COBEA Manual

Release 0.11

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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).

CHAPTER

ONE

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
- **`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.

`delphi_jmw`

Ripken-Mais phase advances per element

`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

`response_matrix`(*dispersion=True*)

generate a 'simulated' response matrix from the present model parameters

Returns **Dev** – 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.

CHAPTER

TWO

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`**(*rslt*, *iprint=-1*)

Implementation of the Optimization layer. It uses L-BFGS [1] as special case of L-BFGS-B [2] in scipy.optimize

[1] D.C.~Liu and J.~Nocedal, ''On the Limited Memory Method for Large Scale Optimization'', Math. Prog. B extbf{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 extbf{23} (4), pp.~550–560, 1997. DOI 10.1145/279232.279236

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

Returns **additional_rslt** – Additional information from the obtimization procedure. The function value and optimum are contained directly in the aforementioned rslt object that acted as input.

Return type dict

`cobea.`**`read_elemnames`**(*fname*)

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

class `cobea.model.`**`BEModel`**

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)`** (*`tuple`*) – 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.

delphi_jmw
Ripken-Mais phase advances per element

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

response_matrix(*dispersion=True*)
generate a 'simulated' response matrix from the present model parameters

Returns **Dev** – 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**
simple representation of the Bilinear-Exponential model (without topology or optimization attributes).

Parameters

- **(K,J,M)** (*tuple*) – 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
- **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 = [fast_bpm*Directions+direction,mode] R: full fast monitor array from TBT data, R.shape = [fast_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 TBT 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`**(*rslt*, *locruns=-1*)
: implementation of the Monitor-Corrector Subspace algorithm

    Parameters

    - **rslt** (*object*) – A valid *cobea.model.Result* object. The object is modified during processing.
    - **locruns** (*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=-1*)
: 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 Bernard Riemann, April 2016

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

cobea.plotting.**delphi_jmw**(*rslt*, *ax*, *m*, *comparison_data={}*, *yl=-1*, *direction='xy'*)
phase-advance plot

cobea.plotting.**monitor_results**(*rslt*, *m=0*, *comparison_data={}*, *direction='xy'*)
plot monitor (and mu) 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_result**(*rslt*, *print_figures=False*, *prefix='.'*, *comparison_data={}*, *direction='xy'*)
plot/printshow results of a factory.

cobea.plotting.**plot_size**(*plot_type=0*)
plot sizes for all plot types

cobea.plotting.**prepare_figure**(*plot_type=0*)
set fonts, tex packages, and figure size. returns figure

PYTHON MODULE INDEX

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