A SUBHARMONIC BUNCHER FOR THE AGOR-CYCLOTRON

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The RF-frequency of AGOR being rather high, neutron TOF measurements have a limited dynamic range and low resolution. This can be improved by injecting beam at a subharmonic of the RF-frequency. By injecting beam only once per orbital period the repetition rate of the extracted beam is divided by the harmonic number (h = 2; 3 or 4), even in case of multi-turn extraction. A single gap sawtooth buncher operating up to 15 MHz with a duty cycle of 80 %, under development for this purpose, is described and first measurements using the regular buncher are discussed.

1 Introduction

The RF system of the superconducting cyclotron AGOR accelerates the ions at the 2^{nd}; 3^{rd} or 4^{th} harmonic of their orbital frequency in order to limit the RF frequency range and to obtain a high energy gain per turn in relation to the maximum voltage on the acceleration electrodes that can be achieved reliably (approx. 90 kV). The latter point is of particular importance because of the aim to achieve single turn extraction for light ions. Consequently the time between beam pulses is rather short: it varies from 16 ns for 200 MeV protons to 42 ns for heavy ions with an energy of 6 MeV per nucleon. This poses serious problems for several experiments in which neutron energies are to be measured with the time-of-flight technique: either the dynamic range for the neutron detection or the neutron energy resolution suffer severely. Consequently there is a strong incentive to develop the possibility to reduce the repetition rate of the beam pulses, both for light and heavy ions.

There are two routes possible to reach this goal:

- With single turn extraction, which has yet to be demonstrated for AGOR, an arbitrary pattern of beam pulses can be produced with a suitable combination of bunching and chopping. This is, however, only feasible for light ions where the intensity from the ion source is such that the injected emittance can be cut to values compatible with the requirements for single turn extraction and that beam losses in the process of bunching and chopping need not be considered.
- Without single turn extraction the repetition rate can be reduced to the orbital frequency (and for the 4^{th} harmonic to twice the orbital frequency as well). This becomes evident by looking stroboscopically at the distribution of beam in the cyclotron (fig. 1). When injecting at the RF frequency the beam is distributed in as many rotating radial "spokes" as the harmonic mode and consequently every RF period particles pass into the extraction channel. Injection at the orbital frequency of the particles (or a subharmonic of it) results in only one "spoke" and consequently beam is extracted only once every orbital period.

Development work on the latter route, which is described below, has been started.

Reducing the repetition frequency of the beam pulses in this way also provides possibilities for beam diagnostics. When beam is present in only one "spoke" the signal on the phase probes will contain a component at the orbital frequency where no perturbations from the RF system are present. By performing the phase measurement at this frequency both the sensitivity and accuracy of the measurement will be increased [1].

When injecting at a low subharmonic frequency there will be many empty buckets inbetween the filled ones inside the cyclotron. By looking at the intensity distribution of the extracted beam over one cycle of the subharmonic buncher one can infer from how many turns beam is simultaneously extracted. This opens the possibility to study the influence of various parameters on the extraction process and to find the optimal conditions which are needed for single turn extraction.

2 Design

For a subharmonic buncher the efficiency is of even more importance than for a buncher operating at the RF frequency: in the latter case particles not collected in the bunch are lost, while for a subharmonic buncher part of the particles not collected in the main bunch are injected in the other buckets during the period of the subharmonic buncher. In fig. 2 the intensity ratio between the main and parasite pulses is displayed as a function of the duty-cycle of the subharmonic buncher for 2^{nd} harmonic mode of the cyclotron; emittance effects have been taken into account in an approximate way. For operation in 3^{rd} and 4^{th} harmonic mode the intensity ratio will a factor two and three higher, respectively.

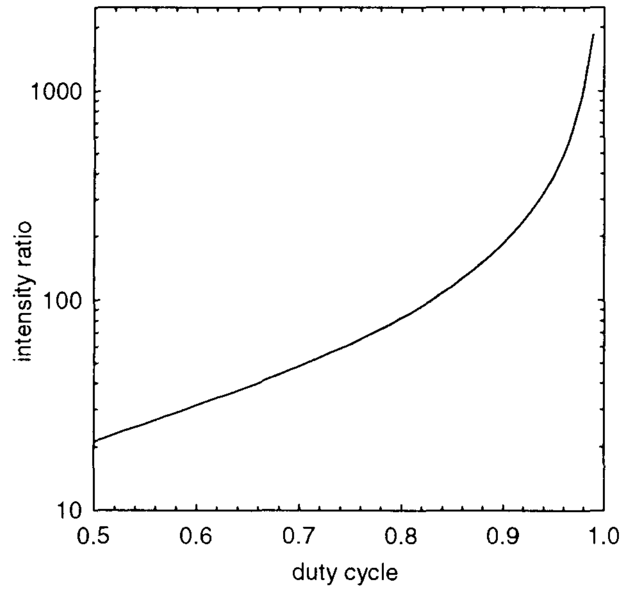

fig. 1 Intensity ratio between main and parasite pulses as a function of buncher duty cycle

Both for the use of subharmonic bunching in experiments and for its use in the study of the extraction process it is of interest to reduce the intensity in the parasite pulses to *e.g.* 1 % or less of the main pulse. This requires a duty-cycle of at least 80 %, which can only be reached by using some kind of sawtooth voltage for the subharmonic buncher.

To be able to bunch at a low subharmonic of the RF frequency (up to 1/8) the subharmonic buncher will be located at a distance of 6.6 m from the injection point, so that the energy modulation of the injected beam is the same (4 %) as that of the normal buncher for an 80 % duty cycle.

The concept adopted for the subharmonic buncher is that developed for the SPIRAL facility at GANIL by Chabert et al. [2]; it is schematically shown in fig. 3.

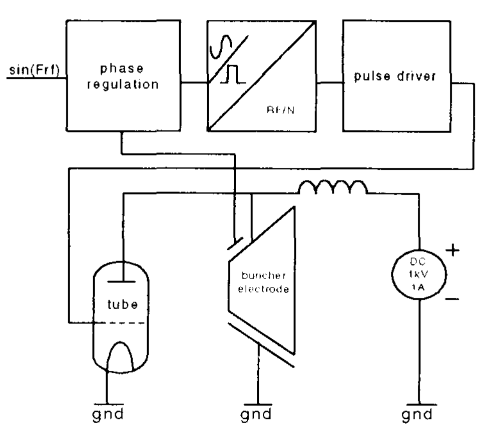

fig. 3 Block diagram of subharmonic sawtooth buncher

The electrode is charged by a voltage source in series with an inductance and is periodically discharged through the triode. A nice feature of this circuit is that the voltage on the electrode is about twice that of the voltage source.

The duty cycle is determined by the time needed to discharge the electrode. In first instance this time is determined by the capacitance of the buncher electrode and the maximum allowable anode current. It is thus important to minimize the buncher capacitance. The discharge time is furthermore determined by the ability of the pulse generator driving the grid to rapidly open the triode, *i.e.* to provide a large current to charge the grid capacitance.

The grid of the triode is driven with two FET's in a push-pull configuration. In this way a pulse with a width of 15 ns, rise and fall times of 5 ns and an amplitude of 60 V have been obtained on the grid.

Since the actual electrode is not available yet, tests have been made with a variable capacitor to replace the electrode. In figure 3 the results obtained for a capacitance value of 20 pF with a 300 V voltage source at 10 MHz are displayed.

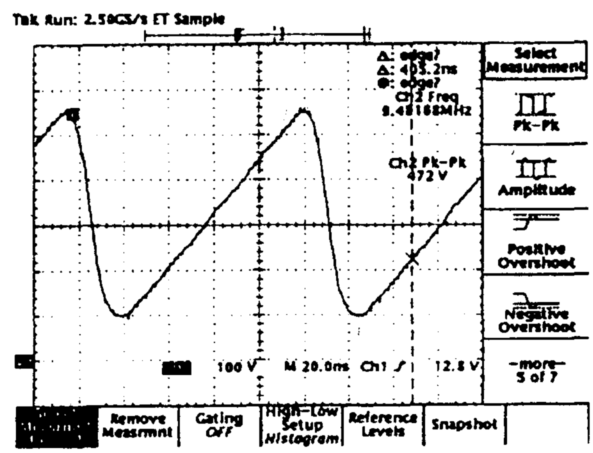

fig. 3 Sawtooth voltage generated with prototype electronics on a 20 pF capacitance

3 Preliminary measurements

The AGOR-cyclotron is equipped with sinusoidal double gap buncher located in the axial hole at a distance of 0.5 from the injection point. The relatively short distance has been chosen in order to be able to produce bunches with a 6° phase width, which are needed for the single turn extraction. The energy modulation of the injected particles is maximum in 2nd harmonic operation, where it amounts to 4 %. The buncher increases the beam intensity in the cyclotron by a factor 5 to 6 as compared to non-bunched injection, which with an assumed phase acceptance of 30° leads to a bunching efficiency of about 45 %. In an experiment with 189 MeV protons, which are accelerated in 2nd harmonic mode at an RF frequency of 60 MHz, the buncher has been operated at 30 MHz in order to demonstrate the feasibility of reducing repetition rate of the beam pulses and to investigate the possibilities to perform beam phase measurements at the orbital frequency, where the signal is entirely due to the beam and no perturbations from the RF system are present. In order to obtain a similar bunching efficiency the bunching voltage should be double the value for normal operation at 60 MHz, well beyond the operating range. The voltage was therefore set to the maximum achievable, about 10 % higher than for normal operation at 60 MHz. According to a simple model about 12 % of the beam in one period of the buncher is collected in one of the two RF buckets in this period, while 2.5 % of the beam is injected in the other bucket. Consequently an intensity difference of about a factor 5 between subsequent beam pulses is expected. The time structure of the extracted beam was determined by measuring the time spectrum of the signals from a small scintillator mounted close to the external beam stop of the cyclotron with respect to the cyclotron RF, which was divided by eight so that the spectrum extended over eight beam pulses. The data showed that the beam intensity of subsequent pulses differs by a factor 4, in reasonable agreement with the expected value.

Acknowledgments

We would like to thank B. Monsanglant and W. Lecoz (IPN, Orsay, France) for fruitful discussions on optimizing the electronics for the subharmonic buncher.

This work has been performed as part of the research programme of the "Stichting voor Fundamenteel Onderzoek der Materie" (FOM) with financial support from the "Nederlandse Organisatie voor Wetenschappelijk Onderzoek" (NWO).

References

[1] S. Brandenburg et al., Beam phase measurement in the AGOR cyclotron, these proceedings

[2] A. Chabert et al., preprint GANIL S97 01