SUB-HARMONIC BUNCHING WITH THE AGOR CYCLOTRON

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Abstract

A quasi-single gap buncher with saw-tooth voltage has been designed and is currently being built at the KVI. It operates at a sub-harmonic of the RF frequency and has a duty cycle of 80 % at 15 MHz. We report on the design of the new buncher, and on results of tests with our sinusoidal buncher to demonstrate the feasibility of the proposed scheme.

1 OBJECTIVES

The RF system of the AGOR cyclotron operates in the frequency range 24 to 62 MHz. A single gap saw-tooth buncher, operating at frequencies up to 15 MHz, to inject a beam at a sub-harmonic of that frequency is under development [1].

The system reduces the burst frequency by a factor h (where h is the harmonic mode) also when operating with multi-turn extraction, thus giving a larger range for time-of-flight measurements.

Furthermore, beam phase measurements at this lower frequency do not suffer from RF pickup from the RF resonators as is the case at the RF frequency itself and the 2nd harmonic, which has sofar been used. Therefore we expect the signal-to-noise ratio of these measurements to be strongly enhanced, provided a sufficiently selective detection technique is available to suppress the very large signal at the RF frequency.

By choosing a suitable sub-harmonic frequency, beam will be injected in a small fraction of the RF buckets only. The time structure of the extracted beam will then allow us to study the process of multi-turn extraction in AGOR, which we hope will pave the way towards single turn extraction.

2 DESIGN

The electronic circuitry of the buncher has been optimized in particular to reduce the fall time of the buncher voltage, during which the buncher capacitance is discharged, to obtain the highest duty cycle possible. The duty cycle realized increases from 80 % at 15 MHz to 96 % at 3 MHz. In figure 1a, the basic circuit of the saw-tooth generator is displayed; it is based on the concept developed at GANIL for the SPIRAL facility [2].

The buncher electrode capacitance C_b is periodically discharged by a high-mu power triode. When the triode switch opens, the buncher capacitor will be charged again via the inductor *L*. The current trough *L* is continuous and care must be taken in the design of the coil with respect to core saturation. Three different coils are used to cover a frequency range from 3 to 15 MHz. The triode requires a pulse amplitude of about 70 V to close. This pulse, with very fast rise and fall time, is generated by a component, which is somewhat unusual for this purpose: a triple 3 ns CRT driver, which can drive capacitive loads like the triode grid.

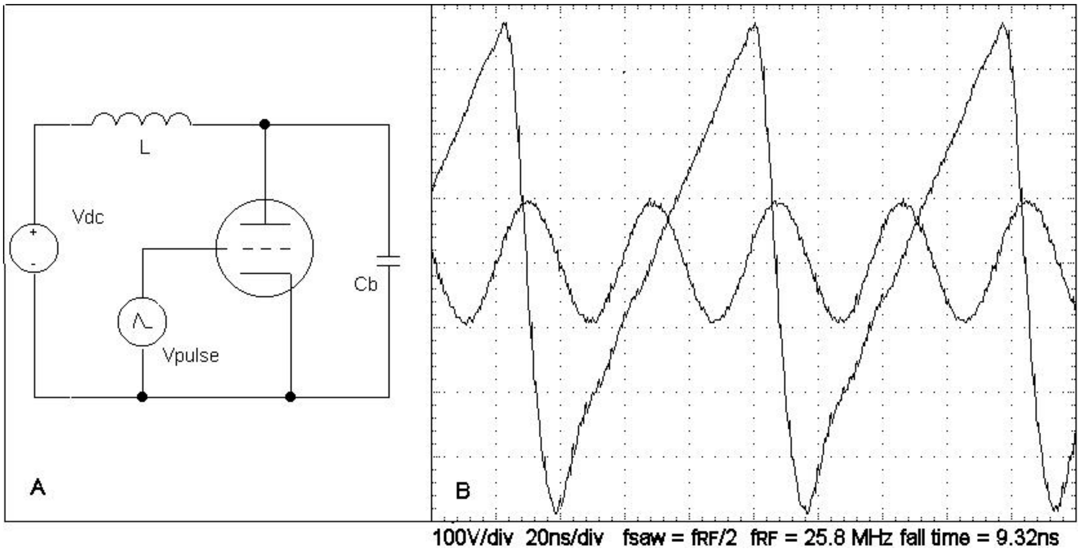

Figure 1: (A) Electrical scheme of the buncher. (B) Actual saw-tooth voltage, taken from a scope.

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A level shifter at the output of the CRT driver is used to bias the triode tube. Figure 1b shows a typical saw-tooth output wave form at one half of the RF. The maximum amplitude of the saw-tooth is about 1500 V.

A capacitively coupled electrode system was designed to maximize the effective voltage of the buncher by spreading out the field in the quasi-gap through which the particles arrive at the actual gap of the buncher. The electrode consists of a set of 10 metal cylinders. All cylinders, different in size and telescoped, are closed from one side with a conducting copper disk. Each disk contains a 15 mm hole trough which the beam passes. *Erta Peek* filling material has been used for mechanical alignment of the cylinders. The static field solver *Pandira* in the computer code collection *Poisson-Superfish f*rom the Los Alamos National Laboratory [3] was used to optimise the geometry of this buncher.

Figure 2 shows a section of the buncher electrode with plotted equipotential lines. An important design issue is the capacitance between the main electrode and ground, which should be kept as low as possible to avoid unnecessarily loading of the saw-tooth generator and to maximize the attainable voltage.

The buncher will be located 6.5 m downstream from the inflector exit. At the maximum injection voltage (34 kV) it introduces a velocity modulation of ±1 %, sufficient to compress the DC beam of a time interval of 4 – 6 RF periods into a single bunch. This velocity modulation is the same as that introduced by the present buncher, it is compatible with the central region acceptance.

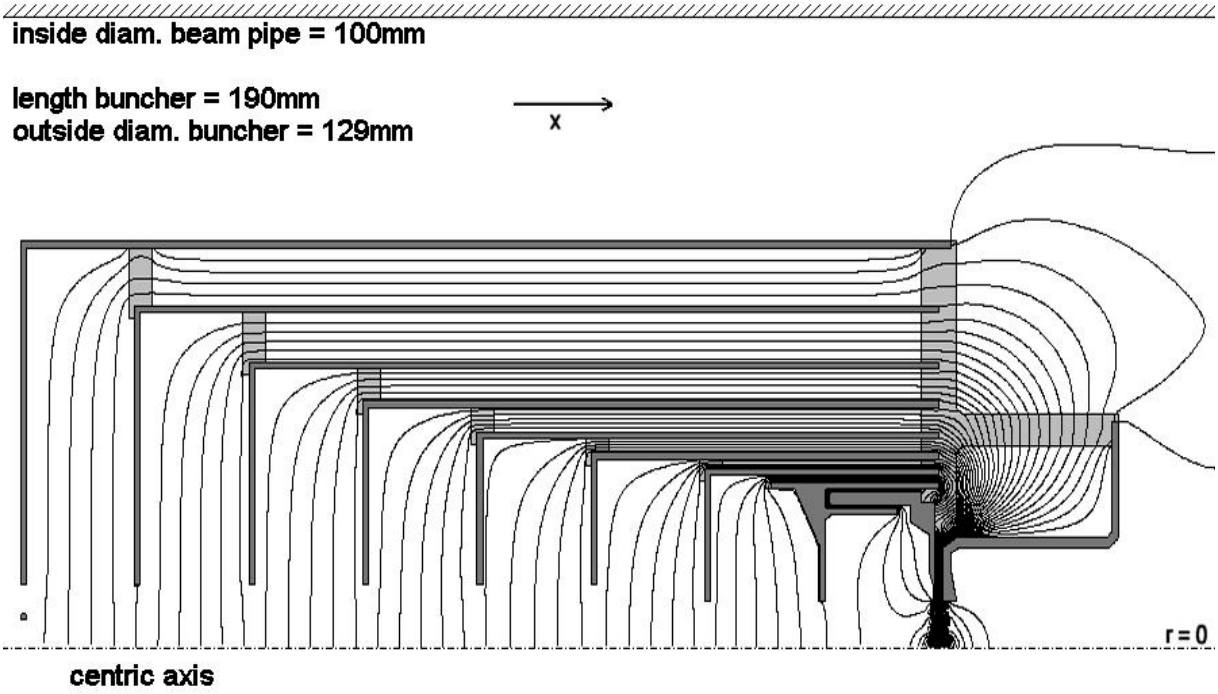

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Figure 2: Upper half of the buncher electrodes, showing the field lines.

3 TESTS

In order to test the proposed scheme tests were made for a 150 MeV proton beam with the present sinusoidal buncher. For this beam the cyclotron operates in the 2nd harmonic mode. The buncher was operated at exactly half the RF frequency, *i.e.* at the orbital frequency of the protons. The extracted beam intensity was maximized using the amplitude and the phase of the buncher voltage. The maximum attainable buncher voltage of around 1000 V was not sufficient to determine whether the optimum had been reached

The ion source was then readjusted to extract a maximum current of 10^5 protons per second from the cyclotron. The time structure of this beam was measured as a function of the amplitude of the buncher voltage with a fast plastic scintillator, which was hit by the direct beam. In Fig. 3 the time structure with the buncher operating at 80 % of the maximum voltage is displayed. It shows that the intensity in every second burst is suppressed by a factor 15.

The suppression factor (i.e. the ratio of the two peak heights) was measured as a function of the buncher voltage. The results are shown in Figure 4 together with the results of a calculation. The data are well explained by a simple model. The time distribution of the beam at the inflector exit is calculated by tracking particles through the buncher up to the inflector exit as a function of their initial phase (which has a flat distribution for a DC beam) and energy (the energy spread of the ion source is about 10 eV).

The emittance of the beam is not taken into account. The beam intensity is then obtained by integrating this distribution over the RF phase acceptance. From the width of the suppressed burst we derive an RF phase acceptance of about 20 °RF.

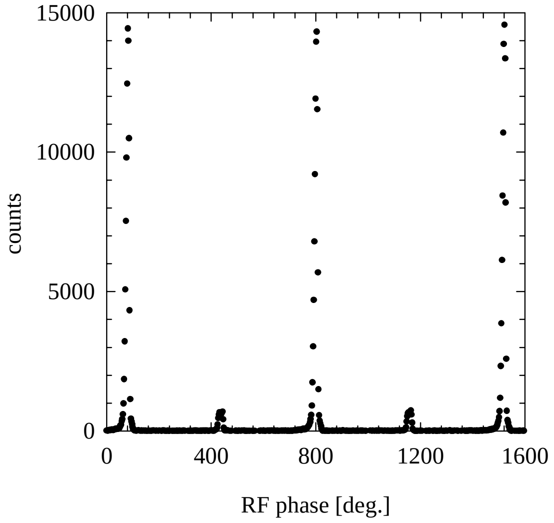

Figure 3: Time structure of a 150 MeV proton beam with the buncher operating at the proton orbital frequency (= half of the RF frequency).

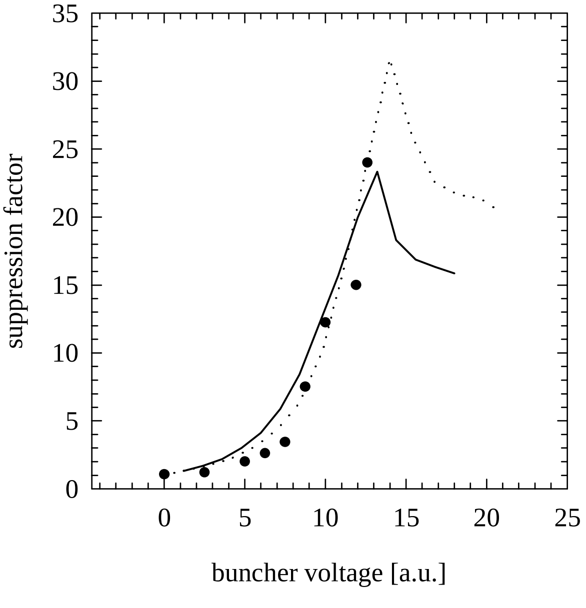

Figure 4: Measured suppression factor as a function of buncher voltage (dots). The full curve corresponds to the calculation for a acceptance of 20 °RF; the dotted curve to an acceptance of 10 °RF.

The comparison between the data and the calculation shows that the measured suppression at maximum buncher voltage is very close to the maximum achievable with the sinusoidal buncher. By reducing the phase acceptance from 20 °RF to 10 °RF the maximum suppression would increase by about 30 %. At high bunching voltages the width of the injected bunch increases beyond the phase acceptance, resulting in a smaller intensity being accepted and thereby in the reduced suppression predicted by the calculation.

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5 REFERENCES

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