Status of Accelerator Facility of Kyushu University

Nov. 13, 2012. FFAG-WS at Osaka University

Dept. of Phys., Kyushu Univ.
Noro, T.
• Brief history and present accelerator activities at Kyusyu University

• Construction of the tandem-FFAG accelerator facility in new campus

• Uses and requirements
Brief History of Accelerators in Kyushu University

• 1943 Construction of Van de Graaff accelerator
  Terminal Voltage : 3 MV (1952)

• 1959 Construction of Cock Croft Walton accelerator
  Acceleration energy : 500 kV (1962)

• 1963 Original pellet Chain Development (VdG)
  Terminal Voltage : 7.5 MV (1970)

• 1972 Construction of Tandem accelerator
  Terminal Voltage : 11 MV (1980)

• Present activities with the Tandem accelerator
  □ Few-nucleon systems  □ $^{12}$C-AMS
  □ Astro-nuclear reaction ($\alpha + 12C \rightarrow 16O + \gamma$)

The tandem accelerator is still used actively.
Campus movement and construction of new facility

Schedule of the movement

2005-6: Faculty of Engineering
2015: Faculty of Science
(The schedule was recently fixed)

The present tandem accelerator is forced to shut down in 2014.

New accelerator facility is being constructed.
- Only an accelerator hall exists.
- Experimental area will be constructed as a part of the campus movement.
The test machine that Prof. Mori developed was transferred and reinstalled.

Newly constructed machine still under development
Further development at Kyushu

A machine with various possibilities
Challenges for new usage

Main accelerator: FFAG Synchrotron

“Center for accelerator and beam applied science”
Present (1st stage) FFAG accelerator facility

Accelerator and Beam Applied Science, Kyushu Univ.

**Design values of the FFAG**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>magnet</td>
<td>Radial sector type (DFD-triplet)</td>
</tr>
<tr>
<td>Cell</td>
<td>12</td>
</tr>
<tr>
<td>K-value</td>
<td>7.62</td>
</tr>
<tr>
<td>Beam energy</td>
<td>12 → 150 MeV</td>
</tr>
<tr>
<td></td>
<td>(10 → 125 MeV)</td>
</tr>
<tr>
<td>Radius</td>
<td>4.47 → 5.20 m</td>
</tr>
<tr>
<td>Betatron tune</td>
<td>H: 3.69～3.80</td>
</tr>
<tr>
<td></td>
<td>V: 1.14～1.30</td>
</tr>
<tr>
<td>Max. field</td>
<td>F-field: 1.63 T</td>
</tr>
<tr>
<td>(along orbit)</td>
<td>D-field: 0.78 T</td>
</tr>
<tr>
<td>Circ. freq.</td>
<td>1.55～4.56 MHz</td>
</tr>
<tr>
<td>Repetition</td>
<td>100 Hz</td>
</tr>
</tbody>
</table>
Present (1st stage) FFAG accelerator facility

Accelerator and Beam Applied Science, Kyushu Univ.

History of the re-installation:

2008- Hardware reconstruction
2011- Commissioning of the injector cyclotron
2011- Commissioning of the FFAG accelerator
2011.12.2. One turn circulation was observed.
2012.11.- Installation of the RF cavities.

Beam signal form a tune monitor (2012.2.)
The 1\textsuperscript{st} stage injector: cyclotron

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>AVF cyclotron</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>10 MeV</td>
</tr>
<tr>
<td>Ion Source</td>
<td>Internal PIG (LaB$_6$ Cathode)</td>
</tr>
<tr>
<td>Extraction Radius</td>
<td>300 mm</td>
</tr>
<tr>
<td>Magnetic Field</td>
<td>Max. 1.54 T</td>
</tr>
<tr>
<td>RF Dee Voltage</td>
<td>40 kV</td>
</tr>
<tr>
<td>RF Frequency</td>
<td>47 MHz (2\textsuperscript{nd} harmonic acceleration)</td>
</tr>
<tr>
<td>Beam Current</td>
<td>2 $\mu$A (Duty 4%, 100Hz)</td>
</tr>
</tbody>
</table>

Limitations:

- Proton (and deuteron) beam only.
- 10MeV is the maximum. (12 MeV is required for 150 MeV acceleration.)
- Time structure does not match the FFAG synchrotron.

→ Replacement of the injector is preferable.
Expected activities of the new facility at Kyushu Univ.

- Development research on the FFAG accelerator
  - various kinds of application

- Extension of present accelerator activities
  - low-energy nuclear physics \(\rightarrow\) astro-nuclear physics
  - AMS

- General purpose use in various fields
  - energy science, material science, life science, medical science (basic)
As a general purpose accelerator facility...

**FFAG development**
Underdeveloped machine just born.

**Accelerator science**
Many possibilities no other machines have.
- Flexible beam time-structure
- Large acceptance, multi-beam
- Possibility as a beam delay
- Acceleration of various beams
- High intensity by fast repetition

**DNA processing, breed improvement**

**Life science**

**Environment science**

**DNA damage by heavy ion**

**Restoration of DNA survival by apoptosis**

**3-body force, nuclear data**

**Hadron science**

**Energy science**

3NF is required in nucleus

1936: Yukawa predicted 2NF
1994: Sagara found experimental evidence of 3NF

**Space simulation**

**Life science**

**Environment science**

**Fronteer**

**Industry use**

**Space medicine**

**Space-use devices**

**Monochro/white neutron field**

**Hadron science**

**Material science**

**Environment science**

**Industry use**

**Reactor material**
Calibration of neutron detectors
Basic data for acc. driven reactor nuclear waste

**Biological irradiation effect**

**Energy transfer process**

**Life science**

**Material science**

**Medical use (basic)**

30% of incident energy are converted to other radiation

- High quality radiation treatment
- Radiation damage process of semiconductor devices

**New field**

- [ ] [ ] [ ]
Expected activities of the accelerator facility at Kyushu Univ.

- Development research on the FFAG accelerator
  - various kinds of application

- Extension of present accelerator activities
  - nuclear physics
  - AMS

- General purpose use in various fields
  - energy science, material science, life science, medical science (basic)

A variety of beams are to be requested.

Introduction of Tandem accelerator, as an injector and for separate use, is preferable.
Transfer of the tandem accelerator from Kyoto Univ.

<table>
<thead>
<tr>
<th>Type</th>
<th>8UD Pelletron (NEC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal Voltage</td>
<td>8 MeV</td>
</tr>
<tr>
<td>Ion Source</td>
<td>SNICS II (→ MC SNICS) ALPHATROS</td>
</tr>
<tr>
<td>Injection Voltage</td>
<td>-200 kV → -80 kV</td>
</tr>
<tr>
<td>Pellet Current</td>
<td>150 μA × 2</td>
</tr>
<tr>
<td>Charge Stripper</td>
<td>C-foil and N₂-gas</td>
</tr>
<tr>
<td>Tank size</td>
<td>3 m⁰ × 13.6 m</td>
</tr>
<tr>
<td>Gas</td>
<td>5 atm SF₆</td>
</tr>
</tbody>
</table>
Plan view of the accelerator facility at Kyushu Univ.
Construction of the accelerator facility

1st phase:
FFAG (E_p=120~150MeV)
(from KEK: 2008-2009)
Feb. 18, 2012
Installation of accelerator tank

Mar. 11, 2012
tandem prefab. and
FFAG bldg.
Re-fabrication of the accelerator is in progress

Nov. 6, 2012
Construction of the accelerator facility

1st phase: FFAG (E_p=120~150MeV)  
(from KEK: 2008-2009)

2nd phase: (recently scheduled)  
Experimental area and apparatus for Tandem experiments  
(campus movement of Faculty of Sci. 2013-2015)

1.5th phase: Tandem accelerator  
(from Kyoto Univ.: 2011-2014)

2th phase (not scheduled):  
Experimental apparatus for FFAG experiments  
(campu
Construction schedule


Campus move

Faculty of Eng.

Faculty of Sci.

Buildings

1st stage
(FFAG bldg.)

2nd stage
(Tandem + exp. area)

FFAG

transfer
construction
commissioning

 Injector cyclotron

Tandem accelerator

transfer  construction  commissioning

Present tandem

shut down
Uses and requirements
① Early stage

Development for stable operation of FFAG

Separate use of tandem-beams
- Astro-nuclear physics
- AMS etc.
General uses of FFAG-tandem system

Requirements:

- **Moderate intense beam, at least**
  - Matching of FFAG (AC) and tandem (DC) is required.
  - One way is to use pulsed ion sources.
    - 100 Hz of FFAG beams is much faster than the time-constant of the tandem terminal.

- **Slow extraction**
  - Essential for nuclear-scattering experiment.
Produced RI (life > 1 min)
- $^7\text{Be}$, $^{10}\text{Be}$, $^{11}\text{C}$, $^{14}\text{C}$, $^{13}\text{N}$, $^{15}\text{O}$, $^{17,18}\text{F}$, ....

Accelerator and production reactions:
- 10 MeV cyclotron (p,n) reactions,
- 8MV tandem accelerator (p,n), (d,X) reactions

Nuclear spectroscopy by Low energy resonance and transfer reactions.

Unstable nuclei
Astro-nuclear phys.
- systematic studies
- technical developments
Requirement for RI acceleration or AMS

- Almost 100% injection of DC beams
  - Charge exchange injection with ionization cooling

Ionization cooling:
Compensation of longitudinal energy-loss in a foil by RF acceleration


( Ray-tracing by Miyaoki )
Luminosity is drastically increased by 3-dimensional cooling using a wedge target.
AMS with post-acceleration

**e.g.** $^{36}\text{Cl}$ $350\text{MeV}$ Full-strip ion beam with 2.5% efficiency*

or $12^+\text{ ion beam with 10% efficiency}^*$

$^{41}\text{Ca}$ $400\text{MeV}$ $13^+$ beam with 10% efficiency*

**Advantage:**
- Easy isotope separation for heavy elements

**Subjects**
- Archeology, Earth science, Life science, ...

**Requirement to accelerator**
- Acceleration of different isotopes with same parameters
- Charge-exchange injection with ionization cooling

*Except FFAG efficiency
⑤ Irradiation of vertical beams and neutrons

Intense primary beams will be given by negative-ion injection

Use of spallation neutrons
BNCT
material science
nuclear data etc.

primary beam

8m deep pit

Shield
Moderator
Phantom
Sample

vertical irradiation

B1F
B2F
• A FFAG-tandem accelerator facility is under construction
  
  Construction of the tandem building and movement of Hakozaki facility was decided recently.

• Many kinds of development works and challenges are required for full use of the facility
  
  I would like to thank Mori-san and other accelerator people for their support.