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FOIL CHANGER FOR THE CHALK RIVER SUPERCONDUCTING CYCLOTRON

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Summary

Capture of an injected beam in the Chalk River superconducting cyclotron requires that a carbon stripping foil be accurately placed in a dee to intercept the incoming beam. Foil radial position must be precisely adjustable and foils must be easily replaced. A foil changing apparatus has been designed, built and tested to meet these requirements. The main components are a supply magazine, a transport system, and unloading and loading mechanisms. The magazine is on top of the cyclotron. It holds 300 foils and can be isolated from machine vacuum for refilling. Each foil is mounted on a stainless steel frame. A stainless steel roller chain fitted with 33 copper sleeves (shrouds) carries foils, one per shroud, down a dee stem to the midplane. A 12-bit absolute optical shaft encoder senses foil position. To replace a foil a shroud is positioned at the top of the cyclotron, a foil is removed, and another is transferred from the magazine to the empty shroud. Three stepping motors and associated electronics provide mechanical drive and are interfaced with a CAMAC control system.

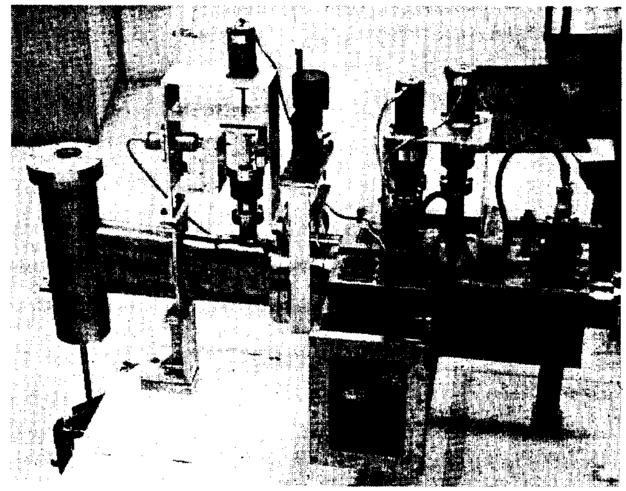


Fig. 2 Photograph of the foil changer system mounted on a bench.

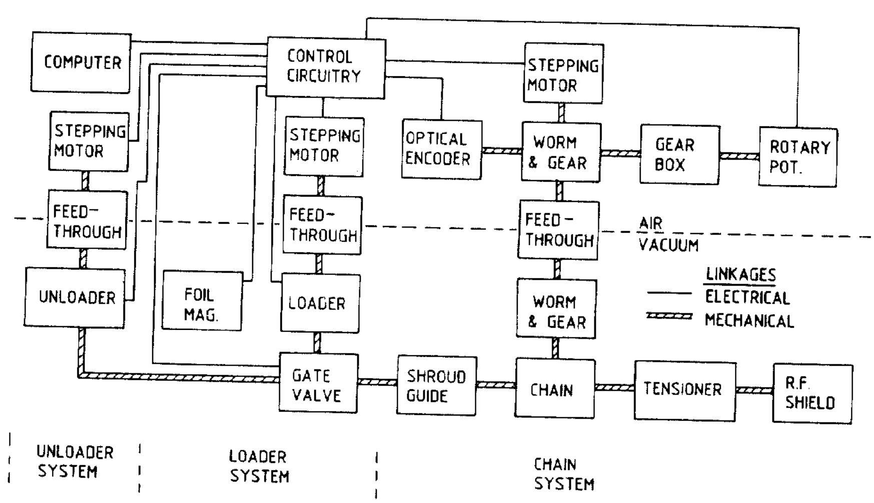
Introduction

The function of the foil changer system in the Chalk River superconducting cyclotron[1] is to provide carbon foils at correct midplane radial positions in a dee to intercept and charge strip injected beams from the Tandem accelerator. The compact size of the cyclotron and consequent space constraints led to a design in which foils supplied in vacuum from a storage magazine on top of the cyclotron are carried down a dee stem to the midplane region. Figure 1 is a block diagram of the system and identifies the major components. They are divided into three major subsystems:

1. foil chain transport, based on carrying foils in copper sleeves (shrouds) fitted to a stainless steel roller chain,
2. foil loader, which is a mechanical mechanism, to transfer foils from the supply magazine to a shroud positioned to receive a foil,
3. foil unloader, which is another mechanical mechanism, to remove a foil from a shroud immediately before loading occurs.

All three systems have stepping motors to drive the various mechanisms through rotary vacuum feedthroughs. The transport system has two worm wheel and gear sets: one drives the chain and the other drives an absolute rotary shaft encoder which provides information for deducing foil position. The loader and unloader mechanisms are housed in a vacuum envelope separate from the chain transport. The connection between them is a narrow body gate valve, through which all loading-unloading operations take place. The gate valve provides isolation from machine vacuum when the loader-unloader vacuum is let up to air to replenish the foil magazine. Figure 2 is a photograph of the overall system mounted on a bench. It shows the two vacuum envelopes connected by the gate valve as well as drive train components for the various

Fig. 1 Block diagram identifying the main components of the foil changer system and their interconnections. Note the air-vacuum boundary and the division of the system into three mechanical subsystems.



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mechanical subsystems. These mechanical features are discussed in following sections and some characteristics of the control circuitry are outlined.

Foil Transport

Figure 3 is a schematic representation of the transport chain installed in a dee. The chain is a standard 6.35 mm pitch stainless steel roller chain, approximately 5 m long. It is threaded in a loop over one drive sprocket and nine idler sprockets. Copper shrouds are located every 152.4 mm (24 chain links) along the length. The whole chain is in a vertical plane oriented at an azimuth of 23.44°. The radial travel in the dee for intercepting beam is 120 mm beginning at radius R = 145 mm. Minimum clearance between the ends of the foils and dee structure (web or stem) is 1 mm. All idler sprockets (stainless steel) are mounted on Waukesha[2] axles. The topmost sprocket is movable and forms part of a system to tension the chain after it is installed. A typical value of tension force is 75 N. The axis of this sprocket is at an elevation of about 1900 mm above the midplane. The drive sprocket is fixed on a common axle with a worm gear, which meshes with a worm mounted on the end of a double universal joint (not shown in Fig. 3). This in turn connects to the shaft of a rotary vacuum feedthrough and ultimately to a stepping motor. Sixty revolutions of the worm drive train are required to move the chain one foil pitch (152.4 mm). The time for the chain to travel one foil pitch is determined by the stepping motor speed. A motor speed of 180 rpm leads to a time of 20 s.

As indicated in Fig. 1 a worm mounted in the chain drive train between the stepping motor and feedthrough engages an antibacklash worm gear to turn it precisely one revolution per one foil pitch of chain travel. An absolute optical encoder is connected to the worm gear axis. It has a resolution of 12 bits and in principle can measure a change in foil position of 0.04 mm, neglecting backlash in the gear train. Measurements of shroud position reproducibility, from one foil pitch to the next, on a test chain suggest an uncertainty of less than ± 0.1 mm for a given shaft encoder setting. Also connected to the worm gear axle is a small gear box and a 10 kΩ rotary potentiometer which is used to identify shroud position on the chain. The gear ratio of 33:1 causes the potentiometer to make precisely one complete turn for one complete cycle of the transport chain.

The vacuum envelope for the chain drive connects to the top end of the dee stem and has an O-ring to make a vacuum seal. The geometrical constraints imposed on the envelope are that it not interfere with sliding short hardware for tuning the dees, fit within the narrow available space between trim rod modules, be self supporting, and allow access to an electrostatic deflector high voltage cable that occupies the same dee stem. The top surface of the envelope is covered with a flange for access to the chain tensioner. The large flange near the drive sprocket mates to the narrow body large bore (152 mm) gate valve.

The chain, sprockets, a chain guide, and support structure immediately above the midplane in the dee are shielded from rf with copper pieces that are in contact with the dee copper. Beryllium-copper fingers attached to the shield touch the shroud as it is moved over its radial range in the dee.

Unloader System

The function of the unloader is to remove spent foils from the shroud when it has been correctly

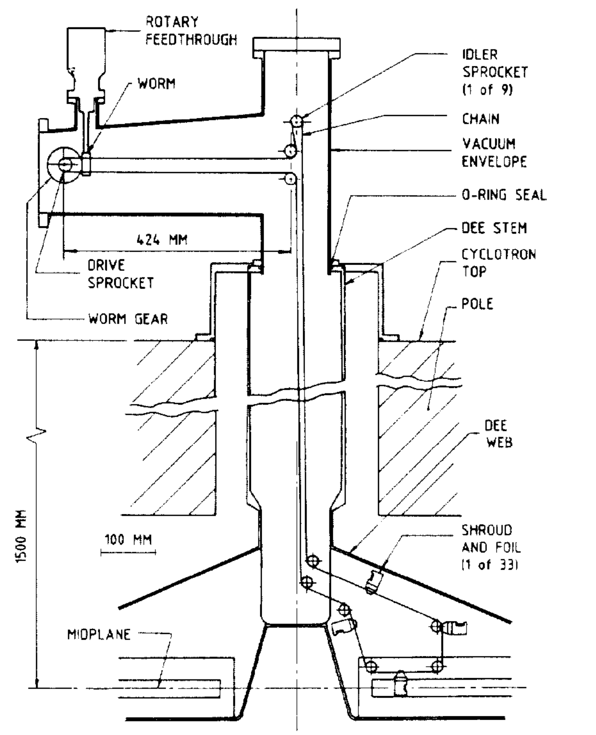

Fig. 3 Schematic representation of the transport chain installed in a dee.

positioned and the loading sequence has been triggered. The unloader mechanism consists of a set of jaws (somewhat like ordinary pliers) mounted on a carriage. The carriage is moved forward and backward as required with a stepping motor driving a stainless steel spur gear in vacuum through a rotary feedthrough. The spur gear meshes with an aluminum rack mounted on the carriage. The range of travel is precisely controlled with vacuum limit switches. The carriage moves on Waukesha wheels in machined stainless steel ways.

To remove a foil from a shroud the jaws are moved through the gate valve to the foil. A mechanical stop trips the jaws which lock onto the foil through a hole in the foil holder frame. Motion is reversed to carry the foil through the gate valve. At the appropriate location a mechanical trip opens the jaws, dropping the foil into a spent foil bay at the bottom of the vacuum envelope. The time required for the unload sequence is 4 s. The unloader travel is 241 mm.

Lateral positioning of the shroud for the loading sequence is controlled with a set of guide rails. Vertical positioning is controlled from the optical encoder drive shaft, which makes one revolution per foil pitch of travel. The required shroud positioning accuracy of ± 1° is well within the resolution of the system. Backlash effects in the drive train are minimized because the chain always travels in the same direction to the load position.

Loader System

The function of the loader is to remove a foil from the magazine, carry it through the gate valve and push it into the shroud. As may be noted in Fig. 4 the foil is secured in the shroud with a spring clip that slips into the rectangular hole at the top end of the foil frame. The loader then returns to its starting position.

The loader system is similar to the unloader

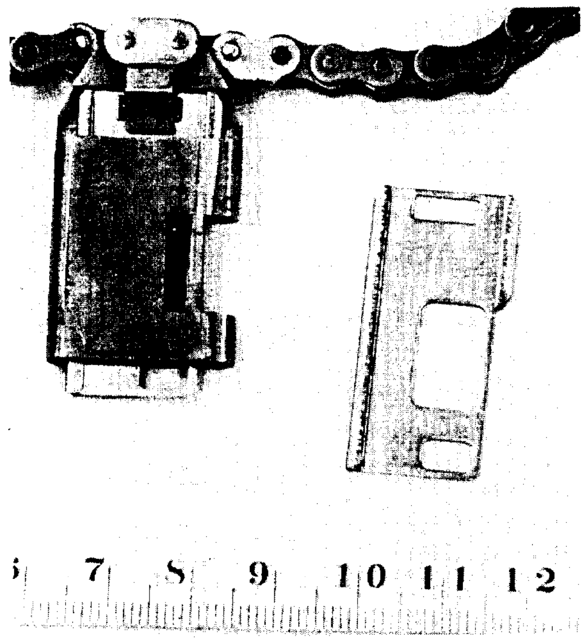

Fig. 4 Photograph of a copper shroud mounted on the chain and a foil holder without a foil.

except that a foil carrier replaces the jaws. The carrier is propelled by a stepping motor via a rotary feedthrough and a rack and spur gear arrangement. Vacuum limit switches are used to control precisely the carriage motion. The loader travel is 222 mm.

The foil supply magazine is basically a precisely fabricated metal box with constant spring loading to push the foils toward an exit end. At the exit end foils can be slid out into the carrier one at a time. The magazine holds up to 300 foils. Each foil is mounted on a stainless steel frame (holder) 0.5 mm thick. Holes are punched out for the carbon foil, the shroud spring and the unloader jaws. The edges of the foil holder are folded over to provide separation between holders in the magazine to protect the delicate carbon film. Typical foil thicknesses are 10 to 20 $\mu g/cm^2$. Figure 5 gives details of the foil holder.

Control System

Control and status monitoring are accomplished with a CAMAC system using three standard modules to interface with the foil changer system:

- Input Gate-Output Register (IGOR) to read the 12-bit shaft encoder to get foil position.
- Stepping Motor Controller (SMC) to interface with the power supply and stepping motor for the chain drive.
- Status Pulse Output (SPO) to monitor status of the loader and unloader systems.

The commands that the system responds to are position a foil to a given value of radius R within the range 145 mm < R < 265 mm, move the chain forward (foils advancing toward larger radii) to clear all foils from the midplane, and move the chain further forward to correctly align a shroud at the drive sprocket for the unloading-loading sequence. The constraints are that the chain may be moved arbitrarily back and forth only when a foil is within the radial range for positioning. Otherwise the chain moves to or from the clear position or forward to the load position. After completion of the load sequence the

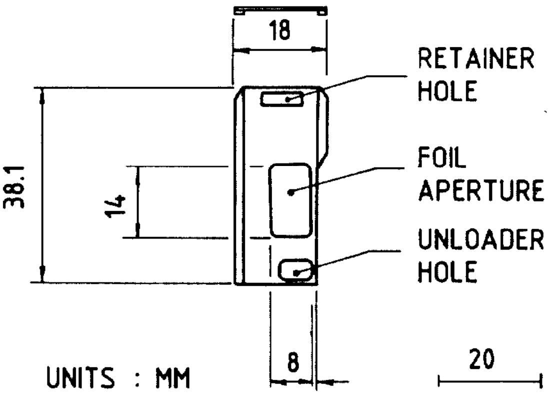

Fig. 5 Schematic of the foil holder made from 0.5 mm thick stainless steel.

chain moves forward again to put the next foil available into the radial positioning range. Typically a load command is given when the current foil intercepting the beam burns out. Then the chain advances to put the first available shroud in the correct position for loading. Correct positioning automatically triggers the unloader-loader sequence. Upon completion of loading the chain automatically advances to put the next foil available at the radial position of the previous burnt out foil. The complete cycle takes less than 1 minute.

The control circuity for the loader-unloader mechanisms is hard-wired. Operation is initiated when a shroud is positioned for loading. Unloading of a foil always precedes loading to avoid having apparatus jammed in the gate valve. For similar reasons the two stepping motors may operate only one at a time. This is ensured through the design of the gating circuits that control separate motor power supplies. In the case of power failure during the load sequence, the system is designed so that on restoration of power loader and unloader return to their parked positions and await further instructions.

The foil magazine is equipped with a limit switch to indicate when the last foil has been loaded.

Mechanical operation of the system has been extensively bench tested, with considerable effort given to exploring fault conditions that may result in blocking the gate valve. Operation is smooth and precise. The system has not yet been operated in the cyclotron (1985 April). It will be installed after dee installation is complete.

Acknowledgments

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References

1. J.A. Hulbert, et al., "First Operation of the Chalk River Superconducting Cyclotron", Proceedings of this Conference, 1985.
2. Waukesha metal #88 is a nickel based alloy suitable for use with stainless steel to avoid galling. Typical composition is (%): Ni-70; Fe-5; Cr-13; Mo-3; Bi-3.8; Sn-4; Mn-0.8; Si-0.35; C-0.05 maximum.