FIRST OPERATION OF THE TASCC BEAM BUNCHING SYSTEM

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Summary

The Chalk River Tandem Accelerator Superconducting Cyclotron (TASCC) system uses a low-energy buncher (LEB) and a high-energy rebuncher (HEB) to produce the required bunched beam at the cyclotron injection stripper foil. The LEB modulates the $\leq$ 300 keV beam from the negative ion source with a fundamental plus 2nd harmonic approximation to an ideal saw tooth to give a time focus at the stripper in the tandem accelerator terminal. The HEB, operating at the 2nd or 4th harmonic, corrects for debunching after the stripper and produces a new time focus at the cyclotron stripper. Transit time jitter through the tandem accelerator is corrected by a phase stabilizing circuit using both energy analysis after the HEB and a correlation with a capacitive phase probe signal. In the first experiments with a low energy ^{12}C beam, the LEB produced bunch lengths of about 1.6 ns and the HEB produced the expected energy dispersion. Beam tests will be described.

Introduction

To achieve the design energy spread of 4×10^{-4} from TASCC[1], the beam injected into the cyclotron must be bunched to three degrees in rf phase. This corresponds to 260 to 130 ps bunches for the 31 to 62 MHz frequency range of the cyclotron rf.

The bunching system consists of a low energy buncher (LEB)[2] followed by a high-energy rebuncher (HEB)[3], as shown in Fig. 1, with achromatic beam line sections[4] before and after the HEB so that the required three degree bunches are formed at the cyclotron stripper.

First beam tests with both bunchers brought the beam to the final cyclotron matching section. A beam-pulse detector (BPD)[5] mounted just upstream from the HEB was used to measure bunch lengths.

Low-Energy Buncher

The LEB has grids 1 mm apart on opposed, capacitively-tuned, quarter-wave stems, resonant at the fundamental and first harmonic of the cyclotron drive frequency. The capacitors are of a commercial design with screw driven linearly moving vanes in a ceramic walled vacuum housing. Stepping motors drive the capacitors through a 10:1 reduction gear to provide tuning ranges in excess of the required 31 to 62 MHz and 62 to 124 MHz respectively.

The rf reference signal is split (with one arm frequency-doubled) into two 50 W solid state linear amplifiers. Two fixed inductive drive loops are tuned to give critical coupling at the low end of the frequency range where maximum power is required. Each drive has phase and amplitude control, and an automatic frequency control (AFC) circuit that compares the phase of the reference signal with the phase of the signal from a small cavity pick-up probe. Cavity resonance corrections are made with the stepping motor drive to the capacitors.

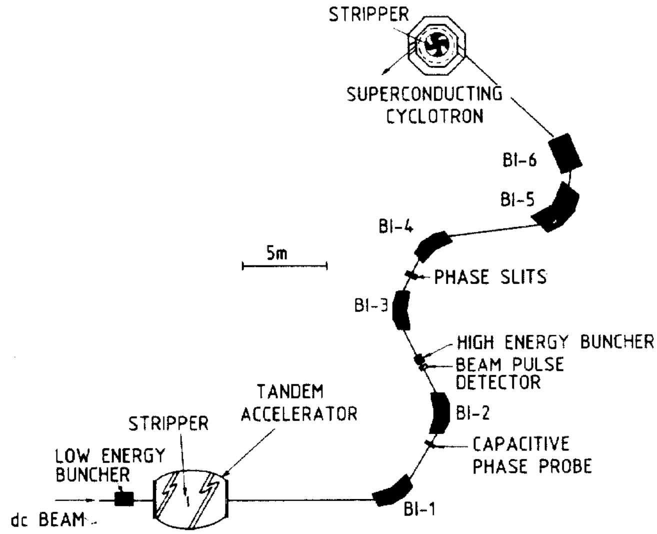

Fig. 1 Layout of injection beam line showing bunchers, capacitive phase probe and beam-pulse detector and the bending magnets labeled BI-1 to BI-6. The focusing and steering magnets and other beam diagnostic elements have been deleted for clarity.

A capacitive divider probe directly monitors the voltage on the accelerating gap. The design grid voltages of 2 kV and 600 V for the fundamental and first harmonic resonators are easily achieved. The relative phase between the grid signal and the reference signal is stable to better than 0.5 degree.

High-Energy Rebuncher

The HEB is a sliding-short, tuned resonator with a 65 mm drift tube accelerating structure operating at twice the cyclotron frequency for cyclotron harmonics (h) 4 or 6 and four times the cyclotron frequency for h=2, i.e., from 62 to 190 MHz. A broad band 200 W amplifier drives the drift tube up to about 20 kV peak.

An input modulator provides a frequency doubled or quadrupled level controlled drive for the power amplifier. An AFC circuit, similar to that used for the LEB, holds the resonator in phase with the reference signal from the rf distribution system by tuning the resonator. The resonator multipactors easily, so a fast switching circuit in the modulator drives the resonator quickly through the low power levels where multipactoring can occur, before a discharge has time to build up.

Capacitive Phase Probe

The CPP (see Fig. 1) consists of a 38 mm diameter 110 mm long insulated copper tube in the beam line. The voltage pulses induced on the tube by the beam bunches are amplified by a broad-band low-noise amplifier, and provide some information on the bunch length, i.e., the rise time depends on the bunch length and is useful for rough setting of the LEB voltage.

For phase stabilization, a band pass filter (31-62 MHz) is used to give a good sine wave for the phase comparator circuit.

Phase Control

The phase control of the radiofrequency system is shown schematically in Fig. 2. The signal from the synthesizer is divided into four individually phase controlled reference waveforms.

It is expected that transit times between the LEB and the HEB may vary sufficiently that an active phase feedback to the LEB from the beam bunches detected near the HEB may be required. The bunch phase error is determined from momentum errors sensed by a momentum analyzer (BI-3 in Fig. 1) after the HEB. Thus, the slit currents at SI-4 in Fig. 1 are used to stabilize the phase of the LEB as indicated in Fig. 2.

However, the HEB operates at two or four times the cyclotron frequency and it could restabilize the beam on the wrong cycle following a large transient.

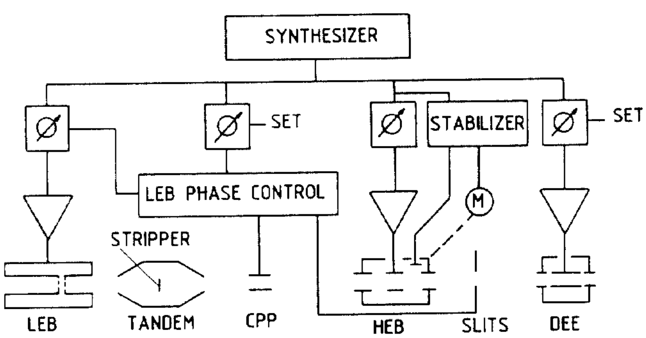

Fig. 2 Schematic of phase control system.

To avoid this, the beam phase is also sensed by the CPP. A phase comparison between this signal and a reference signal is used to control the LEB phase during transients and to return the beam bunches to the correct HEB cycle.

Beam-Pulse Detector

The BPD[5] is located just in front of the HEB (see Fig. 1). It consists of a grounded vertical cylinder with holes to allow the beam to pass across a diameter. A vertical 50 μm wire can be positioned remotely in the beam. The wire is held at approximately -2000 V so that electrons ejected by the beam pulse are accelerated towards the cylinder and some pass through a slot to enter a channel plate multiplier. The signal from the 50 ohm collector is fed directly to a fast discriminator. The fast discriminator pulse goes to the start input of a time-to-amplitude converter (TAC) that is then stopped by a reference pulse derived from the radiofrequency waveform to the buncher. The output of the TAC is analyzed in a pulse-height analyzer located in the accelerator control room.

The resulting spectrum is the beam-pulse intensity as a function of time with the time scale reversed. The measured intrinsic resolution of the BPD is less than 110 ps FWHM.

Computer Control

The rf distribution system and the bunchers may be operated either from a local control panel or from the control room via the CAMAC dataway and PDP-11/44 control computer. Parameters may be monitored as listings or as MIMIC diagrams on a CRT and settings may be adjusted through a touch panel or through an assignable control knob. The MIMIC diagram for the LEB is shown in Fig. 3 as an example. The computer control system is a close copy of that developed for VICKSI[6].

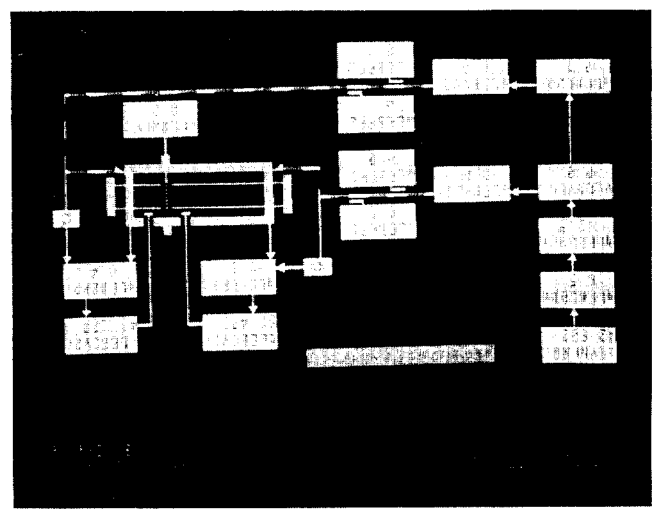

Fig. 3 Mimic diagram for LEB control.

Bunching Experiments

The first buncher tests were with a 30 MeV $^{12}C^{3+}$ beam transported to BI-4 or BI-5 (see Fig. 1). The negative-ion source injection voltage was -150 kV and positive-ion beam currents were up to 100 nA. The LEB was run at 35, 60 and 31 MHz with the HEB at 70, 120 and 124 MHz respectively.

The LEB was set up by adjusting the phase and amplitude of the harmonic voltage to give a smooth approximation to a "sawtooth" waveform on the grid as observed on an oscilloscope in the control room. The amplitude was then adjusted to maximize the pulse signal observed on the CPP with an unfiltered 200 MHz amplifier and oscilloscope. Figure 4 shows the sawtooth waveform (bottom trace) and the corresponding CPP pulse signal (top trace). The CPP signal consisted of a positive transient caused by the entrance of the positive-ion bunch, followed in ≈ 5 ns by a negative exiting transient; the signal repeats each 28.5 ns period. Figure 5 shows the CPP waveform with a 200 nA average beam current.

The LEB settings were further optimized using the BPD to measure the bunch lengths. An example of a BPD time spectrum is shown in Fig. 6. The shortest bunch lengths observed in these tests were about 1.6 ns FWHM for both 35 and 60 MHz (corresponding to 20° and 36° of one cycle respectively). There are several factors that can contribute to the observed length, e.g., ion

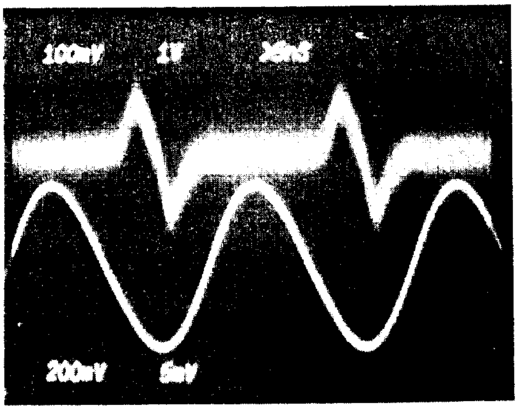

Fig. 4 LEB voltage waveform (below) and CPP signal for a bunched $^{12}C^{3+}$ of ≈ 100 nA average current.

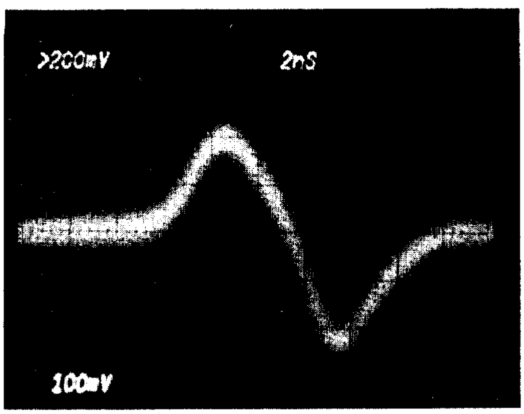

Fig. 5 CPP signal for a bunched $^{12}C^{3+}$ beam of 200 nA average current.

source noise, ion source voltage fluctuation, tandem voltage fluctuations and energy straggling in the tandem stripper. The latter was investigated by changing the stripper gas pressure and the results showed that only a fraction of the width was caused by straggling.

In the most recent tests, the contribution from ion source noise was investigated by increasing the injection voltage to -180 kV from the -150 kV. No decrease in bunch length, expected if the length were caused primarily by source noise, was observed. Also in tests with a $^{12}C^{2+}$ beam and thinner stripper bunch lengths were only slightly shorter.

These bunch lengths are well within the capability of the HEB to rebunch at the cyclotron but the beam line monitoring required to demonstrate this was not installed at the time of writing. However, HEB tests did show that the bunched-beam dispersion at the phase stabilization slits was approximately as expected and that the LEB phase could be stabilized to better than ± 1/2° (35 MHz) either by the CPP signal at beam currents > 100 nA or by the slits at somewhat smaller currents. This easily corrected for up to ± 3° phase jitter observed for the unstabilized beam and reduced possible contributions to bunch lengths from ion injection or tandem voltage jitter to a negligible level.

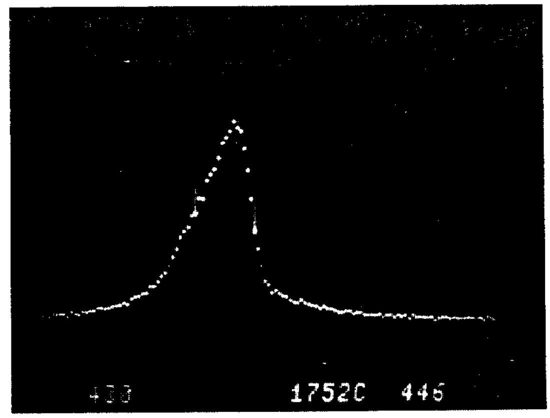

Fig. 6 Beam-pulse detector time spectrum, the peak is about 1.6 ns FWHM. The slower particles are to the left of the maximum.

Conclusions

The results indicate that the beam bunching system will produce input bunch lengths short enough and with the required phase stability to obtain the desired resolution ($4 \times 10^{-}$) at the output of the cyclotron.

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