Status of the JAEA-ADS Superconducting Linac Design

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Abstract

The Japan Atomic Energy Agency (JAEA) is working in the research and development of an Accelerator Driven Subcritical System (ADS) for the transmutation of nuclear waste. To this end, JAEA is designing a 30-MW cw proton linear accelerator (linac) with a beam current of 20 mA. The JAEA-ADS linac starts with a Normal Conducting (NC) up to an energy of 2.5 MeV. Then, five Superconducting (SC) sections accelerate the beam up to 1.5 GeV. The biggest challenge for this ADS linac is the stringent reliability required to avoid thermal stress in the subcritical reactor, which is higher than the achieved in present accelerators. For this purpose, the linac pursues a strong-stable design that ensures the operation with low beam loss and fault-tolerance capabilities to continue operating in case of failure. This work presents the beam dynamics results toward achieving high reliability for the JAEA-ADS linac.

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Introduction

Japan Atomic Energy Agency (**JAEA**) is developing an Accelerator Driven Subcritical System (**ADS**) for the transmutation of nuclear waste.

Fig.1: General scheme for the ADS [1].

Table 1: Main characteristics of the JAEA-ADS accelerator.

Parameter		Beam trip duration
Particle	Proton	
Beam current (mA)	20	
Beam energy (GeV)	1.5	
Duty factor (%)	100 (cw)	
Beam loss (W/m)	< 1	
Length (m)	429	
Beam trips per year [2]	2×10^4	≤ 10 s
	2×10^3	from 10 s to 5 min
	42	> 5 min

The main challenge of an **ADS** accelerator is the **severe restriction** in the allowable beam trips and their duration. To this end, a **reliability-oriented** design is pursued.

[1] K. Tsujimoto et al., "Neutronics design for lead bismuth cooled accelerator-driven system for transmutation of minor actinide", JNST, vol. 41, no. 21, p. 21, Jan. 2004.

[2] H. Takei, et al., "Estimation of acceptable beam-trip frequencies of accelerators for accelerator- driven systems and comparison with existing performance data", J. Nucl. Sci. Techol., vol. 49, p. 384, Sep. 2012.

Reliability-oriented design

- A **reliability-oriented** design is based on the strategy presented by the European ADS project (MYRRHA)[1].

Robust lattice design:

- Control of the beam loss.
- Simple design.
- Derating components operation.

Fault-tolerance:

- Serial and parallel redundancy.

Repairability:

- Online and manual tunning.
- Maintenance.

[1] J.L. Biarrotte, *Reliability and fault-tolerance in the European ADS project,* CERN Yellow Report CERN-2013-001, pp.481-494 .

JAEA-ADS linac design

A strong optics design has been developed

- **Control** of the beam envelopes and emittance growth.
- Equipartitioning condition (**EP**).
- Among others…

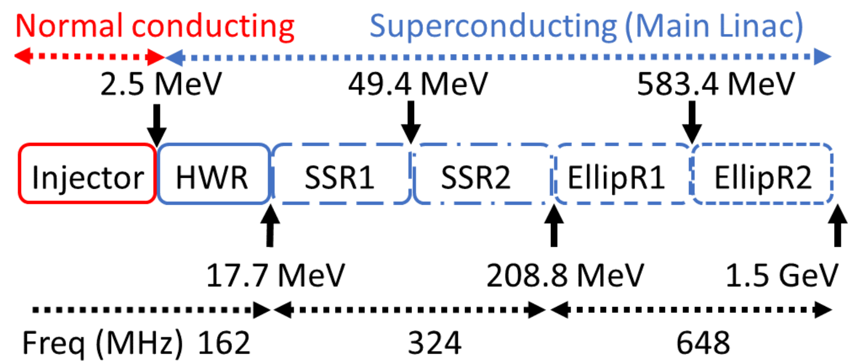

Fig. 2: Layout of the JAEA-ADS.

The optics performance was evaluated for the Ideal Machine (**IM**) and errors cases (Static Element Errors (**SEE**), Dynamic Element Errors (**DEE**), and Input Beam Errors (**IBE**)).

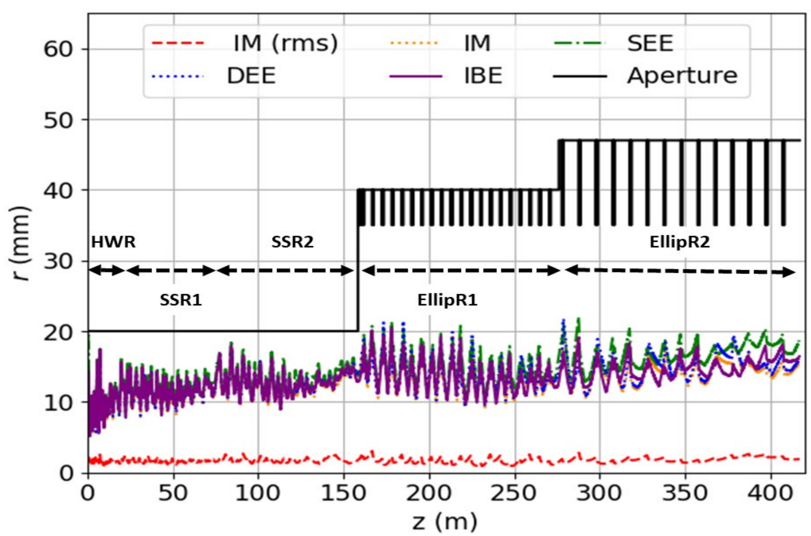

Fig. 3: Maximum radial envelopes for different beam cases.

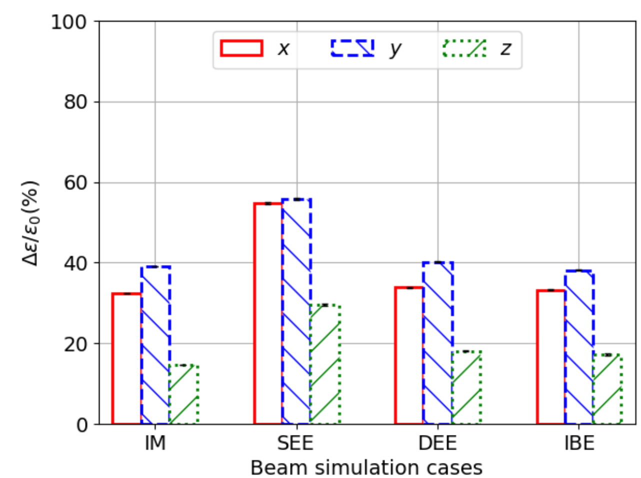

Fig. 4: Emittance growth

Fault-tolerance

The **ability to operate** the accelerator with an **acceptable** beam performance in the presence of undesired behavior of machine components, the so-called **Fault-tolerance**[1].
This study investigated serial redundancy.

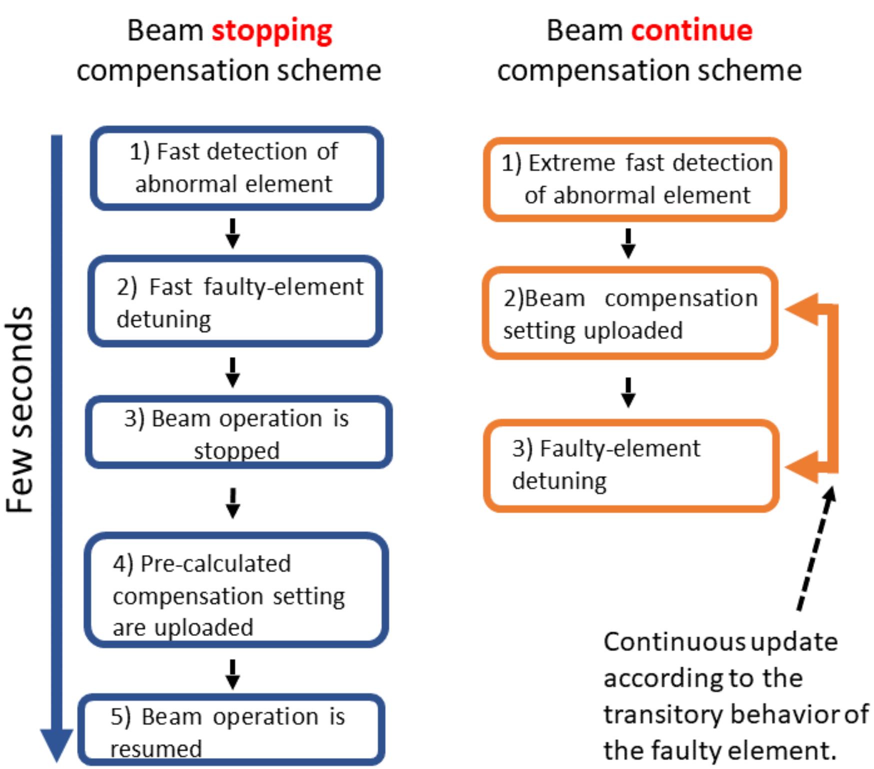

Fig. 5: Serial redundancy strategies

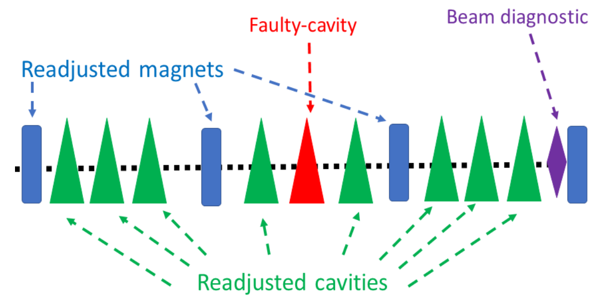

Fig. 6: Serial redundancy scheme.

The two schemes were implemented to achieve:

- Beam loss < 1 W/m
- $\frac{\Delta E}{E_0} < \pm 1\%$
- $\frac{\Delta \varepsilon_{rms}}{\varepsilon_0} <$ double
- $M < 0.2$
- $\Delta E_{acc} = 20\%$ (for stopping) and 50% (for continue)

[1] J. L. Biarrote et al, "Beam Dynamics Studies for the Fault Tolerance Assessment of the PDS-XADS Linac Design", in Proc. 9th European Particle Accelerator Conf. (EPAC'04), Lucerne, Switzerland, Jul. 2004.

Serial redundancies results

Stopping scheme

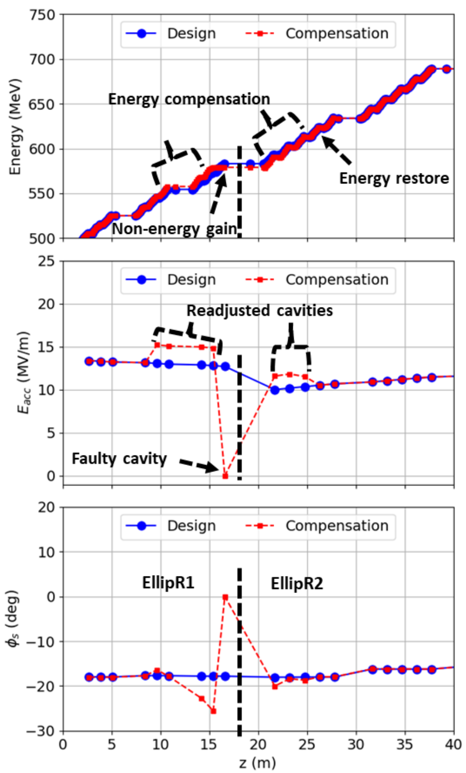

Fig. 7: Compensation scheme for the failure in the last EllipR1's cavity

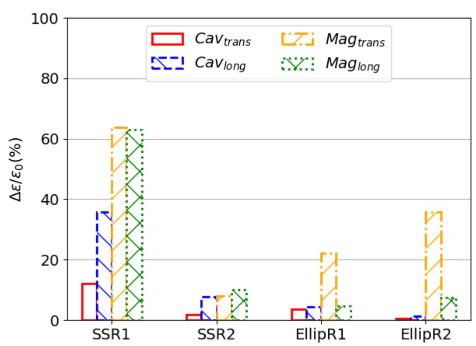

Fig. 8: Normalized rms emittance growth for the worst compensation case in SC region.

Continue scheme

Faulty cavity at the end of the SSR1 region

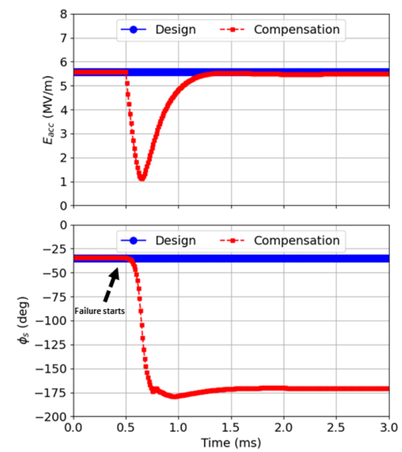

Fig. 9: Transient behavior of the faulty SSR1 cavity.

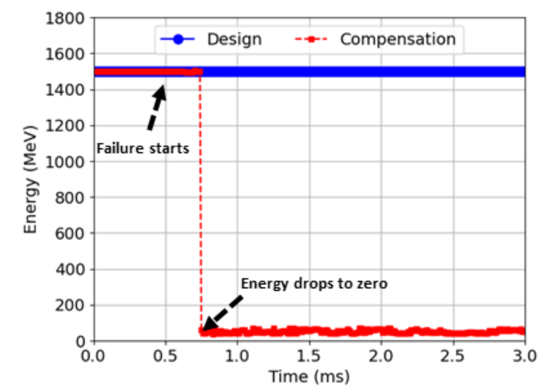

Fig. 10: Transient behavior of the energy at the end of the linac for the failure case.

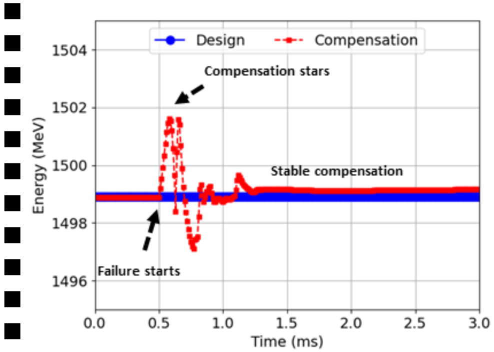

Fig. 11: Transient behavior of the energy at the end of the linac for the compensation case.

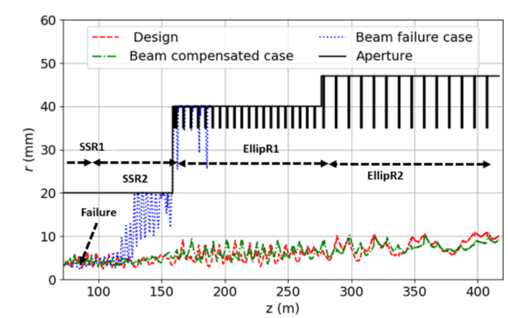

Fig. 12: Maximum radial beam size.

Conclusions

- The multiparticle tracking studies showed:
  - Beam **losses** of **20 mW/m** in error cases.
  - Proper **control** of the beam **envelopes** and **emittance growth**.
- The fault-tolerance analysis:
  - **Serial redundancy** could be applied **from** the **spoke** section to the end of the linac.
  - **Acceptable** beam **output** properties.
  - **Without** compromise the **cavity operation**.
  - **Neither** a significant **increase** of the **RF power budget**.
- The results represent a step **towards** achieving a **reliability-oriented linac** for the JAEA-ADS project.