The MESA Energy-recovery LINAC

-new possibilities for accelerator-based experiments at low energies

GSI accelerator seminar November, 19, 2020
by Kurt Aulenbacher
The ERL – not a new idea

1960‘s: Maury Tigner proposes to recuperate the kinetic energy of an beam to operate colliders….

…Concept similar to hybrid car recuperation system
- very few ERL‘s have been realized so far - why?

AD 1900: C. Lohner/ F. Porsche: Hybrid electric car:
(look at the all wheel drive!): But - commercial failure!
→ Progress and the appearance of new requirements may change the issue!
The synchrotron is cost/energy efficient, the linac experiment is easier: Combine both advantages by using an ERL:

- High luminosity at low costs of RF-system
- Stationary beam conditions, low emittance, no beam cooling required
Recirculating accelerators and ERL‘s

upper picture: „Conventional one turn recirculating linac“: particles are accelerated twice
lower picture: „One turn ERL“ only one acceleration takes place particles are decellerated in second pass.
– ideally, there is no beam loading
Example for multi-turn recirculating accelerator: Mainz Microtron cascade (MAMI-C)

- 1.6 GeV beam energy, c.w. beam
- Up to 150kW beam power
- RF installation: 18 Klystrons (50kW each)
- In operation since 2007.
- Power consumption ~3MW
New project: MESA
(Mainz Energy-recovering Superconducting Accelerator)

- "World class" electron scattering experiments below Pion production threshold
- Requires at least 10 times beam intensity of MAMI (1-10mA vs. 0.1mA)
- MESA energy consumption 30% of MAMI
- Blue area available for MESA + extension building
Extension Building “CFP-1” (Hall-1)
Building status November 2020

Occupation readiness planned for November 2021
MESA Accelerator Layout

Double sided recirculation design with normal-conducting injector and superconducting main linac

Two different modes of operation:

(1300 MHz CW beam)

- EB-operation (P2/BDX experiment): polarized beam, up to 150 µA @ 155 MeV
- ERL-operation (MAGIX experiment): (un)polarized beam, up to 1 (10) mA @ 105 MeV
MESA Accelerator Layout

Source and Beam preparation system:
MESA Low Energy Beam Apparatus (MELBA)

- Defines the quality of the MESA beam
Source/beam preparation (MELBA) until July 2019

→ Operation with up to 100keV beam and up to 10mA beam current (>150kV possible, but not required)
→ 4 PhD theses finished within this subproject
→ MELBA was dis-assembled and put in storage due to start of hall renovation for MESA
Source/beam preparation (MELBA) commissioning in 2021

Photosource „STEAM“ (polarized beam)

High bunch charge/beam current source (unpolarized beam)

Double scattering Mott polarimeter

Spin Manipulation

Circular Chopper

f/2f buncher cavities

To MAMBO injector
10mA „spin-polarized mode“ beam with source „STEAM“

Surface charge limit effect in NEA photocathodes!


steady state-current measurements with the MESA-source
at 2.5MV/m, 500µs long pulses, doping level 1-2*10¹⁹

For practical purposes it is obviously important to avoid reduction of q.e.
MELBA with STEAM: Specs for polarized beam achieved/falls a little short of stage-1 goal for unpolarized beam

Deviation to simulation is attributed to sextupoles of correctors and large excitations because of insufficient magnetic shielding.
Non interfering bunch length measurement at buncher focus by coherent Smith Purcell radiation - controlling function of harmonic buncher

P. Heil et al. Proceedings IPAC 18

SPR power $P$ for different beam currents with adjusted second harmonic buncher.

$$P \sim I_s \cdot [S_{\text{inc}}(\eta, \zeta) + N_e S_{\text{koh}}(\eta, \zeta)]$$

RMS 4ps is required for Injection in MAMBO…

- Achievable for beam currents of a few mA
- Minimum bunch length at lower charge <1ps.
MESA Accelerator Layout

MESA injector linear accelerator: Milli-AMpere-Booster (MAMBO)

In ERL mode, all beam power (up to 50kW) comes from the injector: MAMBO is the „powerhouse“ of MESA
MAMBO Booster Linac

- Design inspired by the robust MAMI injector LINAC
- Energy gain 4.9MeV, beam power up to 50kW
- 4 room temperature RF structures
- RF-Amplifiers: one with ~75 kW (section 1) and 3 x ~60 kW (sections 2-4)

[Diagram showing the layout of the MAMBO Booster Linac]

Cross section view

[Diagram showing the cross section of the linac]

9m

100 keV

100 keV

5 MeV

Design of MAMBO: R. Heine
MAMBO Booster: Prototype Cavity

- Prototype needed for testing „multipacting“ behavior
  (Result: Prototype is stable also with longitudinal field, if processed correctly)

Pictures: R. Heine
MAMBO Booster: Prototype RF-Amplifier

- 15kW RF-powersource prototype:
- Modular (8*2kW, combined) Solid State Amplifier
- Used for tests of MAMBO RF-section ...and also for Cryomodule tests
- ~25 Amplifiers needed for MESA RF-system
- Redesign/optimization completed

Pictures: R. Heine
MAMBO Booster Linac-Status

- Final design and ordering of Rf-cavities in Spring 19 (delivery starts Jan 21)
- Ordering of Rf-amplifiers: December 19 (delivery of first unit mid 21)

Pictures: R. Heine

100 keV

5 MeV

Pictures and Design of MAMBO: R. Heine
Cryomodules

MESA ELBE-Enhanced Cryomodule (MEEC):

Superconducting RF-cavities provide large energy gain on small footprint and enable Energy-recovery-Linac (ERL)-operation
SRF-System: MEEC-Cryomodules

3.5 meter

Specs: 25MeV Energy gain at <40 Watt thermal loss at 2Kelvin
Production of 2 Cryomodules

- 2015: 2 MEEC’s ordered at RI Research Instruments GmbH
- Until 2017 SRF testing infrastructure became available at HIM
- 9/2018: First cryomodule does not meet specs at HIM → refurbishment by vendor
- 3/2019: Second tested cryomodule achieves specs during test at HIM/Mainz
- 8/2020: refurbished cryomodule tested and fulfills specs.

PhD thesis Timo Stengler
See also: T. Stengler et al. Proc. SRF 2019
doi:10.18429/JACoW-SRF2019-TUP041
Lattice ERL/EB mode
**Lattice**

ERL-Lattice – not completely symmetrical due to energy (gain) dependent focussing of RF-structures.

PhD theses Ch. Stoll and D. Simon
BBU investigation

13mA BBU limit at Target in 4pass configuration 2up/2down (without countermeasures)

PhD thesis Christian Stoll,
See also: C. Stoll and F. Hug: proceedings IPAC 2019
doi:10.18429/JACoW-IPAC2019-MOPGW025

Note:
Technical limitation: Heating of HOM coupler in TESLA cavities. (~1mA CW estimation, but needs to be determined experimentally)
Beschleunigte Aufbaumassnahme MESA (BAM)

2019: Layout using Linac tunnel, Modulatorenhalle and MEX-4

Most of instrumentation will be installed in Modulatorenhalle

Basis for the implementation of „BAM“ is the success of KPH-institute to manage fire-protection-modernization in the existing building

NEW (CFP-1)
OLD
MEX4-Hall
Linac-tunnel
Status CC/BAM and implications for schedule

- Our goal: 5MeV injector operational when CFP-1 is finalized
- Installation of MESA recirculator can begin 1/2022
- 15 month installation, 6 month comissioning
- begin of operations for experiments 10/2023
Thank you