ECR2 Source Upgrade

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Introduction

At the beginning of last May, ECR2 experienced a failure that was determined to be due to inadequate cooling of the hexapole. Subsequently, the hexapole had to be almost totally disassembled, the plasma chamber extensively modified, and finally everything reassembled. The source was finally turned back on after the 2001-2002 reporting period, but its initial performance will be reported here.

Failure Mode

In addition to conditioning the source, efforts were being made to make the 14.5 GHz transmitter more reliable and to be able to transmit more power into the source. The protection circuitry of the transmitter was worked on, and in addition the transmitter was moved closer to the source and the wave-guide water-cooled. The performance of the source began to decrease, however, and the plasma chamber was opened for examination. The aluminum wall of the chamber was found to be melted in a small spot directly on one of the plasma flutes near the midplane of the source. With a Hall probe, it was found that the hexapole field near the spot was lowered from 0.79 Tesla to below the ECR field for 14.5 GHZ (0.52 Tesla). The field of the other bars was found to be nominal. When the hexapole was pulled apart using the assembly fixture it was found that the two magnets next to the melted spot had suffered demagnetization in small areas. The 12 magnets of this bar were separated and the two damaged ones were returned to the manufacturer for remagnetizing. Before reassembling the hexapole, the cause of the failure had to be determined and a solution found. Since the bar and wall were damaged on a plasma flute near the midplane of the source where the axial field is low, heating by plasma electrons and insufficient cooling were assumed to be responsible. In this scenario a slightly lower magnetic field in one bar near the midplane allowed excess heating in this spot due to slightly lower electron confinement. With enough microwave power and with insufficient cooling of the bars, this small field asymmetry eventually caused a runaway effect where the temperature of a volume of the permanent-magnet material rose above its Curie point. The same energy that caused demagnetization also caused the wall melting.

The cooling of the wall had been accomplished with water-flow along the sides of each magnet bar, as in ECR1. Assuming that most of the microwave power was converted to heat along the plasma flutes, it was calculated that the temperature difference between the aluminum wall near the flute and the water would put the permanent magnets at risk above about a kilowatt. The aluminum is thicker for ECR 1, so it can handle somewhat more power. It was decided that a liner that directed water flow directly along the face of the hexapole bars was a reasonable solution.

Redesign

In order to accomplish this without sacrificing too much of the pole strength at the walls, the original chamber was machined to a larger ID, so that it could still function as the hexapole holder. Then a liner with an ID of 13.0 cm. was fabricated with seven water channels over the inner face of each hexapole bar. Both the liner and the hexapole holder were machined to accept three stainless steel inserts that function as radial ports (Fig. 1).

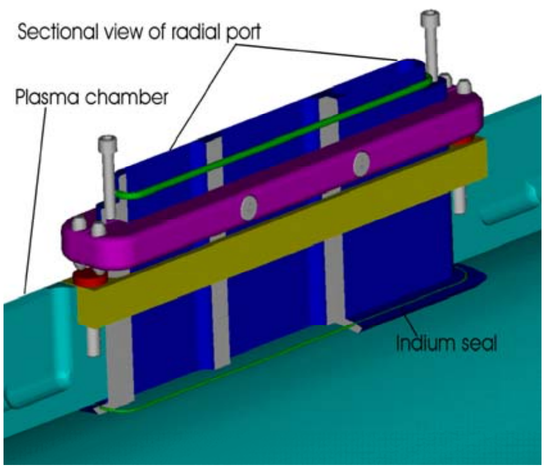

Figure 1: Stainless steel radial port plasma chamber insert. One of three, spaced 120° apart.

Indium o-rings between the flanges of the inserts and the inside of the liner form vacuum-water seals while viton o-rings fitting around the inserts form water-air seals. The seals are compressed via screws accessible from the outside of the assembly.

Testing and Assembly

The liner was inserted into the hexapole holder so that various tests could be performed. First, the indium seals were tested as to the proper thickness of indium wire and proper compression. Water flow through the liner was tested and demonstrated that a good flow could be maintained with only a small amount of water pressure. However, with too much pressure the liner was observed to flex. This occurred at 30 psi with no vacuum, so it was determined that the water pressure on the liner should be limited to 15 psi with vacuum. A gravity-feed water system using the low-conductivity water in the laboratory was designed to accomplish this.

The repaired hexapole bar had been previously assembled. Now the liner was inserted into the holder without radial inserts and the bars guided into their positions in the holder. Using a hand held Hall probe the pole strength along the inner wall of the chamber was measured to be 7.6 kilogauss and quite uniform. After wrapping this assembly in its stainless steel sheath and Teflon shrink rube, it was inserted into the coils. ECR2 was then moved into its position above the K500, the radial inserts were assembled, the extraction steel was guided into place and vacuum connections were made. Finally, the injection-end assembly with waveguides and biased plate was inserted and the injection-end steel plug mounted after it.

Commissioning and Results

With commissioning several problems have been solved. Earlier, the control circuitry of the 14.5 GHz transmitter had been repaired and adjusted so that its operation was much more stable. (Problems with the klystron have not reoccurred.) With the source under vacuum a leak developed with high current in the axial coils. It was determined to be a water leak into the vacuum through one of the indium seals, and was corrected by further tightening on that seal. The axial field coils must exert a torque on the hexapole bars, causing the chamber to distort. Next, the water-flow interlock required some adjusting to allow the transmitter to stay on for long periods. Finally, with high power copper blocks that had been soldered onto the 14.5 copper GHZ waveguide to act as braces for the microwave vacuum-HV window began to falloff with disastrous results. These were redesigned to bring them closer to the water-cooling and have not been a problem since.

The source began operation in the first week of May 2002 and for one month the vacuum as measured by an ion gauge on the top pumping port of the source has remained in the mid 10^{-7} range. The spectrum shows very little nitrogen, but large amounts of oxygen and hydrogen; so one possibility is that some water remains inside the source. If this is the case, repeated venting to dry nitrogen will probably help.

Because of this high vacuum, only small amounts of gas can be introduced into the source without degrading its performance. However, the performance is already pretty good. For oxygen ECR2 has produced 206 e:A of 6^{+} and 68 e:A of 7^{+} at 10 kV extraction voltage through a 13mm collimator onto a biased faraday cup. This is with 1.3 kW of microwave power. Also at this power level and running argon, the source has produced 77 e:A of 11^{+} and 44 e:A of 12^{+}. For gold, this source produces 4.2 e:A of 31^{+}. Gold was sputtered into the source through a side port, proving that this method of material feed works easily with ECR2.

Future

The performance of the source should improve dramatically as the vacuum improves. As higher microwave power is used, close attention should be paid to the temperature of the returning water-flow from the six water circuits on the hexapole. When the 6.4 GHz transmitter is repaired, two-frequency operation will be attempted again as well as solo 6.4 GHz operation. A gas system and multiple sputtering feeds will be installed in the near future. Also, a high-temperature oven will eventually be designed and fabricated. After the addition of a gas system and more shielding of the high x-ray flux from the source, ECR2 should soon be ready for cyclotron operation.