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OPERATION OF THE GTS-LHC ECR ION SOURCE IN AFTERGLOW WITH VARYING KLYSTRON FREQUENCY

D. Küchler†, M. O'Neil
CERN, BE Department, CH-1211 Geneva, Switzerland
V. Toivanen
Grand Accélérateur National d'Ions Lourds (GANIL), F-14076 Caen Cedex 05, France

Abstract

The GTS-LHC ECR ion source delivers lead ions for the CERN heavy ion programme at the LHC and the SPS fixed target physics. The source is normally operated with a main microwave frequency of 14.5 GHz in the afterglow mode. As part of the consolidation the microwave generator was replaced with a klystron based generator that allows free variation of the operating frequency in a range of 14.0 – 14.5 GHz.

The aim of this study was to see how the lead charge state Pb^{29+}, which is the main ion species produced for experiments, is influenced by the different frequencies. Variations in performance were observed (beam intensity and beam stability), but no frequencies were found that would provide significant performance improvements compared to normal operation at 14.5 GHz. The results in general suggest that for the GTS-LHC ion source the optimal operating frequency depends on the overall source tuning and the influence of varying the main frequency is comparable to adjusting the other tuning parameters.

INTRODUCTION

The GTS-LHC ECR ion source is based on the original Grenoble Test Source (GTS) and provides since 2005 the CERN heavy ion injector complex with ions [1]. Over the last years the source has delivered lead, argon and xenon ions for the two main clients — the fixed target experiments in the North Area of the Super Proton Synchotron (SPS) and the experiments at the LHC.

The main 14.5 GHz microwave generator of the source was taken over from the predecessor source (ECR4) and was meanwhile more than 20 years old. As the old generator suffered from increasing failure rate and obsolete components it was decided to replace it within the CERN consolidation project.

Recent experiments with a travelling wave tube amplifier (TWTA) showed that for the lead ion of interest (Pb^{29+}) some increase of the beam intensity can be reached [2]. And as the frequency where this happens is covered by the new microwave generator it became of interest to study the ion beam production varying the frequency from the microwave generator and to see if a similar behaviour as with the TWTA can be reproduced. This would help to get a better understanding of the TWTA experimental results and in the positive case provide more beam for the users.

† detlef.kuchler@cern.ch

THE MICROWAVE GENERATOR

The spare generator of the source, which was used in the past for experiments with 18 GHz [3], was delivered by Sairem. To have only one provider for the source microwave generators it was decided to have also the new main generator from Sairem.

The new microwave generator has the following characteristics:

- Klystron based
- frequency range: 14.0 – 14.5 GHz
- number of Klystron channels: 20
- bandwidth of each Klystron channel: 25 MHz
- step size of the synthesizer: 1 kHz
- nominal peak power: 2.2 kW (for a matched load)
- operation mode: cw or pulsed (via external timing)

Table 1: Central Frequencies of the 20 Klystron Channels.

channel number	central frequency/GHz
1	14.0125
2	14.0375
3	14.0625
4	14.0875
5	14.1125
6	14.1375
7	14.1625
8	14.1875
9	14.2125
10	14.2375
11	14.2625
12	14.2875
13	14.3125
14	14.3375
15	14.3625
16	14.3875
17	14.4125
18	14.4375
19	14.4625
20	14.4875

The change of the Klystron channels is motorized and the synthesizer can be programmed via a USB interface from a Windows based computer.

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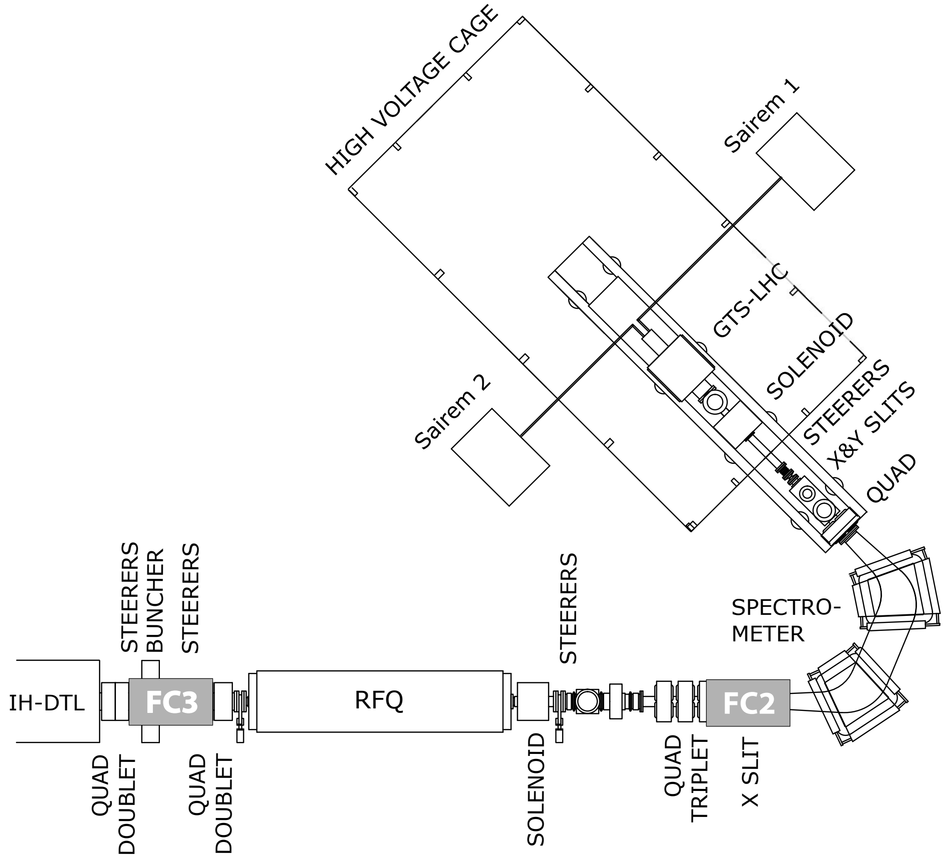

Figure 1: Schematic overview of the low energy part of Linac3. The position of the two Faraday cups (FC2 and FC3) used for the measurements are marked. Sairem 2 is the main microwave generator used for the experiment. Sairem 1 is the spare microwave generator.

The generator communicates via an Ethernet Modbus protocol with an external PLC which is fully integrated in the CERN accelerator controls architecture.

EXPERIMENTS WITH VARIED FREQUENCY

The experiment was done during the start-up preparation of the source. Before the experiment the source was optimized using a frequency of 14.5 GHz. The source was always tuned on Pb^{29+}.

Experiences from the past show that especially for metal ion beams a proper source conditioning may take from several days up to some weeks to reach the full performance (stable and intense beam). Due to the limited time it was not possible to wait for the final optimum conditioning for each frequency step. Data were taken when a temporary stability was reached.

Multiple frequency sweeps were performed with different source settings. The beam intensity was measured in a Faraday cup (FC2) directly after the spectrometer and in a Faraday cup (FC3) after the Radiofrequency Quadrupole (RFQ) (see Fig. 1). The beam emittance could not be measured.

Table 2: Source Settings For Different Frequency Scans.

	a)	b)	c)	d)
microwave power/W	1650	1700	1650	1000
bias disk/V	320	280	300	295
injection sol./A	1270	1270	1270	1270
central sol./A	180	200	150	220
extraction sol./A	1210	1200	1200	1185
gas/a.u.	9.780	9.710	9.740	9.755
extraction voltage/kV	18.89	18.89	18.89	18.89

Before each sweep the source and the Low Energy Beam Transport (LEBT) were optimized. The most relevant ion source parameters for the sweeps are summarized in Table 2 and the resulting ion current behavior as a function of the microwave frequency is presented in Fig. 2. In the sweeps the center frequencies of each channel were used, except for channel 20. For this the center frequency and the highest available frequency (14.5 GHz) were measured. For the cases a) to c) it seems that the starting point was also the

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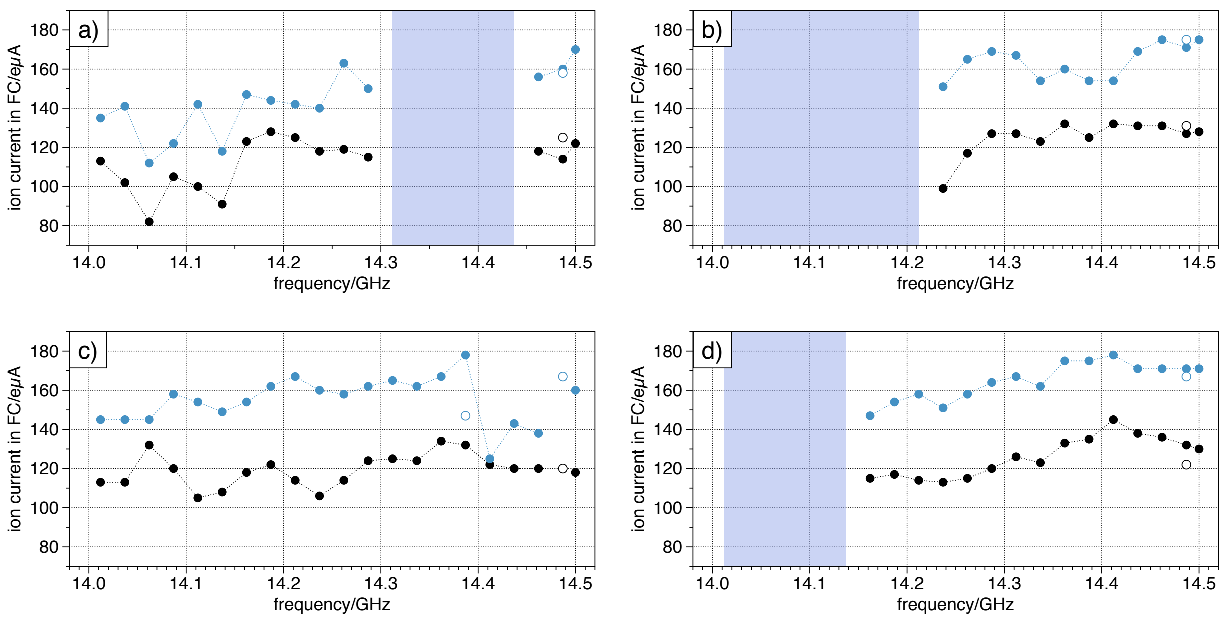

Figure 2: Ion currents in FC2 (blue) and FC3 (black) for different frequency scans. The main source parameters for the different scans can be found in Table 2. Grayed out areas indicate frequency regions with very unstable beam. The open circles indicate repeat measurements after the frequency scan. These measurements can give an impression of the reproducibility.

point with the highest beam intensity in FC2 (sweeps a) and b) were started at channel 20 (14.5 GHz) and sweep c) was started at channel 15 (14.3625 GHz)). For case d) the sweep started at channel 20 (14.5 GHz) and the highest beam current was recorded at channel 17 (14.4125 GHz). All scans went from high to low frequency.

As a general trend one can observe that on average the beam currents seem to increase towards higher frequencies. This could be due to the global frequency scaling effect. On top of the global current increase a fine structure was observed with frequency. But a reproducible, stable pattern independent of the other source parameters could not be identified. Based on the present results one cannot draw a clear conclusion if the fine structure is caused by out-gassing or by improved/degraded ionization conditions due to the varied microwave conditions, or microwave coupling issues.

For some combinations of source setting and frequency it was impossible to stabilize the extracted beam (grayed out regions in Fig. 2). The position and width of these regions vary in dependence of the source settings. No improvement of these beams could be observed over time compared to more out-gassing related instabilities.

Assuming an intensity independent transmission through the RFQ (at least in a certain intensity range) one would expect a constant ratio of the ion beam intensity between FC2 and FC3. But as one can see in Fig. 3 this is not the case. This seems to indicate that the beam emitted from the source occupies a different volume (size and/or shape) in phase space for the different microwave frequencies.[1] It is known that the transmission through the LEBT and the RFQ is sensitive concerning changes of the beam energy.

[1] As mentioned before it was not possible to measure the emittance directly.

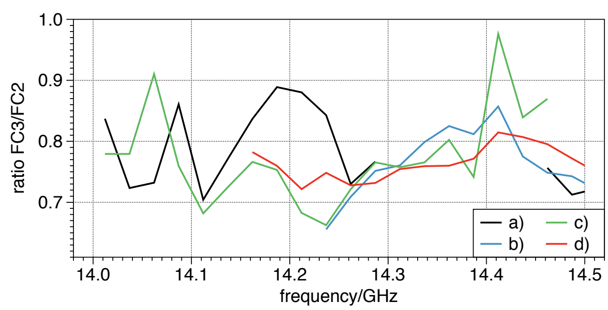

Figure 3: Ratio of the ion beam intensities between FC2 and FC3 given in Fig. 2.

Although the source was well conditioned at 14.5 GHz before the experiment started a significant out-gassing was noticed while changing to some of the lower frequencies. Running the source for a while at these specific frequencies lead to a recovery of the vacuum conditions. The reason for this behaviour could be that with the lower frequencies parts of the plasma chamber gets bombarded with particles which do not see any or only a limited number of particle interactions at the reference frequency of 14.5 GHz.

In general one can say that the tuning of the source influences clearly the response to the different frequencies.

Comparing the charge state distributions of some special cases (see Fig. 4) one can clearly see the enhancement of the beam intensity for lower charge states. The distributions seem to be broadened towards the lower charge states. This

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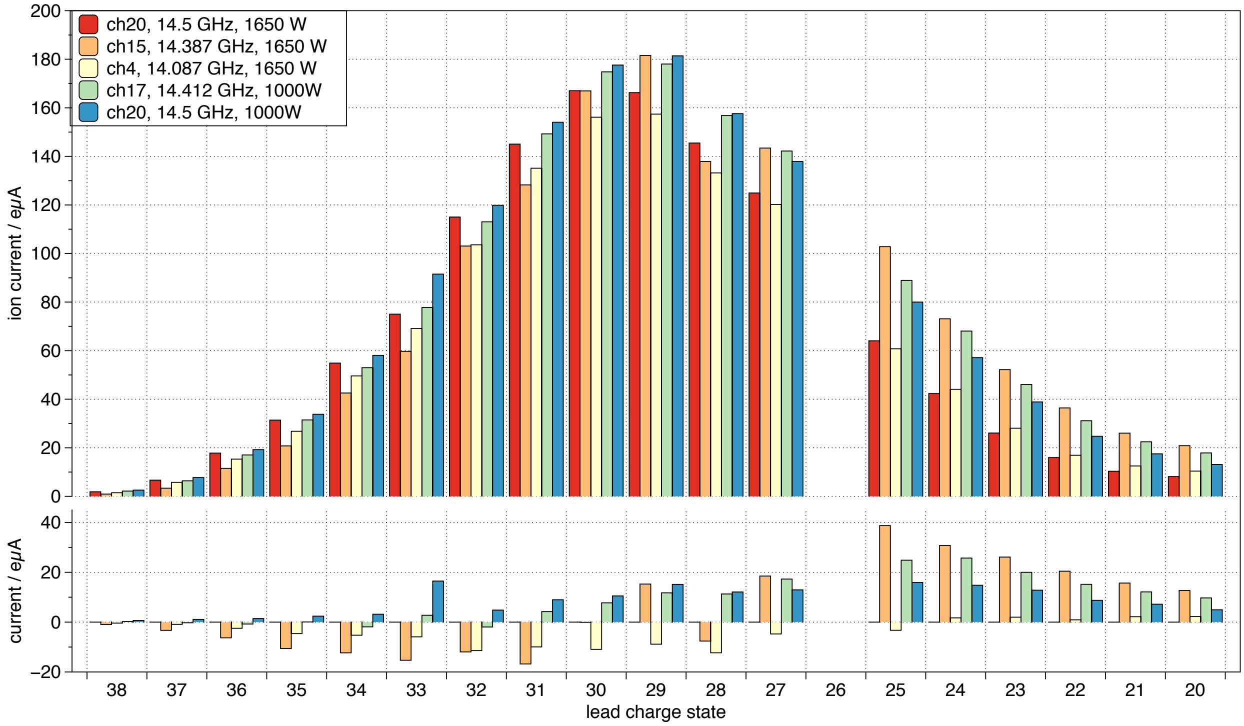

Figure 4: Charge state distributions for different source settings. The lower part shows the difference of the ion current in respect to the nominal setting (ch20). For the relation between channel number and frequency see Table 1.

is also reflected in a tendency of higher total drain current from the source (see Fig. 5).

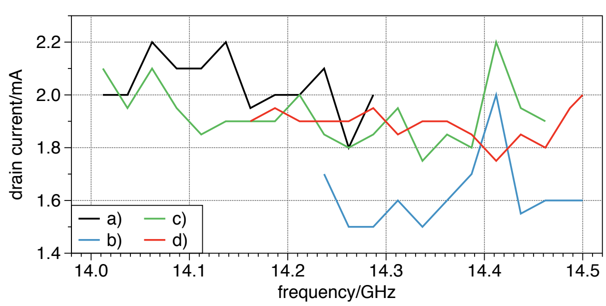

Figure 5: Drain current of the source high voltage power supply for the scans shown in Fig. 2.

Looking at Pb^{29+} one can see some gain for medium frequencies (channel 15 and 17) and also for the reference frequency at lower power. Especially the last case points towards the issue of insufficient conditioning for all the different settings as normally at this low power the beam intensity is also much lower compared to a nominal microwave power of around 1700 W.

If one assumes that the varying frequency alters the exact location of where the plasma particle flux interacts with the chamber wall this shift in performance could be caused by the enhanced recirculation of the lead from the plasma chamber walls and in this case one would expect this to be only a temporary phenomenon.

DISCUSSION AND CONCLUSION

In previous measurements using a TWTA [2] some enhancement of beam intensity around a frequency of 14.2 GHz was observed. A similar behaviour could not be reproduced with the Klystron driven generator. This suggests that the observed effects with the TWTA were caused by the combined influence of the klystron and the TWTA, which were operated in double frequency mode, and the same conditions can not be achieved with only a single microwave source.

Even more the measurements seem to show that there is no clear preferred frequency. The source behaviour found suggests that the frequency becomes a tuning parameter as all the other settings of the source.

This suggests that the observed fine structure in Fig. 2 is not defined by e.g. the plasma chamber geometry or other fixed properties of the source, but is rather the result of dynamic processes taking place in the plasma volume. This result is in line with observations presented in Ref. [4] showing that the frequency structure defined by the chamber disappears in the presence of plasma.

In general it must be stated that the oven settings were not tuned for the different frequencies during the experiments and it was observed that the source condition was clearly altered after performing the frequency sweeps. This makes it difficult to draw strong final conclusions based on these results. Longer runs in the future on selected frequencies will clarify these issues and allow a better assessment of the early findings presented here.

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