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ORIC STRIPPING FOIL POSITIONER FOR TANDEM BEAM INJECTION*

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Abstract.-The Oak Ridge Isochronous Cyclotron (ORIC) is used as an energy booster for heavy ions from a 25 MV tandem accelerator. This operation requires precise placement of a stripping foil in the cyclotron for capture of the injected ions into an acceleration orbit. The mechanical design and control of the foil positioning device are described.

1. Introduction.-Coupled operation of the 25 MV tandem accelerator and the ORIC was demonstrated on January 27, 1981[1,2]. Heavy ions accelerated by the tandem enter the cyclotron through the rf resonator. In order to receive further acceleration, the incoming beam must have a sufficiently large rigidity (Bρ) to cross the cyclotron field. The ions must then be stripped in order to capture the beam in an orbit of smaller radius suitable for acceleration. To achieve this end, the beam is directed by a movable inflection magnet in the resonator to a stripping foil placed outside the single dee (Fig. 1). The injected ions pass through the foil, are stripped, and must miss the foil and its frame on the first acceleration orbit.

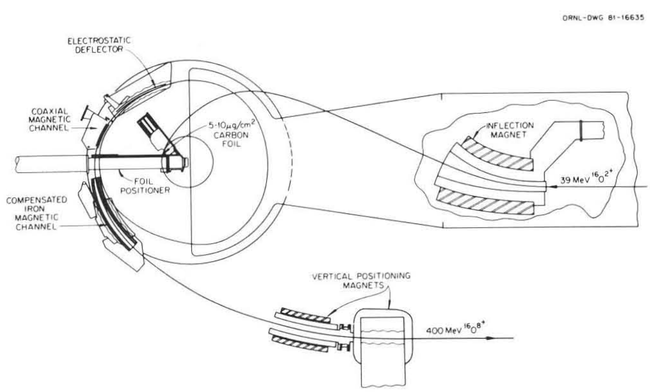

Fig. 1 : Foil positioner shown in position for boosting $^{16}O^{2+}$ tandem beam to 25 MeV/amu. Pole-tip diameter (dashed circle) is 193 cm.

2. Foil Positioning Mechanism.-The entire foil positioner assembly is interchangeable with the cyclotron's internal ion source. The exchange of assemblies takes approximately two hours. The mechanism is at the end of a stem that penetrates the vacuum chamber through a vacuum lock. A set of expended foils can be replaced in approximately 30 minutes.

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The foil positioner is comprised of an arm that can be rotated to any angle over a 90° range from the horizontal to vertical positions; a carrier with holders for 20 foil frames; a drive mechanism to index a foil frame on the carrier into the median plane of the cyclotron; and a carrier drive element that positions the carrier radially along the arm.

All elements are driven by stepping motors outside of the vacuum system. Positions of the elements are monitored by synchros. Coupling between gear sets, internal and external to the vacuum system, is accomplished by shafts ∿ 4 m long that extend the length of the assembly stem penetrating a bulkhead through O-ring seals.

In order to accommodate injected beams of varying energies, a foil must be able to be positioned over an azimuthal range of ∿ 85° and a radial range of 24-51 cm. Figure 2 shows the arm raised to a typical

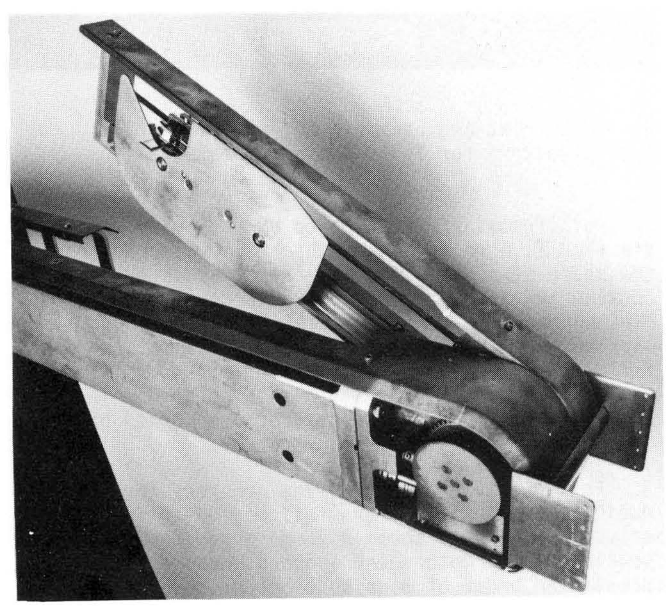

Fig. 2 : The arm raised to a typical operating position with "upper insertion" carrier installed. An empty foil frame can be seen in the position to intercept injected beam.

operating angle. A foil carrier is shown at a relatively large radius with a foil frame rotated into the median plane to intercept the beam near the top of the arm. The remaining 19 foils are in vertical positions behind the protective shield. A second type of carrier provides for rotation of the foil frame into the beam at the diagonally opposite corner from the one shown. This permits foil insertion at the required smaller radii. Not shown is a small, second shield that protrudes into the median plane preventing unaccelerated beam from striking the inner radius side of the foil holder. This shield not only protects the foil changing mechanism from thermal damage, but serves as a current monitor useful for defining beam trajectories while tuning injection parameters.

Two foil carriers without shields are shown in Figure 3. Foil frame holders are attached to a chain that is driven by a Geneva mechanism. These holders are spring loaded to force them against the carrier body holding the foil frame in the plane of the carrier. A ramp is attached to the carrier body at the location where the foil frame is to be inserted into the median plane. The frame holder rotates 90° as the chain pulls the holder over this ramp, thereby positioning the foil into the beam. A new foil can be brought into position in less than a minute.

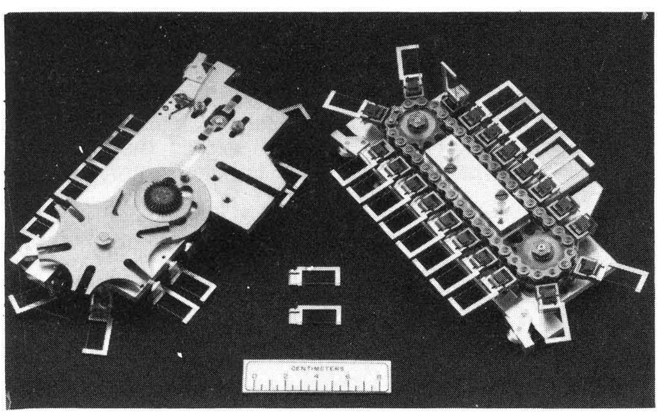

Fig. 3 : Front and back view of a foil carrier. Twenty holders for foils are provided.

Foil frames are fabricated by attaching a 0.5-mm-diameter Ta wire to 1.6-mm-thick Al plate machined in the shape of a "u". The wire size was determined by considering the turn spacing for various heavy ions. Finite beam size orbit calculations predicted that the wire must be smaller than 0.66 mm in diameter. The foils, 5-10 $\mu g/cm^2$-thick, are made by deposition of carbon from an ethylene gas glow discharge. They cover the entire rectangular aperture formed by the frame and the wire.

3. Foil Positioner Control-The accuracy for reproducible positioning of the foil was determined to be ± 0.05° in azimuth and ± 0.3 mm in radius. The gearing of the motors and synchros was designed to provide an order of magnitude better resolution in control and monitoring to permit fine tuning of the system.

Stepping motor controllers and synchro to digital converters were purchased in commercially available CAMAC modules. The CAMAC crate powering this equipment is connected to the ORIC control computer via a serial highway.

The control software permits "manual" control of all elements with position information displayed in "real-time." Gear-set backlash and wind-up of coupling shafts are accounted for as the direction of travel of the elements is changed. The programs also correct the carrier position readout to compensate for the radial motion of the carrier along the arm as the arm angle is changed. This movement is caused by the planetary motion of the carrier lead screw bevel gear about its drive member and is not detected by the carrier position synchro.

Because the pivot point of the arm is located 11 cm from the center of the cyclotron, motion of either the arm or carrier alone simultaneously changes both the radius and azimuth of the foil with respect to the center of the cyclotron. The computer performs the necessary coordinate transformation and displays the proper positions to the operator so he may tune the element properly.

A sizable fraction of the software is designed to prevent a potential mechanical interference between the foil carrier and the internal beam current monitoring probe (Fig. 4). This probe moves radially in the median plane between the two halves of the stem that supports the foil positioner. Because the interference point is a complex function of the positions of the probe, arm, and carrier no reliable hard-wired protective circuit could be devised to prevent a collision of these elements. Consequently, the control computer performs the necessary geometry calculation each time the operator attempts to change the position of an element to determine if the motion will lead to the interference. The computer will not permit the requested motion if it determines contact will result and informs the operator of its decision.

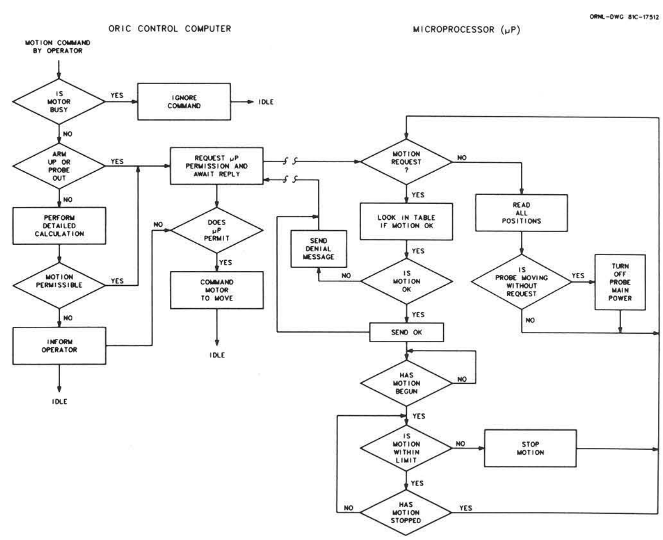

Fig. 4 : Flow chart of ORIC control computer - microprocessor communications.

In anticipation that the computer can err at the most inappropriate moment or that the programmer may not have found a subtle error in the code, it was decided that a microprocessor verify the results of the main computer. If the main computer decides that the desired motion is permissible it must request approval from the microprocessor before a motor can be energized.

The microprocessor resides in the CAMAC crate along with the stepping motor controllers, the synchro to digital converters, and the probe motor-enabling circuitry. It continuously monitors the position information and awaits requests for motion from the main computer. The microcomputer is not well suited to perform complex trignometric calculations rapidly. Consequently, serious degradation in response time of the system would occur if detailed calculations were performed with each motion request. Therefore, the microprocessor code was reduced to a table-look up routine where the results of the complex calculation are stored in read-only memory ($\sim$ 12,000 words) in a relatively coarse grid. Interpolation is performed rapidly with barely noticeable degradation in operation speed. Ideally the microprocessor should never veto the main computer's request. The operator is informed immediately if a disagreement occurs so that human judgment may resolve the discrepancy.

4. Operation Experience-Operation experience to date has been extremely successful. The foil position, at the completion of tuning of the beam at the exit of the cyclotron, has been repeatedly within a few millimeters of pre-calculated values. The major discrepancy has been in azimuth, where the tuning range has been rather broad for the ions accelerated to this time.

References

1. R. S. LORD et al., IEEE Trans. Nucl. Sci. NS-28, No. 3, 2083 (1981).

2. C. A. LUDEMANN et al., proceedings this conference.