COBEA Manual

Release 0.14

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The *cobea* module [1] is a Python implementation of Closed-Orbit Bilinear-Exponential Analysis [2], an algorithm for studying closed-orbit response matrices of storage rings (particle accelerators).

If you publish material using this software, please cite one or more of the references [1-2].

For more information, visit https://bitbucket.org/b-riemann/cobea .

(References)

[1] B. Riemann et al., ''COBEA - Optical Parameters From Response Matrices Without Knowledge of Magnet Strengths'', in Proc. IPAC17, paper MOPIK066, 2017.

[2] B. Riemann, ''[The Bilinear-Exponential Closed-Orbit Model and its Application to Storage Ring Beam Diagnostics](http://dx.doi.org/10.17877/DE290R-17221)'', Ph.D. Dissertation, TU Dortmund University, 2016. DOI [10.17877/DE290R-17221](http://dx.doi.org/10.17877/DE290R-17221).

QUICK START TUTORIAL

This is a brief introduction on how to use the cobea module.

1.1 Reading in data

COBEAs input consists of

- A set of corrector names corresponding to rows of your matrix

- A set of monitor names corresponding to columns of your matrix

- The response matrix itself

- The ordering information, given as a list of monitor and corrector names, ordered along the beampath (downstream)

You need to convert your response data into a standardized input for COBEA. This is handled by the *Response* class:

class cobea.model.**Response** (*matrix*, *corr_names*, *mon_names*, *line*, *include_dispersion=True*, *unit=''*)
Representation of COBEA input, used as such for the function *cobea.cobea()*

During creation of the this object, py:data:*matrix* rows and columns, as well as the corresponding py:data:*corr_names* and py:data:*mon_names*, are resorted to their respective order in py:data:*line*.

>   **Parameters**
>
>   - **matrix** (*array*) – input response matrix of shape (correctors, monitors, directions). If only one direction is considered, the last dimension can be omitted.
>
>   - **corr_names** (*list*) – a list of corrector labels corresponding to each row of the matrix
>
>   - **mon_names** (*list*) – a list of monitor labels corresponding to each column of the matrix
>
>   - **line** (*list*) – a list of element names in ascending s order
>
>   - **include_dispersion** (*bool*) – whether to use a model with or without dispersion for fitting. default: True
>
>   - **unit** (*str*) – unit for the input values of the matrix (optional)

> **topology**
>   *object* – A Topology object holding the re-ordered py:data:'corr_names', py:data:'mon_names', and py:data:'line' as attributes.

> **matrix**
>   *array* – re-ordered input response matrix.

1.2 Running the algorithm

The COBEA algorithm is then applied using the function *cobea.cobea()* (click link, return back to 1.3 afterwards)

1.3 Obtaining and plotting results

The *cobea* function returns a *Result* object. This object contains all computed information.

class `cobea.model.`**Result**(*response*, *additional={}*, ***kwargs*)
COBEA Result.

Besides the attributes and methods contained in `BEModel`, the following information is included.

matrix
array – Original input response matrix

error
object – computed BE model errors, represented as `ErrorModel` object

additional
dict – may contain the following keywords

coretime [float] time used for computation in the start and optimization layer.

err [dict] dictionary with additional model parameter error estimates.

conv [dict] dictionary with L-BFGS convergence information (if convergence_info was True)

invariants [array] computed during normalization of monitor vectors if drift space is given. These are just returned for completeness and do not contain information about beam physics.

pca_singvals [array] custom info from MCS algorithm

pca_orbits [array] custom info from MCS algorithm

version [str] version of the object

cbeta_jmw
Ripken-Mais beta parameters * constant. If self.R_jmw is normalized, constant = 1.

cbeta_km
const*beta at correctors assuming decoupled optics and thin correctors

delphi_jmw
Ripken-Mais phase advances per element

delphi_km
Betatron phase advances per corrector assuming decoupled optics and thin correctors

flip_mu(*m*)
switch the sign of mu_m for given m, simultaneously changing the conjugation of `R_jmw` and `A_km` so that the response matrix remains unchanged

phase_integral(*m*)
integrated phase from first to last BPM (not one turn!), used for `tune()` computation

phi_jmw
Compute Ripken-Mais betatron phases in units of degrees

response_matrix()
generate a 'simulated' response matrix from the present model parameters

> **Returns rsim_kjw** – response array of shape (K, J, M)
>
> **Return type** array

save(*filename*)

> save the Result object as a pickle file with the given filename. The object can be reloaded using *cobea.load_result()* (which simply uses pickle)

tune(*m*)

> compute tune including integer part for a given mode m

update_errors()

> compute errors in attribute *error* for given BE-Model parameters and input response, including errors for Ripken-Mais parameters

The module *cobea.plotting* includes many helper functions to view these results. A summary of results is created by the *cobea.plotting.plot_result()* function.

API

This page contains automatic documentation of the complete cobea module.

2.1 cobea (main namespace)

Closed-Orbit Bilinear-Exponential Analysis (COBEA)

This is a Python implementation of the COBEA algorithm [1] to be used for studying betatron oscillations in particle accelerators by closed-orbit information.

[1] B. Riemann. ''The Bilinear-Exponential Model and its Application to Storage Ring Beam Diagnostics'',
PhD Dissertation (TU Dortmund University, 2016), DOI Link: (https://dx.doi.org/10.17877/DE290R-17221)

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cobea.**cobea**(*response*, *drift_space=nan*, *convergence_info=False*)
Main COBEA function with pre- and postprocessing.

> **Parameters**
>
> - **response** (*object*) – A valid *cobea.model.Response* object representing the input.
>
> - **drift_space** (*tuple*) – if not-NaN, a tuple with 3 elements (monitor name 1, monitor name 2, drift space length / m)
>
> - **convergence_info** (*bool*) – if True, convergence information from L-BFGS is added to the result dictionary (before saving).
>
> **Returns result** – A *cobea.model.Result* object.
>
> **Return type** object

cobea.**l_bfgs_iterate**(*alloc_items=10000*)
convert the iterate.dat file produced by L-BFGS-B

> **Parameters alloc_items** (*int*) – the number of maximum iterations for which memory is allocated.
>
> **Returns**
>
> **iter** –
>
> **a dictionary with the following fields. The field names and descriptions have been copied from a demo outpu**
>
> > **'it'** [array] iteration number
> >
> > **'nf'** [array] number of function evaluations
> >
> > **'nseg'** [array] number of segments explored during the Cauchy search
> >
> > **'nact'** [array] number of active bounds at the generalized Cauchy point

'sub' [str]

manner in which the subspace minimization terminated con = converged, bnd = a bound was reached

'itls' [int] number of iterations performed in the line search

'stepl' [float] step length used

'tstep' [float] norm of the displacement (total step)

'projg' [float] norm of the projected gradient

'f' [float] function value

Return type dict

cobea.**load_result**(*savefile*)

Load (un-pickle) a Result object (or any other object)

cobea.**optimization_layer**(*result*, *iprint=-1*)

Implementation of the Optimization layer. It uses L-BFGS [1] as special case of L-BFGS-B [2] in scipy.optimize. The result object is modified to yield the optimal BEModel. A sub-dictionary with additional information is added under the key result.additional['Opt'].

[1] D.C. Liu and J. Nocedal, ''On the Limited Memory Method for Large Scale Optimization'', Math. Prog. B 45 (3), pp.~503–528, 1989. DOI 10.1007/BF01589116

[2] C. Zhu, R.H. Byrd and J. Nocedal, ''Algorithm 778: L-BFGS-B: Fortran subroutines for large-scale bound-constrained optimization'', ACM Trans. Math. Software 23 (4), pp.~550–560, 1997. DOI 10.1145/279232.279236

Parameters result (*object*) – A valid *cobea.model.Result* object. The object is modified during processing; the model variables are set to their optimal values.

Returns result – Identical to input object.

Return type object

cobea.**read_elemnames**(*finame*)

A helper function to read element names from text files into a list of strings. Standard input is a text file with linebreaks between elements.

2.2 cobea.model: COBEA classes and objects

This COBEA submodule defines all classes used by *cobea*. Besides input (*Response*) and output (*Result*) containers, this also includes gradient-based optimization procedures in BE_Model.

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class cobea.model.**BEModel**(*K*, *J*, *M*, *topology*, *include_dispersion*, *init_fun=<built-in function empty>*)

Bases: *cobea.model.BasicModel*

Bilinear-Exponential model with topology information and optimization routines. Besides the attributes and methods contained in Bare_Model, the following information is included.

Parameters

- **K,J,M** (*int*) – dimensions of the model, with K being the number of correctors, J being the number of monitors, and M the number of modes respectively directions.

- **init_fun** (*function*) – a (possibly self-defined) initialization function like zeros() or empty() from numpy.

topology

object – input topology, represented as *Topology* object

cbeta_jmw
Ripken-Mais beta parameters * constant. If self.R_jmw is normalized, constant = 1.

cbeta_km
const*beta at correctors assuming decoupled optics and thin correctors

delphi_jmw
Ripken-Mais phase advances per element

delphi_km
Betatron phase advances per corrector assuming decoupled optics and thin correctors

flip_mu(*m*)
switch the sign of mu_m for given m, simultaneously changing the conjugation of R_jmw and A_km so that the response matrix remains unchanged

phase_integral(*m*)
integrated phase from first to last BPM (not one turn!), used for *tune()* computation

phi_jmw
Compute Ripken-Mais betatron phases in units of degrees

response_matrix()
generate a 'simulated' response matrix from the present model parameters

> **Returns rsim_kjw** – response array of shape (K, J, M)
>
> **Return type** array

tune(*m*)
compute tune including integer part for a given mode m

class cobea.model.**BasicModel**(*K*, *J*, *M*, *init_fun=<built-in function empty>*)
simple representation of the Bilinear-Exponential model (without topology or optimization attributes).

> **Parameters**
>
> - **K,J,M** (*int*) – dimensions of the model, with K being the number of correctors, J being the number of monitors, and M the number of modes respectively directions.
>
> - **init_fun** (*function*) – a (possibly self-defined) initialization function like zeros() or empty() from numpy.

K
int – total number of correctors. defines limit of corrector index k.

J
int – total number of monitors. defines limit of monitor index j.

M
int – number of directions respectively modes. defines limits of mode index m and direction index w.

R_jmw
array – monitor vectors in format [monitor, mode, direction]

A_km
array – corrector parameters, format [corrector, mode]

d_jw
array – unnormalized dispersion function at monitors, format [monitor, direction]

b_k
array – unnormalized dispersion coefficients at correctors, format [corrector]

mu_m
array – fractional phase advances per turn (in rad)

A reduced model class without topology or gradient computation

class `cobea.model.`**`Response`**(*matrix*, *corr_names*, *mon_names*, *line*, *include_dispersion=True*, *unit=''*)

Representation of COBEA input, used as such for the function `cobea.cobea()`

During creation of the this object, py:data:*matrix* rows and columns, as well as the corresponding py:data:*corr_names* and py:data:*mon_names*, are resorted to their respective order in py:data:*line*.

> **Parameters**
>
> - **`matrix`** (`array`) – input response matrix of shape (correctors, monitors, directions). If only one direction is considered, the last dimension can be omitted.
>
> - **`corr_names`** (`list`) – a list of corrector labels corresponding to each row of the matrix
>
> - **`mon_names`** (`list`) – a list of monitor labels corresponding to each column of the matrix
>
> - **`line`** (`list`) – a list of element names in ascending s order
>
> - **`include_dispersion`** (`bool`) – whether to use a model with or without dispersion for fitting. default: True
>
> - **`unit`** (`str`) – unit for the input values of the matrix (optional)

> **`topology`**
>
> *object* – A `Topology` object holding the re-ordered py:data:'corr_names', py:data:'mon_names', and py:data:'line' as attributes.

> **`matrix`**
>
> *array* – re-ordered input response matrix.

class `cobea.model.`**`Result`**(*response*, *additional={}*, ***kwargs*)

Bases: `cobea.model.BEModel`

COBEA Result.

Besides the attributes and methods contained in `BEModel`, the following information is included.

> **`matrix`**
>
> *array* – Original input response matrix

> **`error`**
>
> *object* – computed BE model errors, represented as `ErrorModel` object

> **`additional`**
>
> *dict* – may contain the following keywords
>
> **coretime** [float] time used for computation in the start and optimization layer.
>
> **err** [dict] dictionary with additional model parameter error estimates.
>
> **conv** [dict] dictionary with L-BFGS convergence information (if convergence_info was True)
>
> **invariants** [array] computed during normalization of monitor vectors if drift space is given. These are just returned for completeness and do not contain information about beam physics.
>
> **pca_singvals** [array] custom info from MCS algorithm
>
> **pca_orbits** [array] custom info from MCS algorithm
>
> **version** [str] version of the object

> **`save`**(*filename*)
>
> save the Result object as a pickle file with the given filename. The object can be reloaded using `cobea.load_result()` (which simply uses pickle)

> **`update_errors`**()
>
> compute errors in attribute `error` for given BE-Model parameters and input response, including errors for Ripken-Mais parameters

class `cobea.model.`**`Topology`**(*corr_names*, *mon_names*, *line*)

> Representation of corrector/monitor labels and the order between them along the ring. During creation, all columns and rows of the input matrix, together with their labels in corr_names, mon_names, are re-ordered in ascending s-position according to the line list.

> #### Parameters
>
> - **`corr_names`** (`list`) – corrector labels (strings), e.g. ['HK01', 'VCM1', 'special_Hcorr', ...]. The list index should correspond to the monitor_index, e.g. matrix[1,:,:] holds all information for the corrector named 'VCM1' in the above example.
>
> - **`mon_names`** (`list`) – monitor labels (strings), e.g. ['BPM1','BPM2a','buggy_BPM',...,'important-bpm42']. the list index should correspond to the monitor_index, e.g. matrix[:,0,:] holds all information for the monitor named 'BPM1' in the above example.
>
> - **`line`** (`list`) – corrector and monitor labels in ascending s position, downstream of the storage ring.

2.3 cobea.mcs: Monitor-Corrector Subspace algorithm

Monitor-Corrector Subset (MCS) algorithm submodule

MCS can be used as start-value layer of COBEA.

`cobea.mcs.`**`complexsolv`**(*realvec*, *mat*)

> solve the half-complex equation system realvec = real(compmat*conj(compsol)) for compsol. :returns: compsol, res (from lstsq),
>
> > realvec_rc: reconstructed realvec from compsol, s: singular values of compmat (from lstsq)

`cobea.mcs.`**`composite_vectors`**(*pcaDev*)

> make two-orbit vectors (similar to phase space vectors) at beginning and end of partial orbits

`cobea.mcs.`**`corrector_matrix_k`**(*R*, *cE*)

> output the complex corrector equation system matrix corrmat for a given corrector. corrmat.shape = [input_bpm*Directions+direction,mode] R: full input monitor array, R.shape = [input_bpm,mode,direction] cE: conj(E[:,k,:]) of Ejkm

`cobea.mcs.`**`corrector_systems`**(*Dev*, *monvec*, *bpm_s*, *corr_s*, *mus*, *printmsg=True*, *E=[]*)

> set up and solve the corrector equation systems. Dev[k,f,d]: Deviations at all correctors for fast BPMs. monvec: all input monitor vectors. returns: D[k,m]: corrector parameters complexsolv parameters as arrays

`cobea.mcs.`**`dice_splitpoints`**(*n*, *monidx*, *splitidx*)

> numpy arrays are passed by reference, so splitidx can be overwritten without return

`cobea.mcs.`**`find_indices`**(*x*, *y*)

> find all indices i for which x[n] = y[i[n]] (j arbitrary). len(x) < len(y). (This function could be re-moved to __init__ later on)

`cobea.mcs.`**`flatten_Dev`**(*Dev*)

> Index transform of Deviation matrix (k,j,w) to PCA processing matrix (k,j*w)

`cobea.mcs.`**`layer`**(*response*, *trials=-1*)

> implementation of the Monitor-Corrector Subspace algorithm

> #### Parameters
>
> - **`response`** (`object`) – A valid *`cobea.model.Response`* object.
>
> - **`trials`** (`int`) – Number of different monitor subsets tried for MCS. If set to -1, value is set automatically.

`cobea.mcs.`**`local_optimization`**(*Dev*, *monidx*, *corridx*, *Nelems*, *include_dispersion*, *runs*)

> solve CES and MES systems compute residual Res error and find optimal splitidx

cobea.mcs.**monitor_matrix_j**(*Y*, *E*)
> output the complex monitor equation system matrix monmat for a given monitor AND direction. monmat.shape = [corrector,mode] Y: corrector parameters, Y.shape = [corrector,mode] E: E[j,:,:] of Ejkm

cobea.mcs.**monitor_systems**(*Dev*, *D*, *all_bpm_s*, *corr_s*, *mus*, *printmsg=True*, *E=[]*)
> set up and solve the monitor equation systems, return R[j,m,d], the full monitor vector set for all monitors. Dev[k,j,d]: Deviations at all correctors for all BPMs. D[k,m]: all corrector parameters.

cobea.mcs.**pca_core**(*Dev*, *principal_orbits=True*)
> Principal Component Analysis of a Deviation matrix.

cobea.mcs.**topo_indices**(*strilist*, *elto*)
> construct indices from stringlists. holds up to level.2 lists. strilist: list of elements elto: larger list of elements in which strilist elements are looked for.

cobea.mcs.**unflatten_Dev**(*pcaproc*, *Devshp*)
> Index transform of PCA processing matrix (k,j*w) to Deviation matrix (k,j,w)

2.4 cobea.plotting: Routines for plotting results

routines for plotting COBEA results

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cobea.plotting.**A_km**(*rslt*, *m*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)
> plot real and imaginary parts of corrector parameters (incl. errors) into an axis for a given mode m

cobea.plotting.**R_jmw**(*rslt*, *ax*, *m*, *direction='xy'*)
> plot real and imaginary parts of monitor vectors (incl. errors) into an axis for a given mode m

cobea.plotting.**cbeta_jmw**(*rslt*, *ax*, *m*, *comparison_data={}*, *direction='xy'*)
> plot beta resp. const*beta (incl. errors) into an axis for a given mode m

cobea.plotting.**cbeta_km**(*rslt*, *m*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)
> plot const*beta at correctors assuming decoupled optics and thin correctors ToDo: errors for this quantity

cobea.plotting.**coleur**(*n=-1*)
> a colorset compiled of: - 0-5: colorbrewer2 2-class paired - 6-11: inverse of 0-5

cobea.plotting.**corrector_label**(*corr_labels=[]*, *spacing=0*, *dir='y'*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)
> apply corrector labels to an axis

cobea.plotting.**corrector_results**(*rslt*, *m=0*)
> create a figure with corrector results for a given mode m

cobea.plotting.**d_jw**(*rslt*, *ax*, *w*, *comparison_data*, *direction='xy'*)
> plot const*dispersion (incl. errors) into an axis for a given direction w (0: x, 1: y)

cobea.plotting.**delphi_jmw**(*rslt*, *ax*, *m*, *comparison_data={}*, *yl=-1*, *direction='xy'*)
> plot phase-advance per monitor (incl. errors) into an axis for a given mode m

cobea.plotting.**monitor_label**(*mon_labels=0*, *spacing=0*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)
> apply monitor labels to an axis

cobea.plotting.**monitor_results**(*rslt*, *m=0*, *comparison_data={}*, *direction='xy'*)
> plot monitor results for mode m, optionally in comparison with comparison_data.

> > **Parameters**
> > - **result** (*object*) – A *cobea.model.Result* object.
> > - **m** (*int*) – mode index to plot results for

- **comparison_data** (`dict`) – a dictionary containing optional data from alternative decoupled storage ring models, which may contain the following keys: 'name': name of the algorithm or model used 'beta': an array of shape (rslt.M,rslt.J) that contains Courant-Snyder beta values for each direction and monitor 'phi': an array of the same shape as 'beta', containing Courant-Snyder betatron phases 'dispersion': an array of the same shape, containing dispersion values

`cobea.plotting.`**plot_Dev_err**(*result*, *w=0*)

create a figure that shows response matrix and residual error for a given direction w (0: x, 1: y)

`cobea.plotting.`**plot_matrix**(*Devdr*, *devlbl*, *cmap=('PRGn'*, *'Greens')*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)

plot an arbitrary matrix with divergent or sequential colormap (helper function)

`cobea.plotting.`**plot_residual**(*result*, *w=0*, *label='residual'*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)

plot fit residual into an axis for a given direction w (0: x, 1: y)

`cobea.plotting.`**plot_response**(*response*, *w=0*, *label='deviation'*, *ax=<matplotlib.axes._subplots.AxesSubplot object>*)

Plot response matrix into an axis for a given direction w (0: x, 1: y)

`cobea.plotting.`**plot_result**(*result*, *print_figures=True*, *prefix='.'*, *comparison_data={}*, *direction='xy'*, *plot_flags='mcdt'*)

plot COBEA results.

> **Parameters**
>
> - **result** (`object`) – A *cobea.model.Result* object.
>
> - **print_figures** (`bool`) – whether to print figures into separate pdf files instead of showing them. Default: True
>
> - **prefix** (`str`) – if print_figures=True, prefix contains the relative path to the current folder where results are printed.
>
> - **comparison_data** (`dict`) – a dictionary containing optional data from alternative decoupled storage ring models, which may contain the following keys: 'name': name of the algorithm or model used 'beta': an array of shape (rslt.M,rslt.J) that contains Courant-Snyder beta values for each direction and monitor 'phi': an array of the same shape as 'beta', containing Courant-Snyder betatron phases 'dispersion': an array of the same shape, containing dispersion values
>
> - **direction** (`str`) – direction characters for the result object. can be 'x','y', or 'xy'.
>
> - **plot_flags** (`str`) – which plots are to be created. Each character represents a different result plot: 'm': monitor_results -> monitor_m*.pdf 'c': corrector_results -> corrector_m*.pdf 'd': plot_Dev_err, hist -> Dev_err_w*.pdf, hist_w*.pdf 't': plot_topology -> topology.pdf 'c': convergence information -> convergence.pdf. Only works if convergence information is available.

`cobea.plotting.`**plot_size**(*plot_type=0*)

plot sizes for all plot types

`cobea.plotting.`**plot_topology**(*topology*)

create a figure that shows the accelerator topology. Input: Topology object

`cobea.plotting.`**prepare_figure**(*plot_type=0*)

set fonts, tex packages, and figure size. returns figure

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