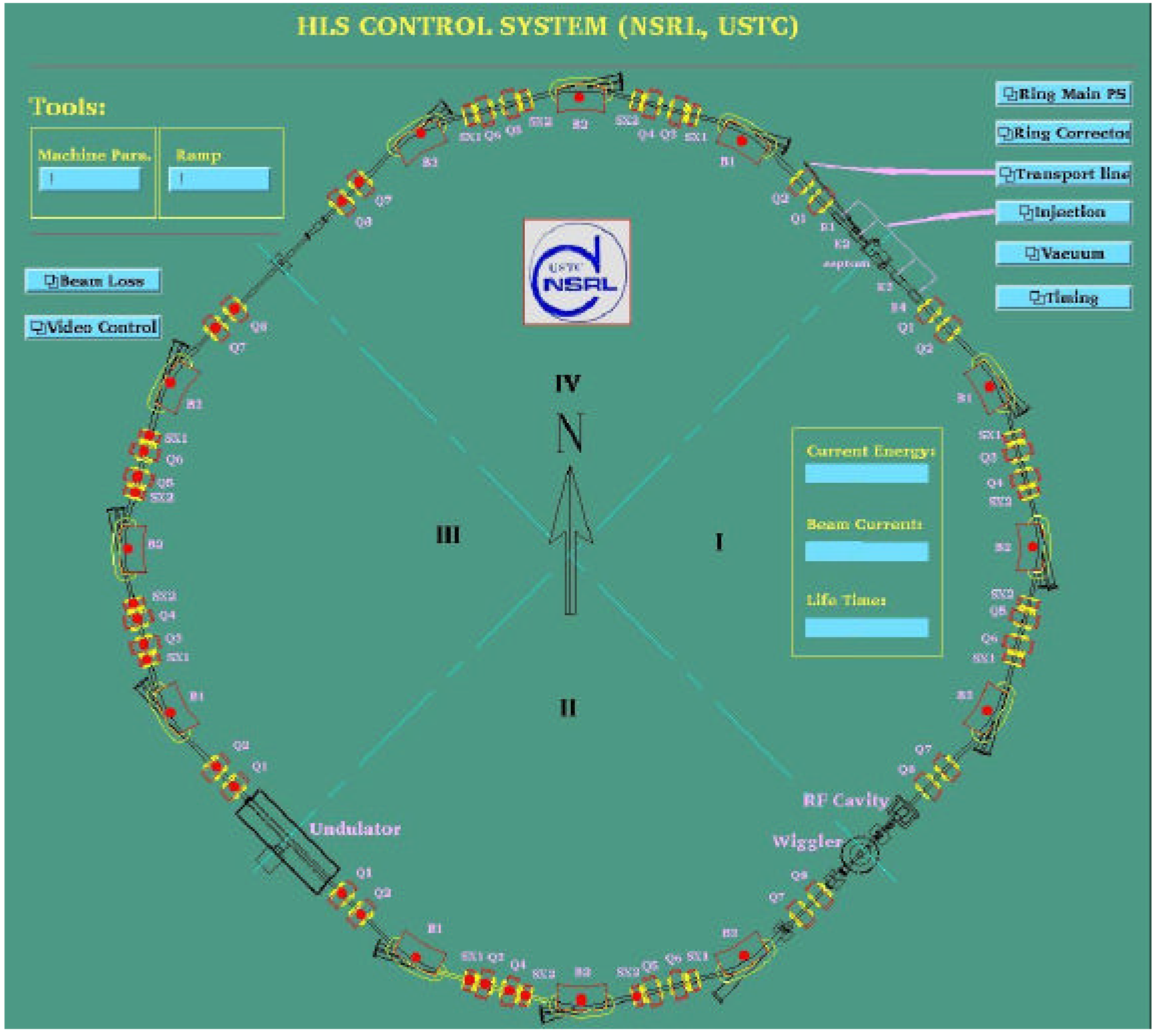
The Closed Orbit Correction in HLS



The Closed Orbit Correction in HLS

Abstract: HLS(Hefei Light Source)which energy is 800MeV dedicate to synchrotron light source. The closed orbit of the stored electrons was often perturbed due to some nonideal errors,the perturbed closed orbit, known as COD (Closed Orbit Distortion).In order to correct the orbit distortion,we developed an closed orbit correction system,which can be periodically or manually invoked to correct the global closed orbit. This system can also be used to adjust the orbit position at some point using local bump.

The Effect of Closed Orbit Distortion

According to the experience of machine operation, COD (Closed Orbit Distortion), has many bad effects. First, it excites the non-linear effect and leads to the decrease of the beam lifetime. Second, it changes the position of the light at the front-end of beam lines, which reduces the brightness of the light going into the beam line and affects the experiment at the responding experiment station.

The effect of magnet field error to beam orbit

- The effect of Dipole field to beam position

$$\begin{cases} x' = -\Delta b_y dz \\ y' = b_x dz \end{cases}$$

- The effect of mounting error of quadrupole to beam orbit

$$\begin{cases} x' = K\Delta x dz \\ y' = -K\Delta y dz \end{cases}$$

HLS

- The effect of Single error to beam position

$$u(s)=\frac{\sqrt{b_s}}{2\sin pn}\sqrt{b_{s0}}q\cos(j_s-j_{s0}+pn)$$

- Beam position in error position

$$u(s_0)=\frac{1}{2}b_{s0}\cot pn$$

- The effect of many error to beam position

$$u(s)=\frac{\sqrt{b_s}}{2\sin pn}\sum_i\sqrt{b_{si}}q_i\cos(j_s-j_{si}+pn)$$

The theory of closed orbit correction

- Harmonic method
- MICADO method
- SVD method
- Local bump method

Singular Value Decomposition（ SVD）

- The corrector strength corresponding to beam position

$$X = R\Theta_n \qquad \Theta_n = -R^{-1}X_m$$

- To a matrix R,

$$R = UWV^T \qquad R^{-1} = VW^{-1}U^T$$

- If reference orbit is X_r, so

$$X = X_m - X_r \qquad R\Theta = -X \qquad \Theta = -R^{-1}X$$

$$S = \left|R\Theta - X\right| = \left|W \cdot \Theta^t - X^t\right| = \left(\sum_{i=n+1}^{m} \left|X_i^t\right|^2\right)^{1/2}$$

- Response matrix and its pseudoinverse matrix be computed to feedback correct.

Local bump method

- Three corrector bump

$$\frac{\sin(j_3 - j_2)}{\sqrt{b_1}} : -\frac{\sin(j_3 - j_1)}{\sqrt{b_2}} : \frac{\sin(j_2 - j_1)}{\sqrt{b_3}}$$

- To get the bump coefficient by SVD

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = -[R_1 \quad R_2]^{-1} R_3 I$$

- also by the least square fit method

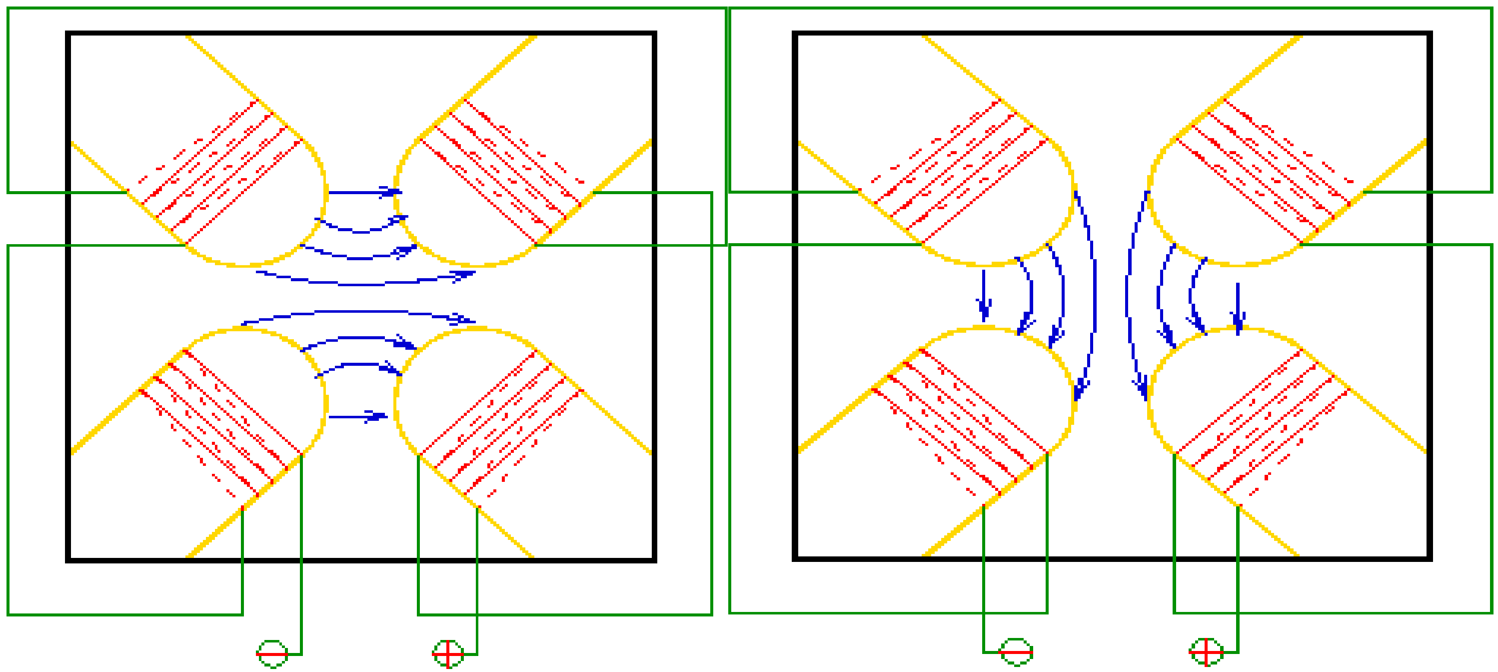
$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix}^{-1} \begin{bmatrix} r_{13} \\ {}_{23} \end{bmatrix}, \quad r \quad is \quad the \quad e\min ent \quad of\ R^T R$$

- Then the beam orbit can be corrected by global correction method.

The correction system of beam orbit in HLS

- Measurement system
  - 22 Bergoz BPM model
  - Digital process by VXI system
  - compute & process by industry PC finally
  - realize digital sharing by network interface(using UDP agreement)
  - EPICS provide the CA serve

- Correction component (the supplement attached coil in quadrupole)
  - 16 horizontal corrector
  - 16 vertical corrector



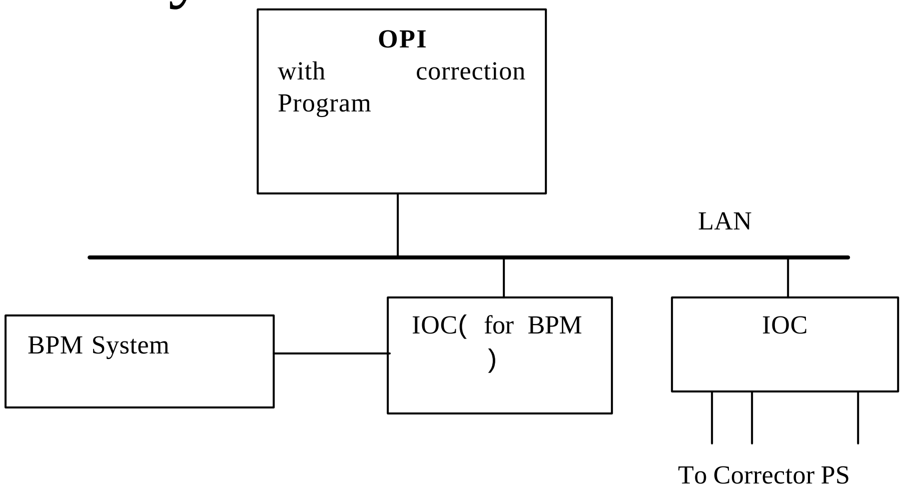
The sketch of magnetic field of corrector

Contorl System of Correctors

- The distribution of corrector

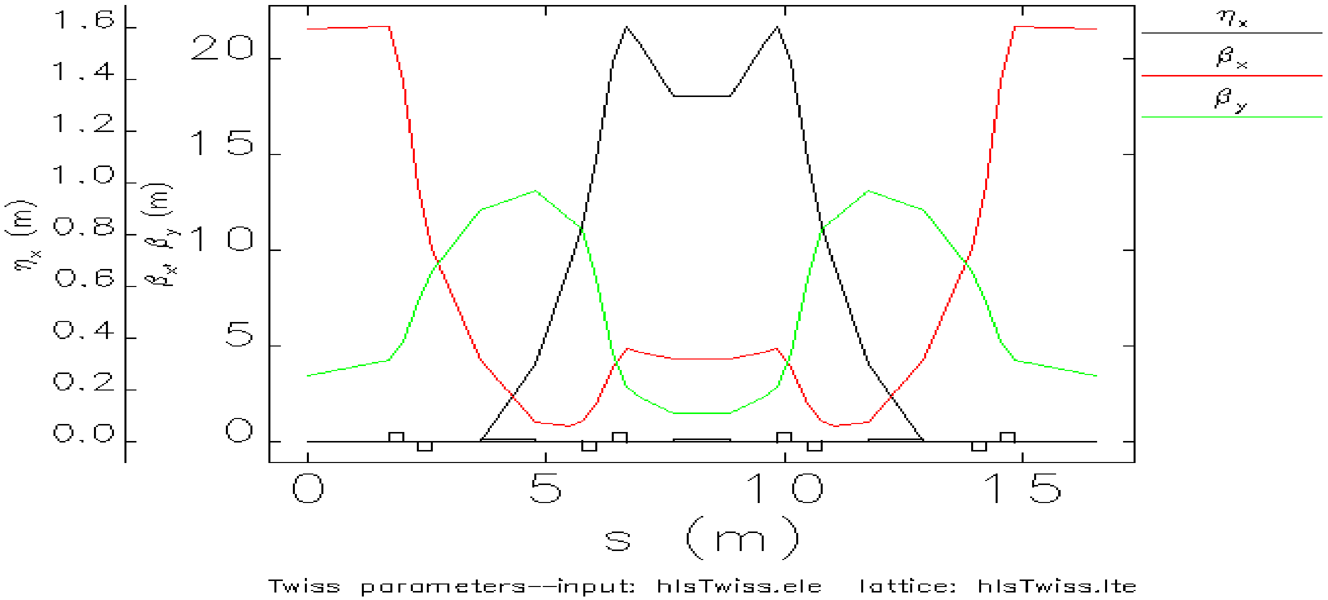
Corrector coil	Position of Corrector	Reason
Horizontal	Q1? Q4? Q5? Q8	βx is larger
Vertical	Q2? Q3? Q6? Q7	βy is larger

- The control system of corrector



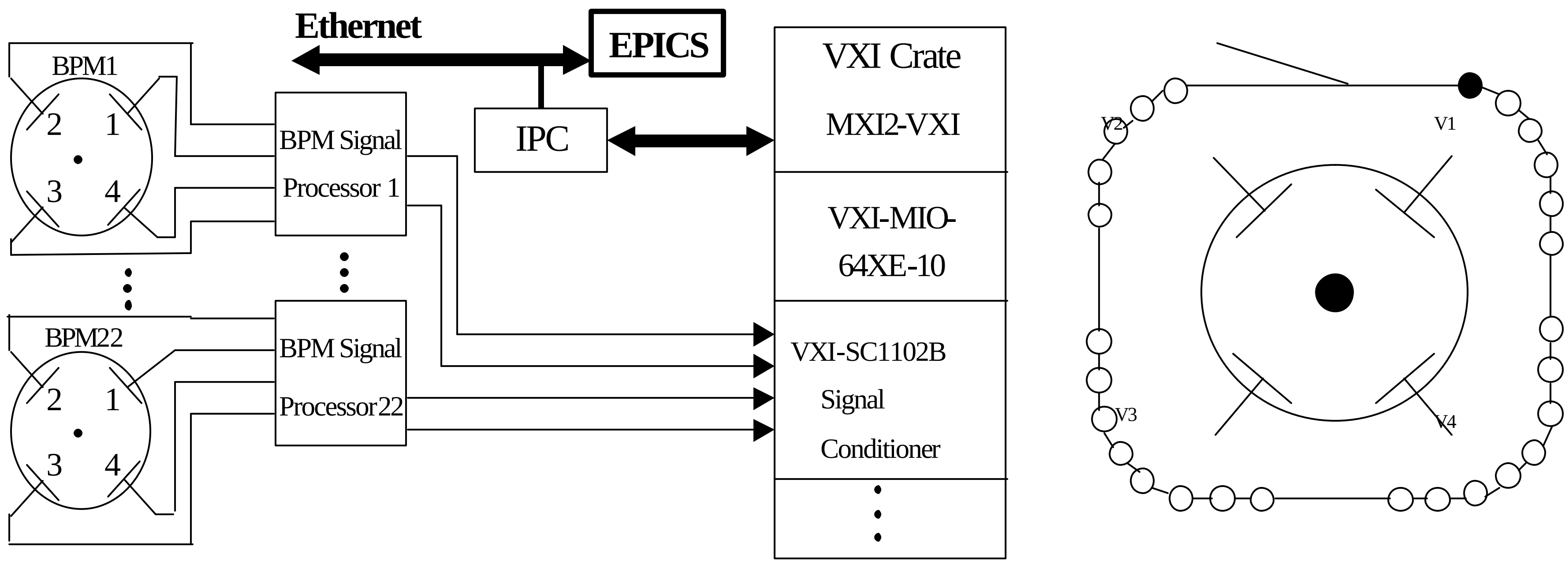
The sketch of the closed orbit correction system of HLS

HLS

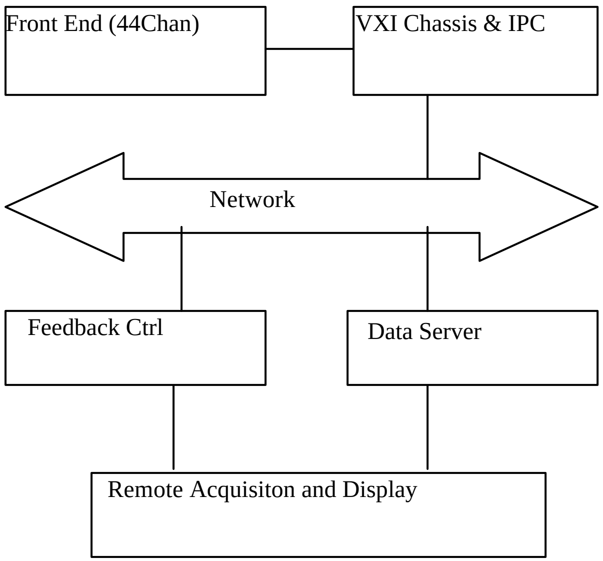


Twice parameters for HLS

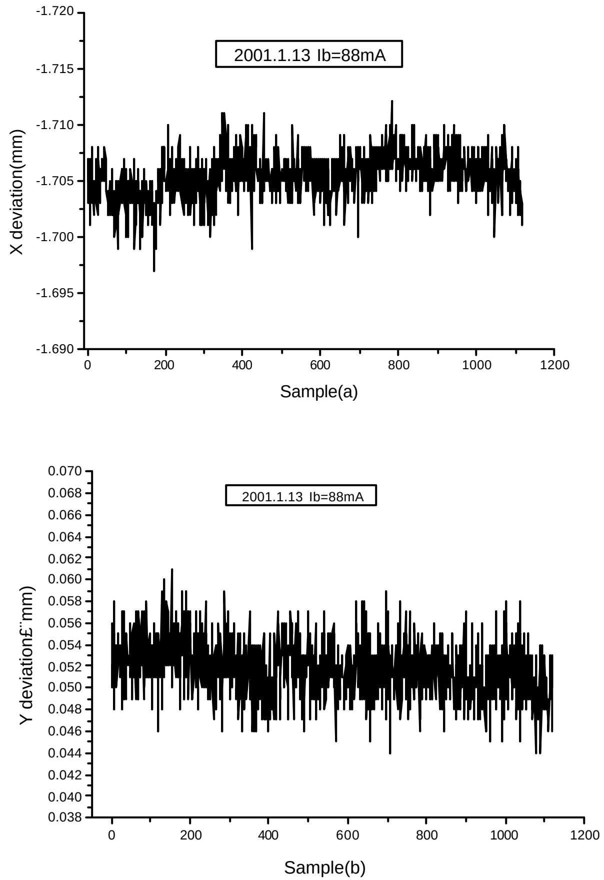
The Hardware System of BPM



The Software System of BPM



BPM software Architecture



1# BPM Operation History Curve

- **The upgrade of BPM system is an important program of NSRL Phase-II project. The new BPM system have operated for two years. Now the upgraded BPM system works with a resolution about 1mm.**

The measurement of response matrix

- The orbit position to the strength of corrector is linear.When the correctors may be provided with a group of setting values,the orbit position to setting values are measured.Then the response matrix can be computed by linear fit.

- If between the orbit position and the current of corrector meets:

$$u = a + bI$$

$$\begin{bmatrix} a \\ b \end{bmatrix} = \frac{1}{N\sum I^2 - \left(\sum I\right)^2} \begin{bmatrix} \sum I^2 & -\sum I \\ -\sum I & N \end{bmatrix} \begin{bmatrix} \sum u \\ \sum (u \cdot I) \end{bmatrix}$$

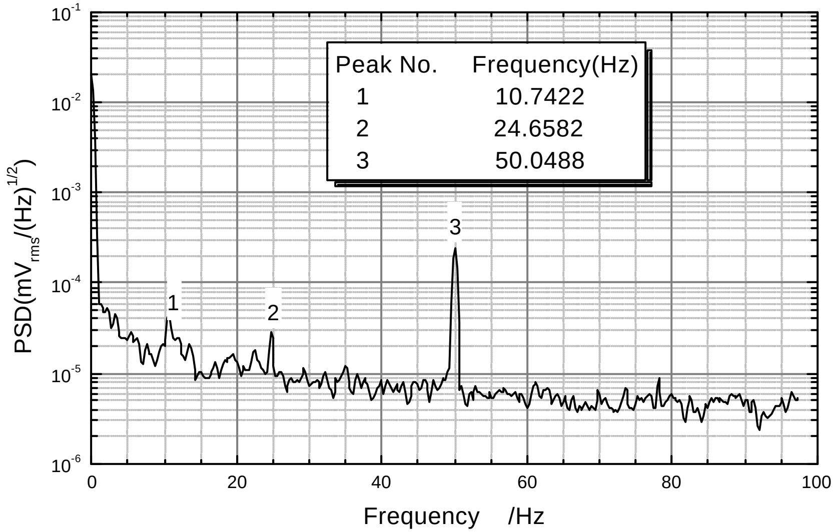
The introduction of PID feedback technique

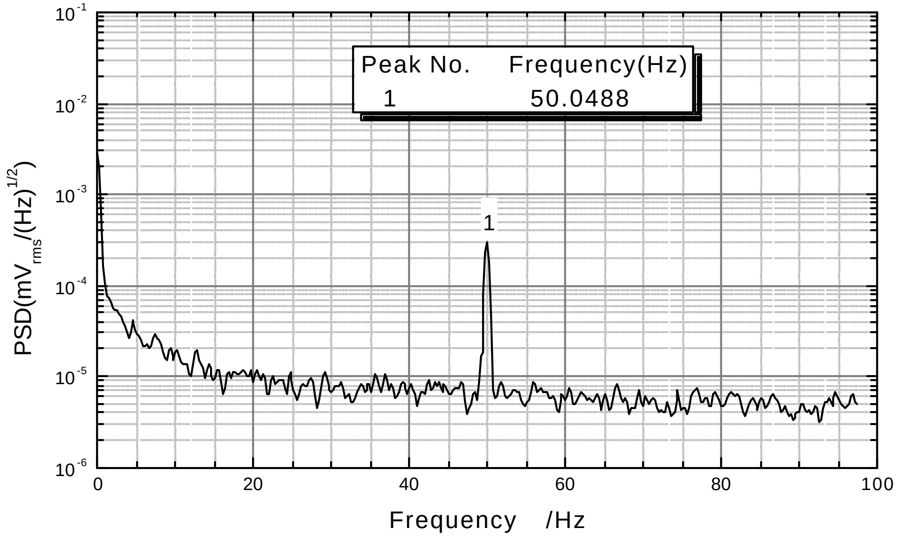
- The reason of correction with feedback method
  - There are some alterative component parts in closed orbit distortion.So these component parts must be removed with the feedback technique.
  - As to direct current component part,it will lead to much bigger vibration of beam.So it must be corrected step by step with feedback technique.
- PID feedback technique(continue and dispersed signals)

$$u(t)=K_p\left[e(t)+\frac{1}{T_I}\int_{t_0}^{t}e(t)dt+T_D\frac{de(t)}{dt}\right]$$

$$u(n)=u(n-1)+K_p\left[e(n)+\frac{\Delta t}{T_I}e(n)+T_D\frac{e(n)-e(n-1)}{\Delta t}\right]$$

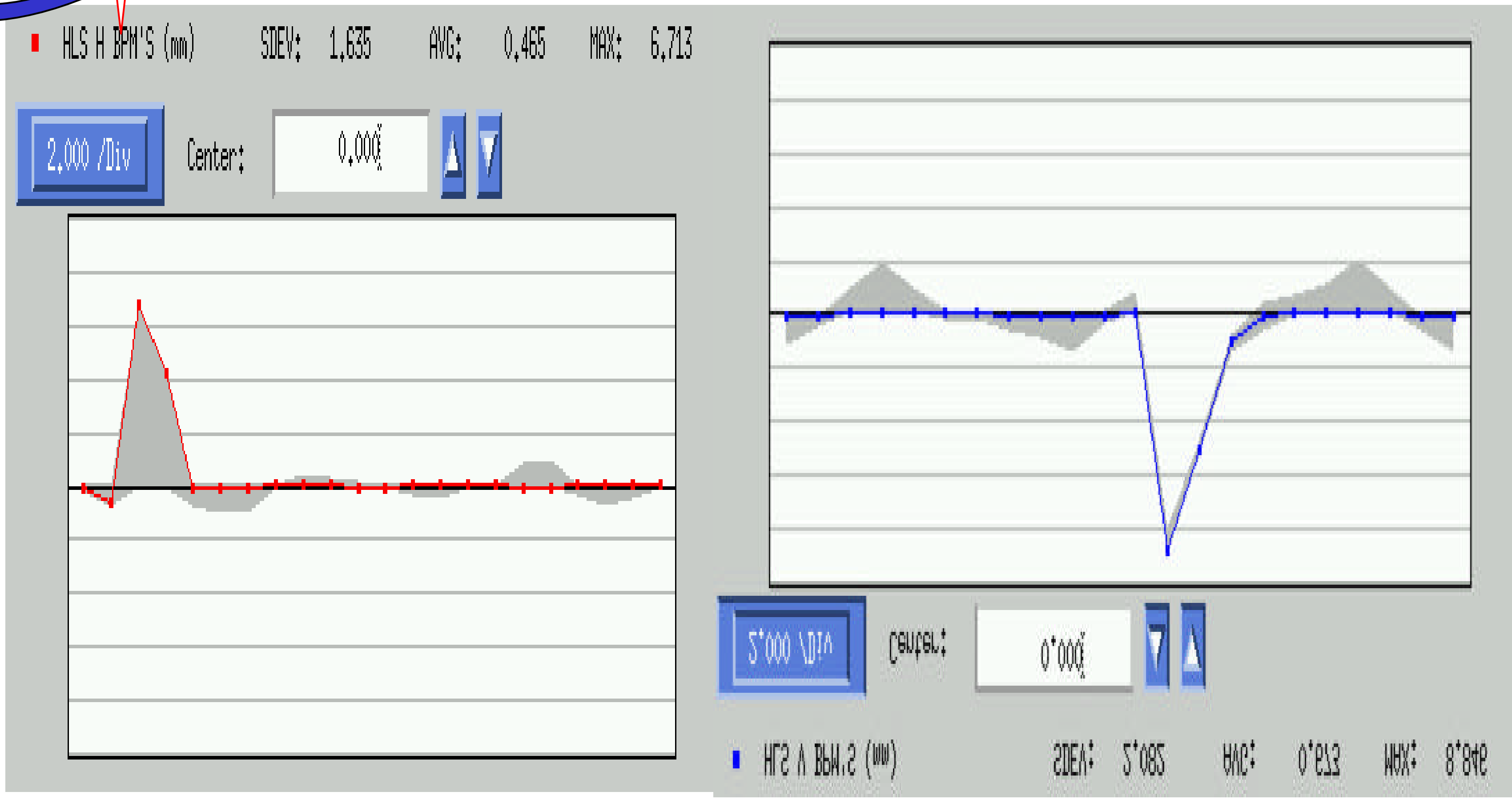
PSD of BPM Signal for HLS





The Local Adjustment And Correction Of HLS Closed Orbit

- The two uses for the local adjustment of closed orbit:
  - For the need of single experiment station
  - For the many machine study,such as:BBA（ Beam Based Alignment） experiment
- Steps
  - Adjust the beam position to suitable position with local bump.
  - Set one reference orbit, which is orbit outer the bump before adjustment and inner the bump after adjustment .
  - Relative to reference orbit, the globe closed orbit correction is taking.



(a) Horizontal (b) Vertical

Local bump using three correctors

The Measurement Of Quadrupole Magnet Center With BBA

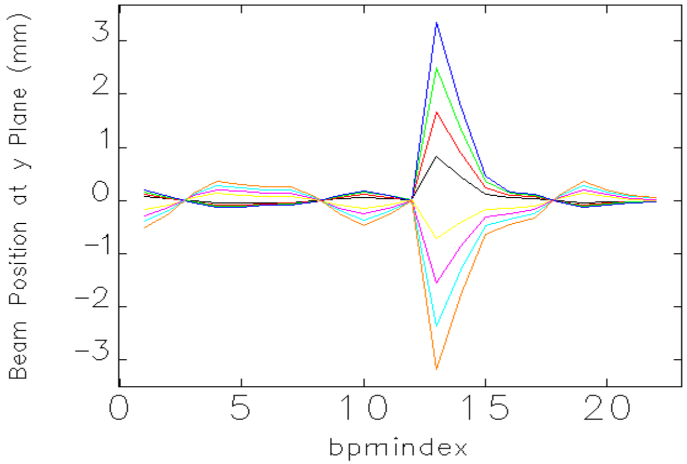
- Measure closed orbit position
- Change the K of one quadrupole,then measure the position of closed orbit.
- The closed position of step1 minus the one of step2,then compute its rms
- Change the beam position with the local bump,repeat the step1-3 to vary the trend of rms change.
- Consider the nonlinear effect,we must fit the measuring results,such as:

$$rms = a_0 + a_1 u + a_2 u^2$$

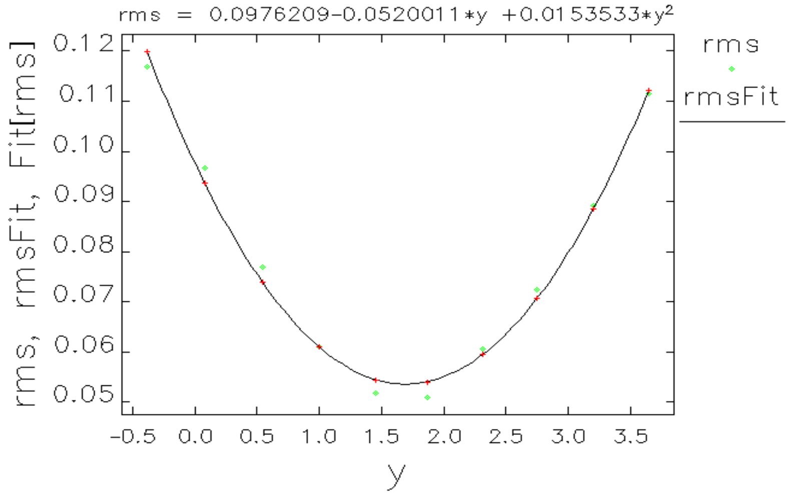
$$\frac{\partial rms}{\partial u} = 0$$

$$u_q = -\frac{a_1}{2a_2}$$

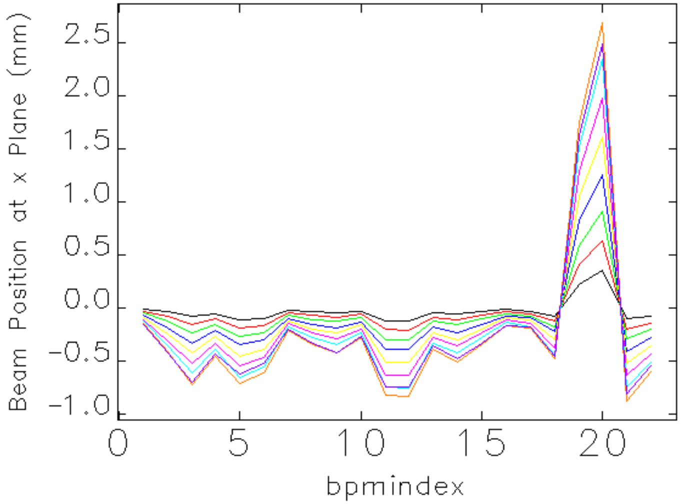
The Measurement Of Quadrupole Magnet Center With BBA



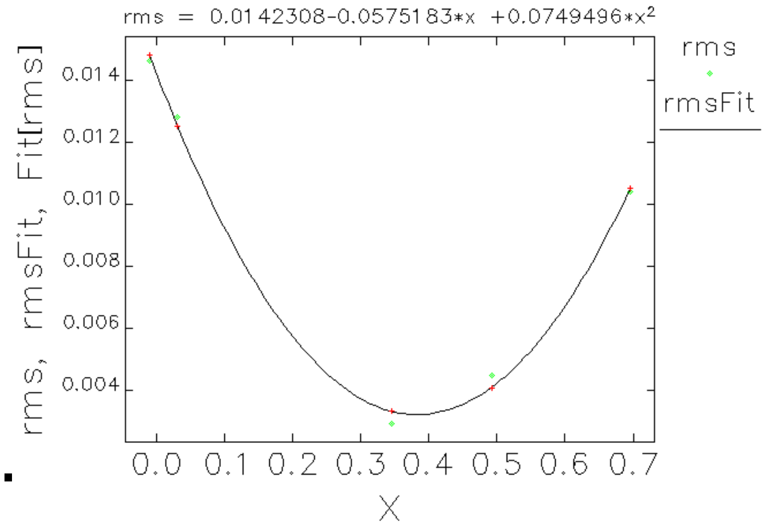
Beam Steering With Local Bump



Q4W-Y's center is at y: 1.69348053146



Beam Steering With Local Bump



Q5N-X's center is at x: 0.383712975433

The Closed Orbit Correction to RF

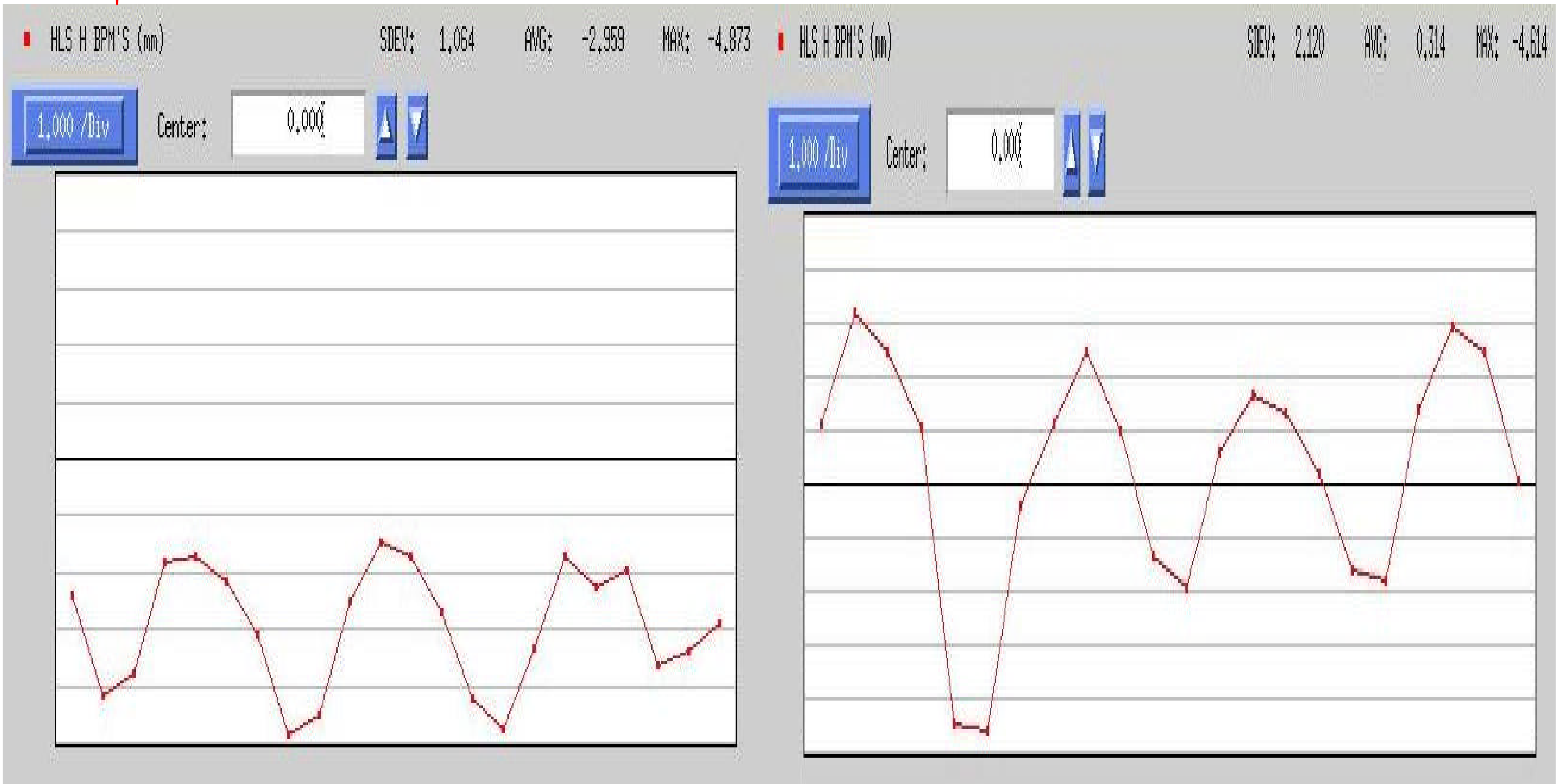
- The closed orbit distortion because of rf error and chromatic dispersion function:

$$X = -\frac{1}{a} \cdot H \cdot \frac{\Delta f_{rf}}{f_{rf}}$$

- Set measured horizontal orbit distortion for X_0, the best adjustment value of RF can be gotten with the least square method:

$$\frac{\Delta f_{rf}}{f_{rf}} = \frac{a}{\|H\|^2} H^T X_0$$

- The RF of HLS can be computed with above formula.The computed result is 204.015MHz



(a) at 204.045MHz **(b) at 204.015MHz**

Horizontal orbit distortion at different RF frequency

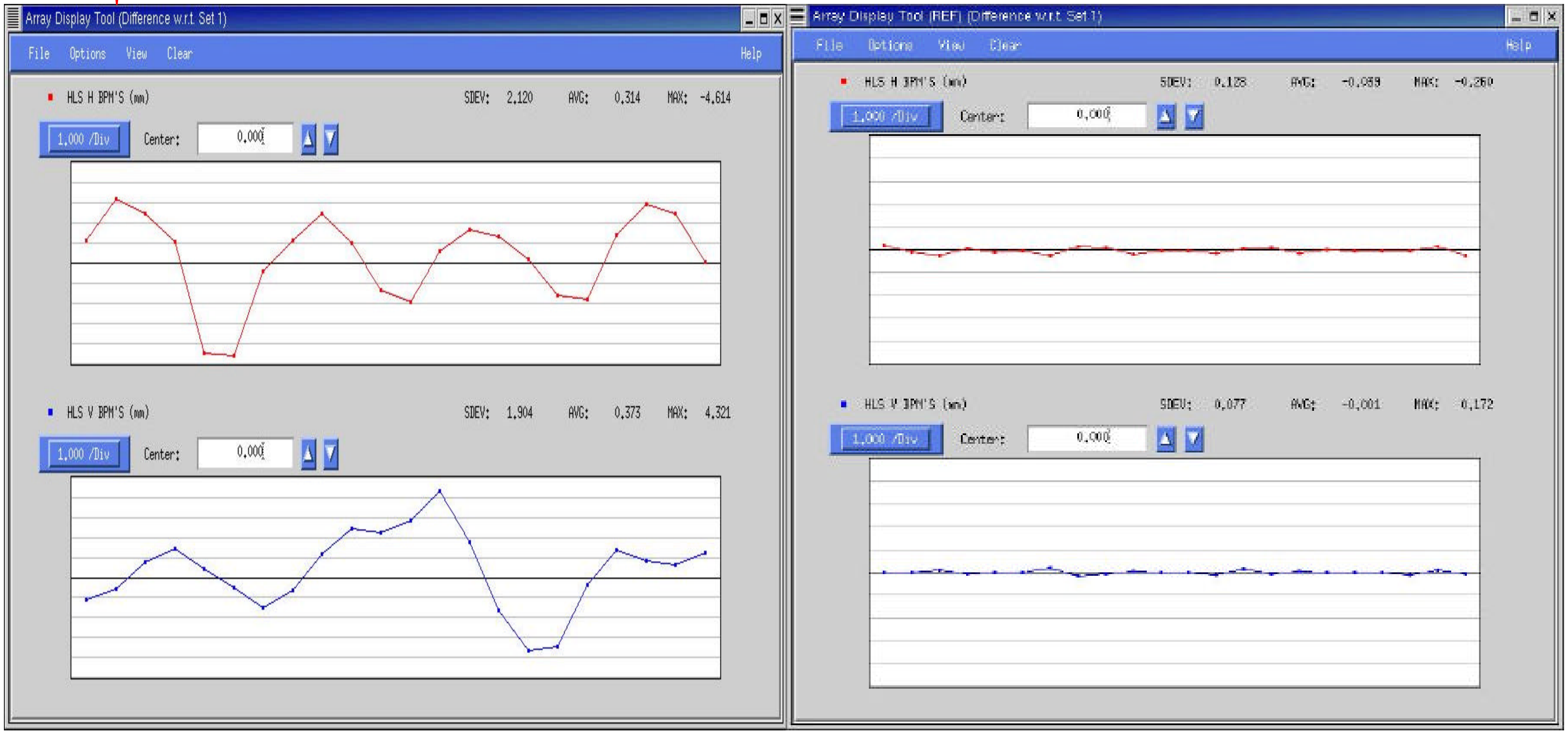
The Globe Feedback Correction Of Closed Orbit Direct Distortion

- The integrated correction

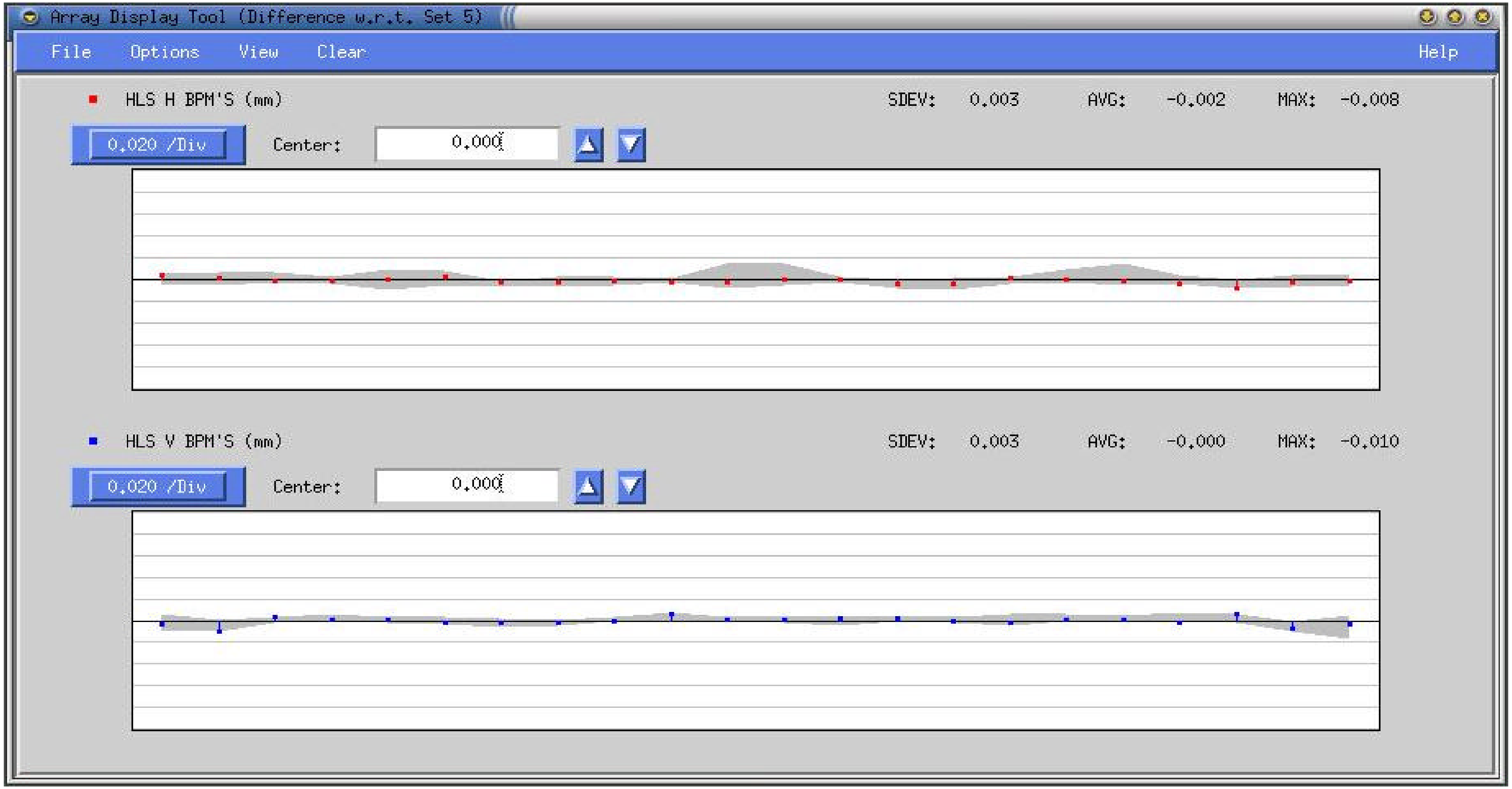
$$\Theta(n)=\Theta(n-1)+\frac{K_p \Delta t}{T_I} R_{Inv} U(n)=\Theta(n-1)+gR_{Inv}U(n)$$

- R_{INV} is measured with SVD: $-1.0<g<0.0$

- After correction,
  - The maximum horizontal deviation is -0.260mm， the square root deviation of the orbit distortion is decreased to 0.132mm
  - The maximum vertical deviation is 0.172mm， is decreased to 0.082mm
  - The vibration of orbit is confined between±0.1mm



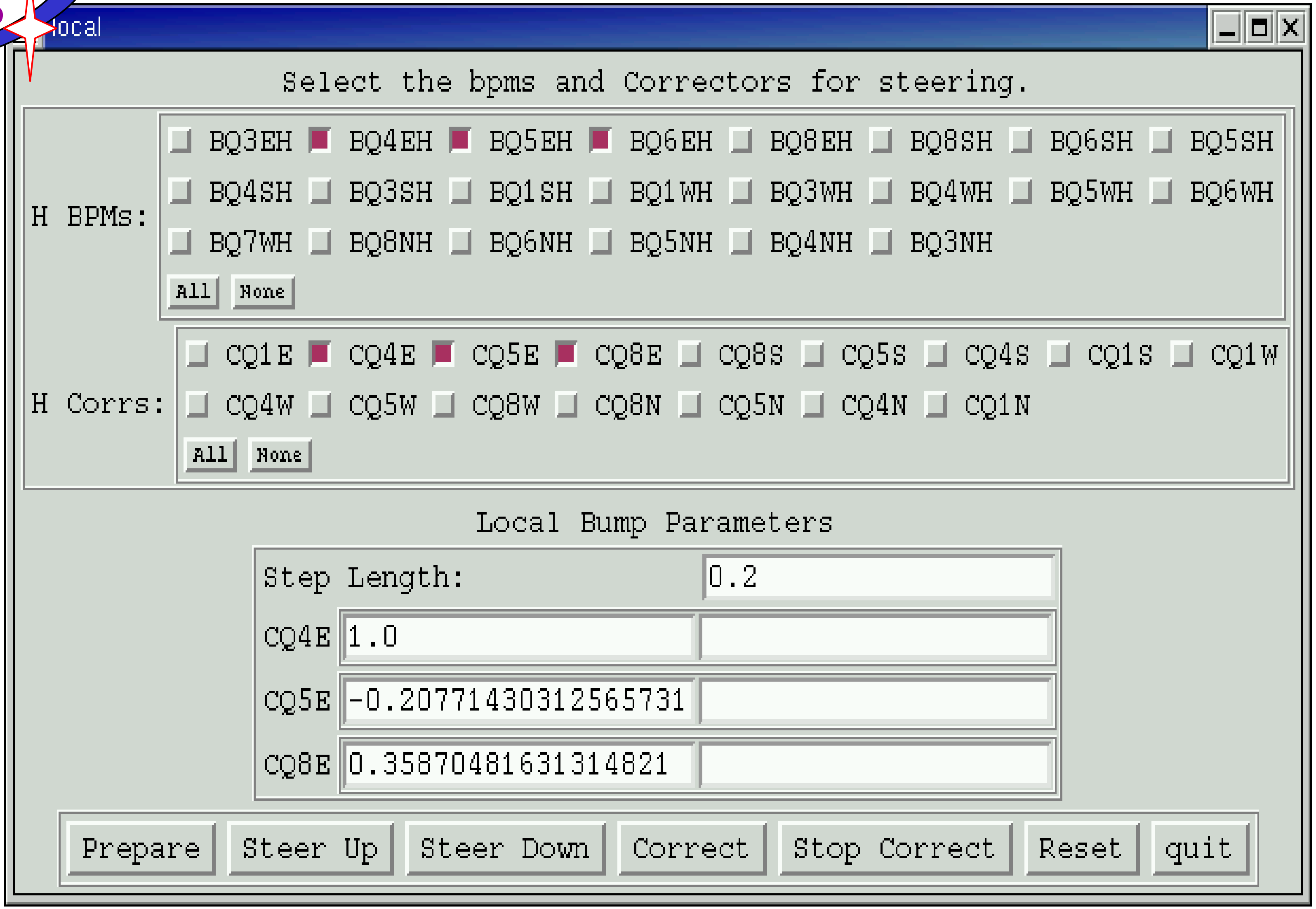
(a) COD without global feedback correction (b) COD with global feedback correction



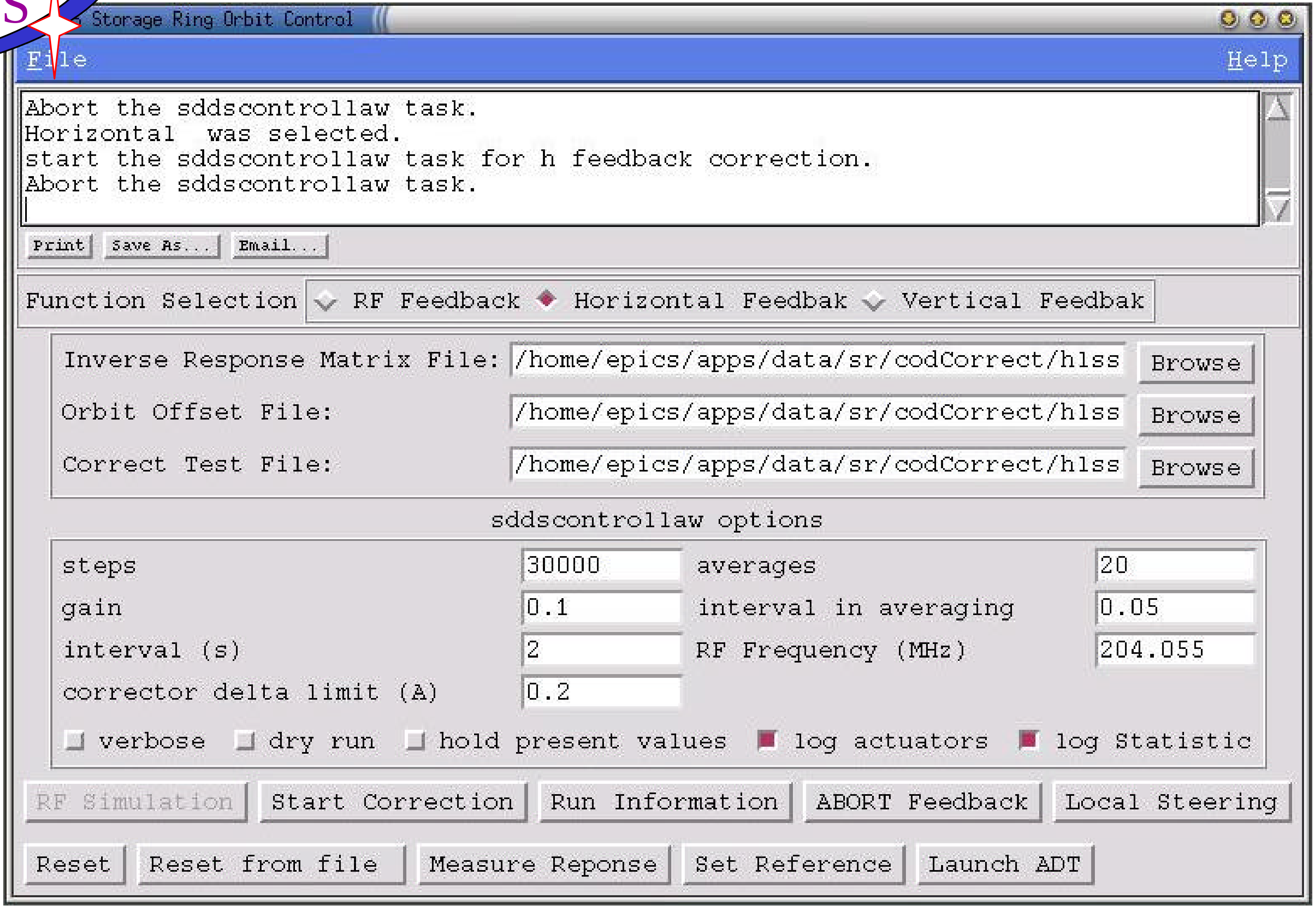
Array Display Tool (Difference w.r.t. Set 5)
File
Options
View
Clear
Help
HLS H BPM'S (mm)
SDEV: 0.003
AVG: -0.002
MAX: -0.008
0.020 /Div
Center:
0.000
HLS V BPM'S (mm)
SDEV: 0.003
AVG: -0.000
MAX: -0.010
0.020 /Div
Center:
0.000

The Control Software Of Closed Orbit Correction

- Solaris or Linux operation system， Tcl/Tk explain: oagwish or rtc
- Sddscontrollaw,which is developed by APS and is used for feedback correction.
- Elegant， which is developed by Michael Borland in APS and mainly used for producing theory response matrix and Lattice parameters.
- The other tools of sdds are developed by APS, which is used for processing and producing parameter files and computing response matrix and inverse matrix and so on.



Interface of selecting the BPMs and correctors for steering



Interface of orbit control for HLS

Summary

- The correction system of beam closed orbit is the important program of phase II Project of HLS?
- The adjustment function of its local bump have acquired satisfactory result in BBA experiment.
- In process of globe correction,the closed orbit distortion which is caused by chromatic dispersion function was eliminated as big as possible.
- The direct orbit derivation and lower frequency orbit oscillation may be corrected effectively.
- The horizontal couple of the beam decrease obviously because the orbit was corrected to the magnet center.
- BBA experiment , response matrix measurement,local bump and globe correction all are realized with software control.
- This system can not correct the high frequency orbit oscillation because the strength of corrector can not vary fast.