OPERATION OF THE KARA BOOSTER IN STORAGE-RING MODE FOR ACCELERATOR STUDIES AND SYSTEM DEVELOPMENT

H. Hoteit*, E. Blomley, A. Malygin, A. Mochihashi, A.-S. Mueller, M. Schuh, J. Steinmann,
Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract

The Karlsruhe Research Accelerator (KARA) booster synchrotron, normally used to accelerate electrons from 53 MeV to 500 MeV for injection into the KARA storage ring, has recently been successfully operated in a stand-alone storage ring mode. This capability was enabled by the modernization of its magnet power supplies and their integration into an EPICS-based control system. Operating the booster in this mode provides a flexible platform for accelerator physics studies, including the development of energy-ramping procedures, characterization of magnet hysteresis effects, and verification of control strategies under low-energy storage conditions. Initial commissioning demonstrated stable beam storage at several energies up to 500 MeV.

The future compact storage ring cSTART, designed for energies of 50-90 MeV, is currently being constructed at KIT. The new power supplies allow preliminary experiments to be conducted across this energy level in the KARA Booster, enabling studies of beam and machine characterizations under realistic conditions. Additionally, the ability to store beam up to 500 MeV supports tests relevant for the KARA storage ring. This mode establishes the booster as a compact and flexible experimental platform prior to deployment in cSTART and the main KARA storage ring. Future work will focus on beam dynamics and diagnostics in the lower energy region with reduced radiation damping, as well as optimization of ramping cycles for stable injector operation.

INTRODUCTION

The KARA booster synchrotron provides electron beams up to 500 MeV for injection into the 2.5 GeV storage ring and is primarily designed for acceleration cycles at 1 Hz [1].The lattice is optimized for booster operation and consists of a single quadrupole family without dedicated sextupoles, limiting flexibility in optics control and chromaticity correction. A detailed description of the machine design can be found in [2]. In its original configuration, continuous beam storage was not feasible due to limited stability and controllability of the legacy magnet power supplies, which were based on a resonant circuit and could not provide sufficiently constant current to maintain high-field operation; additionally, the associated cabling required upgrades.

A recent upgrade replaced these power supplies with high-stability units equipped with embedded EPICS support, enabling direct integration into the existing EPICS-based control system [3]. This enables steady-state operation at fixed energies, allowing the booster to operate as a storage ring over an energy range of approximately 50 MeV to 500 MeV.

In this energy range, radiation damping is weaker compared to operation at higher energies, such as in the 2.5 GeV KARA storage ring, while space charge, wakefield effects, magnet hysteresis, and longitudinal beam dynamics have a stronger impact. Since this range overlaps with the design energies of future compact storage rings like cSTART [4], the booster serves as a convenient test platform.

This work represents the first demonstration of stable beam storage and controlled energy ramping in a booster synchrotron originally designed for cycling at 1 Hz operation. This significantly extends the operational capabilities of the KARA booster and establishes it as a flexible platform for accelerator studies in a low-energy regime relevant to future compact storage rings.

COMMISSIONING AND STORAGE TESTS

A dedicated measurement campaign was conducted to evaluate storage-ring operation.

Stable beam storage was first achieved at 500 MeV following injection at 53 MeV and acceleration to top energy (see Fig. 1). During flat-top operation, magnet currents and RF voltage were held constant, resulting in reproducible beam conditions with no abrupt beam losses observed

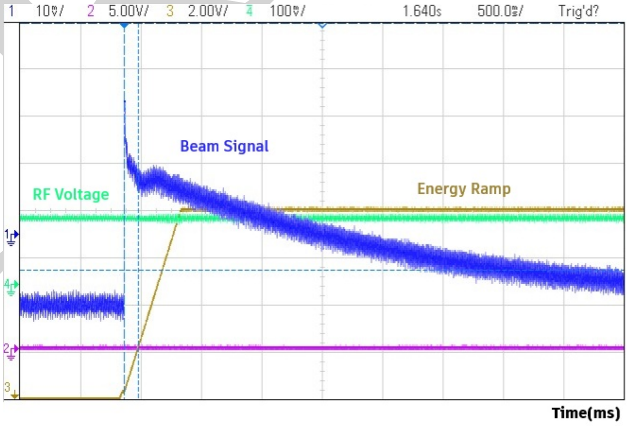


Figure 1: Beam signal during acceleration to 500 MeV and subsequent flat-top operation at 23 kV RF voltage.

Subsequently, beam storage was demonstrated at 53 MeV, 250 MeV,(see Fig. 2), and 500 MeV by operating the magnet currents at fixed values and adjusting the RF voltage for stable beam capture. These measurements confirmed that the booster optics can be reproducibly set over a wide energy range.

At 250 MeV with 10 kV RF voltage, the beam intensity remained approximately constant over the observation window, indicating stable beam storage under these conditions. In contrast, a faster beam decay was observed at 500 MeV with

---

* houssameddine.hoteit@kit.edu

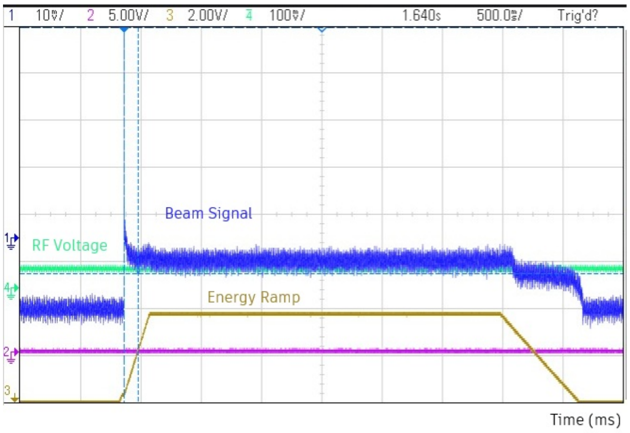


Figure 2: Beam signal during acceleration to 250 MeV and subsequent flat-top operation at 10 kV RF voltage.

23 kV RF voltage, suggesting that the available RF voltage is not sufficient to maintain long beam lifetimes at higher energy. The improved stability at lower energy is consistent with increased bunch length and reduced particle density, which can help mitigate Touschek scattering effects.

To further explore operational limits, the beam was decelerated below the nominal injection energy to approximately 45 MeV (see Fig. 3). Beam signals were clearly observed at this energy, demonstrating that both the magnet system and RF configuration remain functional in this extended regime.

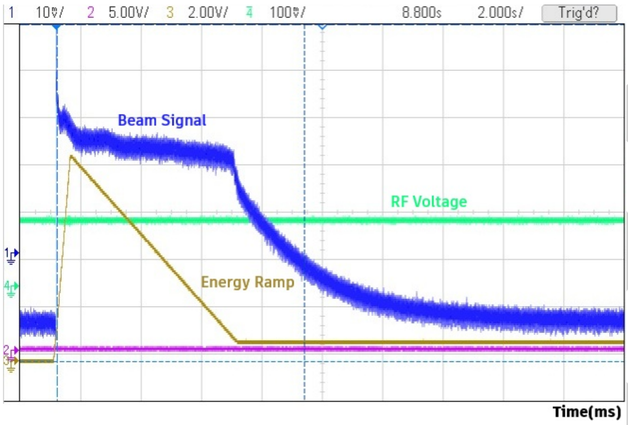
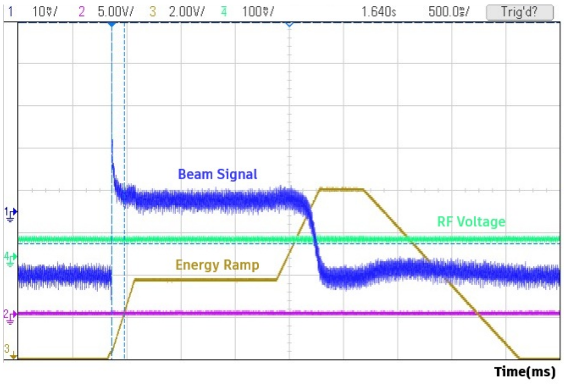


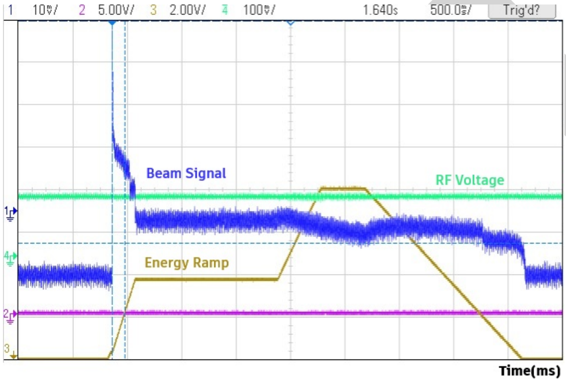
Figure 3: Beam current signal during operation at 45 MeV. Beam storage is achieved at low energy, but with reduced lifetime and increased sensitivity to RF settings due to weaker radiation damping.

In addition, a systematic variation of the RF voltage between 10 kV and 23 kV was performed (see Fig. 4). Beam capture and storage during energy ramps were found, as expected, to depend strongly on the RF voltage, motivating a more detailed analysis of beam stability under different operating conditions.

In addition to RF voltage, the effect of ramp speed on beam survival was investigated. A comparison of ramp step durations was performed for the transition from 250 MeV to 500 MeV at fixed RF voltage (23 kV) (see Fig. 5). Increasing the step duration resulted in improved beam preservation during the ramp. The slower ramp shows a more gradual evolution of the beam signal with reduced losses, while the faster ramp exhibits a sharper intensity drop at the beginning of the transition.



(a) RF voltage 10 kV



(b) RF voltage 23 kV

Figure 4: Beam current evolution during energy ramp from 250 MeV to 500 MeV for two RF voltages. Higher RF voltage increases longitudinal acceptance and improves beam survival during acceleration.

During the subsequent flat-top operation at 500 MeV, both cases show a similar decay behavior. During ramp-down towards lower energy, additional beam losses are observed in both cases, with increased sensitivity at reduced energy.

These results demonstrate that beam survival depends not only on RF voltage but also on ramp speed, highlighting the importance of optimized ramp profiles for efficient multi-energy operation.

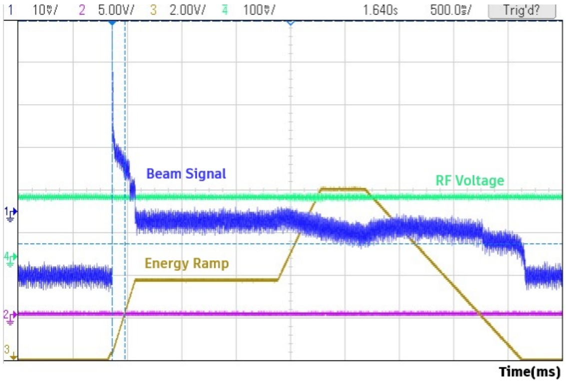
BEAM LIFETIME AND STABILITY ANALYSIS

Beam stability was evaluated using DCCT signals. As the device is not absolutely calibrated and is influenced by neighbouring magnet fields, the extracted lifetimes are indicative and used for relative comparison.

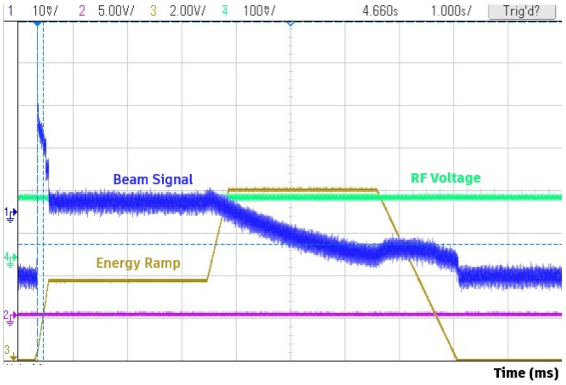
Lifetimes were determined by fitting the beam decay with an exponential function of the form

$$I(t) = I_0 e^{-t/\tau}. \tag{1}$$

At 500 MeV with 23 kV RF voltage, an effective lifetime of 8–10 s was observed. At 250 MeV with 10 kV RF volt-



(a) Step duration 500 ms



(b) Step duration 1 s

Figure 5: Beam current evolution during energy ramp from 250 MeV to 500 MeV at fixed RF voltage (23 kV) for two ramp step durations. Increasing the step duration improves beam preservation by enhancing longitudinal adiabaticity.

age, the lifetime increased to 12–15 s. These results lead to further discussion about the characterisation of beam parameters, which are especially related to longitudinal beam dynamics, including the bunch length, momentum acceptance and the resulting Touschek lifetime.

At lower energies (≤ 53 MeV), lifetimes decreased significantly to approximately 1–3 s, reflecting smaller Touschek beam lifetime, weaker radiation damping and increased sensitivity to scattering processes and machine imperfections.

ENERGY RAMPING PERFORMANCE

Controlled energy ramping between 53 MeV, 250 MeV, and 500 MeV was achieved using programmable magnet current tables within the EPICS control system.

Beam capture was maintained during acceleration to 500 MeV, demonstrating reliable synchronization between magnet currents and RF systems.

Beam survival strongly depended on RF voltage. At 10 kV, significant beam losses were observed during acceleration, indicating insufficient longitudinal acceptance due to limited RF bucket height. Increasing the RF voltage to 23 kV improved beam capture and reduced losses, resulting in higher transmitted beam intensity.

During ramp-down, additional beam losses were observed, attributed primarily to magnet hysteresis and optics mismatch at low excitation levels.

CONCLUSION

Operation of the KARA booster in storage-ring mode has been successfully demonstrated over an energy range of 45 MeV to 500 MeV. Stable beam storage and controlled energy ramping confirm the performance of the upgraded magnet power supplies and control system.

Effective beam lifetimes in the range of approximately 1–15 s were observed, showing a strong dependence on both RF voltage and energy. While higher RF voltage improves longitudinal acceptance and beam capture, the lifetime is additionally influenced by energy-dependent effects such as radiation damping and scattering processes.

The demonstrated low-energy capability establishes the booster as a compact and versatile testbed for accelerator studies relevant to future storage ring concepts such as cSTART.

Future work will focus on hysteresis compensation, systematic lifetime measurements with calibrated diagnostics, and optimization of ramping cycles.

REFERENCES

[1] KARA — Karlsruhe Research Accelerator, `https://www.ibpt.kit.edu/kara`

[2] L. H. Praestegaard, "Investigations of the ANKA Injector: Lattice, Beam Properties and Performance," PhD Thesis, Aarhus University, 2001. `https://phys.au.dk/fileadmin/site_files/publikationer/phd/Lars_Praestegaard.pdf`

[3] H. Hoteit *et al.*, "Modernizing of magnet power supplies at KARA and a transition to EPICS-based control system," in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 3739–3741. `doi:10.18429/JACoW-IPAC2024-THPS08`

[4] compact STorage ring for Accelerator Research and Technology, `https://www.ibpt.kit.edu/p_cSTART.php`