Welcome to SAD/FFS & SADScript

The FFS commands are shown in uppercases. The minimum abbreviated form of each command is enclosed in (). Down to that form each command can be shorten. The optional arguments for the commands are usually enclosed in [].

SAD/FFS Examples

- ABORT
- APPEND(APP)
- ATTRIBUTE(ATTR)
- BYE
- command-syntax
- components
- CALCULATE(CAL)
- CHROMATICITY(CHRO)
- CLOSE(CLO)
- COUPLE(COUP)
- DISPLAY(DISP)
- ACCELERATION(A)
- ALL
- BEAM(B)
- DUMPOPTICS(D)
- GEOMETRY(G)
- OGEOMETRY(OG)
- ORBIT(O)
- pattern-string
- PHYSICAL(P)
- region


Please go to this page and use browser’s search
Optics

<table>
<thead>
<tr>
<th>Light</th>
<th>Particle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focusing</strong></td>
<td>Axially symmetric, mostly</td>
</tr>
<tr>
<td>Emittance</td>
<td>$\lambda/4\pi \approx 50 \text{ nm}$</td>
</tr>
<tr>
<td>f-number</td>
<td>$f \geq 1.0$</td>
</tr>
<tr>
<td>Transverse Aberrations</td>
<td>large, corrected by surface curvatures, aspherical lenses, etc.</td>
</tr>
<tr>
<td>Chromaticity</td>
<td>depends on the lens materials; corrected by their combinations</td>
</tr>
<tr>
<td>Zoom</td>
<td>by moving lenses physically</td>
</tr>
<tr>
<td>Storage</td>
<td>$F \leq 10,000?$</td>
</tr>
<tr>
<td>Wave behavior</td>
<td>visible</td>
</tr>
</tbody>
</table>
Despite a number of these differences, the light/particle beam optics have fundamental similarities!

<table>
<thead>
<tr>
<th></th>
<th>Light</th>
<th>Particle Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focusing</strong></td>
<td>Axially symmetric, mostly</td>
<td>Axially asymmetric</td>
</tr>
<tr>
<td><strong>Emittance</strong></td>
<td>$\frac{\lambda}{4\pi} \approx 50$ nm</td>
<td></td>
</tr>
<tr>
<td><strong>f-number</strong></td>
<td>$f \gtrsim 1.0$</td>
<td>$f \gtrsim 10$</td>
</tr>
<tr>
<td><strong>Transverse Aberrations</strong></td>
<td>large, corrected by surface curvatures;</td>
<td>small</td>
</tr>
<tr>
<td></td>
<td>confirmed by aspherical lenses, etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Chromaticity</strong></td>
<td>depends on the lens materials; corrected by their combinations</td>
<td>all lenses (drifts) have same chromatics effects; corrected by dispersion + sextupoles</td>
</tr>
<tr>
<td><strong>Zoom</strong></td>
<td>by moving lenses physically</td>
<td>by changing strengths of lenses</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>$F \leq 10,000$?</td>
<td>$&gt; 10^{10}$ turns</td>
</tr>
<tr>
<td><strong>Wave behavior</strong></td>
<td>visible</td>
<td>mostly negligible</td>
</tr>
</tbody>
</table>
SAD deck

! **MAIN** Level

! COMMAND arg [arg1 ...] ;

OFF CTIME; ON ECHO; ! a recommended setting of these flags.
! input after ‘!’ is skipped.

\[
\text{element_type}\_\text{command element}\_\text{name} = (key = value|expression \ [unit] [key1 = value1 ...]) [element\_name1 = ...] ;
\]

…

\[
\text{LINE line}\_\text{name} = ([n*|-] element\_name|line\_name ....) [line\_name1 = ...] ;
\]

…

**FFS** [USE=\text{line}\_\text{name}];

! enters the FFS level

! Comments can be written within (* *).

\[
\text{command|expression} \ [arg [arg1...]] [;] ... 
\]

! Commands take args as many as acceptable: it is recommended to use ’;’ to terminate a command for clarification.
SAD deck (2)

! The units are basically in MKSA, eV, radian. Some FFS commands take tune $\equiv \frac{1}{2}\pi$ (NX, NY), degree (CHI1, CHI2, CHI3), etc as default.

! *Expressions* in FFS are *Mathematica*-like, can represent data or programs.

! FFS commands can be used in an expression using a function FFS["commands ; ; ..."] .

! The input stream on a terminal can be interrupted by end

! and resumed by in 77
Data types in FFS

- **Real number:** (no integer type)
  
  1   3.14   3e8

- **Character string:**
  
  "Hello World!"
  "\"Hello\n\t World!\""
  "A long character string can be written in multiple lines by placing "\\\" at the end of a line."

- **Symbol:** starting with an alphabet or $, case-sensitive.

- **List:**

  `head[body1, ...]`

  \{1, 2, 3\}   \equiv\ List[1, 2, 3]
  
  \((1 + 2 + 3)\times 4\)   \equiv\ Times[Plus[1, 2, 3], 4]
  
  \{1, 2, 3\}[[2]]   \equiv\ Part[{1, 2, 3}, 2]
  
  `If[ x > 0, y = Sin[x] -1]`   \equiv\ `If[ Greater[x, 0], Set[ y, Plus[Sin[x], -1]]]`

- **All programs in SAD Script are expressed by List, similar to LISP, Mathematica, etc.**
Beam lines

A beam line must start with a MARK element, if it is the object of USE.
Elements and components

SetElement[]
also outside of the
current beam line

Element[]
within the current
beam line

LINE[]
within the current
beam line

Saved Element
QF

Element
QF

Component
QF.1

Component
QF.2

SAVE

RESET

USE

expanded by CALC,
GO, EMIT, etc.
Wildcards in FFS

* matches any number of (including zero) chars

% matches any one character

{...} matches any one character in {}

{^... } matches any one character not in {}

a|b|... alternative; matches a or b ...
**Element[] and LINE[]**

- `Element[key*, name*]` and `LINE[key*, name*]` accesses the element and component in the current beam line.

- Element and LINE are bidirectional.

- Arguments `key` and `name` are listable, and can be character strings with wildcards.

- **Examples:**
  
  ```
  Element["K1","Q*"]
  Element["K1","Q{FD}*"]
  LINE[{"K1","L"},{"QF1.*","B1.*"}]
  LINE[{"NAME","K1","L"},{"QF1.*|B1.*"}]
  p=LINE["POSITION","QF1.*"]; k1=LINE["K1",p]
  ```
Some predefined symbols

True (≡ 1)
False (≡ 0)

Pi   (PI in the MAIN level)
Degree (≡ 180/Pi)

SpeedOfLight (m/s)
ElectronCharge (Coulomb)
ElectronMass (eV)
FineStructureConstant
ElectronRadius (m)
DRIFT: Drift Space: the source of chromaticity (and some nonlinearity)

\[
x \rightarrow x + \left( \frac{p_x}{p_z} \right) \ell \approx x + \left( \frac{p_x}{p} \right) \ell
\]

\[
y \rightarrow y + \left( \frac{p_y}{p_z} \right) \ell \approx y + \left( \frac{p_y}{p} \right) \ell
\]

\[
p_z = \sqrt{p^2 - p_x^2 - p_y^2}
\]

- Even if a particle has same \( p_x \) and \( p_y \), the displacement after a drift can be different depending on \( p \): the source of chromaticity.

- A quadrupole gives the same \( \Delta p_{x,y} \) for any particle, independent on \( p \).
Kn: Strength of magnets

\[ Kn = \frac{B^{(n)} \ell_s}{(B \rho)} \]

\[ B \rho \equiv (p_0/e) \]

- Kn \((n = 0 .. )\) represents the integrated strength of magnets in SAD.
- The length \(\ell_s\) is the straight effective length of the magnet.
- Positive for horizontal focusing.
BEND: Bending dipole: Why ANGLE?

If ANGLE ≠ 0, the coordinate after the bend follows it. No orbit distortion arises.

If ANGLE = 0, the beam can be still bent by K0, but an orbit arises.
QUAD: Why $K1$?  

$$K1 = \frac{B'\ell_s}{(B\rho)} = k$$

$$B\rho \equiv (p_0/e)$$

The transfer matrix $M$ of a quadrupole in x-direction with $k > 0$ is approximated as

$$M = \begin{pmatrix}
\cos \sqrt{k\ell} & \sqrt{\ell/k} \sin \sqrt{k\ell} \\
-\sqrt{k/\ell} \sin \sqrt{k\ell} & \cos \sqrt{k\ell}
\end{pmatrix},$$

where $\ell = \ell_s$. In the most cases $\ell \ll 1/k$, i.e., the thickness of a lens is much smaller than the focal length. Then the matrix $M$ is approximated as

$$M \approx \begin{pmatrix}
1 & 0 \\
-k & 1
\end{pmatrix} + \epsilon \begin{pmatrix}
-1/2 & 1/k \\
k/6 & -1/2
\end{pmatrix} + O(\epsilon)^2 ,$$

where $\epsilon = k\ell$. Thus $M$ is represented only by $k$ at the lowest order of $\epsilon$. This is the merit of using $K1$ instead of something else like $B'/((B\rho)$.
### Some important variables in FFS (* common with MAIN)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MOMENTUM</strong></td>
<td>design momentum at the entrance of the beam line (eV/c).</td>
</tr>
<tr>
<td><strong>MASS</strong></td>
<td>mass of the particle (eV). Defaults ElectronMass.</td>
</tr>
<tr>
<td><strong>CHARGE</strong></td>
<td>electric charge of the particle (e). Defaults 1.</td>
</tr>
<tr>
<td><strong>CONVERGENCE</strong></td>
<td>goal of matching residual for GO. Defaults 1e-9, less than 1e-20 is recommended.</td>
</tr>
<tr>
<td><strong>DP</strong></td>
<td>width of the off-momentum matching.</td>
</tr>
<tr>
<td><strong>DPO</strong></td>
<td>Momentum offset of the optics.</td>
</tr>
<tr>
<td><strong>MatchingResidual</strong></td>
<td>the residual of matching: if it is less than CONVERGENCE(× # of eps), judged as &quot;Matched&quot;.</td>
</tr>
<tr>
<td><strong>NetResidual</strong></td>
<td>The sum of square of the residual of eqs (× weight).</td>
</tr>
<tr>
<td><strong>StabilityLevel</strong></td>
<td>number of unstable optics</td>
</tr>
<tr>
<td><strong>PBUNCH</strong></td>
<td>particles / bunch</td>
</tr>
<tr>
<td><strong>MINCOUP</strong></td>
<td>minimum y/x emittance ratio assumed in EMIT, etc.</td>
</tr>
<tr>
<td><strong>FSHIFT</strong></td>
<td>df/f0 to compensate orbit dilation due to closed orbit distortion, (also chicanes, RADCOD, etc.)</td>
</tr>
</tbody>
</table>
Some flags (common with MAIN)

<table>
<thead>
<tr>
<th>Flag</th>
<th>antonym</th>
<th>default</th>
<th>effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELL</td>
<td>INS</td>
<td>INS</td>
<td>impose a periodic condition on the entire beam optics</td>
</tr>
<tr>
<td>RING</td>
<td>TRPT</td>
<td>RING</td>
<td>design momentum is constant through the beam line, etc.</td>
</tr>
<tr>
<td>RFSW</td>
<td>NORFSW</td>
<td>RFSW</td>
<td>turns on acceleration</td>
</tr>
<tr>
<td>RAD</td>
<td>NORAD</td>
<td>NORAD</td>
<td>turns on synchrotron radiation in the tracking</td>
</tr>
<tr>
<td>RADCOD</td>
<td>NORADCOD</td>
<td>NORADCOD</td>
<td>include the radiation loss in the optics calculation</td>
</tr>
<tr>
<td>INTRA</td>
<td>NOINTRA</td>
<td>NOINTRA</td>
<td>calculate intrabeam scattering in EMIT or Emittance[]</td>
</tr>
<tr>
<td>CONV</td>
<td></td>
<td></td>
<td>True when matched, False otherwise</td>
</tr>
</tbody>
</table>

In FFS, flags can be set by just saying `flag;`. In expressions, Use FFS["flag;"] .
Why matching?

• Even when the optics is linear, the solution for the parameters of elements (length, strength, etc.) to satisfy the condition cannot be written analytically.
  
  – The number of equations is usually more than 4.

• Thus a numerical solution is inevitable: called matching.

• Equations for matching in FFS:
  
  – built-in optical functions (fast)
  
  – any equations with FitFunction (slow).

• Variables for matching:
  
  – any key of an element
  
  – dependence between keys can be expressed by ElementValues.
Matching basics

- Location to be matched:
  FIT [loc | loc1 loc2]

- where loc has the form of
  element[.nth][+-offset]

- The location specified by FIT is valid through the session, unless the beam line is switched by USE.

- Special locations:
  ^^^ beginning of the beam line
  $$$ end of the beam line

- loc defaults $$$.
- If two locs are given it specifies a relative matching or region matching.
Matching basics (2)

- Goal of matching:
  \[ \text{fun}[M] \text{ value } [\text{nopts}]; \]

- where \text{fun} is the built-in optical function at the current \text{loc} given by FIT, and \text{value} the goal value.

- If \text{M} is attached, it specifies the maximum value of \text{fun}.

- \text{nopts} is the number of optics for off-momentum matching.

- Goals of matching can be rejected by
  
  \text{REJ } \text{fun*}; (* rejects \text{funs} matching to \text{fun* at this loc} *)
  
  \text{REJ } *; (* rejects all \text{funs at this loc} *)
  
  \text{REJ total}; (* rejects all \text{funs at all locs} *)
Goals by FitFunction:

FitFunction := a list of expressions

where each expression is to be matched to 0:

FitFunction := Module[{e = Emittance[]},
{Max[0, Emittances[[1]]/emitx0 - 1],
MomentumCompaction/alpha0 -1}/.e];

above tries to match the maximum horizontal emittance
and momentum compaction factor to be emitx0 and alpha0,
respectively.

FitFunction persists even after USE, so it should be
cleared by:

FitFunction :=.
### Optical functions for matching

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AX, AY</td>
<td>$\alpha_x, \alpha_y$</td>
</tr>
<tr>
<td>BX, BY</td>
<td>$\beta_x, \beta_y$</td>
</tr>
<tr>
<td>NX, NY</td>
<td>$\psi_x, \psi_y (1/2\pi)$</td>
</tr>
<tr>
<td>EX, EY</td>
<td>$\eta_x, \eta_y$ (in the normalized coordinate)</td>
</tr>
<tr>
<td>EPX, EPY</td>
<td>$\eta_{px}, \eta_{py}$ (in the normalized coordinate)</td>
</tr>
<tr>
<td>R1, R4</td>
<td>x-y coupling parameter</td>
</tr>
<tr>
<td>R2</td>
<td>x-y coupling parameter (m)</td>
</tr>
<tr>
<td>R3</td>
<td>x-y coupling parameter (1/m)</td>
</tr>
<tr>
<td>DX, DY</td>
<td>$\Delta_x, \Delta_y$</td>
</tr>
<tr>
<td>DPX, DPY</td>
<td>$\Delta_{px}, \Delta_{py}$</td>
</tr>
<tr>
<td>DZ, DDP</td>
<td>$\Delta_z, \Delta_{p/p_0}$</td>
</tr>
<tr>
<td>PEX, PEY</td>
<td>$\eta_x, \eta_y$ (in the physical coordinate)</td>
</tr>
<tr>
<td>PEPX, PEPY</td>
<td>$\eta_{px}, \eta_{py}$ (in the physical coordinate)</td>
</tr>
</tbody>
</table>
Geometrical functions for matching

<table>
<thead>
<tr>
<th>LENG</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>GX, GY, GZ</td>
<td>geometrical position $\xi_x, \xi_y, \xi_z$</td>
</tr>
<tr>
<td>CHI1, CHI2, CHI3</td>
<td>rotation of local coordinate $\chi_1, \chi_2, \chi_3$ (degree).</td>
</tr>
</tbody>
</table>

- The origin of the geometrical functions can be given by the ORG command.
  
  ```
  ORG loc ΔGX, ΔGY, ΔGZ, CHI1, CHI2, CHI3;
  ```

- If a flag SORG is on, the origin of $s$ is set to the loc given by ORG.
Control the goal value by FitValue

• It is possible to modify the goal value using a function FitValue:

\[
\text{FitValue}[\text{loc}, \text{fun}, \{\text{id}_-, \text{dp}_-\}, \nu_, \text{x}_-]:= \text{expr};
\]

• where \( \nu \) is the goal value given by \text{fun} command, and \( \text{x} \) is the current value of \text{fun}.

• If FitValue returns a real number, it is used as the goal value. If a non-real is returned, the matching condition for \text{fun} is ignored.

• Example:

\[
\text{FitValue}["\$$","\text{EX}",\_,\nu_,\text{x}_-]:=
\quad \text{Which}[\text{x} < \nu*0.9, \nu*0.9,
\quad \text{x} > \nu*1.1, \nu*1.1, \text{True, Null }];
\]

• The example above matches EX within \( 0.9*\nu \leq x \leq 1.1*\nu \).
Matching basics (3)

- Matching variables:
  
  ```
  FREE element [key] [element1 [key1]...];
  ```

- Wildcards can be used for `element`.
  
  ```
  FREE Q* B* B* L;
  ```

- The default keys (can be changed by VARY command):

<table>
<thead>
<tr>
<th>DRIFT</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEND</td>
<td>ANGLE</td>
</tr>
<tr>
<td>QUAD</td>
<td>K1</td>
</tr>
<tr>
<td>SEXT</td>
<td>K2</td>
</tr>
<tr>
<td>MULT</td>
<td>K1</td>
</tr>
</tbody>
</table>

- Variables are fixed by FIX with the same syntax as FREE.
Coupling between variables

- The default variables can be coupled to each other by the COUP command:

  COUP slave master ratio;

  where slave and master must be single elements, no wildcards are allowed. ratio is an expression giving a real number to give the ratio slave/master.

- For more general relations, use ElementValues:

  ElementValues= {"key"["element"]:> expr, ...};

  where expr is a general expression which may also contain "key1"["element1"]:

  Bq=1; (* pole-tip field of a quad *)
  aq=0.02; (* bore radius of a quad *)
  ElementValues=With[{q=#}, "L"[q]:= Abs["K1"[q]] * aq * Brho/Bq]&
  /@ Element["NAME", "Q*"]; (* give the lengths of quads, keeping their pole-tip field constant. *)

- ElementValues is persistent even switched to the other beam line. It should be cleared by

  ElementValues=.

before USE.
Matching basics (4)

- Some commands for matching

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALC</td>
<td>calculate the current optics</td>
</tr>
<tr>
<td>GO</td>
<td>do matching</td>
</tr>
<tr>
<td>REC</td>
<td>recover the optics before the previous GO (only one step)</td>
</tr>
<tr>
<td>SAVE [elem*</td>
<td>all]</td>
</tr>
<tr>
<td>RESET [elem*]</td>
<td>restore parameters from MAIN</td>
</tr>
<tr>
<td>SHOW</td>
<td>display the current matching conditions</td>
</tr>
<tr>
<td>VAR [elem*]</td>
<td>display variables</td>
</tr>
</tbody>
</table>
fit nx 0.375 ny 0.125;
free q*;
go;

<table>
<thead>
<tr>
<th>Iterations</th>
<th>Residual</th>
<th>Method</th>
<th>Reduction</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.9726</td>
<td>(NEWTON)</td>
<td>1.000</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6.6733E-03</td>
<td>(NEWTON)</td>
<td>1.000</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1.2168E-05</td>
<td>(NEWTON)</td>
<td>1.000</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>3.7061E-11</td>
<td>(NEWTON)</td>
<td>1.000</td>
<td>2</td>
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Matched. (3.4175E-22) DP = 0.01000  DP0 = 0.00000  ExponentOfResidual = 2.0
OffMomentumWeight = 1.000

$\$$ f AX ####### # -3.874436 $$f$$ f BX ####### # 12.491610
$\$$ f NX .375 1 .375000 $$f$$ f AY ####### # 1.233800
$\$$ f BY ####### # 3.967586 $$f$$ f NY .125 1 .125000
$\$$ f LENG ####### # 6.000000

In[18]:= CALC

Matched. (3.4175E-22) DP = 0.01000  DP0 = 0.00000  ExponentOfResidual = 2.0
OffMomentumWeight = 1.000

$\$$ f AX ####### # -3.874436 $$f$$ f BX ####### # 12.491610
$\$$ f NX .375 1 .375000 $$f$$ f AY ####### # 1.233800
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$\$$ f LENG ####### # 6.000000

In[19]=:
```math
fit nx 0.375 ny 0.125;
free q*;
go;

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Matched. (3.4175E-22) DP = 0.01000 DP0 = 0.00000 ExponentOfResidual = 2.0
OffMomentumWeight = 1.000

\[
\begin{align*}
\text{result with MatchingResidual} \\
\text{In[18]} & := \text{CALC} \\
\text{Matched. (3.4175E-22) DP = 0.01000 DP0 = 0.00000 ExponentOfResidual = 2.0} \\
\text{OffMomentumWeight = 1.000} \\
\text{In[19]} & :=
\end{align*}
\]
GO and CALC

fit nx 0.375 ny 0.125;
free q*;
go;

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$$$ f AX # -3.874436 $$$ f BX # 12.491610
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$$$ f BY # 3.967586 $$$ f NY .125 1 .125000
$$$ f LENG # 6.000000

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In[19]:=
```plaintext
GO and CALC

```
GO and CALC

fit nx 0.375 ny 0.125;
free q*;
go;

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In[19]:=
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GO and CALC

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fit nx 0.375 ny 0.125;
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GO and CALC

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Matched. ( 3.4175E-22)  
DP = 0.01000  DP0 = 0.00000  ExponentOfResidual = 2.0  
OffMomentumWeight = 1.000

### Function current value

| f AX       | -3.874436 |
| f NX .375  | .375000   |
| f BY       | 3.967586  |
| f LENG     | 6.000000  |

In[18]:= CALC
Matched. ( 3.4175E-22)  
DP = 0.01000  DP0 = 0.00000  ExponentOfResidual = 2.0  
OffMomentumWeight = 1.000

### Function goal value

| f AX       | -3.874436 |
| f NX .375  | .375000   |
| f BY       | 3.967586  |
| f LENG     | 6.000000  |

In[19]:= 
```
**DISP [R|O|A|G|B] [elem*] [range1 [range2]];**

none: standard functions with length and values of elements

**R:** x-y coupling parameters  **O:** orbits

**A:** acceleration with emittances  **G:** geometry  **B:** beam sizes

### disp

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### disp o

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</tbody>
</table>
Movable range of variables

- The movable range of a default key can be limited by MIN MAX, and MINMAX:
  - QF* MIN 0; (* 0 ≤ x *)
  - QD* MAX 0; (* x ≤ 0 *)
  - B* MINMAX 0.1 (* -0.1 ≤ x ≤ 0.1 *)

- For any variable, a function `VariableRange` sets the range:

  Bmax=1.5;
  `VariableRange["B1","L",v_]:=`
    `{0, Brho / Bmax * Abs[LINE["ANGLE","B1"]]};`
Execute FFS commands in expressions

- **FFS[commands_string]** excuses character-storing commands_string as FFS commands. It may return the results for some commands such as CALC, GO, VAR, SHOW, etc.

  ```math
  In[10]:= FFS["CALC"]
  Out[11]:=
  {{0},{0},{{3.417528475389843e-22,1,1}},{{"$$","","AX"},
  {-3.874435819115132}},{"$$","","BX"},{12.491609914888326}},{"$$","","NX"},
  {2.3561944901925274}},{"$$","","AY"},{1.2338003736307515}},{"$$","","BY"},
  {3.9675855895685537}},{"$$","","NY"},{.7853981633789626}},{"$$","","LENG"},{6}}}
  ```

- Multiple commands are accepted by a single FFS[]:

  ```math
  FFS[" cell;
  fit nx 0.375 ny 0.125;
  free q*; go;"
  ```

- **FFS[commands_string, out]** redirect the output to unit number out. If out is $Output or -1, it redirects to the current output unit.
VAR and SHOW

In[21]:= var

<table>
<thead>
<tr>
<th>Variable</th>
<th>Keyword</th>
<th>Now</th>
<th>Previous</th>
<th>Saved</th>
<th>Minimum</th>
<th>Maximum</th>
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</table>

In[22]:= FFS["VAR"]

Out[232]:= 

```
In[23]:= show

<table>
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<tr>
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<th>component2</th>
<th>fun</th>
<th>goal-value</th>
<th>np</th>
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<tr>
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<td>.125000000</td>
<td>1 ! * 6.283185307</td>
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</table>
```

Out[23]:= FFS["SHOW"]

Out[24]:= 

```
In[23]:= 
```
EMIT

The EMIT command calculates the equilibrium beam matrix:

\[ B \equiv \langle q_i q_j \rangle, \quad q_i = (x, p_x, y, p_y, z, \delta) \]  

(1)

using

\[ B = MBM^T + b, \]  

(2)

where \( M \) is the one-turn transfer matrix including damping, and \( b \) the excitation matrix due to synchrotron radiation and intrabeam scattering. This is a simple but powerful method especially when \( M \) has \( x-y \) or \( x-y-z \) coupling terms.

Closed orbit:

\[
\begin{array}{cccccc}
    x & px/p0 & y & py/p0 & z & dp/p0 \\


    Entrance : & .000000 & .000000 & .000000 & .000000 & .000000 \\

    Exit : & .000000 & .000000 & .000000 & .000000 & .000000 \\

\end{array}
\]

Imag.tune:-0.000000 0.000000 -0.000000
Real tune: 0.3750000 0.1250000 -0.000000

Extended Twiss Parameters:

\[
\begin{array}{cccc}
    AX : -3.87443 & BX : 12.49161 & ZX : 5.86E-16 & EX : .338461 \\
    PSIX : -1.6E-17 & ZPX : 2.93E-16 & EPX : .105191 & \\
    R1 : .000000 & R2 : .000000 & ZY : .000000 & AY : 1.233800 \\
    ZY : .000000 & BZ : 1.000000 & EPY : .000000 & PSIZ : .000000 \\
    R3 : .000000 & R4 : .000000 & EPY : .000000 & PSIY : .000000 \\
    PSIZ : .000000 & \\
\end{array}
\]

Damping per one revolution:

\[
\begin{array}{cccc}
    X : -1.0000000 & Y : -1.1249998 & Z : -2.3544068 \\

    Damping time (sec):
    X : 1.720978E-02 & Y : 1.707013E-02 & Z : 8.500592E-03 \\

    Tune shift due to radiation:

    Damping partition number:
    X : 0.9919 & Y : 1.0000 & Z : 2.0081 \\
\end{array}
\]

Units: B(X,Y,Z), E(X,Y), R2: m | PSI(X,Y,Z): radian | ZP(X,Y), R3: 1/m

Design momentum \( P_0 = 3.0000000 \) GeV Revolution freq. \( f_0 = 49965408. \) Hz
Energy loss per turn \( U_0 = 0.0070347 \) MV Effective voltage \( V_c = 0.0000000 \) MV
Bunch Length \( = .0000000 \) mm Beam tilt \( = .0000000 \) rad
Equilibrium position \( dz = 0.0000000 \) mm Momentum compact. alpha = .0054089
Orbit dilation \( d1 = 0.0000000 \) mm Effective harmonic # h = .0000000
Bucket height \( dV/P_0 = 0.000000 \)

Emittance X = 8.64279E-9 m Emittance Y = 0.0000000 m
Emittance Z = 0.0000000 m Energy spread = 5.08214E-4
Beam size xi = 37087720 mm Beam size eta = 0.0000000 mm
Emittance[] does the same thing as EMIT, but returns the result as a list of Rules (->):

In[11]:= Emittance[]
Out[11]:= 
{Stable->1,Tunes->{.37500000000002826,.12499999999705737,-0},
EnergyLossU0->7034.697060646969,RfVoltageVc->0, EquilibriumPosition>0,
MomentumCompaction->.0054089333078228795, OrbitDilation->0,
BucketHeight->0,HarmonicNumber->0, OrbitAtExit->{0,0,0,0,0},DampingRate->
{-1.1629345513699653e-06,-1.172448675392321e-06,-2.3544061662267986e-06},
Emittances->{8.642785032172451e-09,0,0},MomentumSpread->000508213708964793,
BunchLength->0,TuneShiftByRadiation->
{-3.0988604689797874e-13,-1.460986955594973e-13,6.080433798344304e-09}}

The result can be obtained by using ReplaceAll (/.):

In[12]:= e=Emittance[];
In[12]:= Emittances[[1]]/.e
Out[12]:= 8.642785032172451e-09
Operations on Lists

• Map (/@):
  
  In[14]:= Map[f, {1, 2, 3}]
  Out[14]:= {f[1], f[2], f[3]}

  In[15]:= f/@{1, 2, 3}
  Out[15]:= {f[1], f[2], f[3]}

  In[16]:= f/@{{1, 2}, {3, 4}, {5, 6}}, {2}]
  Out[16]:= {{f[1], f[2]}, {f[3], f[4]}, {f[5], f[6]}}

• Apply (@@):
  
  In[17]:= Apply[f, {1, 2, 3}]
  Out[17]:= f[1, 2, 3]

  In[18]:= f@@{1, 2, 3}
  Out[18]:= f[1, 2, 3]

  In[19]:= f@@{{1, 2}, {3, 4}, {5, 6}}, {1}]
  Out[19]:= {f[1, 2], f[3, 4], f[5, 6]}
# More functions for list operations

<table>
<thead>
<tr>
<th>function</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thread</td>
<td>Thread[{{1,2,3},{4,5,6}}] → {{1,4},{2,5},{3,6}}</td>
</tr>
<tr>
<td>MapThread</td>
<td>MapThread[f, {{1,2,3},{4,5,6}}] → {f[1,4],f[2,5],f[3,6]}</td>
</tr>
<tr>
<td>Scan</td>
<td>Map without output; faster &amp; less memory</td>
</tr>
<tr>
<td>Position</td>
<td>Position[{a,b,c,d,a,e}, a] → {{1},{5}}</td>
</tr>
<tr>
<td>Cases</td>
<td>Cases[{a,b,c,d,a,e}, a</td>
</tr>
<tr>
<td>DeleteCases</td>
<td>DeleteCases[{a,b,c,d,a,e}, a</td>
</tr>
<tr>
<td>Select</td>
<td>Select[{1,4,-1,1,2}, (#&gt;1)&amp;] → {4,2}</td>
</tr>
<tr>
<td>Sort</td>
<td>Sort[{1,4,-1,1,2}] → {-1,1,1,2,4}</td>
</tr>
<tr>
<td>Union</td>
<td>Union[{1,4,-1,1,2},{3,-1}] → {-1,1,2,3,4}</td>
</tr>
<tr>
<td>Intersection</td>
<td>Intersection[{1,4,-1,1,2}, {3,-1}] → {-1}</td>
</tr>
</tbody>
</table>
More functions for list operations (2)

<table>
<thead>
<tr>
<th>function</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>number of elements in a list</td>
</tr>
<tr>
<td>Dimensions</td>
<td>dimensions of a matrix or a tensor</td>
</tr>
</tbody>
</table>
| Part      | {{1,2,3},{4,5,6}}[[2]] → {4,5,6}  
{{1,2,3},{4,5,6}}[[2,-2]] → {1,2,3}  
{{1,2,3},{4,5,6}}[[1,2]] → 2  
{{1,2,3},{4,5,6}}[[2, {1,3}]] → {4,6} |
| Take      | Take[{1,4,-1,1,2},3] → {1,4,-1}  
Take[{1,4,-1,1,2},-3] → {-1,1,2}  
Take[{1,4,-1,1,2},{3,-2}] → {-1,1} |
| Drop      | Drop[{1,4,-1,1,2},3] → {1,2}  
Drop[{1,4,-1,1,2},-3] → {1,4}  
Drop[{1,4,-1,1,2},{3,-2}] → {1,4,2} |

... and more
Listable operations

• Many arithmetic operations and functions are "listable", i.e., they operate parts by parts:
  \{a, b, c\} \times \{d, e, f\} \rightarrow \{a \cdot d, b \cdot e, c \cdot f\}
  r \cdot \{a, b, c\} \rightarrow \{r \cdot a, r \cdot b, r \cdot c\}
  \text{Sin}\{\{a, b, c\}\} \rightarrow \{\text{Sin}[a], \text{Sin}[b], \text{Sin}[c]\}

• A listable operation is faster than an operation using Part and index, so is encouraged to use:

  \text{In}[21]:= u = \text{Range}[1000]
  \text{Out}[21]:={1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, \ldots
  \text{In}[22]:= \text{Timing}[u \times 2]
  \text{Out}[22]:= \{2.7000904083251953 \times 10^{-05},
  \{2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, \ldots
  \text{In}[23]:= \text{Timing}[\text{Table}[u[[i]] \times 2, \{i, \text{Length}[u]\}]]
  \text{Out}[23]:= \{0.0005450248718261719, \{2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44, 46, \ldots

Pure function

• A pure function is a function without name:

$$(# + #2)[a, b] \rightarrow a+b$$

$$\text{ave} = ((\text{Plus}@[#]) / \text{Length}[#]) &[\text{list}]$$

$$\text{rms} = \text{Sqrt}[\text{Plus}@[(# - \text{ave})^2)] / \text{Length}[#] & [\text{list}]$$

• Another form of pure function:

$$\text{Function}[[a, b, c], a+b+c][1, 2, 3] \rightarrow 6$$
Module

- Module[{var1, ...}, body] defines local symbols var1,..., which are usable within body, then evaluate body. Local symbols are abandoned after the exit of Module.

  a=1; Module[{a}, a=2]; a \rightarrow 1

- The local symbols must explicitly appear in body.

  Clear[a,f]; f=a; Module[{a}, a=2; {f,a}] \rightarrow \{a, 2\}

- The initial values of local symbols can be given as:

  Module[{var1=value, \{value2, value3, ...\}=list, ...}, body]
Defining a function

• A function $f$ with arguments $arg1,...$ can be defined as:

$$f[arg1_, ...]:= body;$$

• where $arg1_\_\_$ is a pattern to match any actual argument when $f[...]$ is evaluated. Every symbol $arg1$ appearing in $body$ is replaced by with the actual argument before the evaluation of $body$.

• The symbol $arg1$ must explicitly appear in body.

---

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x__$</td>
<td>matches anything, replacing symbol $x$</td>
</tr>
<tr>
<td>$x___$</td>
<td>matches any non-null sequence, replacing symbol $x$</td>
</tr>
<tr>
<td>$x____$</td>
<td>matches any sequence, can be null, replacing symbol $x$</td>
</tr>
<tr>
<td>$x__h$</td>
<td>matches anything having head $h$</td>
</tr>
<tr>
<td>$x_?(test)$</td>
<td>matches anything $test[x]$ gives True</td>
</tr>
</tbody>
</table>
Defining a function (2)

- Example:

```math
f[x_] := \text{Sin}[x]/x;
f[0] = 1;
Plot[f[x], \{x, -2\pi, 2\pi\}];
Update[];
```
Defining a function (2)

- Example:

```math
f[x_] := Sin[x]/x;
f[0] = 1;
Plot[f[x], {x, -2Pi, 2Pi}];
Update[];
```
What are we building in this seminar?

- A 3 GeV ring.

![Diagram of a 3 GeV ring with DS1, DS2, RF, and Arc; FODO sections. The circumference is approximately 500 m.]
Exchange $x$ & $y$

- $x$ and $y$ coordinates interchange, if they are inverted along the $y'$ axis. The coordinates $(x', y')$ are rotated by 45 deg from $(x, y)$: the axes of a skew quadrupole.