An Online Model for Multi-Turn Extraction

Summer Student Project supervised by Guido Sterbini
Based on work by Alexander Huschauer
BE-ABP-HSC section meeting

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Introduction

Munich, Capital of Bavaria

CRESST – Dark Matter Direct Detection at Gran Sasso Laboratories and Max-Planck-Institut für Physik München
Outline

Multi-Turn Extraction (MTE) Overview

Scope of the Online Model

Optimization Methods and Examples
  Extraction Quality
  Extraction Reproducibility
Multi-Turn Extraction (MTE) Overview
PS Injection for SPS Fixed Target Program

Fill 10/11 of SPS from 2 PS fillings
PS to SPS Extraction: CT vs. MTE

Continuous Transfer (CT)

Multi-Turn Extraction (MTE)
MTE: Control of a Non-Linear Accelerator
MTE: Capture

from: MTE design report 2006
MTE: Extraction

1. Capture Core and Islands in Closed Orbits
2. Approach magnetic septum 16 with high-energy dipoles and slow bump
3. Islands Extraction Kick: 13 & 21 on for five turns
4. Core Extraction Kick: add 4 & 71 for the last turn
We use the low energy quadrupole to control the $Q_H$ ramp.
MTE: Extraction

The sextupoles, octupoles and damper kicker

The MTE O/X (39 and 55) and the ring octupoles (ODE).

slide courtesy of Guido Sterbini
MTE: Extraction

Closed orbit correction
MTE: Extraction

Slow extraction bump
MTE: Extraction

Fast bump and extraction kickers

The K13 and K21 are used for the islands extraction. The K71 and K04 give the additional kick for the core extraction.

slide courtesy of Guido Sterbini
MTE: Extraction

Kicker Settings:
- KFA04 80.0000 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 410.0000 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 1.148 mm
- 0.032 mrad

SMH16
MTE: Extraction

Kicker Settings:
- KFA04 80.0000 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 410.0000 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 1.148 mm
- 0.032 mrad

SMH16

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- KFA21 75.0000 kV
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Pedestals:
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- BFA21 0.0000 kV

Extraction Spread:
- 1.148 mm
- 0.032 mrad

SMH16

0 0.02 0.04 0.06 0.08 0.1 0.12
PX [rad]

# 10 -3
-4
-3
-2
-1
0
1
2
3
4
Beam becomes invisible after splitting...
Scope of the Online Model
Online Model: Paradigms

- PS element settings and readouts
- Workspace variables
- MTE Online Model
- Matlab Class

MADX models

MADX models

MatlabJapc

madx2matlab
Multi-Turn Extraction (MTE) Overview
Scope of the Online Model
Optimization Methods and Examples

Display Overview

MACHINE VALUES
- Quadrupoles [A]
  PR.GSQFN2: 7.04
  PR.GSQDN2: 3.65
- Hexacorrection [A]
  PR.GSQH2: 3.79
  PR.GSQH22: 3.79
- Quadmultiples [A]
  PR.GSQMN: 16.33

HECorrectors [A]
- PR.GSDHZ05-FT: -31.72
- PR.GSDHZ18-FT: 81.15
- PR.GSDHZ60-FT: -60.65

HEMultipoles [A]
- PR.GSODN: -43.90
- PR.GSONO39: 22.30
- PR.GSONO55: 82.10
- PR.GSXNO39: 110.00
- PR.GSXNO55: 160.00

Transverse Feedback
- Amplitude: 0.40
- Frequency: 9.25
- startTime: 718 ms
- endTime: 745 ms

Magnetic Septum [A]
- PE.SMH16: 15303.51

Bumper Currents [A]
- PE.BSW12: 416.71
- PE.BSW14: -417.86
- PE.BSW20: 415.52
- PE.BSW22: -424.82

Status good.

WORKSPACE VALUES
- Quadrupoles [A]
  PR.GSQFN2: 5.18
  PR.GSQDN2: 2.88
- Hexacorrection [A]
  PR.GDHZ05-FT: -31.72
  PR.GDHZ18-FT: 81.15
  PR.GDHZ60-FT: 60.65

HEMultipoles [A]
- PR.GSODN: -43.90
- PR.GSONO39: 22.30
- PR.GSONO55: 82.10
- PR.GSXNO39: 110.00
- PR.GSXNO55: 160.00

Bumper Currents [A]
- PE.BSW12: 412.51
- PE.BSW14: -423.30
- PE.BSW20: 412.51
- PE.BSW22: -423.30

Pedestals [kV]
- PE.BFA9P-V: 0.00
  PE.BFA21P-V: 0.00

Extraction Kickers [kV]
- PE.KFA04: 80.00
- PE.KFA13: 71.00
- PE.KFA21: 75.00
- PE.KFA71: 410.00

Status good.
Acquired Closed Orbit
Split Beam
Slow Bump
Island Extraction Turn 1
Island Extraction Turn 2
Island Extraction Turn 3
Core Extraction
Optimization Methods and Examples

Extraction Quality

Extraction Reproducibility
Extraction Spread in Transverse Phase Space

Kicker Settings:
- KFA04 80.0000 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 410.0000 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- SMH16
  - 1.147 mm
  - 0.033 mrad
Iteration from Response Matrices
Iteration from Response Matrices
Iteration from Response Matrices
Iteration from Response Matrices
Extraction Spread in Transverse Phase Space

Kicker Settings:
- KFA04 80.0000 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 410.0000 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 1.147 mm
- 0.033 mrad

SMH16
Closing the Kick with respect to the Core

Kicker Settings:
- KFA04 67.2175 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 341.9125 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 1.147 mm
- 0.033 mrad

SMH16
Closing the Kick with respect to the Core

Kicker Settings:
- KFA04 33.0694 kV
- KFA13 71.0000 kV
- KFA21 8.2437 kV
- KFA71 405.0149 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 104.7582 kV

Extraction Spread:
- 0.793 mm
- 0.099 mrad

SMH16

\[ 4 \times 10^{-3} \]
Matching Island Extraction

![Graph showing phase advance in extraction region with different islands and markers KFA13, SMH16, KFA21]
Matching Island Extraction

Phase Advance in Extraction Region

- Core
- Island1
- Island2
- Island3
- Island4

KFA13

S [m]
122 124 126 128 130 132 134

KFA21

\( \mu_{x} - \mu_{\text{KFA13}} \)
Matching Island Extraction

Building a response matrix:

- from four different trajectories
- from responses after four different turn numbers
- controlling 4 angles + 4 positions = 8 d.o.f. with 2 parameters?
Matching Island Extraction

Building a response matrix:

- from four different trajectories
- from responses after four different turn numbers
- controlling 4 angles + 4 positions = 8 d.o.f. with 2 parameters?
- controlling 4 positions = 4 d.o.f. with 2 parameters?
Matching Island Extraction

Building a response matrix:

- from four different trajectories
- from responses after four different turn numbers
- controlling 4 angles + 4 positions = 8 d.o.f. with 2 parameters?
- controlling 4 positions = 4 d.o.f. with 2 parameters?
- controlling 4 relative positions = 3 d.o.f. with 2 parameters
Island Extraction: Nominal Settings

Kicker Settings:
- KFA04 67.2175 kV
- KFA13 71.0000 kV
- KFA21 75.0000 kV
- KFA71 341.9125 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 1.147 mm
- 0.033 mrad

SMH16
Island Extraction: Minimized Spread

Kicker Settings:
- KFA04 52.4607 kV
- KFA13 35.8601 kV
- KFA21 36.8236 kV
- KFA71 372.1882 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 0.514 mm
- 0.034 mrad
Island Extraction: Lower Bound on Mean Position

Kicker Settings:
- KFA04 57.7202 kV
- KFA13 58.1995 kV
- KFA21 60.8662 kV
- KFA71 358.8924 kV

Pedestals:
- BFA09 0.0000 kV
- BFA21 0.0000 kV

Extraction Spread:
- 0.861 mm
- 0.025 mrad

SMH16
Island Extraction: Improvement

\[
\begin{array}{c|c|c|c}
X [\text{m}] & 0.06 & 0.065 & 0.07 \\
PX [\text{rad}] & 10^{-3} & -2.5 & -2.4 \\
\end{array}
\]

SMH16

\[
\times 10^{-3}
\]

0.06 0.065 0.07 0.075

X [m]

0.06 0.065 0.07 0.075

PX [rad]
Island Extraction: Improvement

![Graph showing Island Extraction Improvement](image-url)
Extraction Reproducibility

MTE setup in the SPS (9 Sept 2015)
Radial Position Stability (Transfer Line)
Radial Position Stability (Transfer Line)
Horizontal Tune and Radial Position

Horizontal Tune: 6.2585
Horizontal Tune and Radial Position

Horizontal Tune: 6.2605
Horizontal Tune and Radial Position

Kicker Settings:
KFA04 80.0000 kV
KFA13 71.0000 kV
KFA21 75.0000 kV
KFA71 410.0000 kV

Pedestals:
BFA09 0.0000 kV
BFA21 0.0000 kV

Extraction Spread:
1.183 mm
0.030 mrad

Horizontal Tune: 6.2625
Horizontal Tune and Radial Position

![Graph showing the relationship between horizontal tune change and relative extraction position.](image-url)
Horizontal Tune and Radial Position

1mm per $10^{-3}$!
Tune Stability from Power Supply Stability

![Graph showing the relationship between current stability and tune stability with a 1mm radial displacement marker.](image-url)
Tune Stability from Power Supply Stability

Power supply ripples can explain the radial position instability!
Outlook
Outlook

wiki.cern.ch/PSOP/MTE+on-line+model
Outlook

- Documentation
- Wiki
- MTE Commissioning
Outlook

- Documentation
- Wiki
- MTE Commissioning
- to be continued...
Appendix

Tune response matrix

\[
\begin{pmatrix}
\Delta Q_X \\
\Delta Q_Y
\end{pmatrix}
= 10^{-3} \cdot
\begin{pmatrix}
+2.8 & +4.8 & -3.2 & -2.7 & -1.2 & +4.1 & -2.2 \\
-1.2 & -3.1 & +5.0 & +4.1 & +1.2 & -2.2 & +4.1
\end{pmatrix}
\begin{pmatrix}
\Delta I_{FN} \\
\Delta I_{FW} \\
\Delta I_{DN} \\
\Delta I_{DW} \\
\Delta I_{8L} \\
\Delta I_{QDN} \\
\Delta I_{QFN}
\end{pmatrix}
\]
Appendix

Currents at Extraction

\[
\begin{pmatrix}
I_{FN} \\
I_{FW} \\
I_{DN} \\
I_{DW} \\
I_{8L} \\
I_{QDN} \\
I_{QFN}
\end{pmatrix}
= 
\begin{pmatrix}
+49.0156 \\
+57.4062 \\
-52.8906 \\
-57.7031 \\
+598.9000 \\
+0.1250
\end{pmatrix}
A
\]