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Development and experimental validation of a machine learning-based methodology for cyclotron beam control: results from the PSI HIPA facility

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Transmutex SA is developing an accelerator-driven system (ADS) designed to generate clean energy while reducing the lifetime of radioactive waste. Such a subcritical reactor concept requires high reliability and a high degree of accelerator automation to ensure operational effectiveness.

To address these demands, a machine learning (ML) methodology was developed and experimentally validated for automatic beam control in cyclotrons. This work reports the first practical demonstration of machine-learning-based beam control in a high power cyclotron, representing a significant step for this class of accelerators.

The validation experiments were performed on the injector ring of the High Intensity Proton Accelerator (HIPA) at the Paul Scherrer Institute (PSI), whose design closely matches the injector concept developed by Transmutex. Key challenges were addressed, including the identification of suitable observables and actuators, adapting the ML model to the accelerator response dynamics, and integrating ML-based control with existing feedback loops. The approach reliably aligned the beam with the reference trajectory, improving extraction efficiency while minimizing losses.

Over an extensive 12-day operational test campaign, remarkably long in the context of real-time ML experiments, the model demonstrated robust performance across a range of operational scenarios, including varying beam currents and different turn numbers.

These results show that machine learning can enhance operational efficiency, reduce operator workload, and increase automation in cyclotron-driven systems.

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Footnotes

Author: Dr HAJ TAHAR, Malek (Transmutex SA)

Co-authors: Mr BARCHETTI, Antonio (Paul Scherrer Institute); Dr BAUMGARTEN, Christian (Paul Scherrer Institute); SOLODKO, Evgeny (Transmutex SA); Dr GRILLENBERGER, Joachim (Paul Scherrer Institute); Dr SNUVERINK, Jochem (Paul Scherrer Institute); Dr BOCCHIO, Marco (Transmutex SA); Dr BUSCH, Marco (Transmutex SA); Dr SAPINSKI, Mariusz (Paul Scherrer Institute); Dr SCHNEIDER, Markus (Paul Scherrer Institute); Mr MARQUIE, Serge (TRANSMUTEX); NEAL, Thierry (TRANSMUTEX); Dr JOHO, Werner (Transmutex SA)

Presenter: NEAL, Thierry (TRANSMUTEX)

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