SUMMARY OF THE WORKING GROUP ON ACCELERATOR SYSTEM DESIGN, INJECTION, AND EXTRACTION

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Abstract

We review the presentations and discussions of the Accelerator System Design, Injection and Extraction working group at the 46th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams.

INTRODUCTION

The working group heard eight oral presentations in two sessions and saw seven posters presented. The first oral session focused on injection and extraction technologies while the second oral session focused on commissioning and accelerator facility designs. The working group had a discussion session between the two sessions. The presentations can be grouped into four major classifications: New Concepts, Technology, and Component Designs; Commissioning Efforts; New Facility Design or Upgrades; and Status of Operational Facilities. We present a brief summary of each presentation and make a few remarks on the working group perspectives.

NEW CONCEPTS, TECHNOLOGY, AND COMPONENT DESIGNS

D. Trbojevic: **Non-Scaling FFAG and their Applications**

The basic concepts of the non-scaling FFAG (NS-FFAG) were discussed. As compared to traditional FODO lattices, the non-scaling FFAG's have very strong focusing and hence small dispersion values and beam size which leads to small magnets. The application of the NS-FFAG lattice design were discussed in terms of how many turns or passes the particles traversed the lattice, from one turn (i.e. medical gantries), to a few turns (i.e. muon acceleration or pion storage rings), to many turns (i.e. accelerator for proton cancer treatment).

O. Heid: **Compact Solid State Direct Drive RF Linac: First Results**

Silicon Carbide (SiC) JFET RF transistors are a key enabling technology utilized in the design and construction of a solid-state direct drive linear induction particle accelerator concept. The presentation describes experimental results of a lower power test for prototype of a direct drive l/4 cavity with a power rating of 1 MW at 150 Mhz. This approach could lead to a substantial decrease in RF power costs for future facilities.

Y. Liu: **Advancements in Laser Technology and Applications to Accelerators**

Yun presented a brief review of recent technology advancements in ultra-high intensity pulsed lasers, laser array beam combination, and power enhancement optical cavities. Applications to accelerators include: laser based diagnostics, photo injectors, laser assisted injection stripping, inverse Compton scattering, laser wakefield plasma acceleration and laser driven ion accelerator. Although many of these applications have been made feasible due to the rapid advancement in laser technology over the last decade, additional R&D is required to achieve the required, laser power and pulse length and repetition rate for many of these applications.

D. Fernandez-Cañoto: **Electrode Design of the Bilbao Accelerator proton Extraction System**

A design study of the extraction system for the ESS-Bilbao ion source is presented with the aim of obtaining an electrode system capable of extracting, accelerating, and delivering a high quality proton beam from the plasma chamber to the LEBT. The system must be capable of delivering beam with a 0.2 π-mm-mr emittance to the LEBT to produce acceptable matching to the RFQ. They included detailed discussion of two electrode system geometries and beam dynamics associated with each.

B. Goddard: **Considerations on a New Fast Extraction Kicker Concept for SPS**

A new 450 GeV/c extraction kicker concept for the SPS which could potentially reduce the beam coupling impedance is introduced. The scheme consists of a c-type kicker magnet with a reduced vertical aperture such that the injected beam is outside the kicker gap and only moved within the gap just prior to extraction. The kicker is excited only from the back leg. The kicker aperture and required magnet and power supply parameters are discussed. The implications on the coupling impedance have been investigated and plans for more extensive beam dynamics simulations were outlined. Additionally, the impact of the new kicker on the lattice and closed orbit control as well as other systems was presented. It was concluded that this concept looks feasible on paper and a list follow-up studies was outlined.

T. Yokoi: **Beam Extraction of PAMELA non-scaling FFAG**

One of the major design challenges for the design of a variable energy NS-FFAG medical accelerator is that of beam extraction and matching into the gantry. This paper describes a vertical extraction scheme utilizing a superconducting combined function septum. This,

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coupled with a FFAG transport allows for a wide range of momentums without changing the setting of the transport line. The potential for energy-variable resonant extraction was also discussed.

COMMISSIONING EFFORTS

B. Muratori: **Injection and Extraction for the EMMA NS-FFAG**

EMMA is being commissioned to demonstrate the world's first operation of a non-scaling FFAG (ns-FFAG). Two of the most challenging aspects of the design are injection and extraction due to the severe pulse shape constraints on the pulsed injection devices. The initial design supported a one-turn injection scheme, but long injection kicker fall times required the adoption of multi-turn injection. This was extensively modelled along with detailed pulsed magnet field measurements. Results of commissioning efforts were presented.

NEW FACILITY DESIGN OR UPGRADES

C. Bracco: **Injection Painting and Associated Hardware for 160 MeV PSB H- Injection**

With the implementation of increasing the injection energy into the PS Booster from 50 MeV to 160 MeV, the introduction of H- multi-turn injection with phase space painting will reduce space charge effects and allow increased beam intensity. The impacts of two painting magnet waveforms were addressed for both high and low intensity injection. It was concluded that a bump with an early exponential decay wave would be preferable. Magnet and waveform parameters have been determined for 2 out of the dozen or so beam scenarios. Additional design studies are planned.

W. Bartmann: **Feasibility of 2 GeV Injection into the CERN PS**

The feasibility of 2 GeV proton injection into the PS and potential solutions are discussed. The existing injection at 1.4 GeV is discussed and injection constraints with regard to lattice and hardware are examined. Two different straight sections are evaluated and one seems clearly the more optimum straight section. This option would require modification of existing hardware and a new septum magnet. It was suggested that modifications to existing transport line be studied to provide better optical matching and a reduction of losses.

J. Jang: **Design Status of the PEFP RCS**

A design study for the addition of a rapid cycling synchrotron (RCS) to the existing 100 MeV proton linac was presented. The main purpose for the RCS would be to add a spallation neutron facility to the PEFP accelerator complex located in Gyeongju City, Korea. The initial beam power is 60 kW for a top beam energy of 1 GeV. The design is being developed so that the injection and extraction energy as well as the repetition rate may be upgraded for an ultimate beam power of 500 kW. The ring layout and lattice are discussed as well as the multi-turn injection process and longitudinal dynamics. First and second order correction schemes are discussed as well.

V. Nagaslaev: **Third Integer Resonance Slow Extraction Scheme for a Mu2e Experiment at Fermilab**

A resonant extraction scheme from the existing Fermilab Antiproton Debuncher ring to provide the required beam intensity and structure for the proposed Muon to electron conversion (Mu2e) experiment was presented. This consisted of third order resonant extraction with the utilization of RF knockout concept to heat small amplitude particles and assist the extraction process. Simulations of the process including analytical predictions and tracking studies were presented. Initial results show that this concept can aid the control of the spill with feedback and help keep losses on the extraction septa at reasonable levels.

D. Johnson: **Project X H- Injection Design History and Challenges**

The evolution of the Fermilab Project X configuration was presented along with the design challenges for the injection system. The Project currently utilizes a low average current CW linac along with a pulsed high energy linac (8 GeV final energy) to inject into the existing Recycler or Main Injector synchrotrons. The low current and long injection times imply a new set of issues as compared to high linac current and short injection times. Issues of foil temperature and beam loss related to foil charge exchange technique were discussed. The prospect of laser assisted stripping was assessed in terms of H- beam requirements and laser requirements. Potential laser system configurations were reviewed.

OPERATIONAL FACILITIES

P. Saha: **Operational Experience with J-PARC Injection and Extraction Systems**

The Japan Proton Accelerator Research Complex is the latest high proton intensity facility to become operational. They reported on commissioning activities at the last HB2008 workshop. This presentation concentrated on the RCS and Main Ring operational parameters and experience, systematic beam study results, and plans for identified improvements to allow further increase in beam intensity and quality. Several issues were addressed in detail such as foil lifetime, foil scattering and losses, leakage field from the extraction DC magnets, RCS extraction kicker issues, and extraction issued from the Main Ring (both fast and slow extraction). It was noted that the foil injection system is the most complicated component. It has performed satisfactorily and many systematic studies have lead to increased understanding, although there are still issues that will need to be addressed to increase power to design levels. Another issue, briefly discussed was that of the Main Ring resonant extraction spill duty factor. It was noted that it was significantly lower than expected during early operation. It has been improved to nearly 12%, however additional studies and improvements are planned to further increase the duty factor. Modifications already installed and those planned for the future were discussed.

M. Plum: **SNS Injection Foil Experience**

The Spallation Neutron Source has been in formal operation since 2006 and has been increasing in beam power to 1 MW. The speaker reported on stripper foil issues and their resolution which allowed the facility to reach the MW beam power. It was reiterated that with MW proton beam power there is kW of electron beam power that must be properly handled. A detailed description of the foil itself, its foil bracket mounting system, and the impact of locating the foil system inside the end field region of one of the injection chicane magnets was presented. Most of the foil related issues observed while increasing the beam power past 850 kW, was traced the handling of the convoy electrons, and charge build up on the foil due to secondary electron and thermionic emission. Once these issues were understood, modifications to the foil itself and the foil mounting system were implemented which allowed a single foil to be utilized for the entire Spring 2010 run accumulating 7359 Coulombs delivered to the target. It was finally pointed out that this is only about 60% of the design integrated charge to the target and plans to double beam power will place even higher demands on the stripper foil.

S. Cousineau: **A Tale of Two Electrons**

A more detailed analysis of the reflected convoy electron trajectories and their impact on the foil bracket was presented. Results of a 3D computational study that explored the dynamics of the foil stripped and uncaught electrons were summarized. Based upon the geometry of the system, the convoy electrons are guided to the bottom of the aperture with a gyro radius of ~12 to impact a carbon electron catcher. For electrons which are not caught in the design fashion by the catcher, MCNPX studies showed a 40 % reflection probability which means some electrons would be reflected back up toward the foil and foil bracket assembly. Results of the simulations were compared with damage locations on the foil bracket assembly and all damage locations corresponded to impact spots identified in the simulation, thus confirming the hypothesis that the observed hardware damage was tied to uncaught electrons from the injection process.

WORKING GROUP PROSPECTIVES

Since the discussion period followed the first oral session much of the discussion focused on operational facilities, the problems encountered, and ways to mitigate the problems for future facilities. This discussion period should be viewed as "lessons learned" for those designing future facilities.

Although there were specific component issues at each of the facilities during commissioning and initial operation, such as kicker rise times, leakage fields from septa, thyratron lifetimes, the major issues that affected both facilities were related to foil injection systems and uncontrolled losses in the injection region and injection dump line.

Both SNS and JPARC noted issues with foil injection although the sources of the issues were different. At SNS, the reflected convoy electrons interacted with the foil bracket assembly thus causing the failure of the bracket assembly. Modifications to the foil mounting bracket helped manage the problem. In addition, SNS uses a diamond foil with a high resistivity which allowed charge build up and vacuum break down. Doping the diamond foil with boron increase the electrical conductivity thus reducing the charge build up. At JPARC the uncontrolled beam loss due to nuclear scattering was "the most considerable issue" as evidenced by two specific loss points downstream of the injection foil. Simulations performed were able to reproduce the loss pattern indicating that the loss points were due to parasitic beam hits of the circulating and the magnitude was proportional to the number of hits and inversely proportional to the final painted emittance. Several mitigation steps have been planned or installed including a reduction in vertical foil size and a collimation system.

Neither facility reported foil lifetime issues due to foil heating. Each facility reported the use of a single foil for extended periods of time, where JPARC has used a single foil with beam powers of 120 kW for a year and SNS reports their latest foil lasted a complete 18 week production period at a beam power of nearly 1 MW. Although both facilities are trying to measure foil temperature, neither facility has a good foil temperature measurement. One of the resounding comments of the working group was that it is important to have an accurate foil temperature measurement to compare with calculations. This is an ongoing effort.

The design of the waste beam dump lines was another topic of discussion. SNS had considerable problems with transporting different species of waste beam leading to high losses. This required several modifications to the dump line to bring losses down to acceptable limits. JPARC has not yet seen any issues with the dump line design and they have developed a measurement of the beam intensity through the dump line which is consistent with the predictions on the amount of H0 produced by the stripping foil.

The take away comments from the working group can be summarized in the following few statements.

- Despite detailed design work, both machines suffered problems in the injection areas.
- Radiation levels are the highest in the injections areas, as expected.
- The amount of manpower and monetary resources that were dedicated to addressing injection region issues after the start of operations was not anticipated.
- In order to reach even higher injected beam powers we need to validate foil models with actual foil temperature measurements so we can rely on the models for foil lifetime limits.

- For higher power beams, the waste beams contain a significant amount of beam power where beam loss in the dump line can become a significant issue. They will need to receive significant attention to detail during the design stages.
- Handling of stripped electrons is important and needs detailed attention during the design stage. This illustrates the importance of accurate 3D modelling with the best field maps of the magnets in the injection region.
- As injected beam powers and energies or the injection time becomes longer serious consideration of alternatives to the standard stationary foil stripping injection systems such as laser assisted stripping or alternative material and geometries should be made.
- Finally for injection energies in the GeV range and above laser technologies have advanced to the point where laser stripping systems have become a serious contender as the primary method of H- multi-turn injection stripping. Continued R&D should seriously be pursued to make laser assisted stripping a reality.