ICFA Mini-Workshop on Slow Extraction 2019

Fermilab, Batavia

Spill Quality and Tune Ripple Cancellation at Ion-Beam Therapy Synchrotrons

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Heidelberg (HIT) and Marburg (MIT) Ion-Beam Therapy Centres



klinikum.uni-heidelberg.de



http://www.mit-marburg.de

HIT and MIT are the only facilities for heavy-ion (p and ¹²C⁶⁺) therapy in Germany.

HIT:

In clinical op. since Nov. 2009

Accelerator design by GSI, based on GSI precursor experiments.

MIT:

In clinical op. since Oct. 2015

Linac: Identical to HIT machine.

Synchrotron + HEBT: re-implementation by Siemens HealthCare / Danfysik.

(Identical machine is in op. at Shanghai Proton and Heavy Ion Centre)



The MIT accelerator



mit-marburg.de



3 x hor., 1 x 45°

Pencil beam scanning method



- 1) Sequence of *pencil-beams* of defined range.
- 2) "Paint" each iso-energetic slice of the target using *scanning magnets*.

Optimum 3D tumour conformity of dose-distribution.





RF-KO system



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Marburger Ionenstrahl-Therapiezentrum



Spill contributed by MIT to the 2016 workshop:

 C^{6+} (298 MeV/u), with DIC, 50 μs binning.















Spill optimisation techniques:

- 1) Extraction from bunched beam.
 - → Sync. motion combined with chromaticity.
 - → Faster sparatrix crossing.

(Adopted from GSI) e.g. Sorge et al., Proc. IPAC 2018

-) "Matching" of RF-KO spectrum and particle tunes.
 - → Excite high betatron amplitudes preferentially.
 - → Faster sparatrix crossing.



RF-KO Spectrum

RF-KO spectrum is generated by random phase-shift keying (PSK).



"Bad": RF-KO ~ Machine tune

"Good": RF-KO \rightarrow Extraction res.



"Bad": RF-KO ~ Machine tune

"Good": RF-KO \rightarrow Extraction res.



"Bad": RF-KO ~ Machine tune

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"Bad": RF-KO ~ Machine tune

"Good": RF-KO \rightarrow Extraction res.



Micro structure: Ripple cancellation



Additional project since 2018:

Reduction of separatrix ripple

→ Stabilise machine tune via fast corrections of the quadrupole fields.

("noise cancellation")



Ripple cancellation @ CNAO

Ripple compensation using an Air Core Quadrupole (ACQ) magnet has been demonstrated at the CNAO hadron therapy centre (Italy).

(cf. presentation by M. Pullia)



image: courtesy of M. Pullia



fondazionecnao.it



At MIT and HIT: Compatibility with DIC RF-KO required

DIC may *vary* the spill rate on the ~ 10 ms scale!

→ Possible ripple cancellation systems must be compatible with this wanted (but random) spill modulation!

A feedback loop could be prone to in-fighting with the DIC





Cancellation of power-grid harmonics



A simple Air-Core Quadrupole magnet: Use at MIT



A simple Air-Core Quadrupole magnet: Use at HIT

















Cancellation of power-grid harmonics

Phase-locking of internal "50-Hz" clock to power-grid ref.

Phase-locked *n* x 50 Hz function generator.

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150	÷	0.1700	÷	-0.23000	ŧ	: 1	F2			
200	*	1.0000	*	0.00000	ŧ	: 1	F3			
250	*	0.9600	*	-1.00000	10	2 :	F4			
300	*	1.0000	.≜ ▼	-0.08000	10	2 :	F5			
350	*	0.2300	*	1.50000	1	2 :	F6			
400	*	0.2500	*	1.30000	:	2	F7			
450	*	1.0000	*	0.00000	÷] :	F8			
500	*	1.0000	*	0.00000	ŧ] :	F9			
550	*	1.0000	*	0.00000	ŧ] :	F10			
600	*	1.0000	*	0.00000	ŧ] :	F11			
650	*	1.0000	*	0.00000	ŧ] :	F12			
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750	*	1.0000	*	0.00000	÷]	: 1	F14			
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,	 Sine wave 									
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Does it work?

First tests (work in progress!)



Data: Ionisation chamber in extraction beam line. MIT: ¹²C⁶⁺ @ 167 MeV/u



Does it work? ... Yes!

First tests (work in progress!)



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Does it work? ... Yes!

First tests (work in progress!)



Data: Ionisation chamber in extraction beam line. MIT: ¹²C⁶⁺ @ 167 MeV/u



First results (@ MIT)

Up to now: Correction function is "hand-made":

→ Operator sets function generator while observing the spill FFT.

Goal: Automatic learning routine populating a "library" of correction functions.





First results (@ MIT)

Histogram of IC measurements (50 µs sampling)







First results (@ HIT)



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Duty-factor (GSI)

First results (@ HIT)



Duty factors all relatively close to 1 due to long detector integration (50 μ s) and high rate.

Decrease of likelihood of high peaks is the most important aspect.

Duty-factor (GSI)



(Sorge et al., Proc. of IPAC 2018)



Outlook: Do we actually need the ACQ?



Outlook: Do we actually need the ACQ?

First tests: Cancellation by F-quads equally possible @ frequencies < 1 kHz ...



Data: Ionisation chamber in extraction beam line. MIT: ${}^{12}C^{6+} @ 167 \text{ MeV/u}$





Intensity-controlled RF-KO excitation, as used at HIT and MIT provides excellent spill structure.

Fast response of the beam to RF-KO is a key feature for the therapy application.

The effect of the **RF-KO spectrum** on the spill quality is significant.

Ripple cancellation by fast correction quadrupole fields seems promising.



Thank You for Your Attention.



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