

# STRIPPER FOIL MECHANISM FOR THE K1200 SUPERCONDUCTING CYCLOTRON\*

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## Abstract

The Coupled Cyclotron Facility at MSU comprises two superconducting cyclotrons, the K500 (injector) and the K1200 (booster). Both cyclotrons are of the compact design with three hills and three dees in the valleys. The beam from the K500 is injected in the K1200 and stripped to a high charge state inside one of the dees of the cyclotron. The stripper mechanism consists of 31 foil holders attached to a bicycle chain, mounted on a moving platter. A complicated design was necessary to fit all the hardware necessary to do foil exchange in the tight space inside the dee. Five different hydraulic cylinders move the foil to the stripping position, exchange foils within the stripper chain, and position the foils in the loading position. We describe in the paper the mechanical design as well as the control programs developed for it.

## 1 INTRODUCTION

The coupled cyclotron facility at Michigan State University [1] accelerates beams from an ECR ion source in the K500 cyclotron to energies up to 17 MeV/u. The beam from the K500 is then transported to the K1200 cyclotron where it is injected radially and stripped to a higher charge state at approximately one third of the extraction radius (see Figure 1). The K1200 cyclotron provides approximately a factor 10 gain in energy, with a maximum energy of 200 MeV/u for  $Q/A=1/2$  ions.

The stripper foil mechanism is located inside one of the three dees (with the dees placed in the valleys between the magnet hills). The equilibrium thickness of carbon foils for our beams is approximately  $0.2 \text{ mg/cm}^2$ . Foils of this thickness are robust enough to be mounted on a carousel like system. The environment where the mechanism must operate imposes strict limitations on the design. It is placed in the cyclotron vacuum chamber where the magnetic field is as high as 5T. Being contained inside the dee with its tight spiral, limits the space available for operation.

Figure 1 shows the path of the injected beam when it enters the beam chamber of the K1200 cyclotron. The beam crosses the back edge of the dee where it receives a kick. It then travels in the gap region between the hill and dee where it receives a transverse kick that depends on the

beam phase with respect to the RF, making short length bunches desirable.

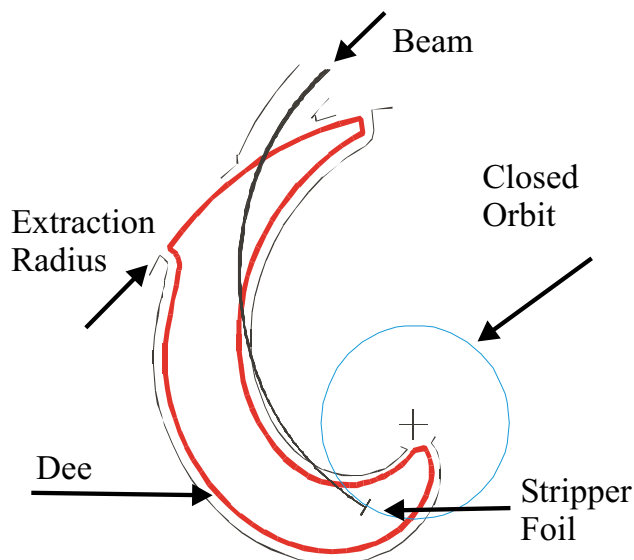


Figure 1: Injection path into the K1200. The red curve outlines the dee profile where the stripper mechanism must be contained. The extraction radius is 1 m.

## 2 FOIL POSITIONER

### 2.1 Foil holders

The carbon foils are mounted on aluminium frames as shown in Figure 2. The frame is then inserted into a frame holder, which is attached via a hinge to a stainless steel bicycle chain. Clips in the frame holder engage the two rectangular holes shown on the right side of Figure 2. An automatic loading system is being developed for frame replacement while maintaining vacuum in the cyclotron. The rectangular hole on the upper left of Figure 2 will be used by the automatic loading system to grab the frame for removal from and insertion into the frame holder. The carbon foil has been partially removed from the frame to show the "C" opening where the foil is mounted. The open side of the "C" is spanned by a 50-micron tungsten wire that supports the carbon foil. We are planning to test

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a version of frame without using the tungsten support wire.

The frame holders, which are also made from aluminium, rest horizontally on a stainless steel track as the bicycle chain is moved. As the frame holder nears the target position, it pivots into a vertical orientation. The

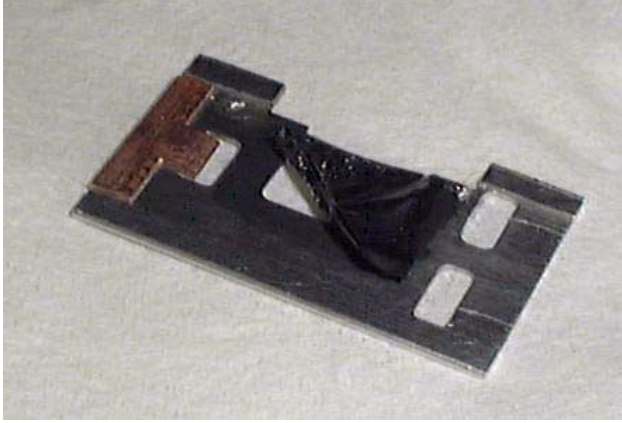


Figure 2: Foil holder with partially lifted carbon foil. The length of the frame is 33 mm

frame holder was silver plated to prevent galling during this vertical transition. During the plating process, a nickel layer was first applied to the frame holder. The nickel plating caused the frame holders to become slightly magnetic and stand-up in the magnetic field. A new version of the holders made of copper is being fabricated.

The short experience that we have with the system has been positive, but we have not accelerated high intensity beams yet. The size of the beam at the foil must be approximately 2 mm. If during high intensity operation the beam moves off the foil and onto the frame it will melt it. There is no cooling of the frame. Anticipating beam deflections due to sparks of the RF system or phase changes, we have implemented an interlock system that stops the acceleration of the beam in the injector cyclotron if the RF system in the booster is not at the correct settings.

## 2.2 Drive mechanism

When a new foil is needed at the target position, the bicycle chain is moved to bring the next foil on the chain into the target position. When the foils need to be replaced, the platter can be moved to a loading position and raised into the median plane so foils can be removed and replaced from outside the cyclotron without raising the cap on the cyclotron.

Five sets of hydraulically coupled cylinders: five cylinders outside the cyclotron (master cylinders) with five mating cylinders inside the cyclotron (slave cylinders), position the platter so the target foil is at the desired stripping location, move the foils on the bicycle chain and raise the platter into the loading position.

Stepper motors drive the two master cylinders that position the platter. The two master cylinders used to move the chain and the one used to raise the platter for foil replacement are driven by a third set of pneumatically controlled cylinders (control cylinders). Four of the five Master Cylinders inside the cyclotron have external compressed air tanks that act as springs to move the cylinders in the opposite direction from their main drives. The fifth master cylinder has an internal mechanical spring as its opposing force. Each slave cylinder in the cyclotron has a bellows isolating the cylinder shaft seal from the cyclotron vacuum.

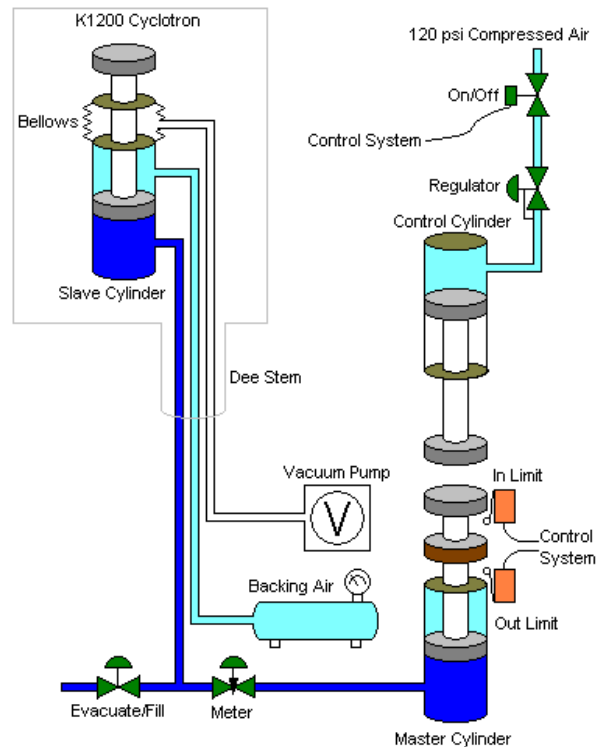


Figure 3: Schematic diagram of the hydraulic system used to move the chain and position the foil.

To connect the internal and external components of the stripper foil mechanism, an assembly of eighteen stainless steel control lines run from the sub-basement of the K1200 vault through the lower dee stem into the lower dee of the K1200. A flexible hose assembly inside the lower dee allows some of the eighteen control lines to interface to the moving chain platter. Eight electrical connections run in the dee stem also; four are used to monitor temperature and RF pickup at the target area of the platter, two are used to control LED's at the target area of the platter for target illumination purposes and two are used to interlock the stepper motor controllers if the platter position reaches a mechanical limit inside the lower C dee.

The stripper foil mechanism is interfaced to the NSCL control system via a MODICON I/O drop which handles discrete inputs such as limit switches and set points and discrete outputs used to open vacuum valves and air solenoids. The MODICON I/O drop also has an analog input module used to read vacuum sensors. The two stepper motor drives are controlled by Whedco Stepper Motor Controllers via an RS232 connection through a DECserver 300 Terminal Server. The Terminal Server uses a TCP/IP communications protocol to communicate with the control system.

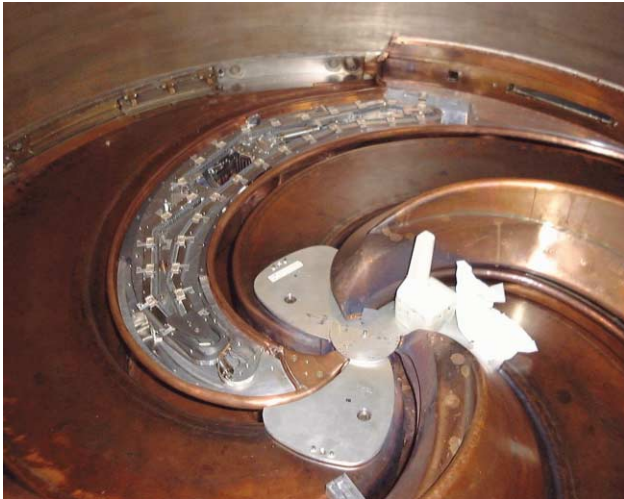


Figure 4: Stripper foil mechanism installed inside the dee in the K1200 cyclotron. The RF shield has been removed.

Two separate software applications are used to control the Stripper Foil Mechanism. Both applications are written using National Instruments LabVIEW graphical programming language. The SFoil application moves the chain platter, which controls the angular and radial position of the target foil in the stripping location. The FoilInterface application is responsible for moving the bicycle chain to position the next foil on the chain in the target position. This application also controls the up and down motion of the platter so foils may be replaced as needed.

### 2.3 RF shield

Our initial estimates of the currents flowing inside the dee were not correct and the temperature of the mechanism was higher than anticipated, melting some of the plastic hoses inside their vacuum vessels. A copper shield that covers a large fraction of the dee was then retrofitted. This shield provides a path for these currents. We now monitor the temperature and RF pick-up inside the dee. The Rf shield moves up and down with the platter during the foil replacement procedure, making contact with the dee using RF spring fingers. We have now used it for many weeks at 140 kV dee voltages with no problems.

## 3 FOIL CHANGER

We have designed and started to build an automatic foil loading system. The purpose is to unload and then reload the 31 foils attached to the chain under vacuum. It will be implemented in stages, starting from a manual operation to verify that the alignments are correct when the multiple foils are placed in the loading position.

## 4 REFERENCES

- [1] R. York et al., Proceedings of the 15<sup>th</sup> International Conference on Cyclotrons and Their Applications, Caen, France, 1998, p 687.