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COUPLED OPERATION OF THE OAK RIDGE ISOCHRONOUS CYCLOTRON AND THE 25 MV TANDEM

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Summary

Coupled operation of the 25 MV tandem and the Oak Ridge Isochronous Cyclotron (ORIC) was achieved on January 27, 1981. A beam of 38 MeV $^{16}O^{2+}$ was injected into ORIC, stripped to 8^+ and accelerated to 324 MeV. Shortly afterwards, the energy was increased to the maximum design value of 25 MeV/amu (400 MeV). A spectrum taken of the scattering of this beam from a thin ^{208}Pb target in the broad range spectrograph exhibited a resolution of 115 keV (FWHM). Performance of the system was in close agreement with that predicted from calculations.

Introduction

ORIC[1] is a K=100 (K=ME/q^2) cyclotron built in the early 1960s as a light-ion machine with heavy-ion capabilities, and recently operated almost exclusively as a heavy ion accelerator. With an internal ion source, it is useful for nuclear experiments up to about mass 40. In 1975, construction commenced on a 25 MV tandem accelerator to be installed near the cyclotron.[2,3] The scope of this project included provision for injecting the tandem beam into the cyclotron for energy boosting.[4,5] In coupled operation, particles of up to mass 160 may be accelerated to energies above the nuclear interaction barrier. Further extension of the capability of this facility to K=300 is the subject of another paper at this conference.[6]

Injection System

The tandem is located about 36 meters from the cyclotron and has a vertical column with a 180-deg magnet following the stripping channel in the terminal. The injection system includes the pair of magnets that turn the beam path from vertical to horizontal, two quadrupoles, an inflection magnet to aim the beam at the right spot in the cyclotron, a stripping foil inside the cyclotron and the control and diagnostic systems. Since the acceptance of the cyclotron for an energy spread of 1 in 1000 is ± 3 deg of the rf period (or 1-2 nsec for the required frequency range), the beam is bunched before acceleration in the tandem. The double-drift klystron buncher, in a test on the EN tandem, was able to put over 50% of the beam in the desired period. To preserve the time structure of the beam, transmission to the cyclotron must take essentially the same time for all portions of the beam bunch. This was accomplished by designing the optics magnets and beam waist locations to minimize the time dispersion (100-150 psec). The optics system must also transform the circular beam spot that comes out of the tandem to a rectangular spot about 1 x 5 mm at the stripping foil in the cyclotron.

The injected beam must be sufficiently rigid as it enters the cyclotron so that it can cross the cyclotron field and arrive at the stripping foil (Fig. 1). This, when the radial limits on the travel of the foil are considered, implies also that a stripping ratio of ∼2:1 or greater is required to capture the beam in an orbit suitable for acceleration. For lighter ions, it is necessary to limit the charge change that occurs in the tandem terminal to assure that a 2:1 charge change at the stripping foil in the cyclotron is achievable. For carbon, nitrogen, and oxygen, which would normally be almost fully stripped in the terminal with ordinary pressures in the stripping channel, this is accomplished with no significant loss of intensity by operating the stripping channel at lower than normal pressure, thus intensifying the desired charge state.[8] For the heavier particles, higher charge states in the terminal are usable and desirable to achieve maximum final energy.

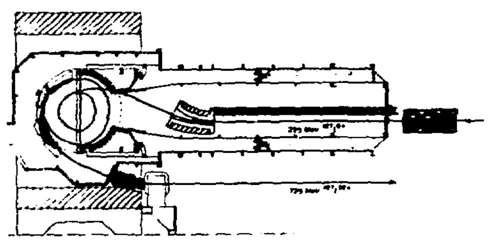

Fig. 1. Beam enters the cyclotron through the rf resonator, is directed by the inflection magnet to the stripping foil which is placed on an orbit suitable for acceleration. The incoming beam must have a sufficiently large rigidity (Bρ) to cross the field to the foil. The inflection magnet is movable radially and has an angular range of 17 to 37 deg to accommodate beams of different rigidity requiring different deflection angles.

Beam Monitoring Diagnostic System

Six quartz-plate viewers with closed-circuit television cameras have been provided for setting up a beam through the injection system. With these viewers the position of the beam can be adjusted to coincide with the axis of the injection line, the shape can be monitored approximately, and it can be determined whether the beam is passing through the quadrupoles on-axis. One of the quartz viewers is located inside the cyclotron and can be substituted in place of the foil for aiming and focusing the beam. The beam also causes the foil to glow visibly during operation. A 3-meter fiber-optic viewing system was required so that this TV camera could be mounted where the cyclotron stray field was sufficiently low. In addition to the TV monitoring systems two Faraday cups are used, one at each of the beam waists. The first is located after the regulating slits between the 25-deg and 65-deg magnets that turn the beam path from vertical to horizontal. Tuning for maximum beam passing through the slits at this point produces a waist that is required for minimum time dispersion. The second cup, about halfway along the line, is capable of measuring the time structure of the beam for initial adjustment of the buncher. Final adjustment of the

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buncher is, of course, done by observing the intensity of the beam extracted from the cyclotron while varying buncher phase and amplitude. A foil can be inserted into the beam ahead of the 65-deg magnet so that the charge state distribution of the stripped beam in the cyclotron can be determined ahead of time.

Foil Positioner

The foil positioner in the cyclotron is designed to be interchangeable with the internal ion source (Figs. 2,3). It can position a foil over an azimuthal range of ∿ 85 deg and a radial range of 24-51 cm to accommodate injected beams of varying energies. A foil carrier (Fig. 4) mounted on the pivoted arm, holds up to 20 foils which can be indexed into position remotely in a few seconds. A different carrier containing a new set of foils can be installed in about 30 minutes by withdrawing the foil positioner through a vacuum lock. The pivot point of the foil positioner arm is not at the center of the cyclotron so the cyclotron control computer calculates the radius and azimuth of the foil with the appropriate coordinate transformation. These parameters are displayed in both coordinate systems. The potential mechanical interference between the foil carrier and the internal beam probe that is mounted on the foil positioner is avoided by a software interlock system that keeps track of the probe and carrier positions. There is also a microprocessor back-up for this software interlock.

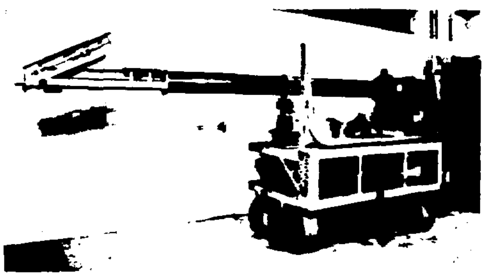

Fig. 2. The foil positioner on its handling dolly. The foil arm is raised to a typical operating position.

Fig. 3. The foil arm with the foil carrier installed. One of the foil holders is flipped out into the operating position.

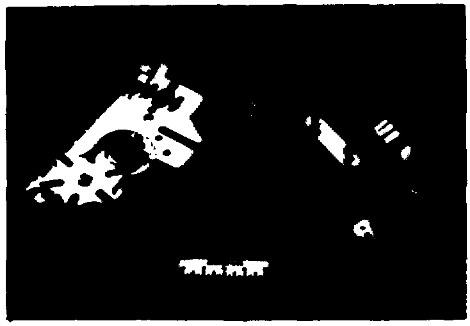

Fig. 4. Front and back view of a foil carrier. Twenty positions for foils are provided.

Beam Dynamics Computations

In 1977, the magnetic field of the cyclotron was remeasured[9] to obtain data for the fringe field and for the high main magnet fields that are now used. The field data was parameterized[10] and programs have been developed for computing trim and harmonic coil settings, injection trajectories, foil azimuth and radius, inflection magnet strength and position, and extraction system mechanical and magnetic settings. The extraction system program is operator interactive so that the system parameters may be iteratively adjusted while observing a graphic display of the calculated extracted beam trajectory (Fig. 5).

The programs for acceleration and extraction of the beam have been in routine use with the internal source since June, 1980, and have proven very successful in producing extracted beam with only minor tuning by the operator. The injection program proved invaluable in predicting the foil position and inflection magnet setting for the first injected beam. The operating position of the foil, determined by optimizing the extracted beam, was only a few millimeters from the predicted position.

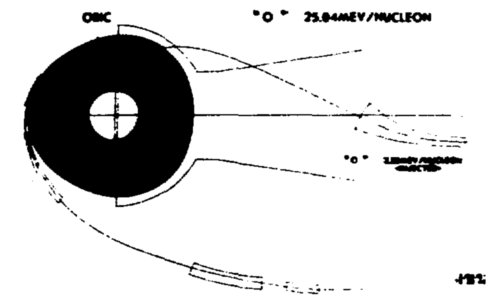

Fig. 5. Calculated injection, acceleration, and extraction trajectories for the 400 MeV $^{16}O^{8+}$ beam. The program finds the optimum positions for the foil and the inflection magnet. The operator iteratively adjusts the positions and strengths of the five extraction elements to achieve the desired calculated result, in a manner similar to actual operation.

Operating Experience

In January, 1981, the tandem, although still undergoing acceptance tests, was made available for two brief tests of coupled operation. During the first 24-hour test the transport and diagnostic systems were checked out with beam, which was then stripped and accelerated to full radius. Because of a water leak in one of the extraction channels when it was energized, we were unable to extract the beam. Two weeks later a period of three days was allotted to testing coupled operation. The first extracted beam (324 MeV $^{16}O^{8+}$) was obtained on January 27 within a few hours of starting the test. The parameters are given in Table 1. This beam was used briefly to obtain a scattering spectrum, then the energy was increased in steps to the full design value (25 MeV/amu) by raising the cyclotron frequency and magnetic field. At this point further measurements were made using a ^{208}Pb foil target and a broad range spectrograph (Fig. 6). The energy resolution during this experiment was ~115 keV (FWHM), or about 1 in 3500. This was as good as, or better than, the predicted energy spread of the beam, and substantially better than the energy spread measured in the previous experiment at 324 MeV.

During these experiments we did not experience a foil failure. This was consistent with the predicted life of 150 pμAh of 38 MeV ^{16}O beam for the 5–10 μg/cm^2 carbon foils made by deposition of carbon from an ethylene gas discharge.

Table 1. Parameters for First Coupled Operation

Tandem:	
Terminal Voltage	12.2 MV
Injector Voltage	300 kV
Low Energy Ion	OH^-
Accelerated Ion	$^{16}O^{2+}$
Analyzed Current	400 nA
Output Energy	38 MeV
Cyclotron:	
Accelerated Ion	$^{16}O^{8+}$
Circulating Beam	180 nA
Extracted Beam	125 nA
Energy	324 MeV
Analyzed Beam on Target	60 nA

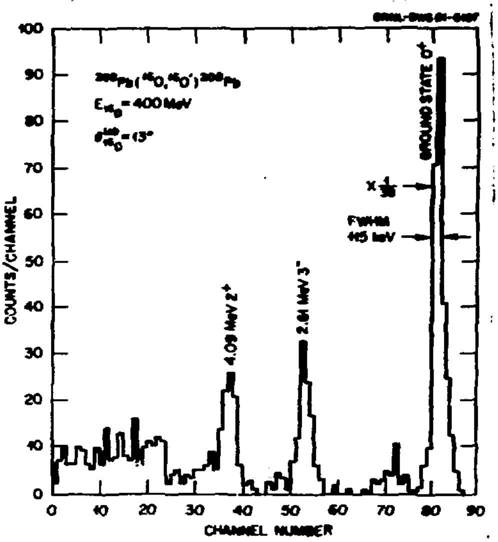

Fig. 6. Spectrum of ^{16}O ions scattered from a ^{208}Pb target. Scattered particles were detected using a silicon position-sensitive detector placed in the focal plane of a magnetic spectrograph. Clearly visible are peaks from elastic scattering (ground state) and excitation of 2.61- and 4.09-MeV levels of the ^{208}Pb nucleus. The measured energy resolution was 115 keV (FWHM), which includes contributions from such sources as the beam energy spread, beam angular divergence, inherent detector resolution, electronic noise spread and energy straggling in the target.

Acknowledgments

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References

1. R.S. Livingston and F.T. Howard, Nucl. Inst. and Meth. 6 (1960) 1.
2. C.M. Jones, Revue Phys. Appl. 12, 1353 (1977).
3. N.F. Ziegler, et al., Proceedings this conference.
4. R.S. Lord, et al., IEEE Trans. Nucl. Sci. NS-22, No. 3, 1679 (1975).
5. R.S. Lord, et al., Proc. of the 7th Int. Conf. on Cyclotrons and Their Applications (1975) 622, Birkhauser Verlag, Basel and Stuttgart.
6. J.A. Martin, et al., Proceedings this Conference.
7. W.T. Milner, IEEE Trans. Nucl. Sci. NS-26, No. 1, 1445 (1979).
8. R.O. Sayer, et al., ORNL-5306, 15-16 (1977).
9. S.W. Mosko, et al., IEEE Trans. Nucl. Sci. NS-24, No. 3, 1269 (1977).
10. T.P. Cleary, IEEE Trans. Nucl. Sci. NS-26, No. 3, 3907 (1979).