Orbit Analysis

3/8/99

Y.Ohnishi

- Strategy and Method
- Orbit Analysis at KEKB Linac
- Orbit Analysis at KEKB Ring
- Summary

Strategy and Method

- Beam position:
  $x(x_0, p_0, E, l, \sigma_z, \ldots)$
- Pulse by pulse:
  $x(x_0+\Delta x_0, p_0+\Delta p_0, \ldots)$
- The data from BPM readings can be stored in a matrix B of N rows and M columns.
- $B = \{x_{ij}\}$.

  $i = 1 \sim N$: #pulses
  $j = 1 \sim M$: #BPMs
  $k = 1 \sim K$: #physical variables

Taylar Expansion:

$$x_{ij} = x_j^{\text{offset}} + \sum_{k=1}^{K} \Delta u_{ik} \frac{\partial x_j}{\partial u_k} + \sum_{k=1}^{K}\sum_{k'=k}^{K} \Delta u_{ik}\Delta u_{ik'} \frac{\partial^2 x_j}{\partial u_k \partial u_{k'}} + \cdots$$

$$\langle x_j \rangle = x_j^{\text{offset}} + \sum_{k=1}^{K} \langle \Delta u_k \rangle \frac{\partial x_j}{\partial u_k} + \sum_{k=1}^{K}\sum_{k'=k}^{K} \langle \Delta u_k \Delta u_{k'} \rangle \frac{\partial^2 x_j}{\partial u_k \partial u_{k'}} + \cdots$$

$$\frac{x_{ij} - \langle x_j \rangle}{\sqrt{NM}} = \frac{1}{\sqrt{NM}} \left\{ \sum_{k=1}^{K} (\Delta u_{ik} - \langle \Delta u_k \rangle) \frac{\partial x_j}{\partial u_k} + \cdots \right\}$$

$$= \sum_{k=1}^{K} \left(\frac{\Delta u_{ik} - \langle \Delta u_k \rangle}{\sqrt{N}\, \Delta u_k^{\text{rms}}} \right) \left(\Delta u_k^{\text{rms}} b_k^{\text{rms}} \right) \left(\frac{\partial x_j}{\sqrt{M}\, b_k^{\text{rms}} \partial u_k} \right) + \cdots$$

B → U^T → Λ → V^T

SVD

$B = U^T \Lambda V^T$ (dimension-less, dimension, dimension-less, [L])

$$\Delta u_k^{\text{rms}} \equiv \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\Delta u_{ik} - \langle \Delta u_k \rangle)^2}$$

$$b_k^{\text{rms}} \equiv \sqrt{\frac{1}{M} \sum_{j=1}^{M} \left(\frac{\partial x_j}{\partial u_k} \right)^2}$$

Strategy and Method (contd.)

Singula Value Decomposition

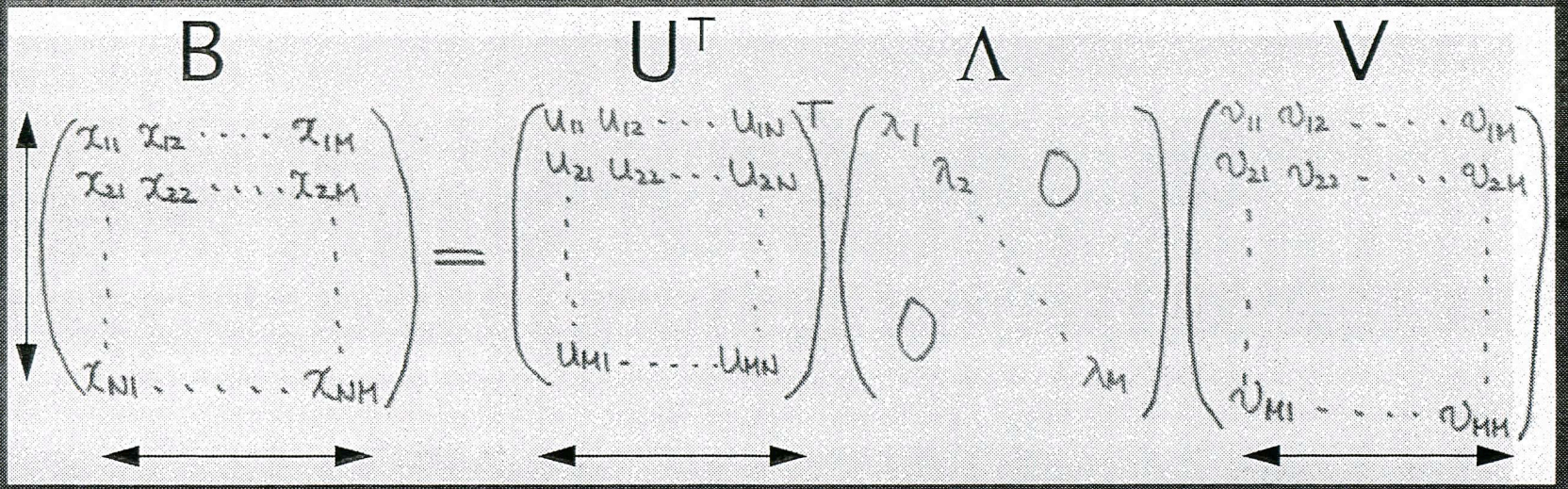
BPM readings
x or y

Time patterns

Physical
variables

Spatial patterns

time



space

Time
Eigen
Vector

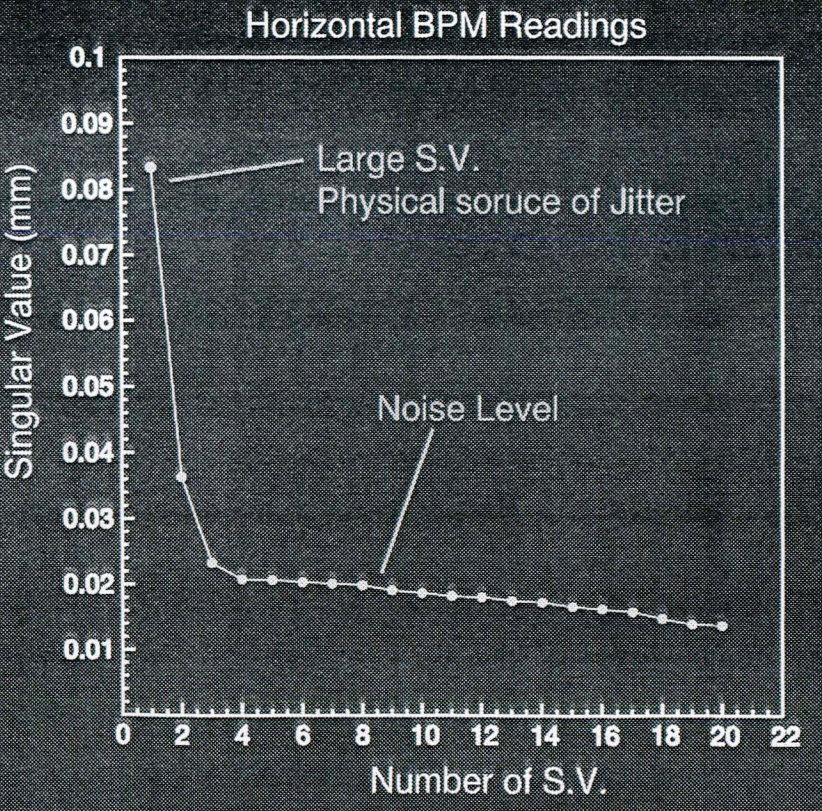
Singular
Values

Spatial
Eigen
Vector

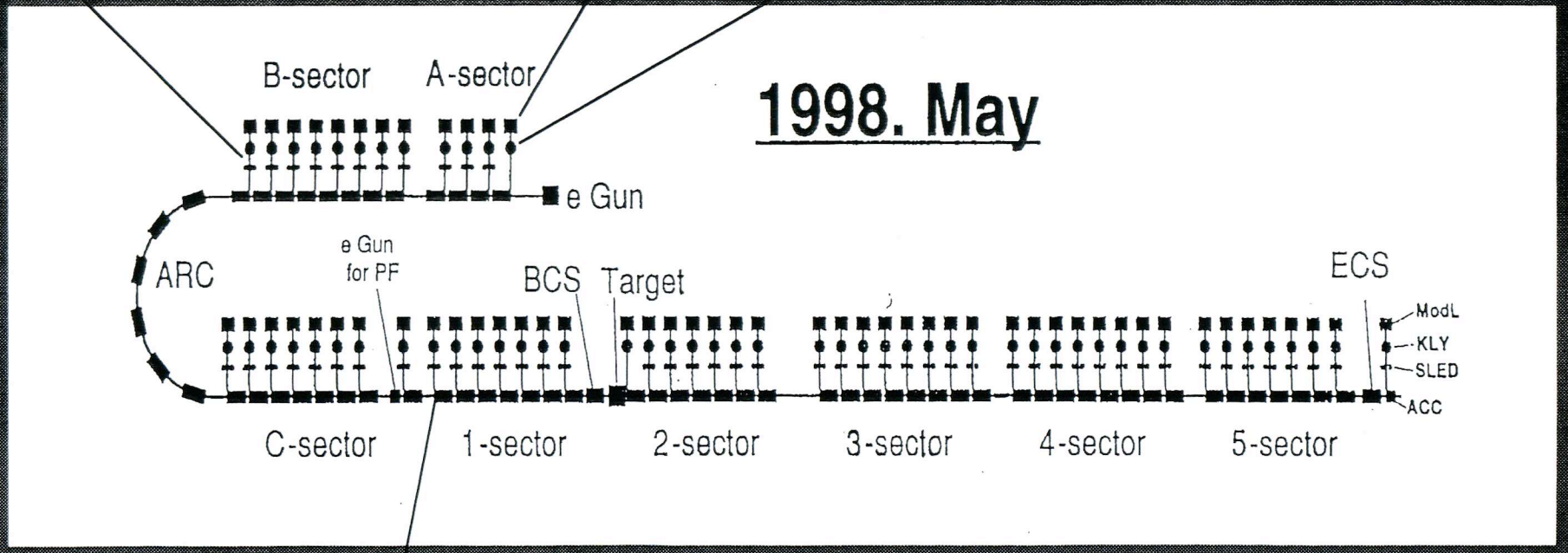
N: #pulses
M: #BPMs

Singular Values

- Figure shows singular values from SVD at KEKB Linac (AB sector only).
- AB sector has 21 BPMs. (13 BPMs for A and 8 BPMs for B sector.)
- 400 pulses
- Physical sources of beam jitter can contribute to singular values.
- Rest is Noise level.



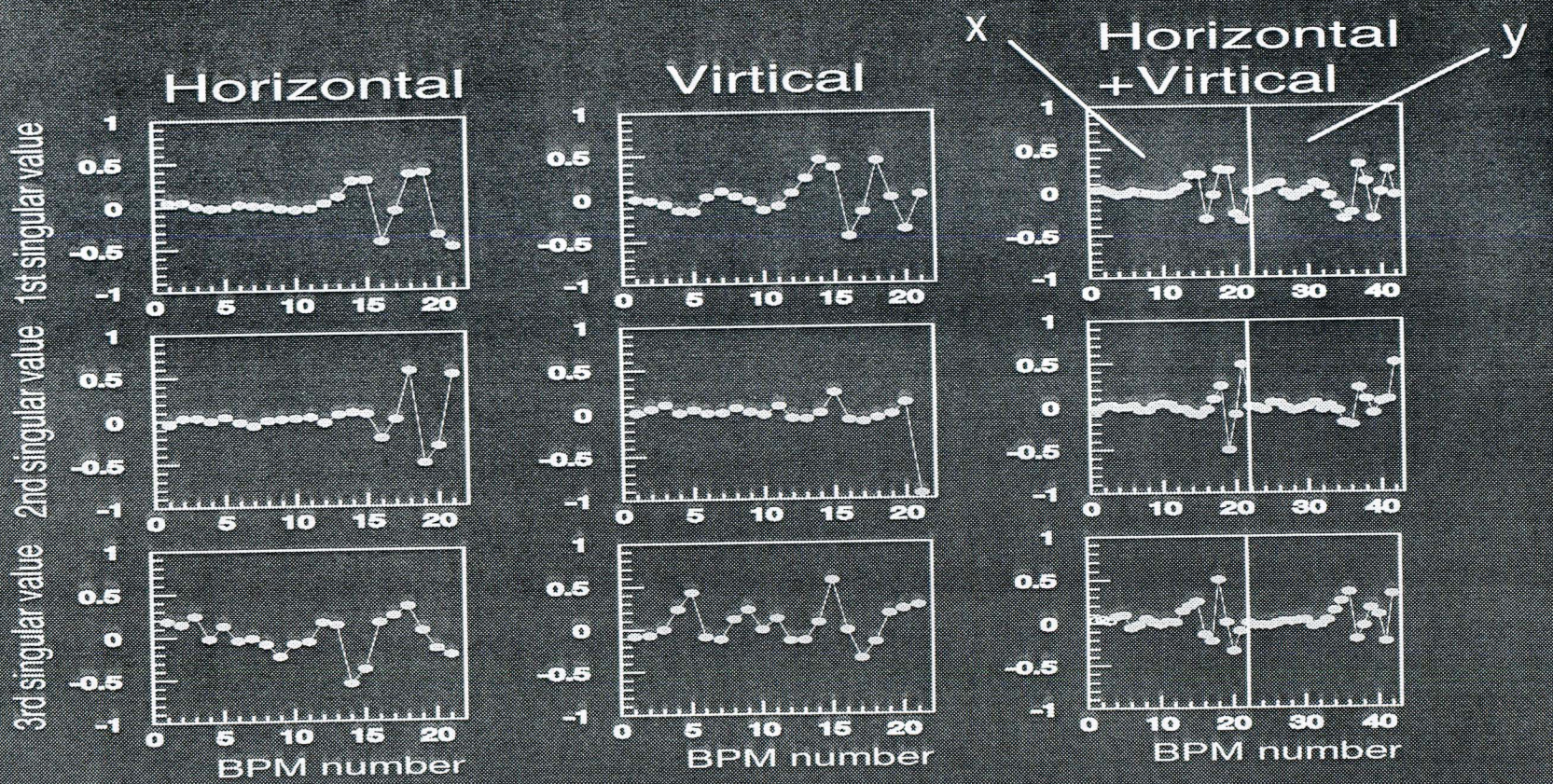
KEKB Linac



Beam Energy 8 GeV for electron

Spatial Eigen Vectors

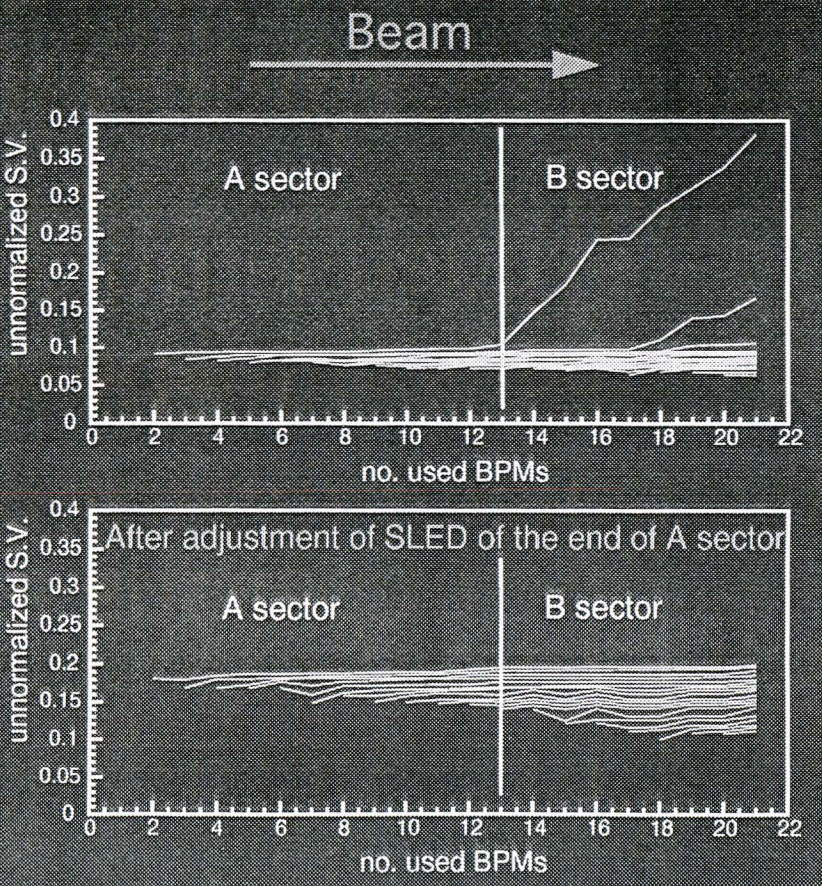
KEKB Linac AB sector



x-y correlation can be seen.

Singular Values with increasing number of BPMs

- Figures show singular values by performing SVDs of the BPM matrix subsets of increasing number of BPMs along beamline. (Horizontal)
- The singular values for differnt subsets are connected into curves.
- The singular value curves are increased from the point of beam jitter sources, misalignment and so on.
- Is jitter source SLED at the end of A sector ?

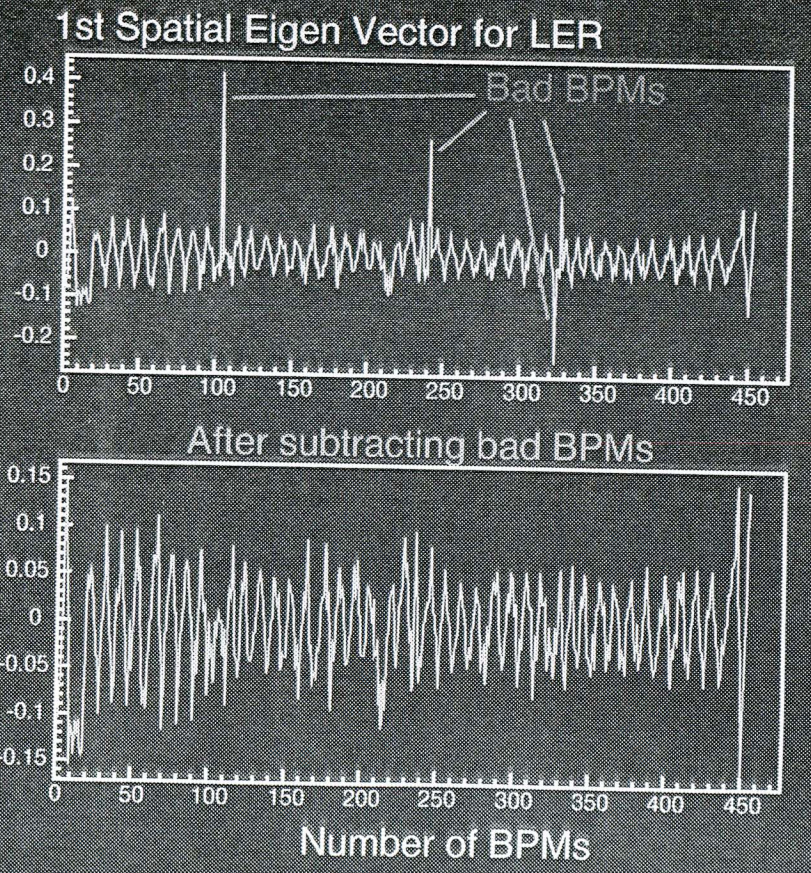


Orbit Analysis at KEKB Ring

- SVD analysis can be applied to storage rings.
- Each beam is independent in linac (single pass), on the other hand, periodicity in rings.
  - » Row vectors of BPM matrix are correlated (weakly).
- Total number of BPMs is about 450.
  - » Huge matrix has to be solved.

Spatial Eigen Vectors
KEKB Ring

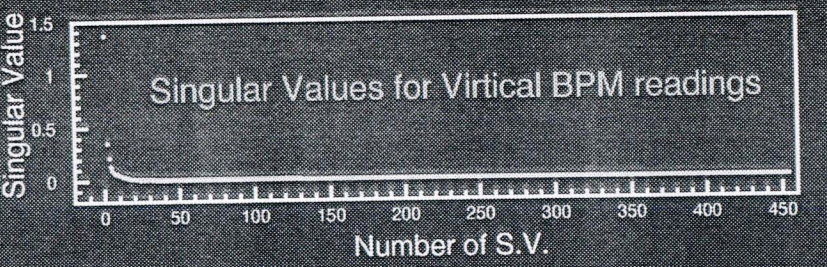
- Bad BPMs can be identified easily.
- Upper fig. shows a spatial eigen vector with outstanding component corresponds to an abnormal BPMs.(Those 4 BPMs were not connected but to single pass monitor.)
- After subtracting abnormal BPMs, SVD analysis should be performed.
- Spatial pattern looks like single-kick orbit. (Betatron motion?)

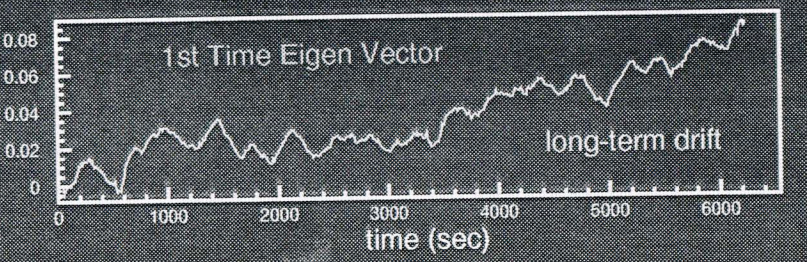


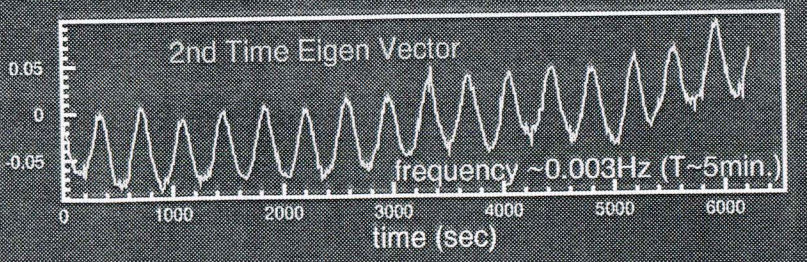
Time Eigen Vectors
KEKB Ring

- SVD Analysis can extract dominant time patterns.
- BPM data is taken at intervals of 10 seconds.
- Long term orbit drift can be seen clearly (see 1st Time Eigen Vector).
- Orbit changes with 5 min. periodicity was observed but disappeared after tuning liquid N_2 flow.

LER







← about 100 minuts →

Summary

- Preliminary studies of orbit analysis using SVD was presented.
- Physical sources(betatron, injection phase, beam current, energy, and bunch length etc.) for beam jitter can be separated from unphysical sources.
- Source point of jitter can be found by SVD with increasing number of BPMs along beamline.
  - » It may allow us to get information about misalignment.
- Bad(noisy) BPMs can be identified easily.
- The dominant time patterns of orbit changes can be extracted by SVD.