PARTICLE DYNAMICS SIMULATION IN WOBBLER SYSTEM FOR HOLLOW HIGH ENERGY HEAVY ION BEAM FORMATION*

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Abstract

Intense heavy ion beam is an efficient tool to generate high energy density states in macroscopic amounts of matter. As result it enables to study astrophysical processes in the laboratory under controlled and reproducible conditions. For advanced experiments in high energy density physics, the cylindrical target irradiated by hollow cylindrical beam is required [1]. A new method for RF rotation of the ion beam is applied for the formation of the required hollow beam. The RF system consisting of two four-cell H-mode cavities with a resonant frequency of 297 MHz was chosen.

The layout of the suggested rotating system (wobbler) for hollow beam formation including focusing elements is presented. The particle dynamics simulation in wobbler was carried out for expecting beam parameters at ITEP Terawatt Accumulator project (ITEP TWAC). The results of simulation are considered in this paper.

INTRODUCTION

The typical target size for Laboratory Planetary Science (LAPLAS) experiment is given in [2]. The external radius of the illuminated area on target shouldn't be greater then 2.1 mm and inner radius shouldn't be less then 0.6 mm. Therefore, the ring-shape beam average radius should be equal to 1.35 mm and beam ring thickness – 1.5 mm. Because of experimental area limitation in ITEP the wobbler system including focusing system shouldn't be longer then 10 meters. Beam dynamics simulations have been carried out to illustrate the feasibility of focused beam rotation on the target.

LAYOUT OF THE WOBBLER SYSTEM

A designed layout of the system for hollow beam formation for ITEP TWAC project was based on the system layout for GSI FAIR project [2]. The wobbler system layout is shown on Fig. 1. The system consists of two deflecting cavities for x- and y-deflections followed by the focusing system including three quadrupole magnetic lenses. The phase shift between RF field oscillations in the cavities is chosen so that the particle with zero deflection in the first x-cavity gains the maximum deflection in the second y-cavity and vice versa. The same figure also shows the transverse beam envelopes for 98% of the particles in x- (upper) and y- (down) planes respectively.

* Work supported by Rosatom contract #N.4e.45.90.1065

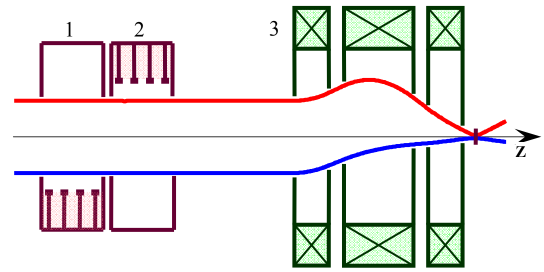

Figure 1: Preliminary designed layout of the system for hollow beam formation. Where 1 – horizontal deflector; 2 – vertical deflector; 3 – focusing system.

The beam parameters used for dynamics simulation in wobbler system are shown in Table 1. From Table 1 one can see that mass-to-charge ratio as well as beam energy for TWAC project is lower then the ones for FAIR project. Therefore, the number of the deflecting cells, amplitude of the deflecting field in cavities and gradients of magnetic field in the focusing lenses may be reduced. For TWAC project two 4-cells cavities for x- and y-deflection was used instead of two 10-cells cavities for FAIR project.

Table 1: Beam Parameters.

	GSI FAIR	ITEP TWAC
Parameter	Value	Value
Ions	U_{238}^{28+}	Co_{59}^{27+}
Beam's energy, AGeV	1.00	0.45
Particle per pulse	$2*10^{12}$	$2*10^{12}$
Pulse length, ns	50	120
Normalized effective beam x-emittance (4 rms), mm*mrad	25	8
Normalized effective beam y-emittance (4 rms), mm*mrad	8	8
Energy spread, %	±1	±1
Particle distribution	Gaussian	Gaussian

PARTICLE DYNAMIC SIMULATION

The particle dynamics simulation was done using a Transit code based on Dynamion code [3]. The real distribution of the deflecting field in the cavities was used. The Gaussian distribution of particles in the beam was used for both transverse phase planes. The longitudinal distribution in the range of ±180 degrees, corresponding to one period of RF oscillation in the deflector, has been assumed uniform. For simulation the beam radius at the entrance of wobbler was taken 60 mm. The deflector aperture is 100 mm.

At first step of the simulation a monochromatic beam with 0 current and without transverse momentum was carried out. The cross-section of the beam at target is shown on Fig. 2. From Fig. 2 one can see that beam size satisfies the required one for LAPLAS experiment. For TWAC project the deflecting field amplitude in both cavities was reduced to 1.5 MV/m instead of deflecting field amplitude in the cavities for FAIR project which equals to 8.5 MV/m and 10 MV/m for x- and y-deflection, correspondently. The less deflecting field amplitude in the cavities allows reducing the requirements for RF power generators. The amplitudes of the focusing fields are less then the one for FAIR project [2]. The focusing system parameters which were found during the simulation are presented in Table 2.

Table 2: Parameters of the Focusing System.

Element	Length, m	Amplitude, T/m
Drift	0.80	-
Lens 1	0.40	13.0
Drift	0.16	-
Lens 2	0.80	-13.5
Drift	0.16	-
Lens 3	0.40	19.0
Drift	0.94	-

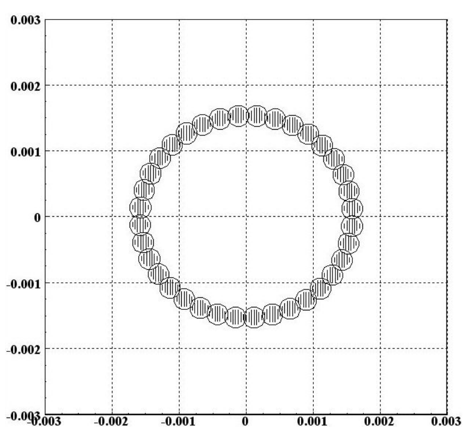

Figure 2: Cross-section of the monochromatic beam on the target. Axes dimensions are given in meters.

At the second step a beam dynamics simulation in wobbler system with real initial beam emittance and zero current was carried out. The cross-section of the beam at target is shown on Fig. 3. The external radius of the ring shape beam equals to 2 mm and the inner radius equals to 1 mm. Therefore, beam size at target satisfies to the required one for LAPLAS experiment. The particle distribution versus radius-vector is shown on Fig. 4. From Fig. 4 one can see that the maximum beam intensity will be achieved at the required target radius.

The focusing system parameters were corrected during the beam dynamics simulation. The corrected parameters of the focusing system are following: 13.35 T/m, -13.71 T/m and 19.23 T/m, correspondently to the Lens 1, Lens 2 and Lens 3 (see Table 2). The distance between lenses was the same as in Table 2. The found magnetic field gradients in the wobbler don't exceed the limitations for lens parameters at ITEP for LAPLAS experiment. The whole length of the wobbler system is about 8 meter which satisfies to the experimental area in ITEP.

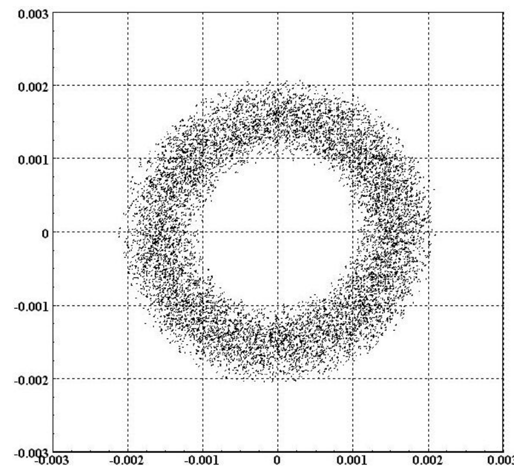

Figure 3: Cross-section of the real particle distribution in the beam on the target. Axes dimensions are given in meters.

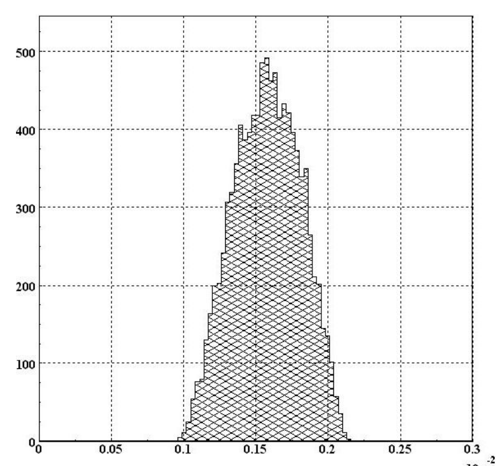

Figure 4: Particle distribution versus radius-vector. The horizontal axis's dimension is given in meters.

As the last step, the beam dynamics simulation in wobbler system for beam with real particles distribution and current was carried out. The cross-section of the beam at target is shown on Fig. 5. A diameter of beam at target calculated for full intensity is practically the same as for zero current. However, the x- and y-focuses are moved far from the last lens for about 10 mm.

It should be mentioned that 0.1% error in magnetic field gradient, for example in the second or third lens from the triplet, leads to the displacement of x- and y-focuses in opposite direction. The beam size in this case doesn't satisfy the beam size for LAPLAS experiment.

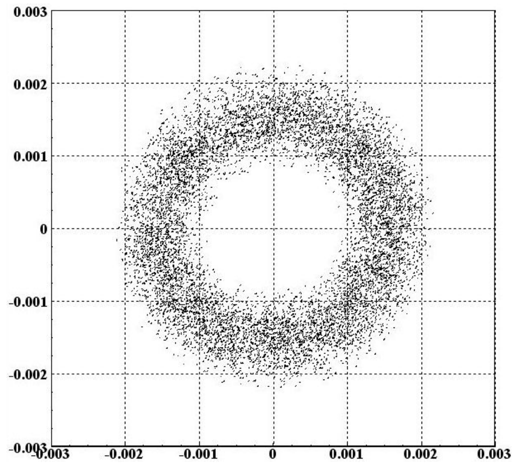

Figure 5. Cross-section of the real particle distribution in the beam with beam's current on the target. Axes dimensions are given in meters.

CONCLUSION

An original deflecting system for the hollow high energy beam formation was proposed. The particle dynamics simulation in wobbler system for hollow high energy heavy ion beam formation was carried out. Wobbler system consists of two four-cell cavities and triplet of quadrupole lenses. The wobbler system parameters were found for required hollow beam formation.

The deflecting RF cavity with H_{114} oscillating mode has been developed [4, 5]. The shape for proposed deflecting plates has been investigated and optimized. The beam deflection uniformity is better then 2.5% over the beam cross-section. The prototype deflector cell was constructed and manufactured.

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