Alignment of LIPAC
the Linear IFMIF Prototype Accelerator:
requirements and current status

F. Scantamburlo et al.
(IFMIF/EVEDA Project Team)
In 2 years, the growth of energy consumption in China was greater than total consumption in Germany.

Medium term Problems
- Greenhouse effect
- Resources are finite

80% of world energy generated from fossil fuels

FUSION ENERGY WILL BECOME A SOLUTION
The first wall of the reactor vessel shall absorb neutrons energy and breed tritium.

ITER first wall will present <2 dpa at the end of its operational life.

In a Fusion power plant ~150 dpa within 5 years are expected.

Transmutation energies threshold of Fe >3 MeV yield α-particles.

He induced embrittlement.

F. Scantamburlo
The accumulation of gas in the materials lattice is intimately related with the neutron energy

\[ ^{56}\text{Fe}(n,\alpha)^{53}\text{Cr} \]

(incident n threshold at \textbf{2.9 MeV})

and

\[ ^{56}\text{Fe}(n, p)^{56}\text{Mn} \]

(incident n threshold at \textbf{0.9 MeV})

Noble gases are not dissolved in metals

Swelling and embrittlement of materials takes place
Existing neutron sources do not provide the needed answers.

Fission reactors n average energy $\sim 2$ MeV

Spallation sources present a wide spectrum with tails in the order of hundreds of MeV

Generation of light isotopes in the order of ppm

No efficient $p^+$ or $\alpha$-particle generation
Do we need Fusion relevant n source?

Understanding the degradation of physical properties of the materials critically exposed to 14.1 MeV n flux is a key parameter for all machines after ITER to allow accomplishment of the design and facility licensing.

Material scientists need experimental data given the number of variables playing a primary role in materials degradation:
- neutrons flux
- neutrons spectrum
- neutrons fluence
- material temperature,
- thermo-mechanical history and microstructure
- mechanical loading
- lattice kinetics...

In ITER ~3 dpa at its end of life
In a Fusion Power plant ~30 dpa/year
IFMIF/EVEDA
A fruitful Japanese-European International collaboration
(Broader Approach Agreement)
with 7 countries involved
with the respective main research labs in Europe
and main universities in Japan
IFMIF
International Fusion Materials Irradiation Facility

EVEDA
Engineering Validation & Engineering Design Activities

Article 1.1 of Annex A of the BA Agreement mandates IFMIF/EVEDA
...to produce an integrated engineering design of IFMIF and the data necessary for future decisions on the construction, operation, exploitation and decommissioning of IFMIF, and to validate continuous and stable operation of each IFMIF subsystem

Signed in February 2007
Entered into force on June 2007
Deuterons at 40 MeV collide on a liquid Li screen flowing at 15 m/s

A flux of $10^{18} \text{n} \cdot \text{m}^{-2} \text{s}^{-1}$ is stripped with a broad peak at 14 MeV

Availability of facility >80%

International Fusion Materials Irradiation Facility
The Design of IFMIF is broken down in 5 facilities

Accelerator Facility
Lithium Target Facility
Test Facility
Post-irradiation and Examination Facility
Conventional Facilities

Objective of Validation activities
Accelerator facility of IFMIF

- 2 x 5 MW beams
- Individual availability of >90%
- the highest intensity
- the highest beam power
- the highest space charge
- the longest RFQ

D\(^+\) source
CW 140 mA
100 keV

RFQ
175 MHz
5 MeV

SRF Linac
HWR 175 MHz
40 MeV

2 accelerators, 2 x 125 mA, 2 x 5 MW

Beam shape
200 x 50 mm\(^2\)

Lithium jet
Deuteron Beam
Low Flux (7.5)
Medium Flux (0.5)
High Flux (0.5)
Features of IFMIF vs LIPAc

d+ accelerator

125 mA CW

5 MW vs 1.125 MW

Space charge issues

Low energy/high power

So are LIPAc as IFMIF within present accelerator technology

NGHIEM, P.H.P. et al., The IFMIF-EVEDA Challenges in Beam Dynamics and their Treatment, Nucl. Inst. Meth. 654 (2011) 63–71

WEI, J. et al., The very high intensity future, IPAC 2014, Dresde, www.jacow.org
Space charge issues are severe at low $\beta$
They cancel in relativistic regions

$$K = \frac{eI}{2\pi\varepsilon_0 m_0 v^3 \gamma^3}$$

LEDA reached 100 mA CW in 1999
at 6.7 MeV protons at the exit of the RFQ
Many lessons learnt have been implemented in LIPAc

LIPAC&IFMIF target 125 mA
at 5 MeV deuterons at the exit of the RFQ

Spoke resonators have been demonstrated in 2000s to perform for light hadrons at low $\beta$

Deuterons present high inelastic cross sections
commissioning would be difficult if done with deuterons
but protons at half energy and half intensity behave as deuterons at nominal conditions

SCANTAMBURLO, F. et al., LIPAc, the 125 mA/9 MeV CW deuteron IFMIF’s prototype accelerator: what lessons have we learnt from LEDA?, IPAC2014
Installed and commissioned in Rokkasho
LEDА reached 100 mA @ 6.7 MeV at the exit of the RFQ with protons in CW in 1999: beam losses mainly due to beam halo.

Beam dynamics calculation on IFMIF accelerator indicates feasibility of nominal performance:
125 mA @ 5 MeV at the exit of the RFQ + SC accelerating stages.

The alignment/learning the position of some components in ± 0.1 mm respect the beam axis is indispensable to:
1. ramp up correctly the current,
2. contain beam losses to 1 W/m to allow hands-on maintenances.

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**Table 1: Errors distribution**

<table>
<thead>
<tr>
<th>Error Type</th>
<th>Error range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEBT</strong></td>
<td></td>
</tr>
<tr>
<td>Solenoids Misalignment [x,y]</td>
<td>±0.2 mm</td>
</tr>
<tr>
<td>Solenoids Tilt [(\varphi_x, \varphi_y)]</td>
<td>±3.5 mrad</td>
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<td><strong>RFQ</strong></td>
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<td>RFQ Segment Misalignment [x,y]</td>
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<td>RFQ Voltage (first harmonic shape)</td>
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<tr>
<td>RFQ Mean Radius</td>
<td>±20 µm</td>
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<td>RFQ Vane Radius</td>
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<tr>
<td><strong>MEBT</strong></td>
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<tr>
<td>Quadrupoles Misalignment [x,y]</td>
<td>±0.2 mm</td>
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<tr>
<td>Buncher cavities Misalignment [x,y]</td>
<td>±1 mm</td>
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<td>Buncher cavities Tilt [(\varphi_x, \varphi_y)]</td>
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<tr>
<td>BPMs Measurement Accuracy</td>
<td>±0.1 mm</td>
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<tr>
<td><strong>SRF linac</strong></td>
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<td>Resonators Misalignment [x,y]</td>
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<td>Resonators Tilt [(\varphi_x, \varphi_y)]</td>
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<td>BPMs Measurement Accuracy</td>
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<tr>
<td>BPMs Measurement Accuracy</td>
<td>±0.1 mm</td>
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</tbody>
</table>

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N. Chauvin et al., *Start-To-End beam dynamics simulations for the prototype accelerator of the IFMIF/EVEDA Project*, IPAC 2011.

Beam halo is known to be a major cause of beam loss and activation in high current hadron Linacs.

LEDA reached 100 mA at 6.7 MeV with protons and demonstrated that beam halo is due to resonances between individual particles and beam core oscillations through optical mismatches in transition regions.

Installation & commissioning key aspects
Precise alignment
Halo-matching approach


J. Wei, *The very high intensity future*, IPAC 2014

Accuracy assembly requirements to meet beam halo requirements are on the limit of instrumentation performances.

Linear IFMIF Prototype Accelerator (LIPAc)

35 m

± 0.1 mm
• **LEICA AT401 Laser Tracker:**
  - One of the most accurate tracker in the market (MPE angle accuracy ±(16μm+5μm/m), MPE distance accuracy: ±10 μm, level accuracy: ± 1 arcsec);
  - Portability

• **Spatial Analyzer Ultimate metrology software:**
  - Experience of F4E ITER Metrology team
  - Capability of estimate the uncertainty of measurements through USMN algorithm
  - Capability of simulations of measurements to optimize measurement process;
  - Verification of instrument performance in the real environment
According to ISO and NIST, GUM, the measurements must be accompanied with their uncertainty.

To assess device position tolerance range +/- 0.1 mm in the assembly hall.

ITER metrology handbook: Target measuring uncertainty < 0.02 mm in the assembly hall.
According to Spatial Analyzer Simulation made by F4E, the uncertainty of locating the tracker would be 0.13 mm which was not compatible with the tolerance range to be assessed +/- 0.1 mm.
New network design - simulations

Placement of 120 new fiducials surveyed 5 times by 5 station will limit measurement uncertainties <0.02 mm with the laser tracker Leica AT401 suitably located in the accelerator hall during all future alignment tasks.
New network design - simulations

Uncertainty field evaluation along the beam line after USMN 1000 samples @ 2 σ

Target uncertainty

Laser Tracker stations

Distance from beam line origin [mm]

Uncertainty [mm]
Upgrade of the alignment network - survey

50 Floor nests

69 Wall supports ad hoc machined

1 datum Pillar with Micro-adjustable screws

Leica AT 401
Real vs simulated measurements
Uncertainty plot
The BLF is intrinsically defined by the coordinate of the 130 network fiducials.

Horizontality has been improved using the AT401 levelling capabilities.
Since the beam line frame is not materialized we retained worth to materialize a coordinate frame in the accelerator vault to make quick checks of the impact on the alignment of exceptional events (i.e. an earthquake).

The origin is placed on a particular floor fiducial. The position of a reference on a pillar has been adjusted to obtain an axis parallel to the beam line.
Effect of thermal expansion of the building

Rokkasho enjoys hard winters and hot summers we established a simple procedure to study and eventually compensate the effect of thermal expansion of the building:
Weekly measurement by LT the distance between two particular points on the floor almost aligned with the beam line
Weekly measurement of the air temperature in the vault and external temperature
Weekly measurement thermometer the temperature of the floor on 30 points evenly spread
Monitoring will continue on a period including at least one winter and one summer

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<td></td>
</tr>
</tbody>
</table>

The injector and the LEBT have been successfully assembled and aligned with TH system in May 2014.

Differently from the other components which will be fiducialized in Europe before delivery in Rokkasho, the Injector and the LEBT were fiducialized by AT401 after TH alignment.
With good success!

Max uncertainty
0.04 mm
Redefinition of the network

An update of the network has been performed in August 2014. Movements of the building not related to the thermal expansion did not allow anymore locating the instrument within the target uncertainty RMS< 0.025 mm.

A deviation of 0.05 mm in transversal (X axis) and vertical (Y axis) of the beam line has been registered.
SA software with USMN has been a key factor for the definition of the network in the accelerator hall.

Simulation tool demonstrated to be very effective to plan, organize and optimize measurement campaigns.

Thermal expansion study is ongoing.

Efficient alignment actions have been in place and we are ready for the alignment of the components coming in the coming months.
L. Semeraro, A. Lo Bue, L. Poncet, F4E T. Morishita, H. Sakaki, H. Shidara, JAEA

THANK YOU!!!
Thank you for your attention