RECTANGULAR ACCELERATING-FOCUSING STRUCTURE HIGH POWER TESTS[1]

V.I. Shvedunov[2], A.N. Ermakov[2], D.I. Ermakov[2], F.N. Nedeoglo[2], G.A. Novikov[2], N.P. Sobenin[3], and W.P. Trower
World Physics Technologies, Inc. Blacksburg VA 24060 USA

Abstract

We built an accelerating-focusing rectangular cavity biperiodic structure (RCBS) for our 70 MeV RaceTrack Microtron (RTM), which we have tested at high Radio Frequency (RF) power with an electron beam. Our structure, powered by a 2,856 MHz, 6 MW, 48-beam KIU-111A klystron, has its 50 keV, 200 mA prebunched beam injected through a rare earth permanent α-magnet. We measured its exiting beam energy spectrum using a 45º bending magnet and its dimensions and emittance using its transition radiation. We obtained the 6 MeV, 100 mA beam with ~2 MW of RF power dissipated in the structure walls.

1 INTRODUCTION

For our 70 MeV pulsed RTM [1], we built [2] a RCBS to accelerate electrons with a 5 MeV synchronous energy gain. Our narrow RCBS allows the 1st orbit beam to clear the structure and has RF quadrupole focusing whose focusing/defocusing direction and amplitude depend on the RF field phase and beam slot height, greatly simplifying the RTM design and operation.

We operated the RCBS under full RF power, injecting the beam as we will in our RTM. We report here the RCBS exit beam parameters, including capture efficiency, energy spectrum, and emittance, which we now use in our ongoing RTM beam dynamics simulations.

2 EXPERIMENTAL SET-UP

Our test stand, shown in Fig. 1, consists of an electron gun, an α-magnet, the RCBS, PM lenses (PML), quadrupoles (Q), steering coils (S), a 45º dipole analyzing magnet, beam current monitors (BCM), a transition radiation detector (TRD), and a Faraday cup (FC). The klystron and its modulator, the gun modulator, and the RF, vacuum, cooling, and control systems are not shown.

2.1 Beam diagnostics

We used the BCMs, TRD, FC, and 45º magnet to determine the beam characteristics. Our BCMs, fast current transformers with sensitivity of 2 A/V, were installed at the electron gun and RCBS exits in special ceramic insertions in the stainless steel beam pipe. To suppress klystron and gun modulator noise, we differentially amplified the BCMs coil output signals. We estimated the beam capture efficiency from the BCM signal ratio by accurately tuning the amplifiers to provide identical signals for equal currents with a sensitivity of 28 A/V.

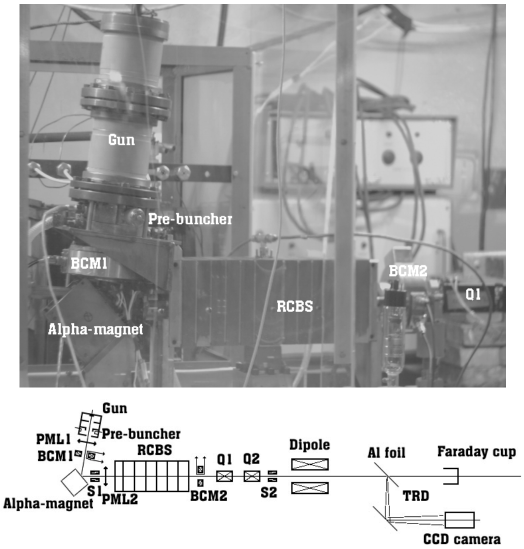

Figure 1: RCBS test stand.

We viewed the beam using a TRD, a 20 μm thick Al foil located 1.2 m from the RCBS exit and set at 45° to the beam. TR, emitted normal to the beam when it crosses the vacuum-Al interface, was reflected by a mirror to a shielded CCD camera whose images we stored. Our TRD was used with average beam current above ~0.1 μA. From these images, we calculated the rms beam dimensions at various levels of beam current. We estimated the effective beam emittance by measuring the beam dimension dependence on Q1 and Q2 currents.

With the 45° dipole entrance/exit poles face angles at ~11.6°, which provided ~0.66 m horizontal and vertical focal lengths and a 25 cm bending radius, we measured the beam energy spectra. We installed in the focal plane a 3 mm wide vertical slit and a FC whose current we measured at various dipole coils excitation currents.

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[1] Work supported in part by the National Science Foundation grant DMI-9704039.

[2] Permanent address: Institute of Nuclear Physics, Moscow State University, 119899, Moscow, Russia.

[3] Permanent address: Moscow Engineering and Physics Institute, 115409, Moscow, Russia.

2.2 Injector

To permit the RTM orbits to pass through the RCBS, we injected the electron gun beam off axis. To increase the capture efficiency, we compressed the beam in a prebuncher. This energy-modulated beam was injected through a dispersion free α-magnet and focused by PMLs installed at the prebuncher exit and RCBS entrance.

An intermediate anode regulated the electron gun current, a second anode was the external prebuncher wall, and the ion pump was attached to the rear of the gun. Fig. 2 shows the exit gun current at various intermediate anode voltages compared with calculations [3].

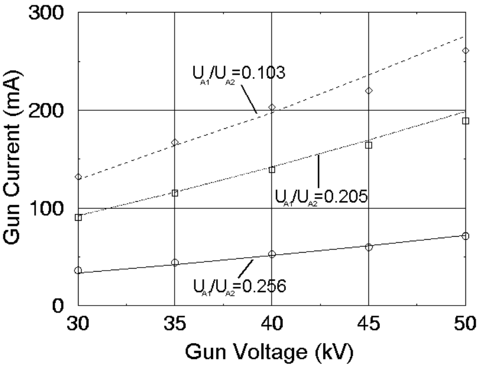

Figure 2: Gun current with intermediate anode voltages.

The prebuncher, a cylindrical cavity with a 9 mm gap width, provided optimal bunching with ~100 W of RF power. The longitudinally magnetized PM ring lenses were resident in the vacuum tubes and had 23/16 mm external/internal diameters. We adjusted the ring lengths to provide the required focal lengths. Our PM α-magnet had a 100 G/cm gradient constant to better than 1% [4].

2.3 RF system

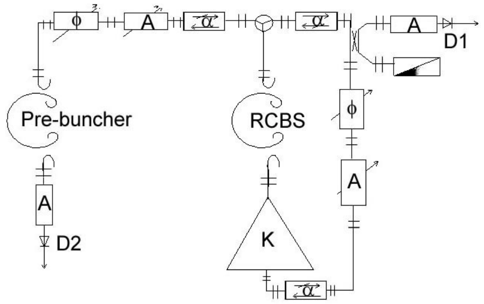

Figure 3: RF-system.

Our simple and reliable RF system, seen in Fig. 3, will be used slightly modified in our RTM. We operated our 2,856 MHz, 6 MW, 48-beam KIU-111A klystron in a feedback loop with the accelerating structure thus eliminating the need for a circulator, isolating gas, stable generator, and preamplifier. We also attached the klystron directly to the accelerating structure. We obtained the most stable auto-oscillating operation with the klystron amplitude characteristic at or above saturation where klystron high voltage instabilities have little effect on the accelerating field amplitude. For klystron high voltage instabilities of ~3% in a ~6 µs pulse, the RF field instabilities were ~2.5% in ~5 µs.

3 RESULTS

3.1 Capture efficiency

We maximized the RCBS capture efficiency, i.e. the RCBS exit current to the gun current ratio, by optimising the main and intermediate gun anode voltages and by adjusting the prebuncher field amplitude and phase. The delay of the gun current with respect to the RF field provided an additional degree of freedom that only influenced the average accelerated current. Optimal gun anode voltages were close to those calculated, 50 kV for the main and ~10.2 kV for the intermediate anodes. Fig. 4 shows typical BCM_1 and BCM_2 signals whose ratio is the capture efficiency.

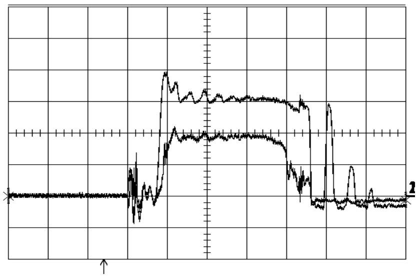

Figure 4: BCM_1 (upper) and BCM_2 (lower) signals.

The capture efficiency dependence on the prebuncher-RCBS field phase difference for the optimal prebuncher field amplitude is shown in Fig. 5 together with the beam dynamics calculations [5]. The smearing of the measured dependence compared with the calculated was due to both the model's limitation and experimental instabilities. The maximum capture efficiency was ~63%.

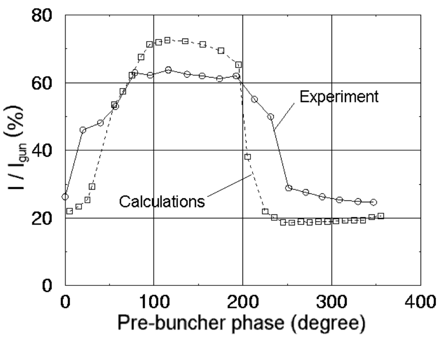

Figure 5: Capture efficiency with phase difference.

3.2 Beam energy, energy spectra

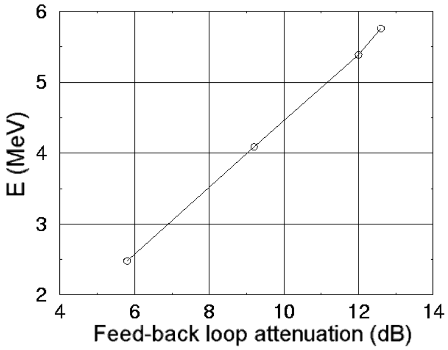

Figure 6: Beam energy with feedback loop attenuation.

We measured the beam energy dependence on the RF field amplitude, as seen in Fig. 6. Because we operated the klystron over-saturated, the attenuation increased the beam energy. We measured the beam energy spectrum and emittance with a field amplitude that would provide a nominal energy gain in our RTM (i.e., 5 MeV at 22° synchronous phase). The beam energy spectra for several prebuncher-RCBS field phase differences with nominal RTM energy gain are shown in Fig. 7. Using the phases of Fig. 5, the late phase corresponds to ~190°, the minimum bunching to ~340°, and the early phase to ~100°.

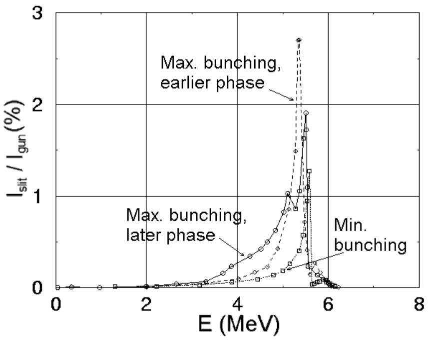

Figure 7: Beam energy spectra with phase differences.

3.3 Beam emittance

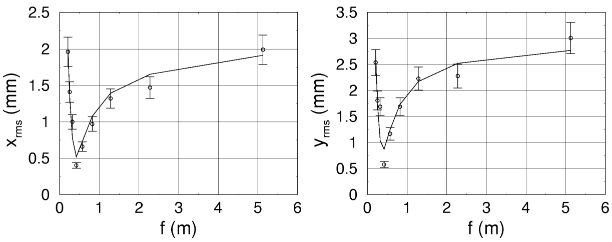

Figure 8: Horizontal (a) and vertical (b) beam radius with Q_1-Q_2 focal length.

We measured the beam emittance using the TRD beam images made at various Q_1-Q_2 with equal but opposite coil current polarities — Q_1 focused vertically and Q_2 horizontally. We varied the Q_1-Q_2 focal length from infinity to ~0.2 m for our 5.3 MeV beam using the early phase. After removing secondary γ-rays and electron CCD hits, we found the rms beam dimensions. The horizontal and vertical rms beam radii dependences on the Q_1-Q_2 focal length at 90% beam current are shown in Fig. 8, where the curves were obtained by fitting the data with an equation connecting the beam ellipse parameters at the RCBS exit and at the Al foil through the transfer matrix. The measured beam emittance is summarized in Table 1 together with the RCBS exit ellipse parameters.

Table 1. Measured beam emittance.

	ε (mm x mrad)	β (mm/mrad)	α
Horizontal	0.98	0.71	-0.43
Vertical	0.68	1.59	-2.30

We used these beam emittance estimates in our RTM beam dynamics simulations, which predict that ~36% of gun current can be accelerated to 70 MeV in 14 RCBS passages.

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