DRAGON: A NEW 18 GHz RT ECRIS WITH A LARGE PLASMA CHAMBER*

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Abstract

Building a strong radial magnetic field with a permanent sextupole magnet for an ECRIS is extremely challenging so that the conventional wisdom recommends a small but not optimal plasma chamber that is typically of ID less or equal to 80 mm. A new 18 GHz RT ECRIS, DRAGON, with a large bore permanent sextupole has been designed and is under construction at IMP. Its plasma chamber is of ID 126 mm, the same as that of the superconducting ion source SECRAL, with maximum radial field strength reaching 1.5 T at the plasma chamber wall. The overall magnetic strengths of DRAGON, with maximum axial fields of 2.7 T at the injection and 1.3 T at the extraction, are very similar to those of SECRAL operating at 18 GHz and hopefully its performance. The source solenoid magnets are cooled by medium evaporation at about 50 °C. In addition, the source is thickly insulated for beam extraction at 50 kV and higher voltage up to 100 kV can be explored. This article will present the design details and discussions of this new ion source.

INTRODUCTION

In recent years ECRIS has made tremendous progress with the continuing increase of magnetic field and higher operating frequency in which the fully superconducting (SC) ECRIS takes the leading roll, while the great contribution from the Hybrid ECRIS remains to be realized. A room temperature (RT) ECRIS has the advantages of easy operation and lower cost in comparison to a SC ECRIS but with lower performance. Because of the filed strength and ac power consumption restraints, there are essentially no new improvements on the RT ECRIS since the great success of the GTS [1]. However, there are still possible rooms to further enhance the RT ECRIS' performance for cost effective applications that do not require super performance.

An RT ECRIS consists of a set of water cooled resistive solenoids and a permanent sextupole magnet. The resistive solenoids are typically made of hollow-conductor cooled by de-ionized pressurized-water. As the field strengths keep increasing for better source performance, building a strong radial magnetic field with a permanent sextupole magnet is extremely challenging. So far all the permanent sextupoles are built with a small plasma chamber of ID less or equal to 80 mm to reach a strong radial field of ~1.2 to 2 T without/with iron tips [2]. These small plasma chambers are not optimal as evidenced by the larger chambers of the SC ECRISs at about the same field profiles. An embodiment is the IMP's SC ECRIS, SECRAL, which has demonstrated great performance [3] while operating at 18 GHz with axial field maxima of 2.5 T on the injection and 1.3 T at the extraction regions and a radial field of 1.4 T at the plasma chamber wall of ID 126 mm. If an RT ECRIS can duplicate these magnetic fields with the same large plasma chamber and can produce about the same performance, it would definitely be a good improvement on RT ECRIS that comes with much lower cost and easier source operation.

In this article, we will present and discuss the design features of DRAGON, the new 18 GHz RT ECRIS being constructed at IMP, Lanzhou, China.

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Figure 1 shows the overall features of DRAGON. Figure 2 shows the axial field profile that reaches 2.7 T at the injection with an iron plug field booster and 1.3 T at the extraction. Figure 3 shows the calculated radial field at the plasma chamber of ID of 126 mm reaches 1.4 T and 1.5 T if six small iron tips are embedded in the plasma chamber cooling channels. Shown in Figure 4 is a cross-section view of the sextupole magnet with a simple easy-axis rotation. DRAGON's plasma chamber volume is about 6 litters, about 15% larger than the SECRAL for a slightly larger ECR volume. The maximum source magnet power consumption is about 400 kW. This new RT ECRIS has a few new features in comparison to the existing RT ECRISs:

Large Bore Sextupole

Most of the high-field RT ECRISs use a Halbach-sextupole [4] of small bore that is typically made of M equal-size sections with the easy-axis rotating 8π/M from section to the next. Such an easy-axis rotation poses a risk of regional de-magnetization when the field approaching certain strength [5]. In addition the fabrication of such a Halbach-sextupole requires very complex and delicate magnet-block cutting and assembling.

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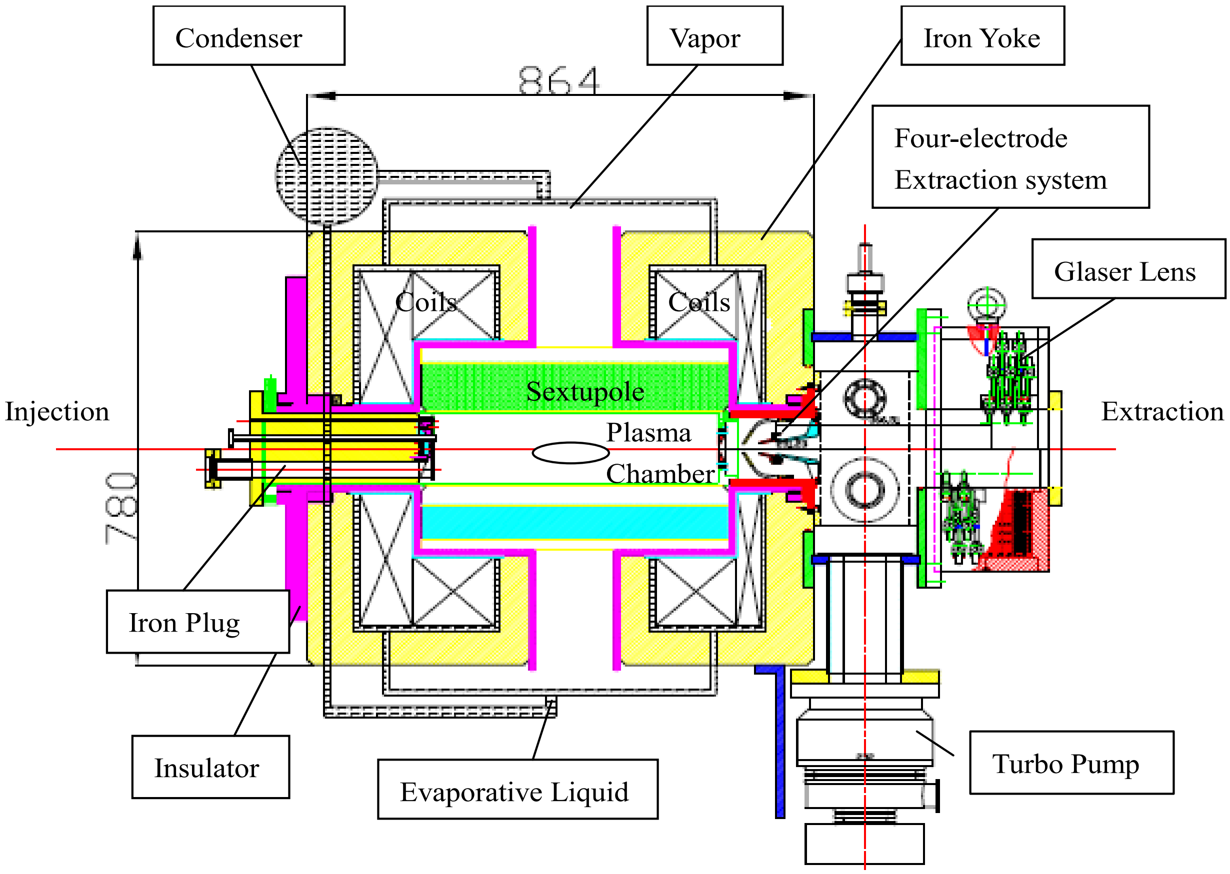

Figure 1: An elevation schematic view of DRAGON. No mechanical pumping at the injection side for simplicity but it may be added in the future. The evaporative cooling condenser and its related pipes are not in scale.

Though the Halbach-sextupole yields the highest field strength, a simplified large-bore non-Halbach-sextupole with about 2% lower field strength and easier fabrication, is being built for DRAGON. This large bore sextupole consists of six sectors and each sector is made of many simply-shaped magnet blocks with simple easy-axis rotation to essentially eliminate the regional de-magnetizations from the adjacent permanent magnet blocks. The DRAGON sextupole bore is of ID 134.5 mm that is large enough to support a stainless steel water-cooled plasma chamber of ID 126 mm, the same size as in SECRAL. This sextupole are made of N50M permanent magnets with an OD of 320 mm and a length of 526 mm.

Evaporative Medium Cooled Solenoids

A new cooling method, evaporative medium cooling at atmosphere pressure and at about 50 °C, may safely and cost effectively increase the coil excitation current density is explored in DRAGON. Typically the RT magnets are cooled with de-ionized pressured-water and it is very costly if the excitation current density reaching above 10 A/mm^2 and magnet power approaching a few hundreds kW. A proprietary evaporative cooling medium [6], developed by the Institute of Electric Engineering, CAS, has a few advantages over the conventional de-ionized pressured-water cooling. The DRAGON magnet coils are wound with solid copper conductors, instead of the normal hollow copper conductors, with adequate cooling channels. Just like the case of LHe cooling the superconducting magnets, the RT magnets are submerged in the cooling medium at atmosphere pressure without any pressure-resistant pipes/tubes and pressure-caused leaks. The high latent-heat-medium evaporates at about 50 °C and efficiently carries away the heat from the magnets. The maximum excitation current density for DRAGON is about 13 A/mm^2 and the magnet power reaches ~ 400 kW for the production of the maximum axial fields.

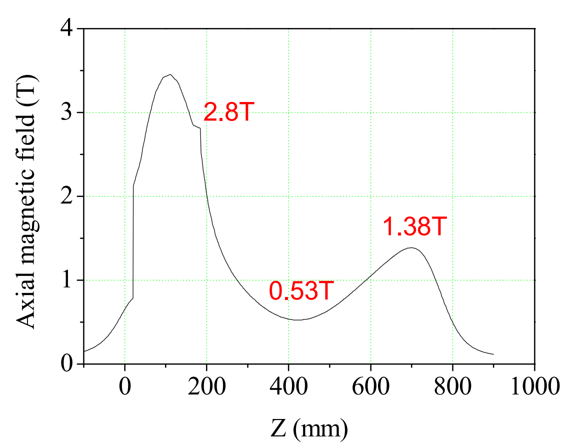

Figure 2: The axial field profile of DRAGON. With an iron plug field booster the maximum axial field reaches 2.7 T at the surface of the bias probe in the injection.

Higher Voltage Beam Extraction

So far the routine maximum ion-beam-extraction from the high-charge-state ECRISs is about 30 kV for the accelerators. However, there are applications where higher beam voltage is required and a practical solution is installing the ECRIS on a high-voltage (HV) platform. However a HV platform comes with many unfavourable consequences, such as higher cost and very inconvenient operations. Higher voltage ion beam extraction from ECRIS could eliminate or reduce the voltage requirement of an HV platform thus to lower the system cost with easier operations. As a study, DRAGON is thickly insulated with 10 mm thick materials so that higher voltage beam extraction can be explored. The goal is to achieve routine 50 kV beam extraction and hopefully to explore beam extraction up to 100 kV with a four-electrode (accel-accel-decel) beam extraction mechanism for better beam transport.

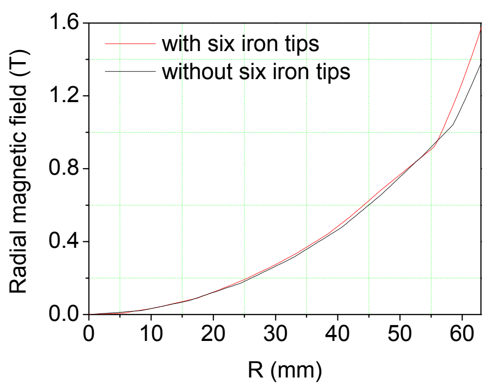

Figure 3: The DRAGON radial field reaches 1.4 and 1.5 T (red line), with six small iron tips embedded in the chamber cooling channels, at the plasma chamber inner surface of ID 126 mm.

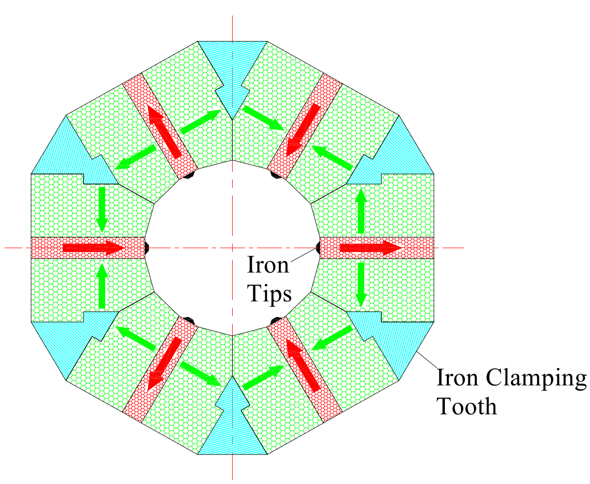

Figure 4: A cross-section view of the DRAGON's sextupole and its easy-axis orientation. There are six 10x2.5 mm^2 small iron tips embedded in the cooling channels to boost the field strength by about 0.1 T and the blue hatched regions are the iron clamping teeth.

DISCUSSIONS

As presented above, the overall parameters of DRAGON are very close to those of SECRAL operating at 18 GHz and the GTS as listed in Table 1. So it is reasonably to expect that DRAGON should be able to perform well at least compatible with the GTS. DRAGON can also operate at 14 GHz alone or double-frequency (14+18 GHz) heating with maximum wave power of about 3.5 kW of any one of the three operation modes. DRAGON is the first high-charge-state RT ECRIS that has been built with a plasma chamber of ID more than 100 mm. Its plasma chamber volume is 6 Litters that is quadrupled in comparison to GTS. This large difference could clearly evidence the effects of a large chamber to the ECRIS performance once DRAGON is being commissioned in about two years.

There is no mechanical pumping, at least in the early development, in the injection side of DRAGON for simplicity. Without the injection mechanical pumping, DRAGON may not be able to produce the highly-charged ion beams as SECRAL does, but hopefully compatible intense multiply-charged heavy ion beams, such as Xe^{27+}, Bi^{32+} and U^{33+}. In addition, the higher voltage beam extraction will help the heavy beam transport and decent beam intensities should be expected.

Table 1: Main Parameters of DRAGON, GTS and SECRAL operating at18 GHz

	DRAGON	GTS	SECRAL
Operating Frequency (GHz)	14. – 18	14 - 18	18
Resonance Length (mm)	14 GHz: 120 18 GHz: 135	14 GHz: 95 18 GHz: 145	105
Plasma Chamber (mm)	L: 480 ϕ: 126	L: 300 ϕ: 80	L: 420 ϕ: 126
Max. Axial Injection field (T)	2.7	2.5	2.5
Max. Chamber Radial field (T)	1.5	1.2	1.4

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