

INJECTION SEQUENCE FOR HIGH-POWER ISOCHRONOUS CYCLOTRONS FOR ADS FISSION*

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Abstract

A high-current injection sequence is being developed for use in a flux-coupled stack of high-current cyclotrons for ADS. The design includes an ECR ion source, LEBT, RF quadrupole and multi-stage chopper. A first cyclotron then accelerates the beams to 100 MeV for injection to a strong-focusing cyclotron. Provisions for control of emittance and bunch tails are described.

OVERVIEW

Texas A&M University is advancing an optimized ADS fission technology, in which a high-power proton driver delivers beams to molten salt fission cores (ADSMS) [1]. The cores are fuelled entirely from the transuranics in spent nuclear fuel, and destroy the transuranics and the long-lived fission products at the same rate they are produced in a conventional fission power plant. It offers a base by which to close the nuclear fuel cycle and the opportunity for a green nuclear power technology. For this purpose we are developing a flux-coupled stack of isochronous cyclotrons that incorporate innovations in strong-focusing transport within the sectors and superconducting rf cavities for efficient, high-gradient acceleration [2]. The injector cyclotron (TAMU100) accelerates from 2.5 MeV to 100 MeV; the main cyclotron (TAMU800) accelerates from 100 MeV to 800 MeV.

The target parameters for the injector are a beam current of 12 mA within an invariant emittance of 10^{-3} m at injection to the TAMU 800 cyclotron. A further objective is to minimize losses (<1 W/m) on the injected orbit entering TAMU800, so that activation in each accelerator is consistent with hands-on maintenance. A third objective is to chop-modulate the beam so that the total 8 MW beam from each TAMU800 can be split into three beams and delivered to spallation targets within three ADS-cores. The power delivered on each spallation target is then within presently accepted bounds for target life. The general overview of the SFC complex is shown in Fig. 1.

INTRODUCTION

The TAMU100 cyclotron receives 2.5 MeV beam from a front-end accelerator chain that is designed to deliver >15 mA CW proton beam. The design of the injector sequence is modeled upon that of presently operating high current, high reliability proton front-ends: the Argonne FE design for the RF quadrupole of Project-X [3], the Rutherford ISIS chopper [4], and the medium energy beam transport (MEBT), designed by LBNL, used in the ORNL Spallation Neutron Source [5].

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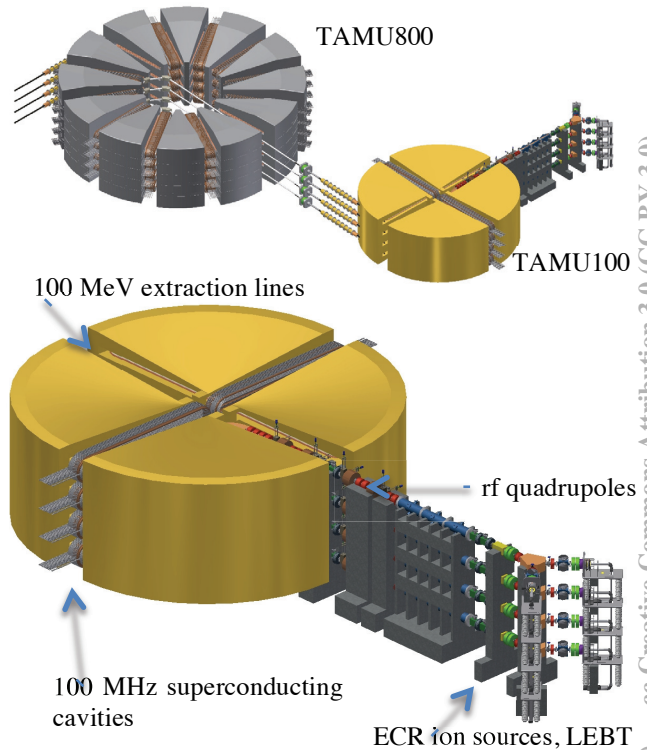


Figure 1: a) Plan view of a flux-coupled stack of four 800 MeV strong-focusing cyclotrons; b) detail of the TAMU100 injector complex.

ECR ION SOURCE

The ion source for the ADS fission project will be an electron cyclotron resonance (ECR) proton source, shown in Fig. 2. These sources are known for their reliability and consistency. The source being designed is based on 2.45 GHz frequency, because many parts are commercially available and the necessary magnetic field of 875 Gauss can be provided using permanent magnets.

Table 1: Ion Source Parameters

Current	12-15 mA
Extraction voltage	65 kV
Emittance	$<0.25 \pi$ -mm-mrad
Duty cycle	100%
MTBF	>1 year
Frequency	2.45 GHz

The plasma chamber will have dimensions 9 cm dia.x10 cm long and will be made of 12 mm Al alloy. Al was chosen because, after oxidation, it provides a dielectric coating on the plasma chamber walls, which discourages electron loss through recombination. The RF system will consist of a launcher, a directional coupler, a 3-stub tuner, two 90° E-bends, a dielectric DC break, and a vacuum window. The waveguide will begin with WR340 and then transition to WR284. The vacuum window will be made from a WR284 Al flange, with an AlN window brazed to the flange.

Solenoid electromagnets will be used to test the effect of various magnetic field configurations on the plasma. We will optimize to suppress leaked magnetic flux into the extraction region. Once sufficient testing has been carried out, the solenoids will be replaced by an array of permanent magnets to match the most desirable magnetic field configuration.

The entire source will be held at a constant 65 kV to facilitate ion extraction. The extraction system will consist of the 3 electrodes; operating at potentials of +60 kV, -1.5 kV, and 0. The RF launcher and all RF instrumentation will be referenced to ground. The extraction system, plasma chamber and solenoid magnets will be water cooled to keep a relatively low operating temperature. The extraction system will also be isolated from the rest of the LEPT by a ceramic insulator.

TAMU FRONT END DESIGN

The purpose of the TAMU low-energy beam transport (LEBT) is to transport the CW proton beam from the ECR ion source into the entrance of the RFQ, where the converging beam needs to fit into the acceptance of the RFQ. Fig. 3 shows a section view of the 4-stack front-end. The LEBT will be based on a four-solenoid design to maximize commissioning flexibility and rapid deployment of the hot test stand. As mentioned above the design, at present, the design parameters are based on the RAL parameters to test the RFQ [4]. The solenoids will incorporate built-in 2(H/V)-dipole correctors for beam steering.

Simulations are being performed based on linearized K-V envelope equations. We clearly see the strong influence between the initial conditions and the space charge forces, even in the 5-10 mA range, as we are keeping the global transverse emittance low. We plan to investigate the relaxed emittance state for our optics, but we will use collimators in the MEBT to meet the requirements for injection to TAMU100.

Table 2: Front End Parameters

	x/x'	y/y'	z	
Emittance	10	10	0.15	π -mm-mrad
Alpha	-8.9	-6.6	0	
Beta	1.53	1.04	34.8	m
Centroid displacement	4.0/2.0	4.0/2.0	1.0	mm/mrad

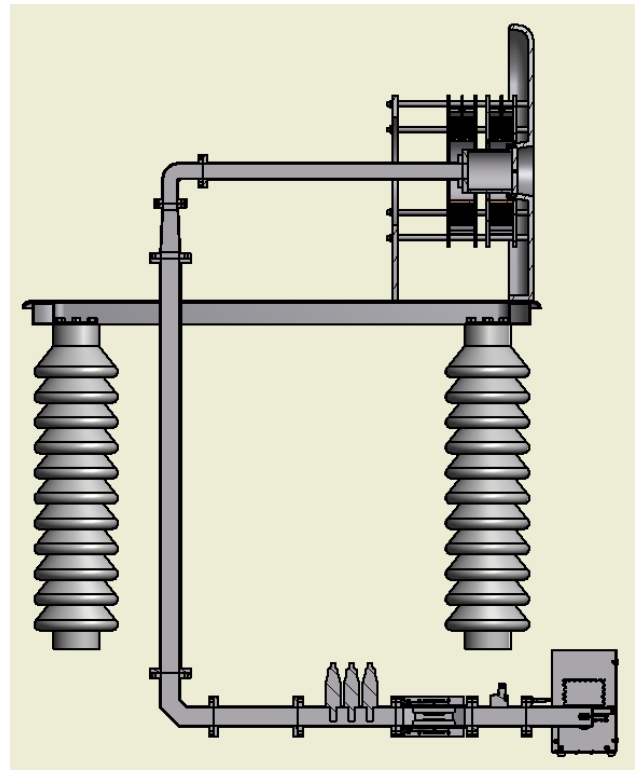


Figure 2: Ion source section view.

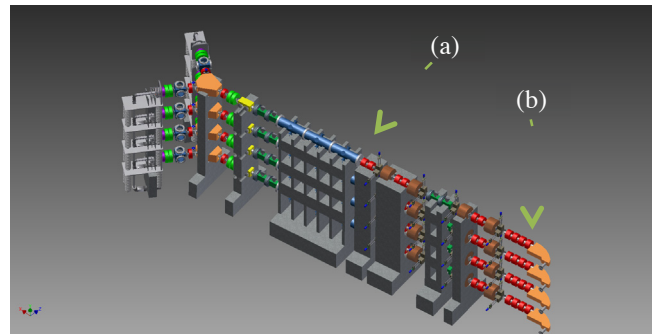


Figure 3: Stack of four front-ends are shown: at the end of the V-shape are the two ECR's, solenoids are light green, quadrupoles are red, RFQ is blue, dipoles are brown and the choppers are dark green.

BEAM CHOPPER

Installation and commissioning of the TAMU cyclotrons rely heavily on low duty factor beam to low-power dumps. As such we are adapting the RAL method of a two-chopper system, shown in Fig. 4, to be able to chop the beam from normal operation of 0.1% to 99.99%. The slow chopper will handle these vast ranges. The fast chopper does the edge-cleaning of the rise and the fall tails of the beam notch. Fig. 5 shows a system that will be used to monitor the performance and tune the parameters of the chopper system.

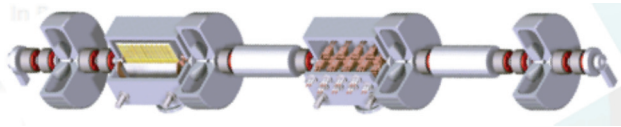


Figure 4: The chopper will be similar to the ISIS fast/slow chopper, but with 0.1% duty factor during normal operation.

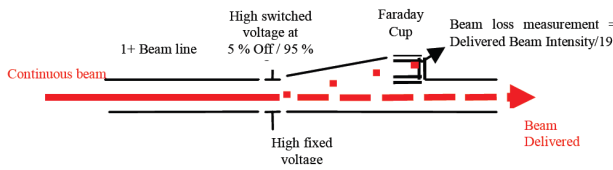


Figure 5: Method for monitoring the chopped beam in the front-end of TAMU.

Both SNS and RAL have demonstrated the feasibility and the reliability of the fast pulse modulators but the high power CW beam still requires high reliability to minimize beam damage to the accelerator. The added electrostatic quadrupole at the exit of every ECR is gated to the chopper in conjunction with the current from the chopped beam. As such, we can turn the beam off in less than 5 μ s.

MEBT

The beam choppers, collimators, Faraday cup dumps are located in the MEBT. Transverse and longitudinal emittance growth control under the influences of nonlinear space charge will be a challenging next step.

A first step in MEBT design has been the general optics ray tracing using TRACE-3D followed by beam emittance growth studies with DYNAC. This program includes space charges and has been benched marked at SNS by E. Tanke against PARMELA [6]. The code developers also support features required for the TAMU800 injector, such as improvement of RFQ beam dynamics calculations.

Fig. 6 shows the results of an initial run we made with 10^5 particles to make certain that the emittance of a 15 mA beam, at 2.5 MeV after transport through the front end and acceleration in the RFQ, fits within the admittance required for injecting to TAMU100. One of our concerns was the length of MEBT, but at <15mA four rebuncher cavities are sufficient to preserve an acceptable longitudinal bunch length, and transverse profiles are collimated after the RFQ to remove any residual halo that might arise from the RFQ acceleration.

The LEBT and other parameters are based on a range of possible initial values, from the source, to give flexibility once the components are constructed. This will provide some adjustment to match the: ion source, LEBT, chopper(s) and the RFQ.

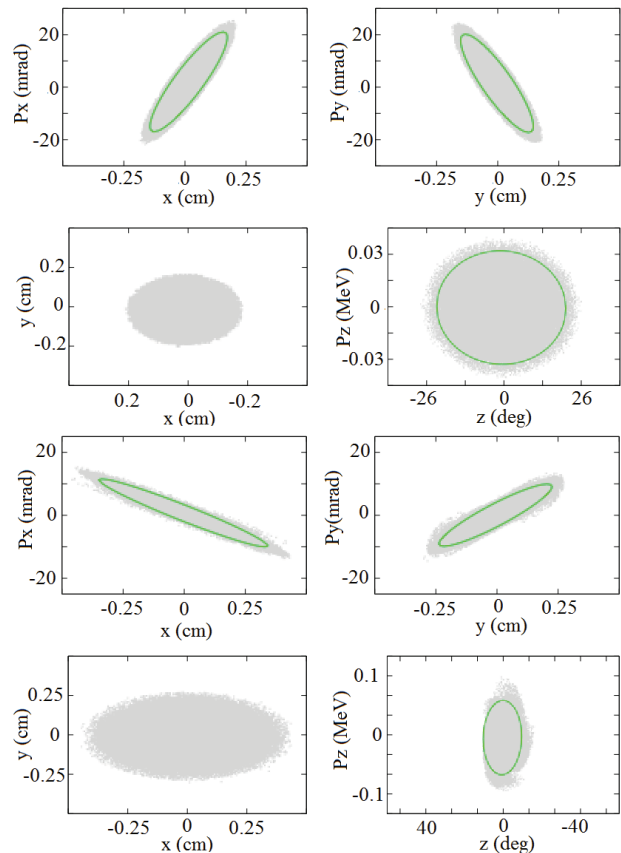


Figure 6: Top plots show input to MEBT (point (a) in figure 3); lower plots show the injection setting to TAMU100 (point (b) in figure 3).

CONCLUSION

An injector chain is being designed for acceleration of >12 mA if proton beam to 100 MeV, with emittance $1 \pi \cdot 10^{-6}$ m, suitable for injection to an 800 MeV strong-focusing cyclotron. Provisions are made to facilitate rebunching and collimation to make it possible to maintain ultra-low tails on the beam in 6-D phase space.

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