THE D-LINE PROJECT AT MICHIGAN STATE UNIVERSITY *

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Abstract

The Coupled Cyclotron Facility (CCF) at Michigan State University (MSU) has been used to produce rare isotope beams for more than a decade. Ions produced by an ECR source are accelerated using two superconducting cyclotrons in tandem with a stripper foil in between to boost their charge state. After the second cyclotron, a target and a fragment separator produce and select the rare isotope beam that is sent to the different experimental vaults. A gas stopper can be used to thermalize the beam before sending it to a low energy experimental area or to a charge breeder before the ReA re-accelerator. The D-line project includes a mass separator after the gas stopper and several beam transfer lines that connect it to the low energy experimental stations and to the charge breeder. In this paper, we will describe the project and give an update of its status including the results of the commissioning.

INTRODUCTION

One of the most important developments at the National Superconducting Cyclotron Laboratory (NSCL) during this past year has been the successful delivery of the first radioactive reaccelerated beam to users [1]. Together with the commissioning of the gas cell in the ion beam thermalization area [2], the charge breeder [3] and the reaccelerator [4], the completion of the D-line was one of the steps necessary to make this possible.

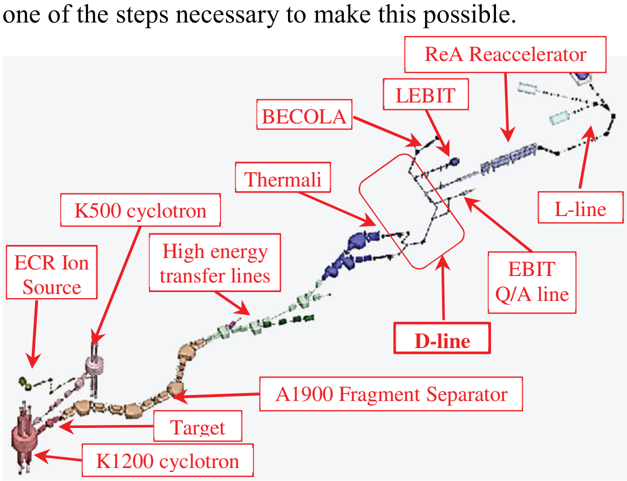

Figure 1: Layout of the CCF and ReA3 facilities (several high energy beam lines and experimental areas are not shown). The D-line connects the thermalization area with the low energy experimental hall and the charge breeder.

DESCRIPTION OF THE LINE

The main purpose of the D-line is to connect the beam thermalization area of the NSCL with the experimental devices in the low-energy experimental hall (LEBIT [5] and BECOLA [6]) or alternatively with the Q/A line before the charge breeder (EBIT) and the ReA3 reaccelerator. In addition, the line includes a mass separator that is used to select the Radioactive Isotope Beam (RIB) that is going to be studied and to clean the unwanted contaminants with a different momentum after extraction from the gas cell.

The line is designed to be able to transport efficiently beams with emittances of ~ 10 π·mm·mrad and energy lower than 60 keV. In its current configuration (Figure 3), the south line is used to transport stable beams from an off-line ion source. This beam has been used for commissioning of the D-line and downstream experimental devices. The north line is used to transport the RIBs previously thermalized in the gas cell.

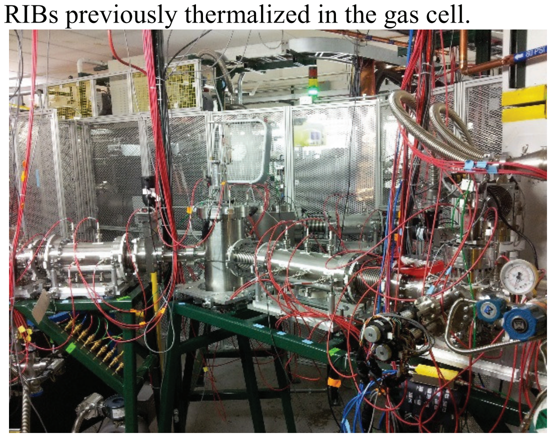

Figure 2: Merging point of the north and south lines. Starting from the left, the picture shows an electrostatic doublet, a bender and a triplet followed by the vacuum and diagnostic station before the mass separator.

With the exception of the dipole magnet used as a mass separator, all the other elements in the D-line are electrostatic. The beam is focused using electrostatic quads (10 cm long, 6 cm aperture, up to ±6 kV bias) normally grouped into doublets. In most cases, opposite electrodes are shorted inside the vacuum chamber and driven by a single power supply. However, some of them can be used as beam steerers since they can be biased independently. In addition, there are horizontal and vertical steering plates in all the diagnostic boxes. Spherical benders (up to ±10 kV bias) are used to deflect the beam 45 degrees at a time. Several of them have also been combined for deflection angles of 90 and 135 degrees. Some of them are mounted in movable drives in order to allow an inserted or retracted state to switch the desired beam and its destination.

A dipole magnet and two electrostatic doublets function

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as a mass separator with a resolving power M/ΔM higher than 100. Horizontal movable slits in the object and image planes can be used to collimate the incoming beam and to discard the unwanted masses.

The 61-degree magnet was designed using TOSCA to produce a 0.79 T field for a current of 217 A (with uniformity better than 10^{-3} in its ±5 cm central region). It has a bending radius of 68 cm, a 6 cm vertical aperture and a 22 cm pole width.

The lattice was designed using COSY INFINITY (Figure 4) to accept beam from both the north and south line and transport it to the object point of the separator, where both beams are matched to. The beam is then transported using point-to-point focus to one of the low-energy experimental stations or to the Q/A line for injection into the charge breeder. The optics of each segment of the line is independent of the destination of the beam and, only the matching triplet before the object point of the mass separator needs to be adjusted when the origin of the beam is changed.

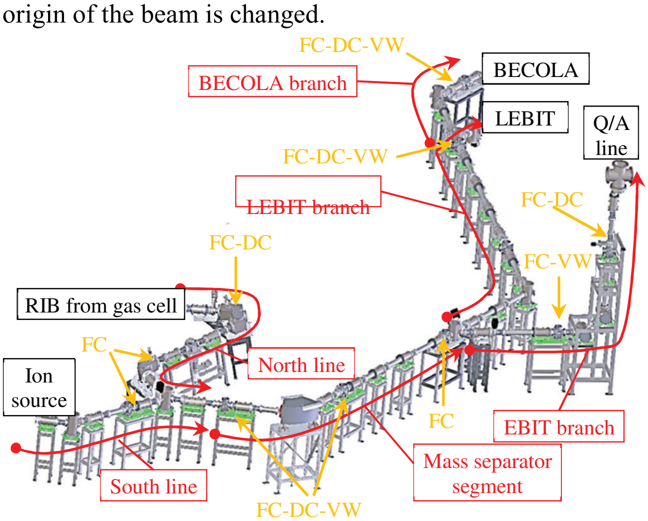

Figure 3: Layout of the D-line broken into different sections (in red), the beam origin/destination (in black) and a list of the diagnostics available at each location (in orange). FC stands for Faraday Cup, VW for MCP viewer and DC for decay counter.

There are ten diagnostic stations in the line and most of them are located at (or near) waists of the beam envelope (Figure 3). All the stations include Faraday cups and 5 mm diameter movable apertures (except for the ones in the object and image points of the separator which have movable horizontal slits). Six of the Faraday cups are equipped with silicon detectors to detect β-decays of the RIBs implanted in the Faraday cup current collector. Details of their design and associated DAQ can be found in [7]. In addition, there are five Multi Channel Plate (MCP) viewers and one more will be added in the future.

There are seven vacuum stations distributed throughout the beam lines. Each vacuum station includes a turbo pump with a gate valve, a cold-cathode gauge, two Pirani gauges and a venting valve. Each turbo pump is backed by a scroll pump (three of them directly, four of them through a common vacuum manifold). The beam line is split into six vacuum sections separated by gate valves to facilitate maintenance. The pressure in the lines typically reaches the 10^{-8} Torr range after two days of pumping.

The relative alignment of consecutive components in the line is better than 250 microns with the exception of some of the benders.

The high level controls have been built using Control System Studio (CSS). Using CSS to scale the energy of the line, to change the beam origin or destination or to complete mass scans is quick and convenient. However, at this time, different software is used to tune the lines and some additional work remains to integrate this capability in CSS.

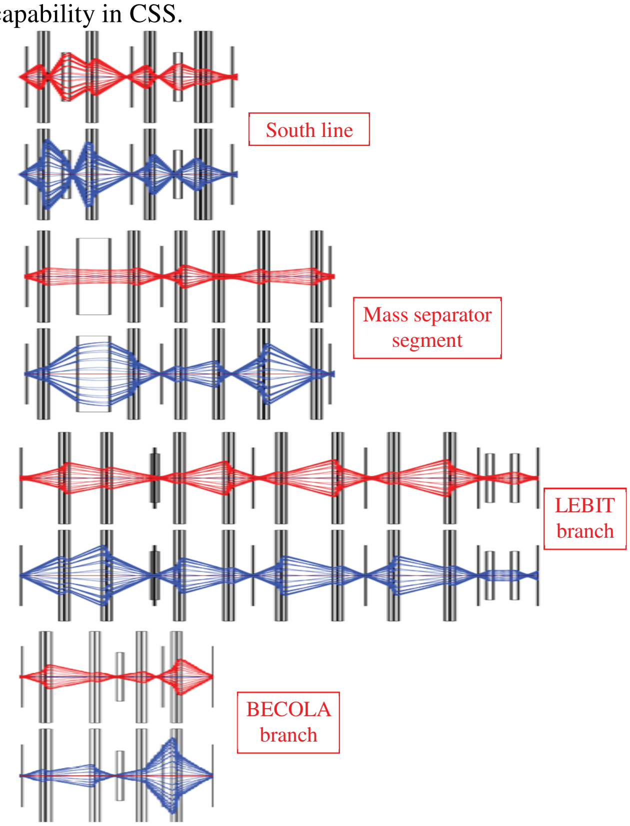

Figure 4: Ray calculations of beam transport in several segments of the line from South line to BECOLA (horizontal in blue, vertical in red)

COMMISSIONING OF THE LINE

Equipment Commissioning

The several hundred HV power supplies used in the line, their cables and connectors were tested during installation to confirm that none of them were damaged and that their polarity was correct. Several problems were identified and corrected during those tests.

The low-level controls and the interlock logic of the diagnostic drives were tested. The cables and electronics of the Faraday cups were checked using a calibrated current source and their electron suppressor biases were measured. Most of the decay counters and their data acquisition hardware and software were also tested using a Sr-90 radioactive source before installation. The low-level controls of the vacuum stations and the interlock logic of the gate valves were also checked.

Stable Beam Commissioning

Most of the segments of the D-line were commissioned using the off-line stable ion source upstream of the beam line. A ~2 mm misalignment in one of the doublets in the line was identified and tracked down to a faulty alignment monument. At the beginning of the commissioning with stable beam, 20-30 % of the beam was lost along the line and very strong non-linearities were observed in the MCP viewers. The problem was solved when the gas pressure in the ion extraction guide upstream of the D-line was increased. Originally, the beam was not cooled enough transversely and its emittance was larger than the acceptance of the line. Using the higher pressure now allows for only a few percent beam loss.

We have empirically found that the optimal settings of the last optical elements for injection into the experimental stations differ to a limited extent from those in the COSY model prediction. Also, slow beam jitter (with a period of several minutes) has been observed when the beam was injected into LEBIT. The sources of these problems have not been identified yet.

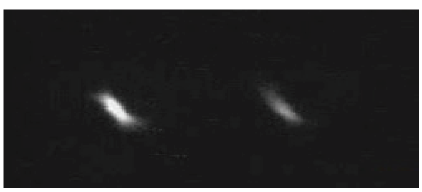

Figure 5: Image of two beams (corresponding to masses 76 and 77) as seen in the MCP viewer after the mass separator during one of the commissioning runs.

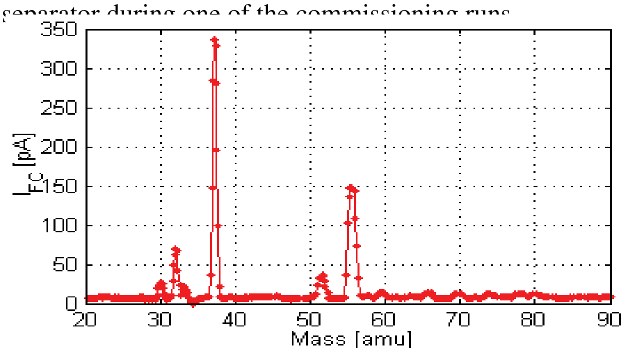

Figure 6: Mass scan during one of the Ga-76 commissioning runs. The different peaks correspond to different contaminant molecular beams produced in the gas cell as the high energy beam is slowed down and interacts with the residual gas. The two highest peaks correspond to mass 37 $[H_5O_2]^+$ and mass 55 $[H_7O_3]^+$.

Radioactive Beam Commissioning

Several commissioning runs with radioactive beams have been conducted during the last year. During these runs, the resolving power of the separator has been found sufficient (Figure 5) and the CSS-based mass scanning software developed for the separator has been tested (Figure 6).

In addition, the decay counters and their DAQ have been tested (Figure 7). The diagnostic team is working to improve their performance by reducing some of the EM

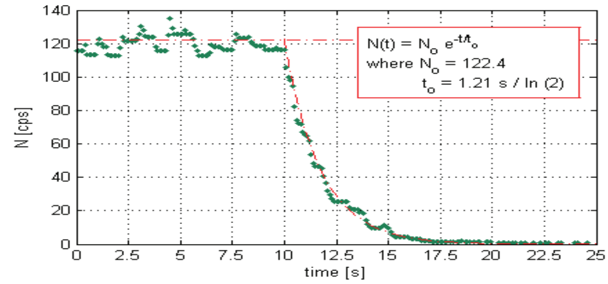

Figure 7: Decay curve for K-37 measured in the decay counter of the diagnostics station after the mass separator. The measured half-life is 1.21 s which is compatible with the expected value of 1.23 s.

CONCLUSION

The D-line project has been completed. All the segments of the line have been commissioned and the transport efficiency in all of them approaches 100 %. The line has been reliable at delivering hundreds of hours of stable and radioactive beams to both the low-energy experimental hall and to the charge breeder before the ReA3 reaccelerator.

ACKNOWLEDGMENT

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