THE OAK RIDGE ISOCHRONOUS CYCLOTRON REFURBISHMENT PROJECT*

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Abstract

The Oak Ridge Isochronous Cyclotron (ORIC) has been in operation for nearly fifty years at the Oak Ridge National Laboratory (ORNL). Presently, it serves as the driver accelerator for the ORNL Holifield Radioactive Ion Beam Facility (HRIBF), where radioactive ion beams are produced using the Isotope Separation Online (ISOL) technique for post-acceleration by the 25URC tandem electrostatic accelerator. Operability and reliability of ORIC are critical issues for the success of HRIBF and have presented increasingly difficult operational challenges for the facility in recent years. In February 2010, a trim coil failure rendered ORIC inoperable for several months. This presented HRIBF with the opportunity to undertake various repairs and maintenance upgrades aimed at restoring the full functionality of ORIC and improving the reliability to a level better than what had been typical over the previous decade. In this paper, we present details of these efforts, including the replacement of the entire trim coil set and measurements of their radial field profile. Comparison of measurements and operating tune parameters with setup code predictions will also be presented.

BACKGROUND

The ORIC was designed and built in the late 50's – early 60's to be a variable energy cyclotron capable of accelerating a wide range of ion species. As such, it was built with a complex magnet system, involving dozens of individually tunable components, as well as a variable-frequency rf system.

The ORIC has undergone a number of configuration changes over the years. Throughout most of the 60's and 70's, it employed an internal Penning ion source capable of producing both hydrogen and heavy-ion beams, although for a time it was used to accelerate polarized protons from an external ion source, injecting them axially and using an electrostatic mirror to turn the beam into the first orbit. In the late 70's, the ORIC was reconfigured to be a booster accelerator for beams from the newly constructed tandem accelerator as part of the Holifield Heavy Ion Research Facility (HHIRF). It was during this phase that the last work on magnetic field mapping was done to upgrade the computer codes for machine setup. In the 90's, the ORIC was reconfigured yet again, resurrecting the internal source and constructing a new beamline, to serve as a light-ion driver for the newly established HRIBF. [1]

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REFURBISHMENT DETAILS

The trim coil failure in February 2010 which made it nearly impossible to extract a sufficient amount of beam for ISOL RIB production meant that the machine was going to be down for an extended period for repairs. This afforded the opportunity to undertake in parallel significant upgrades to other components as well. Because the cyclotron is critical to the production of the radioactive ion beams (RIBs) which are at the heart of the HRIBF mission, it has been very difficult, historically, to schedule these types of upgrades. This excerpt from the 1998 HRIBF annual report is illustrative:

> [Isochronizing the field] in ORIC is accomplished via a set of 10 concentric trimming coils mounted to the main magnet pole faces. During FY97, trimming coil T9 failed with an internal water leak. Combined with the 1986 loss of T10 and the 1988 loss of one-third of T8, operation of ORIC became more difficult. However, calculations indicated that most beams could be isochronized even with these coil losses, and that proved to be the case with skilled operator tuning. However, loss of another coil in the almost 40-year-old assemblies could result in a lengthy shutdown period. Thus it was determined that a new set of trimming coils should be fabricated. [2]

This new set of trim coils was fabricated (see Figure 1) that year and placed in storage, where they sat for the next ten years, awaiting the need to be installed.

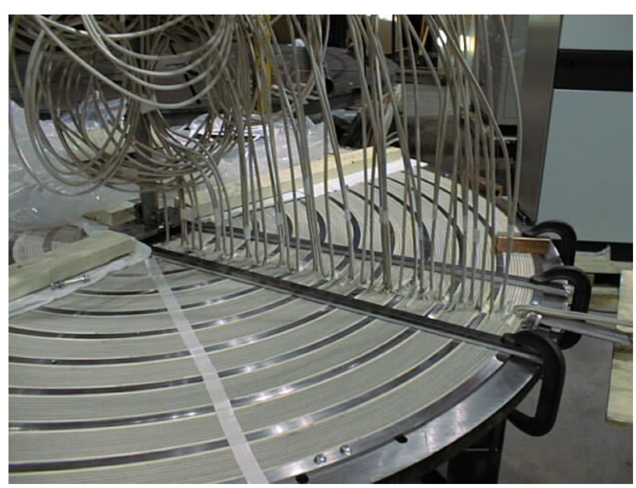

Figure 1: Photograph of single trim coil assembly taken during winding of the 10 concentric coils, prior to vacuum canning.

Magnet System

Although the primary task for the magnet system was the replacement of the trim coil assemblies, a significant amount of other upgrade and maintenance work was undertaken, including:

- replacement of trim coil flow switches and hoses
- re-insulation of the trim coil power bus
- preventive maintenance on all ten trim coil supplies, as well as all harmonic coil supplies
- installation of new power supplies for the #1 harmonic coil
- passivation of the aluminum main magnet coils

RF System

The rf system has had a number of reliability issues in recent years. The extended maintenance period has afforded the facility the opportunity to perform some important upgrades, extensive inspections, preventive maintenance and other repair and cleanup work, including:

- replacement of four ENI-A300 broad band amplifiers by modernized versions having improved components with better heat dissipation
- repair of dee tip voltmeters
- replacement of deteriorated cables
- repair of shorting plane water and air leaks
- repair of the power amplifier tube filament power supply
- complete inspection of rf dee stem and liner

Additionally, it was discovered that the various earlier failures in the trim coils had resulted in warping of the trim coil assemblies. This applied pressure to the main rf resonator ground planes, adding capacitance to the resonator which increased the drive power requirements. Replacing the trim coil assemblies has alleviated this hidden problem, resulting in great improvement in rf system stability.

Extraction System

The three main components of the extraction system: electrostatic deflector, coaxial magnetic channel and lower magnetic channel, were removed from the machine and cleaned, inspected and tested. The deflector septum was replaced and the high-voltage element cleaned. Water flow switches for the magnetic elements were replaced. Linear potentiometers for position feedback of the extraction elements and ion source position were replaced. The lower channel entrance positioning system had its vacuum feedthrough, gearbox and drive shaft rebuilt.

Utilities and Controls

A great many preventive maintenance, upgrade and repair items in this area were undertaken as well, including

- vacuum system— replacement of seals on tank flanges, access plates and utility penetrations where possible; check-out and repair of both 32" diffusion pump heater circuits; installation of new finishing and roughing header baffles and refrigeration units
- water system—installation of pressure relief valves and pressure monitoring wiring; installation of blow-down systems to collect and return the deionized water after draining the various systems; installation of a system for remote continuous radiation monitoring of the water

RESULTS

Trim Coil Measurements

After the new trim coil assemblies were installed, measurements of the magnetic field radial profile were undertaken to verify that the trim coils were both correctly installed and produced fields identical to the old set. Because no modern, usable mapping gear for ORIC exists, it was decided to do a quick series of measurements along a single azimuth using the existing ORIC radial beam probe as a platform for mounting and positioning a Hall probe. This beam probe travels approximately along the 180° azimuth from well beyond the extraction radius in to within about 4.5" of the machine center. Unfortunately, the bracket mounted on the beam probe to hold the Hall probe limited the probe travel such that the full radial range had to be traversed in two steps for each radial scan, repositioning the Hall probe on the bracket in between. In this way, radial scans that crossed the machine center could be accomplished. However, because the 180° azimuth happens to lie along, and in fact twice crosses, a hill edge, where there are large field gradients, the measurements were very sensitive to azimuthal position errors.

Figure 2 shows the results of scans for three of the 10 trim coils. The solid curves are data extracted from the ORIC setup codes based on field mapping done in the 70's, when the ORIC was being converted to a booster for the Holifield tandem accelerator. The measurements are in close enough agreement with the values in the setup code to give confidence that the coils were correctly installed

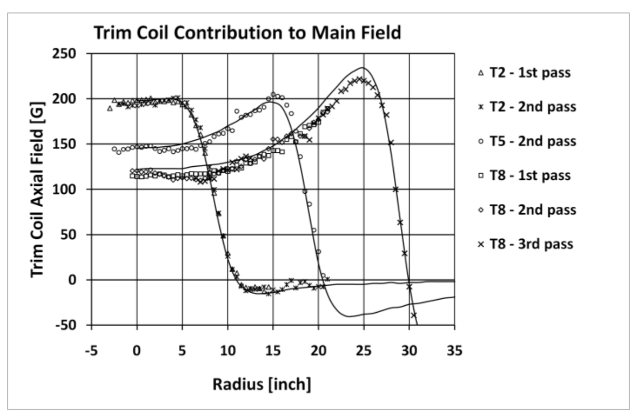

Figure 2: Radial trim coil profiles. Solid curves are profiles as calculated in the setup codes. Symbols are measured values, obtained by subtracting the field profile with the trim coil off from the profile with it on.

and nearly identical to the prior set. During initial ORIC operation following the refurbishment period, very close agreement between the experimental values for the trim coil currents and those predicted by the setup codes was observed.

Setup Codes

A set of orbit codes has been maintained since the 70's and has currently been updated to run on Windows-based PC's. Results from the most recent machine setup calculation are given in Figures 3-5, which illustrate the orbits in the machine, both in terms of particle path and orbit center path. In Figure 3, the beam orbits counterclockwise in a vertical plane, with the 0° azimuth being to the right in the figure. Extraction begins near 90° at the top of the machine as the beam enters the deflector. The entrance to the last extraction element (shown in the figure) is near 180°.

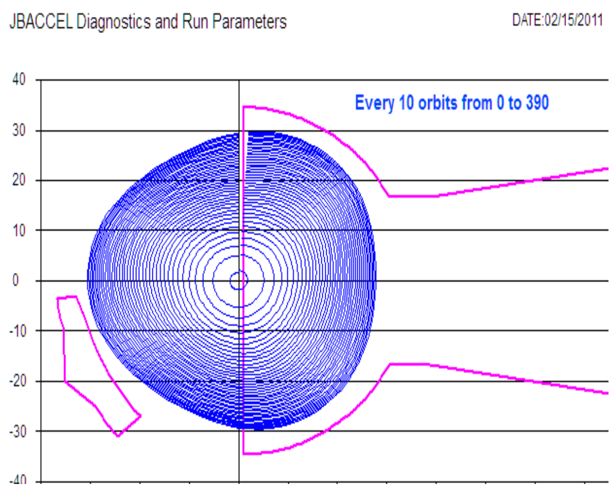

Figure 3: Output from the ORIC setup calculation. Dimensions are in inches. The outline of the dee and the lower magnetic channel are shown, along with the path of every 10th orbit.

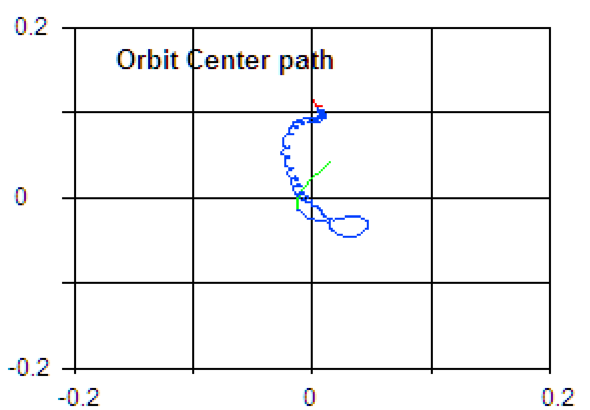

Figure 4: An x-y plot of the motion of the center of the orbit in the median plane. The maximum excursion of just over 0.1" occurs as the beam enters the deflector.

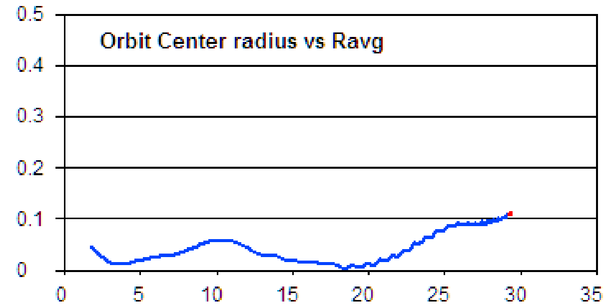

Figure 5: A plot of the radial position of the center of the orbit as a function of beam average radius, showing that the center of the orbit moves the beam toward the deflector as the beam approaches extraction radius.

Operational Experience

In the two months of operation since restart in January, the cyclotron has been in almost continuous operation, providing beams for approximately 1000 hours of RIB operation without a single significant failure. Startup and tuning of the machine have been relatively straightforward, with setup code predictions providing good starting points for the tune. Restoring the full use of T8 for the first time since 1988 and adding a small field contribution from T9 have led to extraction efficiencies of 30–40% while producing the highest historically recorded beam intensities of 10–15 μA at the ISOL target. It will be interesting in the future to attempt to extract at greater radius employing the newly-restored T9 and T10 functionality.

CONCLUSIONS

Following a trim coil failure that rendered the ORIC inoperable, a half-year period of refurbishment and repair was undertaken, with significant work being performed on every major ORIC system. The cyclotron has now been functioning extremely well, providing approximately 1000 hours of beam for RIB production in the first two months since restart. The repairs and upgrades to the rf system, magnet system, extraction system and utilities and controls have collectively led to improved extraction efficiency at high beam intensities and subsequently the most stable and consistent performance from the ORIC in decades.

REFERENCES

[1] B.A. Tatum, D.T. Dowling, J.R. Beene, in Proceedings of the 16th International Conference on Cyclotrons and their Applications 2001, East Lansing, MI, AIP Conference Proceedings 600, 148 (2001).

[2] ORNL Physics Division Annual Report (1998).