This circumference is supported by the increase of the instability threshold with an increase of bunching RF voltage, increasing of separatrix size and energy spread. With high RF voltage it is unstable and only the central (coherent) part of the beam is lost.

With a broad betatrone tune spread, it is possible to produce stable space charge compensated ion and electron beams because e-p instability (electron cloud effect, ion instability) is suppressed by Landau damping [13, 14, 15].

We hope that the production of a superintense beam can be done more easily in the BBB with the stable, close to integrable, nonlinear focusing proposed in [2].

As a prototype of BBB magnetic system can be used a magnetic system of VEPP 2000 round beams collider in BINP with a strong solenoidal focusing of the beams at colliding points [17]. For energies up to 10 MeV, it is possible to use a supersonic gas jet as a stripping target as was used in the small scale proton storage ring in BINP [3-5]. The RFQ and small linac can be used as an injector with an H^- beam ~100 mA, 2-10 MeV.

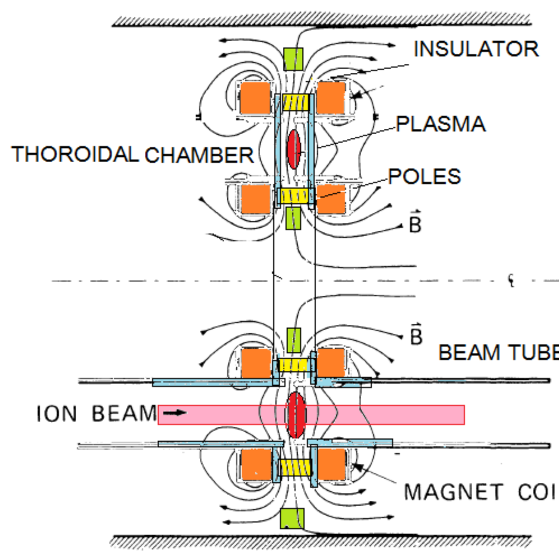

Figure 3: Ion beam acceleration with space charge compensation in the gap with cross field drift plasma (thoroidal chamber).

Some other methods of space charge compensation were discussed in [9,18].

Space charge compensation should not be lost during acceleration. For this, an acceleration system with a closed electron drift in crossed ExB fields as shown in Fig. 3 is proposed. A radial magnetic field is created by magnet coils in toroidal or disc chamber. An accelerating electric field is applied to the insulating gap. Electrons drift in the crossed ExB fields, compensating a space charge and not loading the accelerating gap as in [19].
Plasma accumulation during accumulation of superintense beam was discussed in [11].

Comprehensive review of e-p instability in different accelerators and storage rings was presented in [20]. A theoretical estimation of self-stabilization is presented in

[21]. A practical usage of space charge neutralization in advanced ion implanters is considered in [22,23].
With the barrier bucket acceleration tried at the AGS in the collaboration between KEK and BNL [24], it is possible to accelerate a long uniform bunch of ions without loss of space charge neutralization.

CONCLUSION

BBB with space charge neutralized superintense ion beams with intensity far above space charge limit can be useful for:

- Inductance Linac with recirculation,
- Inertial Fusion
- Neutron, Antiproton, and Mu meson Generators
- Resonant reaction with internal targets
- High Power Density Physics
- FFAG accelerators,
- Inductive Synchrotrons.

It is very appealing to repeat the accumulation of a Superintense ion beam with modern high current injectors. High current density beams should be stable without secondary ions.
Barrier bucket acceleration [24] can be used for acceleration of a long uniform bunch of ions without loss of space charge neutralization.
Now from a RFQ it is possible to have a H- beam with current ~100 mA and Energy ~2-3 MeV.
This can be enough for accumulation of ~ 1 kA of circulating proton beam in a small storage ring with R~1m.

As a first step, it is possible to conduct realistic simulations of superintense beam accumulation with enhanced ionization cooling. Simulation of self-stabilization of the e-p instability can become a basis for new advanced accelerators and storage rings with intensities significantly above the space charge limit (by many orders of magnitude). This opens the way for new applications of accelerator technology in high energy density physics and technology. With a high injection current and nonlinear focusing, it is possible to have e-p instability self-stabilization without high density secondary plasma.

The important tasks are the development of a physical model of electron multiplication, including ion generation, slow ion dynamics, ion/electron secondary emission, and gas desorption by ion and electron impact. An important aspect of this work is the estimation of parameters and scales for physical processes, leading to the development of a mathematical model. It is necessary to then verify the proposed physical model. The system of Vlasov equations is nonlinear, requiring the use of numerical methods to solve. At first it is proper to perform 1D and 2D simulations, and compare the results of the simulations with appropriate experimental data and published results of simulations based on other codes [1-5,11-20].

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