EFFECTS OF MICROWAVE FREQUENCY FINE TUNING ON THE PERFORMANCE OF JYFL 14 GHz ECRIS*

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Abstract

Measurements have been carried out at the Department of Physics, University of Jyväskylä (JYFL) to study the effects of microwave frequency fine tuning on the performance of JYFL 14 GHz electron cyclotron resonance ion source. The frequency was varied within an 85 MHz band around the normal operation frequency of 14.085 GHz. The radial bremsstrahlung emission was measured for plasma diagnostics purposes and mass separated ion beam currents extracted from the ion source were recorded at the same time. Also, beam quality studies were conducted by measuring the ion beam emittance and shape with and without enhanced space charge compensation achieved by increased neutral gas pressure in the beam line. The obtained results are presented and possible origins of observed phenomena in measured quantities are discussed.

INTRODUCTION

The microwave frequency fine tuning has become an interesting subject concerning the enhancement of ECR ion source capabilities. In this method the ECRIS microwave frequency is altered in a narrow frequency band around the normal operation point to achieve improved source performance. Studies done by L. Celona et al. have given promising results showing strong frequency dependent variations in ion beam currents and beam shape [1]. Encouraged by these results, similar experiments were conducted with JYFL 14 GHz ECRIS including studies of mass separated ion beam currents and emittance. The results were promising but the origin of many phenomena were still left unanswered [2]. It was clear that additional measurements were needed. This paper presents the results of the latest frequency tuning measurements conducted at JYFL.

ELECTROMAGNETIC MODE STRUCTURE

When microwaves are fed into an ECRIS plasma chamber in vacuum, certain kinds of electromagnetic field structures can be excited inside. With frequencies around 14 GHz and typical plasma chamber dimensions these electromagnetic modes are closely packed and have separation of the order of some MHz [3]. Thus only a slight change in the feeding microwave frequency can induce a notable difference in the electric field structure on the ECR surface.

It is not clear how the situation changes when the chamber is filled with anisotropic inhomogeneous plasma. If the mode structure behavior remains, it should affect the electron heating efficiency, charge state distribution, ion dynamics and confinement time in the plasma, having an obvious influence on the characteristics of the ion beam [4].

EXPERIMENTAL PROCEDURE AND RESULTS

All measurements were conducted with JYFL 14 GHz ECR ion source [5]. The local 14.085 GHz oscillator was replaced with Rohde & Schwartz signal generator set to sweep a frequency range of 14.050 - 14.135 GHz in 100 seconds. The klystron was set to maintain constant power output during the sweeps. A signal given by the signal generator at the beginning of each sweep was used for triggering and time stamping of all time resolved data acquisition. Bremsstrahlung was measured radially from the plasma chamber with a germanium detector. The ECRIS and beam parameters were collectively measured with a computerized data acquisition system. The quality studies of m/q separated beams were conducted by measuring the beam emittance with an Allison type emittance scanner and the beam shape with a KBr scintillation screen at discrete frequencies. In these measurements the enhancement of space charge compensation (ESCC) was achieved by feeding argon into the beam line section between the ECRIS and the analyzing magnet resulting to beam line pressure of $4 \cdot 10^{-6}$ mbar. More details of similar gas feeding method can be found from reference [6]. All measurements were performed using argon beams with charge states between 5+ and 16+, except the transmission studies, where oxygen and krypton beams were also used. The ion source tuning was performed with 14.085 GHz frequency.

Beam current, bremsstrahlung and reflected power studies

The ion beam currents exhibited a clear oscillating behavior with varying microwave frequency. The fluctuations

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increased with increasing charge state of the ion beam. With low charge states the current remained practically constant, but with the highest up to 50% variations were seen during the frequency sweep compared to the normal operation frequency. Similar oscillations were seen also in the bremsstrahlung emission and the behavior was matched with the oscillations seen in the reflected microwave power (see Fig. 1). This suggests that the current variations are caused mainly by fluctuations in the transmitted power.

As the behavior of reflected power has had an important role in the earlier discussions concerning the existence of mode structure inside the plasma chamber [2], and is clearly reflected in the behavior of beam current and bremsstrahlung emission, a special effort was given to further study its origin. When the sweep time and the frequency range were varied, the location of the maxima and the minima of the oscillations remained unchanged, ruling out the possibility of outside interference with fixed frequency. Varying the ion source parameters, such as neutral gas pressure, magnetic field and microwave power, had no distinctive effect to the location of the minima and maxima either. When the length of the plain wave guide between klystron and ion source (before high voltage and vacuum breaks) was varied, the number of maxima in a fixed frequency range changed. The number of maxima increased with increasing wave guide length and vice versa. It was also observed that with high powers the location of maxima drifted slightly towards lower frequencies with time. This was caused by increasing wave guide length due to heat expansion. To further study the connection between the oscillations of reflected power and plasma conditions inside the ion source, the plasma chamber was disconnected from the wave guide and replaced with a low-VSWR (voltage standing wave ratio) load element. The measurements were repeated with the load element at different locations along the wave guide with and without the high voltage break. It was observed that the high voltage break increases the measured reflected power significantly (by a factor of about 4) but does not change the oscillating behavior. The oscillations remained, as can be seen in Fig. 2 and the number of maxima depended clearly on the wave guide length. This indicates that the oscillatory fine structure of the reflected power is not connected to the mode structure inside the plasma chamber.

The oscillating behavior seems to be connected to a phase dependent phenomenon. When the phase of the electromagnetic wave is calculated at the end of the wave guide, it is observed that the consecutive reflected power maxima correspond to phase shift of $\pi/2$ $(\lambda/4)$. This relation holds very well for all the measured cases.

In the measurements with the plasma chamber there is a clear increase in the reflected power with the highest frequencies, a phenomenon which is not seen with the load element. This effect most probably originates from the plasma. However, comparing the signals with the load element and the plasma chamber shows that possible narrow frequency range (a few MHz) effects coming from the

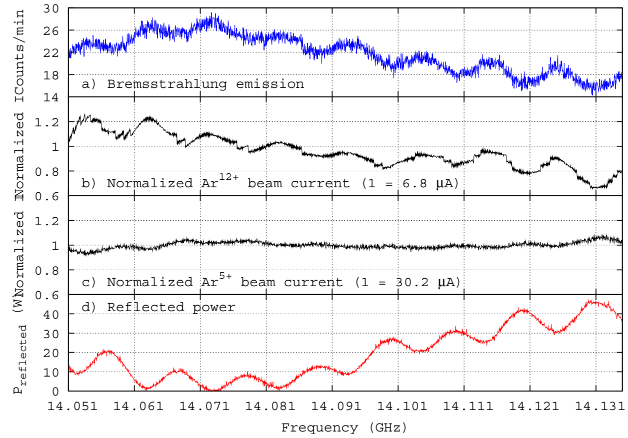

Figure 1: The bremsstrahlung count rate, normalized Ar^{12+} and Ar^{5+} beam currents and the reflected power with varied frequency. Constant forward power of 460 W. Note with the bremsstrahlung count rate that only relative efficiency calibration was used for the detector.

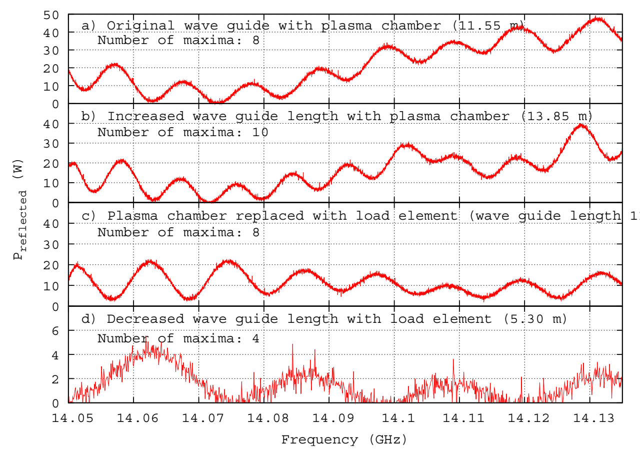

Figure 2: Reflected power with load element or plasma chamber and varied wave guide length. All cases with the same ECRIS settings and 500 W of forward power.

chamber must be very weak compared to the effects caused by the wave guide system. This makes it very difficult to say anything about the mode structure inside the plasma chamber using the reflected power signal in the case of JYFL 14 GHz ECRIS.

Beam quality and transmission studies

Changes of up to tens of percent were seen in the beam emittance with varying frequency compared to the normal operation point (see Fig. 3). These variations correlated well with changes in the structure of the beam profile and beam current instabilities. The behavior was very sensitive to the ion source settings and variation of any parameters could change it radically.

With ESCC the beam emittance was lowered signifi-

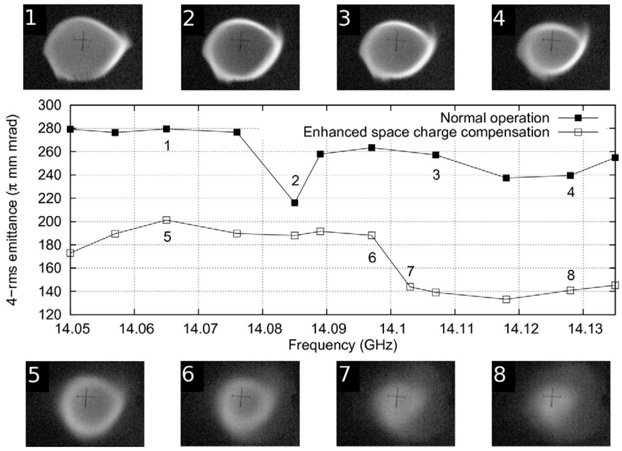

Figure 3: 4-rms emittance of Ar^{9+} with and without ESCC and beam profiles at selected frequencies.

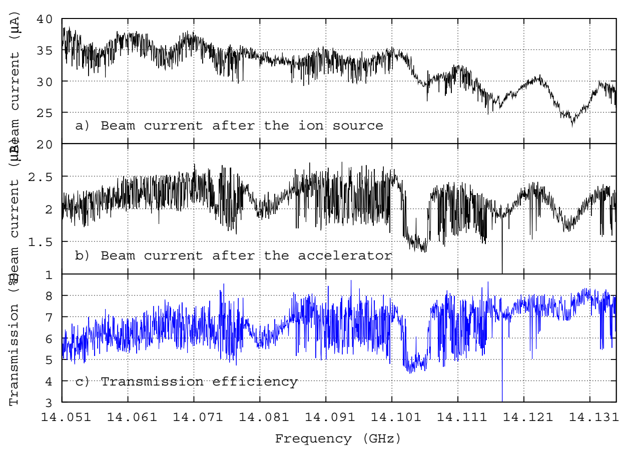

Figure 4: Ar^{12+} beam currents and transmission with varying frequency. Constant forward power of 667 W.

cantly. At low frequencies the general behavior of the emittance remained mostly unchanged. However, at around 14.1 GHz the emittance exhibited a steplike change accompanied by a change in the beam structure. The low and medium charge states, which normally have a hollow beam shape, became uniform and the emittance was lowered significantly. At the same time the profiles of high charge states expanded, became less dense and the beam emittance increased.

Transmission through the K-130 cyclotron was studied using $^{16}O^{6+}$, $^{40}Ar^{12+}$ and $^{82}Kr^{22+}$ beams. The beam currents were optimized through the injection line and the cyclotron. After this, the frequency was varied and the beam currents after the ion source and after the cyclotron were recorded. The transmission was also measured for a set of discrete frequencies, each optimized separately through the system. The frequencies were chosen based on changes in the beam emittance and profile. The results are presented in Table 1. The transmission of O^{6+} is considerably lower than what is normally achieved due to tuning problems with

Table 1: Transmission efficiency T and maximum ion beam current $I_{\max}$ after the cyclotron for frequency sweeps and separately tuned discrete frequencies.

	Frequency sweep		Discrete frequencies	
Beam	T (%)	$I_{\max}$ (µA)	T (%)	$I_{\max}$ (µA)
$^{16}O^{6+}$	1.0 - 1.4	2.9	1.2 - 1.4	2.7
$^{40}Ar^{12+}$	4.5 - 8.0	2.6	3.8 - 7.4	2.2
$^{82}Kr^{22+}$	2.5 - 9.0	1.3	6.1 - 7.5	1.1

the accelerator. The transmission for Ar^{12+} sweep is presented in Fig. 4.

DISCUSSION

The studies presented in this article show that microwave frequency fine tuning does produce clear variations to many of the measurable quantities connected to the performance of the JYFL 14 GHz ECRIS. However, the varying input power makes it difficult to separate which effects are caused by the frequency variations and not the power fluctuations. This is the case especially with the beam currents. The beam emittance and profile exhibited clear variations which were further strenghtened with the ESCC. These effects on the beam quality were clearly reflected as significant variations in the transmission efficiency.

Compared to the behavior reported in [1], the reflected power and consequently the reflection coefficient behavior is vastly different with JYFL 14 GHz ECRIS. The results presented in [1] were obtained from measurements with a Caprice type ECR ion source. Compared to JYFL 14 GHz ECRIS, which is of the A-ECR type, the microwave coupling scheme is radically different. The Caprice source has a multistage coupling from wave guide to coaxial microwave feeding into the plasma chamber, as JYFL 14 GHz ECRIS uses rectangular wave guide all the way into the plasma chamber. As presented in this paper, the wave guide system at JYFL produces strong variations into the reflected power, which obscures any other possible narrow frequency range effects that could be seen in the signal. However, there seems to be some behavior present at broader frequency band. Whether this has something to do with the possible mode structure inside the plasma chamber, it is difficult to say without further studies.

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