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TRANSVERSE OPTICS
IN THE ERL ARCS

31 May - 10 June 2016
Cern Accelerator School
Free Electron Lasers and Energy Recovery Linacs
from previous lectures…
WHAT HAVE YOU LEARNED SO FAR?

Concept of ENERGY RECOVERY

✧ The electron-beam energy, produced by accelerating electrons in electromagnetic fields of particle accelerators, can be recycled

✧ The RF fields, by proper choice of the time of arrival of the electron bunches in the linac beam, are used to both accelerate and decelerate the same beam

Potential of ENERGY RECOVERY LINAC

✧ Combines the two worlds of storage rings and linacs and it features some advantages of both arrangements

✧ Flexible modes of operation adaptable to user requirements

Applications of ENERGY RECOVERY LINAC

✧ Many projects and proposals worldwide
   Light sources, colliders, fixed target and gas target experiment, electron cooling, compact sources…
WHAT HAVE YOU LEARNED SO FAR?

Main features to be addressed when designing an ERL accelerator

✧ Choice of injection energy

✧ Number of passes through the linac

✧ General features of the linac topology, such as the use of single or multiple linacs, the use of asymmetric gains in multiple linacs, and the connectivity of the recirculation path

✧ Details of phase-space management, such as the degree of functional modularity and specific schemes for longitudinal and transverse matching

✧ Phase-space preservation throughout the acceleration and energy-recovery cycle

✧ Control of beam halo
ERL Beam Dynamics: potentials and issues

- Goal Beam Parameter & Energy Recovery Issues
  - efficient energy recovery
  - beam quality
  - Bunch manipulation

- Linear Beam Optics
- Nonlinear Beam Optics

- Collective Effects
  - Space charge effects
  - Coherent synchrotron radiation
  - Geometric waves

- BBU – beam break up

- Unwanted Beam: dark current & halo

- Ion trapping
WHAT WILL YOU LEARN NOW?

Optics in the ERL design

✧ **Optics design and optimization**
  - Linac
  - Arcs
  - Spreader and Re-combiner

✧ Per each component, constraints, issues and possible solutions will be showed along with examples from studies on existing/proposed machines

✧ The idea is to give you a method, a possible way to proceed

✧ **Simulation tools**
ERL-general features
EXAMPLE OF A MULTI-PASS ERL

Main components
- Injector
- Linacs
- Optics transport lines
- Beam dump

Two passes ‘up’ for acceleration
After acceleration the beam is phase shifted by 180° and then sent back through the recirculating linac at a decelerating RF phase.

**Two passes ‘down’** for deceleration.

During deceleration the energy stored in the beam is reconverted to RF energy and the final beam, at its original energy, is directed to a beam dump.
Transport Optics
Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality.

The design comprises different regions: the linac optics.

The focusing strength of the quadrupoles along the linac needs to be set to transport co-propagating beams of different energy and to (eventually) support a large number of passes.

The focusing profile depends on many parameters such as number of cavity, BBU threshold current, beam properties…
Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality.

The design comprises different regions:

**The Spreader optics**

At the end of the linac the beams need to be directed into the appropriate energy dependent arc.

Spreaders separate horizontally or vertically beams and match optics functions to arcs.

**Important parameters:** energy loss and $\beta$ values
Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality.

The design comprises different regions:

The Arc optics

Choice of the base cell depends on main parameters:

e.g. In high-energy machines disturbing effects on the beam phase-space such as cumulative emittance and momentum growth have to be counteracted through a pertinent choice of the basic optics cell.
Appropriate recirculation optics are of fundamental concern in a multi-pass machine to preserve beam quality.

The design comprises different regions:

**The Re-combiner optics**

Spreader and combiners are mirror symmetric.

Combiners merge horizontally or vertically beams and match optics functions to linac.
Linac Optics
Define the main constraints in the optics design for the linac

How linac optics has been designed?

CEBAF recirculating linear accelerator
5-pass ERL
When decelerating, the beam keeps turning in the same direction, therefore any possible arc matching aiming at optimising the Twiss functions at each linac injection during the acceleration, would cause a mismatch during the deceleration.

The Twiss functions must be preserved, with the only exception of the sign of $\beta' = -2\alpha$. 
The optics of the two linacs are symmetric, the first being matched to the first accelerating passage and the second to the last decelerating one.
1. The optimization of the linac optics aims at mitigating the impact of imperfections and collective effects such as wake-fields driven by

\[ \left\langle \frac{\beta}{E} \right\rangle = \int_{\text{Acceleration}} \frac{\beta}{E} ds, \]

**MINIMUM**

Free parameters:
- Input optics functions (\(\beta\) function and its derivative)
- Quads Strength profile

2. One should also consider the interaction of bunches at different turns, resulting in the integrals

\[ I_{ij} = \int_{\text{Linac1,2}} \frac{\sqrt{\beta_i \beta_j}}{\sqrt{E_i E_j}} ds, \]

where the energy and the \(\beta\) functions need to be evaluated for the different turn numbers: \(i, j\)

\[ F = \sqrt{(I_{11} + I_{22} + I_{33})^2 + 2(I_{12} + I_{23})^2 + 2(I_{13})^2}. \]

Merit function (for acceleration only) to be minimised
MULTI-PASS LINAC OPTICS: OPTIMIZATION

‘Drift Linac’

Evaluate different optics to find a minimum of

90° FODO
MULTI-PASS LINAC OPTICS: OPTIMIZATION

‘Drift Linac’

DRIFT LINAC, no focusing elements

Evaluate different optics to find a minimum of

60° FODO
‘Drift Linac’

Evaluate different optics to find a minimum of

$\langle E \rangle = \frac{1}{L} \int_{s_{min}} E \, ds$

30° FODO
MULTI-PASS LINAC OPTICS: OPTIMIZATION

‘Drift Linac’

DRIFT LINAC, no focusing elements

FIND A SOLUTION

60° FODO
LHeC recirculating linear accelerator
3-pass ERL

1. 0.5 Gev injector
2. Two 1km SCRF linacs (10 GeV per pass)
3. Six 180° arcs, each arc 1 km radius
4. Re-accelerating stations
5. Switching stations
6. Matching optics
7. Extraction dump at 0.5 GeV
10 GEV LINAC OPTICS: FOCUSING PROFILE

**Diagram 1:**
- **Quad:** L_c
- **Cavity Cryo:** 8 RF cavities
- **Optics functions in Linac 1**

**Diagram 2:**
- **Beta X & Y:**
- **Disp X & Y:**

**Legend:**
- Red square: Quad
- Black arrows: Cavity Cryo: 8 RF cavities

Note: The diagrams illustrate the focusing profile and optics functions in Linac 1, with specific emphasis on the beta and dispersion parameters across the linac sections.
10 GeV LINAC OPTICS: FOCUISING PROFILE

MINIMUM

$\langle \frac{\beta}{E} \rangle = \int_{\text{Acceleration}} \frac{\beta}{E} ds$, 

130° FODO

Optics function for 3 passes up for acceleration and 3 passes down for deceleration
The optics of the two linacs are symmetric, the first being matched to the first accelerating passage and the second to the last decelerating one.
Solution is never unique!

Substantial improvements have been obtained doubling the number of quadrupoles (placing a quadrupole after every cryomodule instead of every two)

In this case the merit function is almost halved but the number of quads is doubled

Possible compromise?
As most of the contribution to the merit function comes from the very low energies, the additional quads could be inserted only in the initial/final part of Linac1/Linac2
Optics in spreader and combiner
OPTICS IN SEPARATION REGIONS

Many possible solutions for different schematics

Vertical separation

Horizontal separation
The spreader consists of a vertical bending magnet that initiates the separation.

The highest energy, at the bottom, is brought back to the horizontal plane with a chicane.

The lower energies are captured with two-steps vertical bendings.
SEPARATION REGIONS: POSSIBLE SOLUTIONS

The vertical dispersion introduced by the first step bend is suppressed by two quadrupoles located appropriately between the two stages.

The single step spreader starts with a dipole and then a defocusing quad to bring back the vertical dispersion. The quadrupole triplet focuses the beam. The next quadrupole does not affect the dispersion as it is placed where it crosses the zero, it offers an extra degree of freedom to control the beta functions.
The two-steps design simplifies the suppression of the vertical dispersion, but could also induce a non-negligible energy loss, moreover it raises the horizontal $\beta$ function to very high values.

In the single step spreader the energy loss is reduced by a factor 5 and at the same time both the dispersion and the $\beta$ functions are mitigated.
Main design Considerations

- Length and Hardware
- Flexibility* and tunability
- Chromatic properties
- Coherent and Incoherent synchrotron radiation

High Transmission

Variable Momentum compaction

Betatron phase advance

Various options, DBA, TBA, Bates Arc …

*Operational flexibility is a fundamental aspect. The intention is to come up with a system design that gives an independent handle on as many different parameters as possible, without adversely influencing others
EXAMPLE OF A HE MACHINE

In the LHeC there are 6 arcs from 10 to 60 GeV

Three different arcs design have been developed due to the need of controlling emittance increase, momentum spread growth and isochronicity

In the design for the lowest energy turns, beta-functions are kept small in order to limit the required vacuum chamber size and consequently the magnet aperture

At the highest energy, the lattice is optimized to keep the emittance growth from synchrotron radiation limited
EMITTANCE INCREASE AND ISOCHRONICITY

Growth of normalized emittance

\[ N = \frac{2}{3} C_q r_0^6 \]

\[ C_q = \frac{55\hbar c}{32\sqrt{3} mc^2} = 3.8319 \times 10^{-13} \text{ m}, \]

\[ r_0 = 2.818 \times 10^{-15} \text{ m}, \]

\[ I_5 = \int_0^L \frac{H}{|\rho|^3} ds = \frac{\theta \langle H \rangle}{\rho^2}, \]

\[ H = \gamma D^2 + 2\alpha DD' + \beta D'^2 \]

\[ \Delta \varepsilon^N = \frac{2}{3} C_q r_0 \gamma^6 \langle H \rangle \frac{\theta}{\rho^2} \]

Momentum compaction

\[ M_{56} = -\int \frac{D}{\rho} ds = -\theta_{\text{bend}} \langle D \rangle \]

\[ \Delta C = -M_{56} \frac{\Delta p}{p} \]

\[ \Delta \phi_{RF} = \frac{360 \times \Delta C}{\lambda_{RF}} = -\frac{360}{\lambda_{RF}} N_{\text{cell}} M_{56}^\text{cell} \frac{\Delta p}{p} \]

Momentum spread growth

\[ \frac{\Delta \sigma_E^2}{E^2} = \frac{55\alpha}{48\sqrt{3}} \left( \frac{\hbar c}{mc^2} \right)^2 \gamma^5 \int_0^L \frac{1}{|\rho|^3} ds \]

\[ \int_0^L \frac{1}{|\rho|^3} ds = \frac{\theta}{\rho^2}, \quad \frac{\Delta \sigma_E^2}{E^2} = \frac{55\alpha}{48\sqrt{3}} \left( \frac{\hbar c}{mc^2} \right)^2 \gamma^5 \frac{\theta}{\rho^2} \]
**ARC OPTICS: FMC CELL**

**Arc 1, Arc2**

*Imaginary $\gamma_i$ Optics*

$$\langle H \rangle = 8.8 \times 10^{-3} \text{ m}$$

**Arc 3, Arc 4**

*DBA-like Optics*

$$\langle H \rangle = 2.2 \times 10^{-3} \text{ m}$$

**Arc 5, Arc 6**

*TME-like Optics*

$$\langle H \rangle = 1.2 \times 10^{-3} \text{ m}$$

*factor of 20 smaller than FODO*

**ARC 1, ARC 2**

At the lowest energy it is possible to compensate for the bunch elongation with a negative momentum compaction setup which, additionally, reduces the beam size.

**ARC 5, ARC 6**

The cells are tuned to contain the dispersion in the bending sections, as in a theoretical minimum emittance lattice.

**ARC 3, ARC 4**

The intermediate energy arcs are tuned to a DBA-like lattice, offering a compromise between bunch lengthening and emittance dilution.
ARC 1 OPTICS (10 GeV)

vert. 2-step spreader

doglegs

dis. sup. cell

58 FMC cells

180 deg. Arc

vert. 2-step recombiner
ARC 3 OPTICS (30 GeV)

Vert. 2-step spreader
Doglegs
Dis. sup. cell
58 FMC cells
Dis. sup. cell
Doglegs
Vert. 2-step recombiner

180 deg. Arc

Arc dipoles:
$L_b=400 \text{ cm}$
$B=1.37 \text{ kGauss}$
The transport of a single bunch from the injector to the dump is the first step to validate the machine design.

Effect of synchrotron radiation on the **emittance** and on the **induced energy spread**.
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with horizontal axis labeled 'z [mm] head <-> tail' and vertical axis labeled 'Internal energy difference [MeV]'. There is a vertical dotted line labeled 'injector (500 MeV)'.]
Effect of RF curvature
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with energy difference in MeV against z in mm. The graph is labeled with arc 2 in (20 GeV).]
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with an energy difference of 20 GeV.](image-url)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 3 in (30 GeV)

Internal energy difference [MeV]

z [mm] head <--- tail
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 3 out (30 GeV)

Internal energy difference [MeV]

z [mm]  head <--- tail
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 4 in (40 GeV)

Internal energy difference [MeV]

z [mm]  head <-> tail
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space.](image-url)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with internal energy difference on the y-axis and z position on the x-axis. The graph includes a label 'arc 6 out (60 GeV)' and indicates the range of energy differences from -200 to 200 MeV. The scale for z ranges from -6 to 6 mm, showing the transition from head to tail.]
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

- Internal energy difference [MeV]
- z [mm] head ---> tail

arc 5 in (50 GeV)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 5 out (50 GeV)

Internal energy difference [MeV]

z [mm]  head <---> tail

-6 -4 -2 0 2 4 6
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with energy difference and position.](image)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 4 out (40 GeV)

Internal energy difference [MeV]

z [mm]  head --- tail
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 3 in (30 GeV)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUINAL PHASE SPACE

arc 3 out (30 GeV)
EVOLUTION OF LONGITUDINAL PHASE SPACE
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with energy difference on the y-axis and z [mm] on the x-axis, indicating a distribution from head to tail.](image-url)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

arc 1 in (10 GeV)
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE
SYNCHROTRON RADIATION

EVOLUTION OF LONGITUDINAL PHASE SPACE

![Graph showing the evolution of longitudinal phase space with points marked for dump (500 MeV) and injector (500 MeV).]
Arc length
In order to avoid boosting short-range wakefields, the lengths of the arcs should be tuned preventing the recombination of different bunches in the same bucket.

The filling of the RF buckets can be controlled tuning the length of the arcs.

Maximise the separation between the bunches at first and last turn.

Multi – bunch effects are enhanced by the value of $\beta/E$.

Low energy particles are more susceptible.

**EXAMPLE CASE**

The choice of 802 MHz RF frequency leads to 19 empty buckets between two injections at 25 ns, that can host the bunches at higher turn numbers.
RECOMBINATION PATTERN

\[ 20 \lambda \approx 25 \text{ ns} \]
RECOMBINATION PATTERN
RECOMBINATION PATTERN
RECOMBINATION PATTERN
A good choice for the recombination pattern consists of almost equal spacing (compatibly with the RF) of the bunches in the RF buckets and a maximal separation between the bunches at the lowest energy that are more subjected to the kicks from the HOMs due to their lower rigidity.

PATTERN 162435 is bad
PATTERN 162435 is bad
PATTERN 162435 is bad
RECOMBINATION PATTERN

PATTERN 162435 is bad
Possible recombination pattern that maximises the separation between the bunches at first and last turn

PATTERN 162435 is bad
PATTERN 152634 is better
Simulation tools
Several codes available for optics and beam dynamics simulations
MADX, OPTIM, ASTRA, ELEGANT, OPAL, PLACET2 …

As example, I will show a possible use of OPTIM*, Computer code for linear and non-linear optics calculations

- **6D computations**
  - large set of optics elements
  - x-y coupling, acceleration (focusing in cavities is taken into account)

- Similar to MADX but has integrated GUI

- Can generate MAD and MADX files from OptiM files

- It has been used for optics support of the following machines
  - Jefferson lab (CEBAF – optics redesign, analysis of optics measurements)
  - Fermilab (Tevatron, Debuncher, Transfer lines, Electron cooler)
  - LHeC …

* [http://pbar.fnal.gov/organizationalchart/lebedev/OptiM/optim.htm](http://pbar.fnal.gov/organizationalchart/lebedev/OptiM/optim.htm)
LHeC LINAC LAYOUT IN OPTIM

LATTICE DESCRIPTION:
order of the elements in the lattice

8 cavities

1 Cryomodule + 1 Cryomodule + 1 Cryomodule + 1 Cryomodule + Optics 130° FODO

1 UNIT + 17 UNITS

18 UNITS = LINAC
1 Cryomodule $\rightarrow$ 8 cavities
In 1 UNIT $\rightarrow$ 4 Cryos $\rightarrow$ 32 cavities
$\Delta E =$ energy gain per cavity $=$ 17.36 MeV

$E_{00} =$ 500 MeV (Injection Energy)
Energy gain/half unit :
$E_{01} =$ $E_{00} + 16 \times \Delta E \cos(F_i)$

10 GeV Linac 1 :
500 MeV $\rightarrow$ 10500 MeV for the first pass
# LHeC LINAC LAYOUT IN OPTIM

## Quads strength profile

<table>
<thead>
<tr>
<th>Element</th>
<th>Length [cm]</th>
<th>Gradient Scaling</th>
<th>Tilt [deg]</th>
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</thead>
<tbody>
<tr>
<td>L01</td>
<td>5</td>
<td>qGF01</td>
<td>0</td>
</tr>
<tr>
<td>L02</td>
<td>5</td>
<td>qGF02</td>
<td>0</td>
</tr>
<tr>
<td>L03</td>
<td>5</td>
<td>qGF03</td>
<td>0</td>
</tr>
<tr>
<td>L04</td>
<td>5</td>
<td>qGF04</td>
<td>0</td>
</tr>
<tr>
<td>L05</td>
<td>5</td>
<td>qGF05</td>
<td>0</td>
</tr>
<tr>
<td>L06</td>
<td>5</td>
<td>qGF06</td>
<td>0</td>
</tr>
<tr>
<td>L07</td>
<td>5</td>
<td>qGF07</td>
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<td>L09</td>
<td>5</td>
<td>qGF09</td>
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<td>L10</td>
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<td>qGF10</td>
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<tr>
<td>L11</td>
<td>5</td>
<td>qGF11</td>
<td>0</td>
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<tr>
<td>L12</td>
<td>5</td>
<td>qGF12</td>
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<tr>
<td>L18</td>
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<td>qGF18</td>
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</tr>
</tbody>
</table>

$GF01 = SGF00^*SP00/SP00; \Rightarrow 0.01026216$

Gradient scaling

$GD01 = SGD00^*SP01/SP01; \Rightarrow -0.160967$

$GF02 = SGF00^*SP02/SP00; \Rightarrow 0.021652923$

$GD02 = SGD00^*SP03/SP01; \Rightarrow -0.027587977$

$GF03 = SGF00^*SP04/SP00; \Rightarrow 0.0330436927$

$GD03 = SGD00^*SP05/SP01; \Rightarrow -0.0397068946$

$GF04 = SGF00^*SP06/SP00; \Rightarrow 0.0444364576$

$GD04 = SGD00^*SP07/SP01; \Rightarrow -0.0505669912$

$GF05 = SGF00^*SP08/SP00; \Rightarrow 0.0558252224$

$GD05 = SGD00^*SP09/SP01; \Rightarrow -0.0620570877$

$GF06 = SGF00^*SP10/SP00; \Rightarrow 0.0672159871$

$GD06 = SGD00^*SP11/SP01; \Rightarrow 0.0735471842$

$GF07 = SGF00^*SP12/SP00; \Rightarrow 0.0786067517$

$GD07 = SGD00^*SP13/SP01; \Rightarrow 0.0850372806$

$GF08 = SGF00^*SP14/SP00; \Rightarrow 0.0899975163$

$GD08 = SGD00^*SP15/SP01; \Rightarrow 0.0965273769$

$GF09 = SGF00^*SP16/SP00; \Rightarrow 0.101388281$

$GD09 = SGD00^*SP17/SP01; \Rightarrow 0.108017473$

$GF10 = SGF00^*SP18/SP00; \Rightarrow 0.112779045$

$GD10 = SGD00^*SP19/SP01; \Rightarrow -0.11950757$

$GF11 = SGF00^*SP20/SP00; \Rightarrow 0.12416981$

$GD11 = SGD00^*SP21/SP01; \Rightarrow -0.130997666$

$GF12 = SGF00^*SP22/SP00; \Rightarrow 0.135560574$

$GD12 = SGD00^*SP23/SP01; \Rightarrow -0.142487762$

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$GD13 = SGD00^*SP25/SP01; \Rightarrow -0.153977839$

$GF14 = SGF00^*SP26/SP00; \Rightarrow 0.153834204$

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$GF16 = SGF00^*SP30/SP00; \Rightarrow 0.181123633$

$GD16 = SGD00^*SP31/SP01; \Rightarrow -0.188448148$

$GF17 = SGF00^*SP32/SP00; \Rightarrow 0.192514397$

$GD17 = SGD00^*SP33/SP01; \Rightarrow -0.199938244$

$GF18 = SGF00^*SP34/SP00; \Rightarrow 0.203905162$

$GD18 = SGD00^*SP35/SP01; \Rightarrow -0.21142834$
MATCHING OF OPTICS FUNCTIONS

Fitting of beta-functions, dispersion and momentum compaction

The program uses the steepest descend method with automatically chosen step. The initial values of steps for length, magnetic field and its gradient are determined here.

Required parameters and their accuracy. To calculate the fitting error (which is minimized in the course of the fitting) the program uses the accuracy parameters for each of fitting parameters.

Elements can be organized in groups so that the elements in each group are changed proportionally during fitting.
ARC OPTICS LAYOUT IN OPTIM

MATH HEADER : numeric variables and calculation

ARC RADIUS

CELLS NUMBER

ARC LENGTH

CELL LENGTH

TOTAL NUMBER OF DIPOLES

DIPOLE LENGTH

B=p/(ρc)
Quad singlet + 5 Dipoles + Quads triplet + 5 Dipoles

1 CELL

begin lattice. Number of periods=1
#
#
oD00 qQ0 bD00 $Dipole bD00 $Dipole bD00 $Dipole bD00 $Dipole bD00 $Dipole
oD00 qQ1 SD01 qQ2 SD01 qQ3 bD00 $Dipole bD00 $Dipole bD00 $Dipole bD00 $Dipole bD00 $Dipole
#
end lattice
Further readings and References
FOR FURTHER INFORMATION

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Many thanks for your attention

Thanks to A. Bogacz and D. Pellegrini for help and material