The KIT accelerator test facilities:
Karlsruhe Research Accelerator KARA, short-pulse linac FLUTE and magnet characterization facilities

Akira Mochihashi, On behalf of IBPT test facilities
Karlsruhe Institute of Technology (KIT)
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- Future plan of the Karlsruhe accelerator test facilities

- Summary
Karlsruhe Research Accelerator KARA

- From ANKA „users facility“ to KARA „accelerator test facility“
  - Mission: research & development of beam physics and technology
  - Additionally, KARA can be operated as a synchrotron radiation light source

- Key parameters of KARA
  - Beam energy: 0.5 – 2.5 GeV
  - Beam current: up to 200 mA
  - Circumference: 110 m
  - 500 MHz RF system
  - RMS bunch length: 50 to few ps

- Outstanding features
  - Superconducting undulators
MCF: Magnet Characterization Facilities

SCU20: First commercial product worldwide

- Installation in December 2017
- Successfully operating in the KIT synchrotron since January 2018 without quenches
- First X-rays 10.1.2018

S. Casalbuoni et al., SRI2018

Courtesy of Dr. S. Casalbuoni
Infrastructure at KIT for SCU technology

To advance SCU technology unique infrastructure to characterize the magnetic field (MCF) of the superconducting coils (quality assurance) and to measure input parameters necessary for the design have been developed.

R. Voutta et al., PRSTAB, 19, 053201 (2016)

Courtesy of Dr. S. Casalbuoni
**FLUTE: short-pulse linac test facility**

- FLUTE (Ferninfrarot Linac- Und Test-Experiment)
  - Linac test facility for *femtosecond electron beam*
  - Generation of *THz coherent synchrotron radiation*
- R&D topics
  - Test bench for new diagnostic methods in fs-range
  - Synchronization on a femtosecond level
  - Bunch compression, beam physics

**First beam from FLUTE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final electron energy</td>
<td>~ 41 MeV</td>
</tr>
<tr>
<td>Electron bunch charge</td>
<td>0.001 - 3 nC</td>
</tr>
<tr>
<td>Electron bunch length</td>
<td>1 - 300 fs</td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>THz E-Field strength</td>
<td>up to 1.2 GV/m</td>
</tr>
</tbody>
</table>

*Courtesy of FLUTE commissioning team*
KARA storage ring: accelerator operation Today

- **Machine physics (588 hrs.)**
  - 1 week per month (in average)
  - Test for new diagnostic device
  - Beam physics & development
  - Low alpha operation etc.

- **User-operation (1194 hrs.)**
  - From Tuesday to Friday
  - Injection: once per a day (150 mA)
  - Energy ramping: 0.5 to 2.5 GeV
  - 70 mA at next injection
  - Beam injection by 1-2 operators
  - Stable beam delivery

- **Start-up**
  - Monday afternoon
  - Accelerator tuning

*We have good activities for machine physics experiment.*
An example of activities: THz CSR&beam physics

- Bursting THz CSR observation: **time-resolved phase space tomography**
  - Low alpha 1.3 GeV
  - MHz line camera KALYPSO
  - Picosecond sampling system KAPTURE
  - EO sampling in KARA

Long. bunch profile

Hor. bunch profile

Intensity of THz rad.

Turn-by-turn resolution

- Microbunching instability
  - Vlasov-Focker-Planck Solver „Inovesa“
  - Physics of microbunching instability
An example of activities: ARIES and EuroCirCol

**ARIES** (Accelerator Research and Innovation for European Science and Society)
- KIT as a member of „Rings with Ultra-Low Emittance (RULE)“ in **ARIES-WP7**
- Beam dynamics in low and **negative momentum compaction factor**
- Transnational Access Scheme (TNA) in ARIES
- KARA & FLUTE: as facilities offering TNA for „Electron and proton beam testing“ in **ARIES-TNA-WP11**

**EuroCirCol** (The European Circular Energy-Frontier Collider Study)
- „Measurements of cryogenic beam vacuum system prototype (KIT, INFN, CERN)“ in **WP4 Task4.6**
FLUTE short-pulse linac facility: present status

- Commissioning of RF photo injector

<table>
<thead>
<tr>
<th>RF photo-injector parameters</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2.998 GHz</td>
<td></td>
</tr>
<tr>
<td>Cells</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Peak E-field</td>
<td>100 MV/m</td>
<td></td>
</tr>
<tr>
<td>Peak power</td>
<td>20 MW</td>
<td></td>
</tr>
<tr>
<td>Output energy</td>
<td>7 MeV</td>
<td></td>
</tr>
</tbody>
</table>

Input power to RF gun: 4 MW

To go proceed RF commissioning:
- Replacement of Circulator on April 2019
- Commissioning of different RF components can be possible after the replacement

First beam on YAG screen

Courtesy of FLUTE commissioning team
FLUTE short-pulse linac facility: ongoing plan

- **Construction of bunch compressor**
  - Dipoles have been delivered
  - Quads are in production

- **Ultra-short bunch diagnostics**
  - Split ring resonator SRR: femtoseconds beam streaking with THz high intense EM field
  - Driven by fs laser for the RF photocathode

**Table: SRR parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gap size in x</td>
<td>20 µm</td>
</tr>
<tr>
<td>Gap size in y</td>
<td>20 µm</td>
</tr>
<tr>
<td>Gap width in z</td>
<td>10 µm</td>
</tr>
<tr>
<td>Resonant frequency</td>
<td>300 GHz</td>
</tr>
<tr>
<td>Peak electric field</td>
<td>500 MV/m</td>
</tr>
<tr>
<td>Integrated field</td>
<td>10kV</td>
</tr>
</tbody>
</table>
Distributed accelerator test facility: ATHENA

ATHENA: Accelerator Technology Helmholtz Infrastructure

- Distributed accelerator test facility in Germany
- Collaboration and Synergy of 6 Helmholtz centers
- DESY, GSI with HI Jena, HZB, HZDR, FZJ, and KIT
- Funded on 2018 with 30 million Euro

ATHENA at KIT

- Real-world applications of LWFA electron beams
- Enable multi-user access for materials and life sciences applications
- Example: MHz-repetition rate terahertz medical imaging facility (TMED)
- Benefits from cSTART and sensor technologies

From acceleration towards accelerators and user-readiness
Compact storage ring test facility: cSTART

- **cSTART**: compact Storage Ring for Accelerator Research and Technology

- **Storage of ultra-short (fs) electron bunches**
- 1st study\(^1\): laser wakefield accelerator (LWFA) injection in ring-based light sources
- Unique design\(^2\): non-equilibrium ring with *very large momentum acceptance*
- Goal: world-wide 1st injection & storage of a LWFA beam in a storage ring

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As facilities of ARIES Transnational Access

- **KARA & FLUTE**
  - Transnational Access Scheme (TNA) in ARIES
  - As facilities offering TNA for „Electron and proton beam testing“ in ARIES-TNA-WP11
  - New experiments and projects in the framework ARIES-TNA has been planned **JUST NOW.**

Please contact to ARIES-TNA if you have some new ideas of interesting experiments in KARA and FLUTE.

We are looking forward to seeing you at KIT with good collaboration!

https://aries.web.cern.ch/ta
As a platform of beam physics experiment
- Installation of „universal device section“ into KARA storage ring
- Users perform „Plug & Play“ experiment with 0.5 – 2.5 GeV beam

Examples of the Plug & Play experiment
- Vacuum chamber with variable aperture & coating: **impedance**
- Beam test for insertion devices & magnets: **light source development**
- Beam instrumentation devices: **beam dynamics & diagnostics**
- RF devices: **RF acceleration & beam manipulation** and more.

Future KARA: Beam Physics Test Facility
- Systematic beam diagnostic measurement is possible **now**
- Flexibility of beam condition: bunch length, beam energy

Advantages of experiment at KARA
- Science: improvement of beam tuning knobs, diagnostics etc.
- Technology: vacuum system design, alignment method etc.

Long straight section: 5.6 m x 4
Short straight section: 2.2 m x 4

So many world-wide contributions to the accelerator physics and technology can be expected.
Future FLUTE: Short-pulse Beam Facility

- Beam physics experiment with **real short-pulse electron beam**
  - Preparation for **experimental station beamline**
  - Users perform experiments with their own instrumentation

- Examples of the experiment with short-pulse beam in FLUTE
  - R&D of beam diagnostics and instrumentation: **beam dynamics & diagnostics**
  - Generation of THz radiation: **light source**
  - Short-pulse electron beam application: **material science & chemistry**

So many contributions to both the accelerator physics and matter science can be expected
Summary: Present status

- Karlsruhe Research Accelerator KARA
  - Accelerator test facility with 0.5-2.5 GeV electron storage ring
  - Activities for machine physics
    - THz CSR generation, microbunching instability etc.
    - ARIES, EuroCirCol project

- FLUTE short-pulse linac test facility
  - First beam confirmed and further commissioning now
  - Ultra-short pulse generation
    - Bunch compression
    - Femtosecond beam diagnostics: splitting ring resonator

- Distributed accelerator test facility: ATHETA
  - Funded and ongoing now

- Compact storage ring test facility: cSTART
  - Funded and ongoing now
Summary: Future plan

Future KARA

- Platform of beam physics experiment
- „Plug & Play“ experiment in „universal device section“ at KARA storage ring
- To keep flexibility of experimental condition and beam operation

Future FLUTE

- Beam physics experiment station with short-pulse electron beam
- Users can bring their own instrumentation and perform their experiment
- Accelerator physics, material science, chemistry etc.

So many contributions to the accelerator physics and related sciences can be expected

Thank you very much for your attention!
Backups
Future plan: KARA storage ring

- **Control & manipulation** of accelerators and beams
  - **Control:** optimization of operating parameters by **machine learning**
    - Optimization of injectors (booster, microtron, beam transport line)
    - Optimization of storage ring for various kind of operating modes
  - **Control:** accelerator operation with **saving energy consumption**
    - Optimization of booster operation: pattern control
    - Optimization of warm-up process in storage ring: start-up/shut-off sequence control
    - Cooling water, air conditioning control

- **Manipulation:** 3-dimensional **beam manipulation**
  - RF gymnastics and modulation
  - Alpha (and lattice) manipulation
  - Expansion of dynamic aperture
  - Improvement of tuning knobs
  - **Control of THz CSR generation**

RF modulation in KARA
Future plan: FLUTE short-pulse linac facility

Control & application of ultra-short pulse beam

- **Control:** bunch compression to ultra-short pulse
  - Beam diagnostics of THz-CSR from bunch compressor section
  - **Feedback** to linac/laser parameters with **machine learning** by THz-CSR diagnostics

Application: ultra-short pulse beam source

- R&D for new detectors and beam diagnostic devices
- Electron beam & THz-CSR beam

Application: an injector for cSTART ultra-short pulse storage ring

- Optimization of injection condition for ultra-short pulse beam

... And more!
IBPT: Institute for Beam Physics and Technology

- Director: Prof. Dr. Anke-Sussane Müller
  - Coordination & project team
  - Safety & radiation protection team
  - Administration team
- Operation-1 & Accelerator R&D Gr.
  - Device team
  - Theory & beam dynamics team
  - Control & instrumentation team
  - THz/IR application team
- Operation-2 & Accelerator R&D Gr.
  - Diagnostics R&D team
  - New accelerator concept team
  - IT team
  - Insertion device team
- Technical Gr.
  - Workshop team
  - Construction team
  - Vacuum, water & cooling team
  - Electricity & electronics team

http://www.ibpt.kit.edu/