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LBNL-40154
UC-413



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February 1997
Presented at the
*13th International Workshop
on Electron Cyclotron
Resonance Ion Sources,*
College Station, TX,
February 26–28, 1997,
and to be published in
the Proceedings



SW9727

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Presented at the Thirteenth International Workshop on
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This work was supported in part by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Division of High Energy Physics, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Design of the 3rd Generation ECR Ion Source

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Abstract

Development of the 3rd Generation ECR ion source has progressed from a concept described in the last ECR Ion Source Workshop to the fabrication of a full scale prototype superconducting magnet structure. The prototype consists of three solenoid coils and six race track coils with iron poles forming the sextupole. The design calls for mirror fields of 4 T at injection and 3 T at extraction and for a radial field strength at the wall of 2.4 T. The prototype magnet will be tested this spring in an existing vertical cryostat to determine its operating characteristics including maximum operating values, training characteristics and to study the interaction between the solenoid and sextupole coils.

Design of the ECR plasma chamber includes aluminum walls to provide an enhanced source of cold electrons, up to three separate microwave feeds to allow simultaneous heating of the plasma electrons at 10, 14 and 18 GHz or at 6, 10 and 14 GHz. Water cooling of the plasma chamber walls and the injection and extraction plates is planned so that up to 10 kW of microwave power can be used without excessive heating of the chamber components. Experience with the AECR-U at LBNL shows that increasing the magnetic fields and using two frequency heating allows operation at lower neutral pressures and higher microwave power density. Both of these conditions are needed to produce very high charge states from elements with masses greater than xenon and the resulting higher energy, more intense heavy beams from the 88-Inch Cyclotron would provide new research opportunities.

Introduction

The 3rd Generation ECR source¹ at LBNL is designed to boost the performance of the 88-Inch Cyclotron by providing more intense high charge state heavy-ion beams and to continue working at the cutting edge of ECR (Electron Cyclotron Resonance) source technology. Recent results with two-frequency heating, high mirror ratios and enhanced supplies of cold electrons indicate that significant advances in ECR technology are possible.²⁻⁶ To incorporate these ideas into a new 3rd Generation ECR source presents significant technical challenges, but improving ion source performance continues to be a cost effective method to better heavy-ion accelerator performance. ECR ion sources play a critical role in nuclear physics by providing high charge state ions for cyclotrons, linacs, and synchrotrons. For example, the relativistic heavy-ion program at CERN relies on an ECR ion source to produce high charge state lead beams. The next generation of ECR sources with increased high charge state intensities and improved pulsing capabilities might be utilized to improve the luminosity of relativistic heavy ion colliders such as RHIC at Brookhaven National Lab.

At LBNL the 88-Inch Cyclotron can accelerate elements up to mass 160 with sufficient energy and intensity for nuclear structure experiments such as those now utilizing Gammasphere.⁷ With the 3rd Generation ECR ion source to increase the usable mass range up to uranium, new scientific opportunities can be provided to the nuclear science research programs. For example, using very heavy ion beams to produce compound nuclei far from stability and study them with state of the art gamma-ray detectors such as Gammasphere or proposed detectors such as the Gamma Ray Energy Tracking Array (GRETA). Another research area which could benefit from higher intensities is the study of the nuclear and chemical properties of heavy elements using a the Berkeley Gas-filled Separator now under construction. The optimum production of these low cross section reactions

will require high intensity beams at about 7 MeV/nucleon from the cyclotron for elements with masses between 30 and 65.

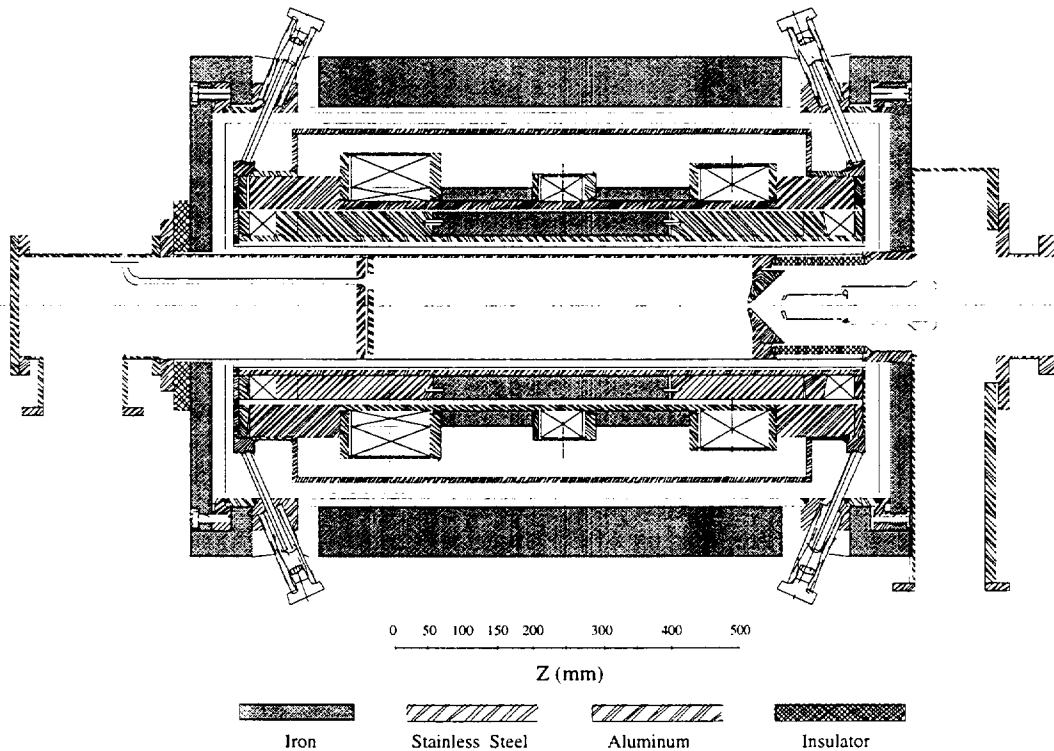


Fig. 1 An elevation view of the 3rd Generation ECR source including the iron yoke, coils and plasma chamber.

Design/Magnet Issues

The design of the 3rd Generation ECR including the magnet assembly and iron yoke is illustrated in Fig 1. In Table 1, the geometry and field strengths of magnet structure are given. These fields are considerably greater than those of earlier superconducting ECR ion sources and early in the initial design study, it became clear that most critical technology centered on the design, fabrication and performance of the superconducting coils. The acquisition of surplus superconducting wires from SSC made it feasible to build a prototype magnet as an R&D project. Therefore it was decided to build and test a prototype magnet. The project is a collaborative effort with Nuclear Science Division and the Supercon group in the Accelerator and Fusion Research Division.

Calculations using the three dimensional codes TOSCA were used to develop the superconducting magnet structure and evaluate designs to support the coils against the inter-coil forces. One of the unique features of this magnet design is the use of iron poles in the superconducting sextupole structure which increase the maximum sextupole field by 15% and decrease the axial field in the center region. A cross section view on one of the sextupole coils with the iron pole tip is shown in Fig. 2. The 80 cm long poles which are a permanent part of each coil, have 35 cm of iron in the center and non-magnetic stainless steel ends as indicated in Fig 1. The magnetic interaction between the sextupole coils and solenoid coils results in very large forces, particularly at the sextupole ends. Forces on the conductor were calculated for design fields with

the sextupole overall current density of 200 A/sq. mm. Figure 3 shows the total radial forces on the coil ends. Forces W-1 and W-2 are the total force in newtons on the coil ends due to the interaction with the solenoid fields and are 37.5 kN and 25.0 kN, respectively. The end of the sextupole was extended 15 cm in axial direction away from the stronger injection mirror coil to reduce the forces. The forces on the ends of the sextupole coils at the extraction end are 16.5 kN inward and 32.4 kN outward.

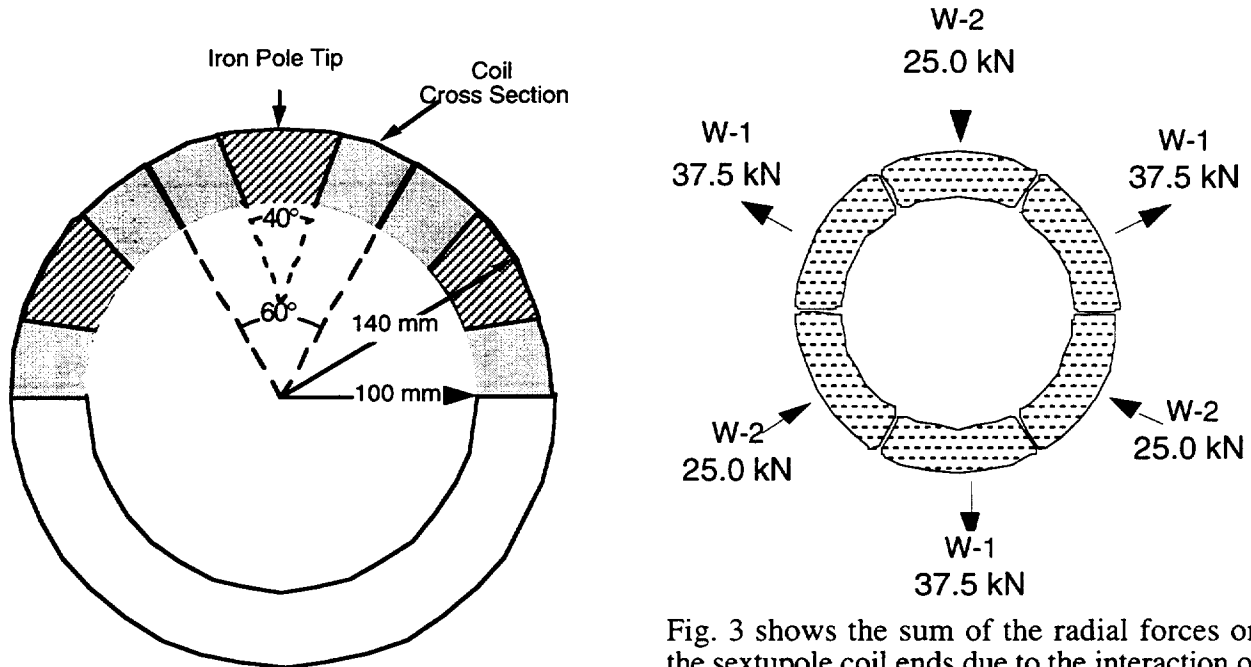


Fig. 2 shows the cross section of the sextupole windings with the iron pole tip.

Fig. 3 shows the sum of the radial forces on the sextupole coil ends due to the interaction of the solenoid fields calculated at the injection end where the axial fields are strongest.

Table 1

Design characteristics of the prototype superconducting magnet structure.

I.D. of plasma chamber	15 cm
Mirror field on axis	4T, 3T
Mirror-mirror spacing	50 cm
Central field (variable)	0 to 1.0T
Typical radial field on I.D. of plasma chamber	2.4 T
Minimum field at I.D. of plasma chamber	2.0 T

All of the superconducting magnets were wound at Wang NMR, Inc. using 48 Km of surplus superconducting wire from the SSC project. The sextupole has 0.8 mm diameter NbTi wire insulated with .05 mm Kapton tape. Each coil was wound and vacuum impregnated using tooling that results in a precise I.D., O.D, and an azimuthal arc of 60 degrees. The ends of pole pieces were shaped to facilitate layer winding of the 1677 turns. Table 2 gives more detail on the parameters of the magnet structure. The six coils were assembled on a 200 mm o.d. bobbin with appropriate ground plane insulation. The assembled and insulated coils were then wrapped with 3

mm of stainless steel wire to provide radial support. Fig. 4 shows the six separate sextupole coils after winding and potting, but before assembly on a cylindrical form which fits into the bore of the mirror coil assembly. Fig. 5 shows the completed mirror coil assembly with three mirror coils wound on a common coil form and vacuum impregnated. The coil assembly was completed last fall and will be installed in an existing 20 inch id. helium dewar, together with quench protection components, magnet current leads, temperature sensors, and voltage sensing leads. It is scheduled to be tested in this spring in a vertical test cryostat.

Table 2
Summary of coil parameters

	Coil #1 inner	Coil #1 outer	Coil #2	Coil #3	Sextupole
No. Turns:	3696	9396	9870	4200	1677
Max. Current (A):	90	90	82.5	60	166
J (A/sq. mm)	120	178	164	119	200
Bmax. (T)	7.28	6.11	6.18	3.57	7.38
Energy Stored (kJ)	24	181	143	15	138

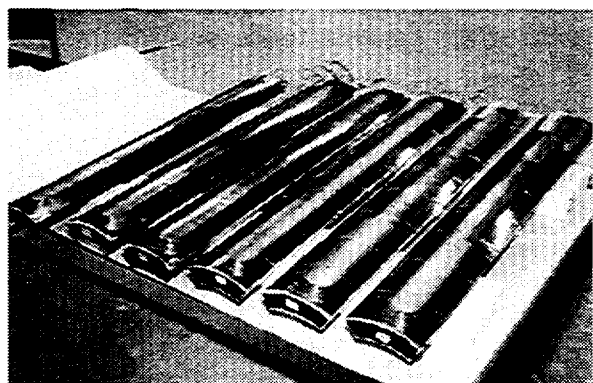


Fig. 4 Sextupole coils after vacuum impregnation prior to assembly.

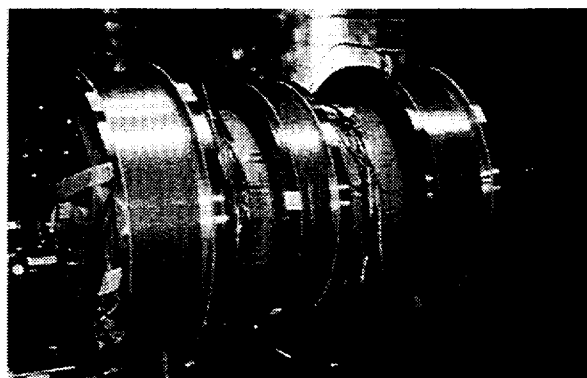


Fig. 5 Completed mirror coils shown prior to assembly with the sextupole structure.

Design of the ECR components

Shown in Figure 1 is an elevation view of the ECR source. The helium supply dewar which is designed to sit vertically above the source is not shown. The plasma chamber walls, injection and extraction plate will be made from aluminum to provide a source of cold electrons for the plasma. This technique has been developed and tested on the LBNL AECR. In addition to the favorable secondary emission properties of the aluminum wall which come from the formation of Al_2O_3 on the surface, the aluminum is very resistant to plasma etching. This reduces contamination in the plasma of ions from the wall and the etching of the extraction electrode. The plate shown on the

injection end of the plasma chamber will be biased to act as a bias probe. Water cooling of all surfaces in contact to the plasma is also planned to minimize the temperature effects caused by plasma and microwave heating at high power. The relatively large plasma chamber diameter, 15 cm, provides sufficient space to bring in 3 or more off-axis microwave feeds as well as ovens for the production of ions from solid feeds. Up to 10 kW of microwave power at frequencies of 6, 10 and 14 GHz or 10, 14 and 18 GHz are being considered. Recent experience with the AECR-U shows that with sufficient magnetic confinement it is possible to operate ECR sources at high power density and low pressures⁶ and since the volume of the 3rd Generation ECR is about a factor 10 larger than the AECR-U it may require 10 kW to reach optimum performance. Pumping will be provided by a turbo pump at the injection end through holes in the injection plate designed to reflect the microwave power.

Acknowledgment

This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, Nuclear Physics Division of the U.S. Department of Energy under Contract DE AC03-76SF00098.

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