Report on LTB Beam Trajectory and Steering

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Summary: The LINAC-to-Booster (LTB) transfer line at SSRL has a long history of manual tuning in order to optimize capture rates in the booster synchrotron. While the tuning has proved productive, the orbit is in some cases many mm from BPM center and contains what appears to be a dispersion component. As a preliminary effort to develop an LTB beam steering software interface, in this paper we report on a) the nominal LTB beam trajectory, b) the measured LTB response matrix, c) dispersion measurements, d) energy scaling of the LTB, and e) horizontal beam steering .

LTB Beam Line: Figure 1 shows a schematic of the LTB beam line including correctors and BPMs. Accounting for two horizontal correctors and two vertical correctors in the LINAC section and the B1-3 trim coils, the LTB contains eight (8) horizontal correctors, six (6) vertical correctors and 5 BPMs. The first BPM is located immediately after the LINAC and the second just after the B1 magnet. BPM5 is located at the entrance to the booster injection septum. For steering applications only 5 correctors are required in each plane (5 BPMs), and although the extra degrees of freedom in each plane could in principle be used to 'iron' corrector strengths via the null-vector method in SVD analysis.

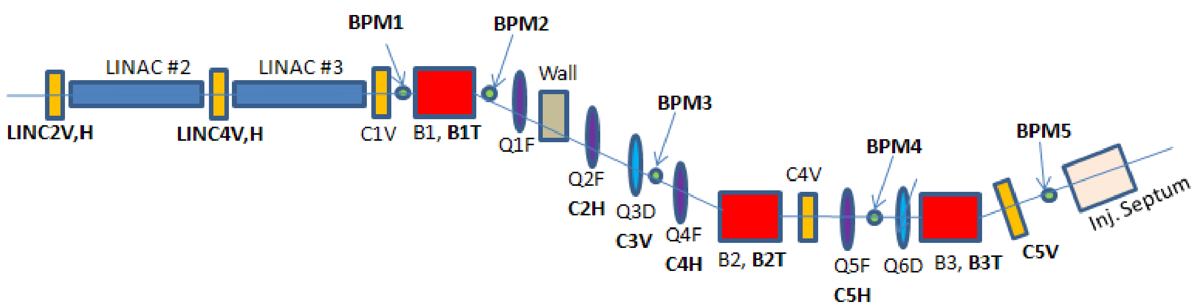

Figure 1: Schematic of LTB beam line

a) **Nominal LTB beam trajectory:** Figure 2 shows a plot of the nominal LTB beam trajectory in the horizontal and vertical planes as well as sum signals. The variance in horizontal BPM measurements fluctuates but is about 100micron on average. If the alignment of quadrupoles Q1F, Q4F and Q5F/Q6D are correct, beam-based alignment at BPMs 1,3,4 may be possible.

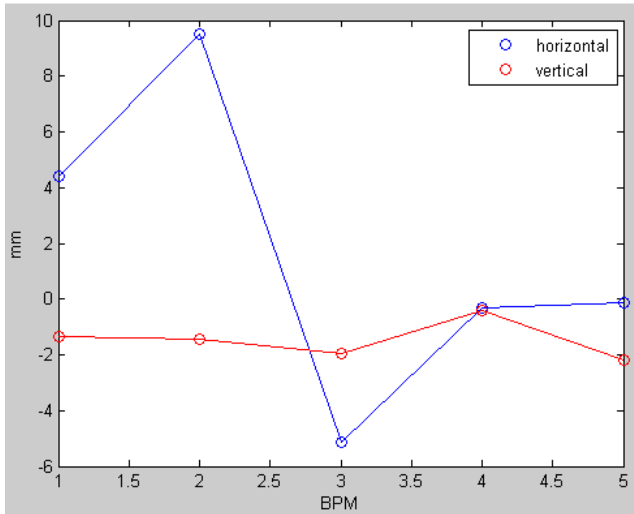

Figure 2: Nominal LTB beam trajectory

b) **LTB beam response matrix:** Figure 3 shows the horizontal response matrix components with respect to the nominal beam trajectory. Note that the vertical scales are not electron beam orbit (mm) rather mm/ampere. Both the in-plane (kick-x, look-x) and out-of-plane (kick-x, look-y) are plotted. From the data both LINC2H and LINC4H appear to indicate a some coupling component that likely arises at or near the B1 magnet. Black stars in the plots (*) indicate BPM locations upstream of corrector magnets that are theoretically not affected by the corrector kick. Similarly figure 4 shows the response matrix data in the vertical plane.

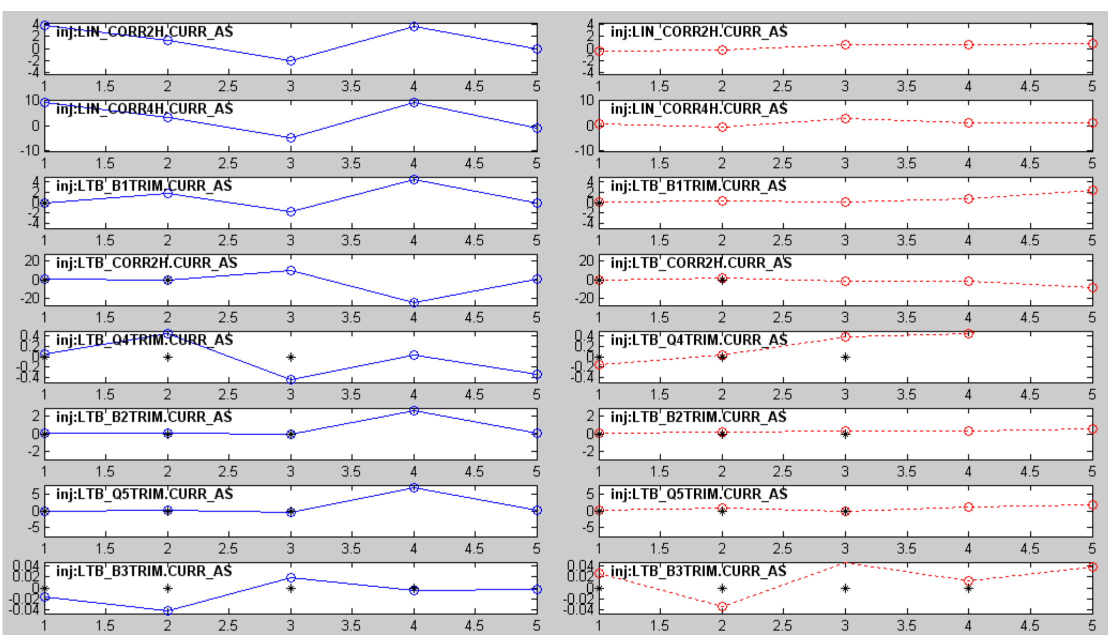

Figure 3: kick-x, look-xand kick-x, look-y response matrix data

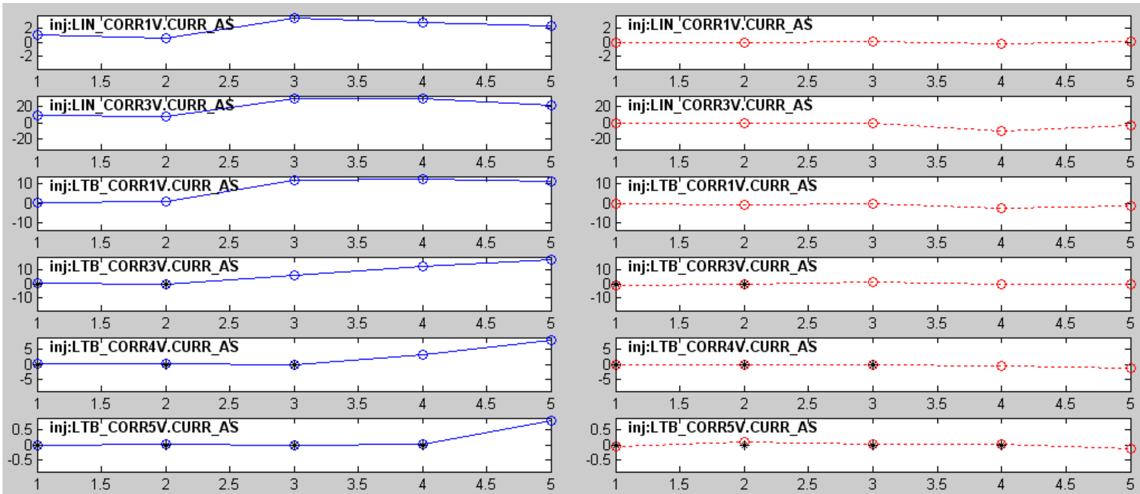

Figure 4: kick-y, look-yand kick-y, look-x response matrix data

Figure 5 shows the response matrix data in terms of orbit deflections in both positive and negative direction. In cases where the orbit is 'symmetric' one can assume functioning corrector magnets and beam position monitors. The horizontal response at BPM5 is weak which might indicate strong focusing at quadrupole Q5F, a faulting BPM or interference from the pulsed magnet system in the booster. Correctors Q4T needs to be re-evaluated and Q5T is clipping because of the unipolar supply. Since there are more horizontal correctors than BPMs, it may be possible to eliminate one or both of these elements. The corresponding vertical data is plotted in Figure 6.

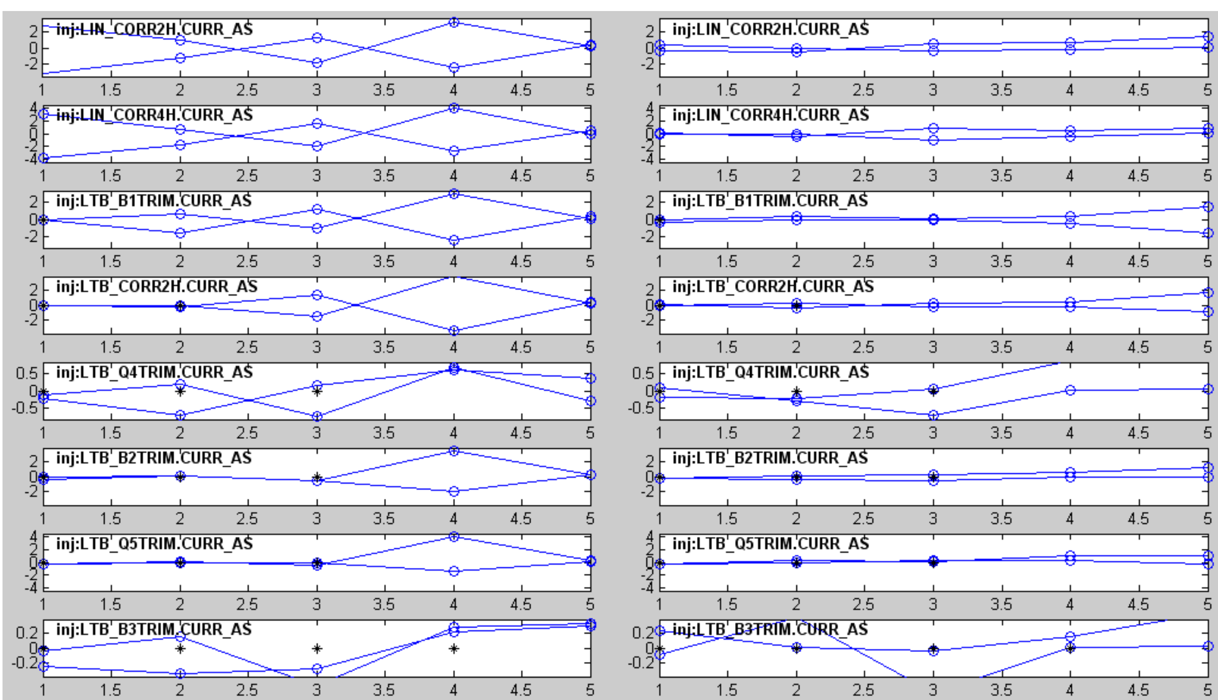

Figure 5: Orbit deflections in terms of millimeters for horizontal correctors.
x-x (left), y-x (right)

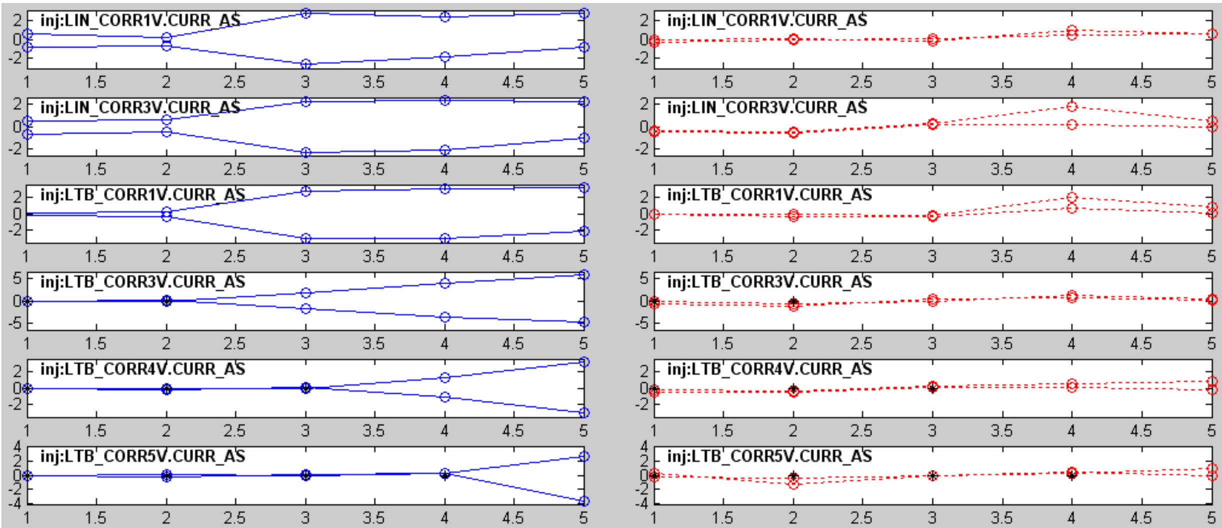

Figure 6: Orbit deflections in terms of millimeters for vertical correctors.
y-y (left), x-y (right)

c) **Dispersion Measurement:** With Steve Gierman at the K3 forward-power LINAC controls, measurements of the LTB beam-orbit ‘energy reponse’ (dispersion) were made. Interestingly, as shown in Figure 7, as the beam energy was decreased the horizontal orbit adjusted toward zero readings on the BPMs. This suggests the energy of the LTB was tuned too low for the incoming electron beam. The corresponding K3 forward power values are:

```
MW=[16.2 16.0 15.8 15.6 15.4 15.2 15.0 16.2 16.4 16.6];
colors=['b'; 'g'; 'r'; 'c'; 'k'; 'b'; 'g'; 'r'; 'c'; 'm'; 'y'; 'k'];
```

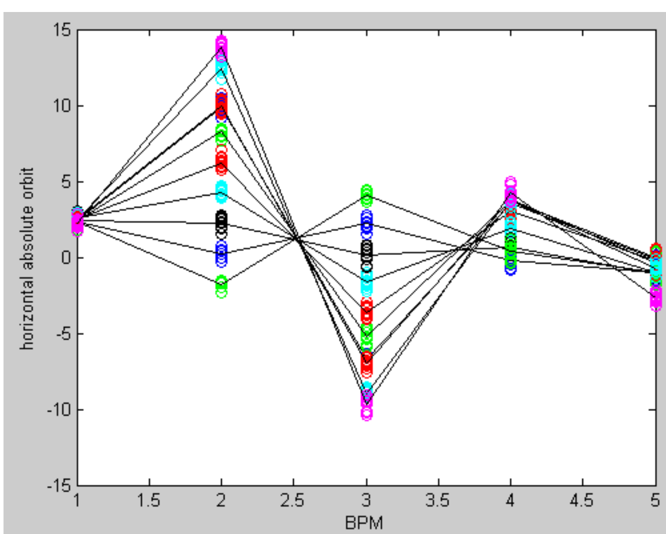

Figure 7: Horizontal dispersion measurement (K3 forward power).

Figure 8 plots the orbit deviation as a function of K3 forward power with the coefficient of the linear fit listed at the top of the plots for LTB BPM #2 and LTB BPM #3. These two BPM would be the most effective candidates for an energy feedback system.

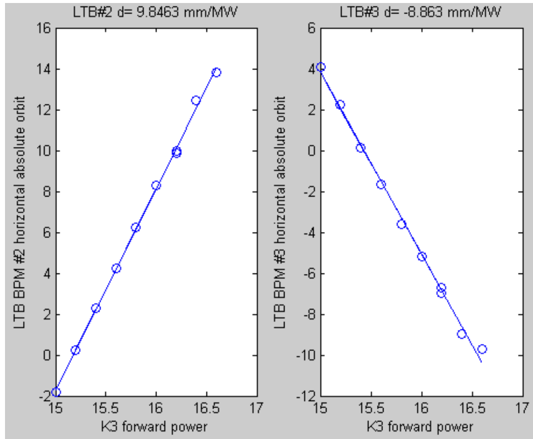

Figure 8: Horizontal dispersion component (mm) at LTB BPM #2, 3. K3 forward power in MW.

d) **Energy Scaling of the LTB:** As a further test, the LTB magnet settings were raised as a group to measure the impact on the horizontal electron beam orbit. All corrector magnets were kept at fixed value. As anticipated the orbit converged toward BPM center values (Figure 9). The effect is clear at BPMs 2,3,4 after the B1 bend magnet and arguably even at BPM5 albeit low amplitude (small dispersion). During the adjustment sequence the booster capture efficiency decreased to small but measureable values. Attempts at tuning to increase the capture efficiency were not successful. Nevertheless it is recommended to raise the LTB transport line energy to match the LINAC energy and pursue optimization of injection into the booster by tuning downstream LTB elements (correctors, quadrupoles) and injection components in the booster (septum, kickers). It is also recommended to steer the beam to the center of BPM #1 at the end of the LINAC provided the offset values are correct.

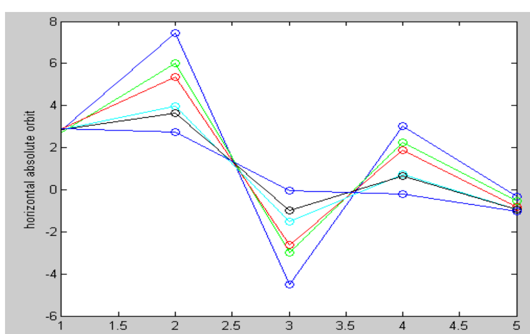

Figure 9: Horizontal orbit change with LTB energy scaling.

```
colors=['b'; 'g'; 'r'; 'c'; 'k'; 'b'];
scale=1.0+[0.001 0.002 0.003 0.004 0.005 0.006];
```

e) **Horizontal Beam Steering:** One of the goals of the LTB study is to reliably control beam steering through the transport line. As a first test, BPMs 1-4 were used in the horizontal response matrix along with horizontal correctors LINC4H, LTBB1T, LTBC2H, LTBB2T to yield the steering correspondence

LINC4H – BPM1
LTBB1T – BPM2
LTBC2H – BPM3
LTBB2T – BPM4

The reduced 4x4 horizontal response matrix is
r([1:4],[2 3 4 6])=

9.1370	-0.0345	0.1243	0.1181
3.2394	1.7846	-0.1495	0.0173
-4.8215	-1.7980	10.1497	-0.0233
9.0455	4.4985	-25.6151	2.6993

with inverse inv(r)=

0.1069	0.0007	-0.0134	-0.0048
-0.1938	0.5675	0.0235	0.0050
0.0167	0.1009	0.0985	-0.0005
0.1235	0.0092	0.9402	0.3731

Starting from an initial orbit
x0 =[4.1221, 9.3098, -5.4535, 0.4310,0.4599]

And requesting an orbit shift dx =[-2 -4 2 1] mm

Yields the change in correctors
dt =[-0.2480, -1.8305, -0.2405, 1.9697] ampere

As plotted in Figure 10, the resulting orbit is
x1 =[2.1565, 5.0886, -2.6892, -1.4614, -0.0583] mm

or an orbit shift close to the request:
x0-x1 =[-1.9656, -4.2212, 2.7643, -1.8924, -0.5181]

With further iteration and averaging of the orbit it is anticipated convergence will be achieved.

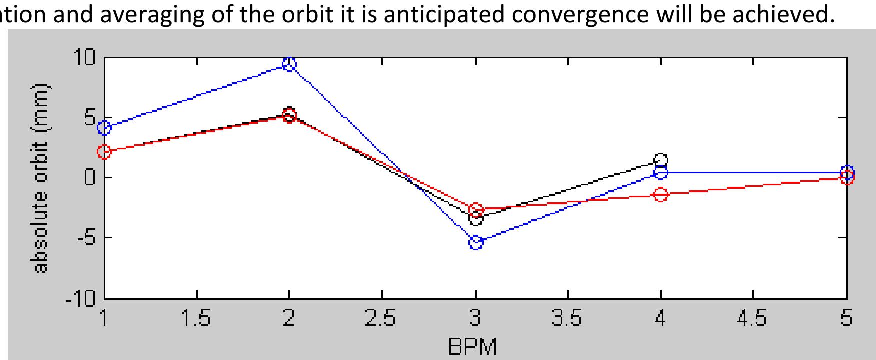

Figure 10: Horizontal orbit shift due to steering after a single shot (no iteration) (blue=starting value, black=predicted, red=actual).

Summary: Preliminary studies of the LTB transport line indicate the horizontal and vertical correctors are operational and at least the first four LTB BPMs are operational. The beam appears to be steered toward positive ‘x’ at the entrance of the LTB and the rather large orbit displacement down the LTB contains a dispersion component that can be corrected with either a LINAC energy change or by changing the energy of the LTB transport line. Further work is needed to take out the dispersion component while maintaining injection efficiency into the booster. The horizontal orbit response at BPM #5 is weak which might indicate strong focusing at quadrupole Q5F, a faulting BPM or interference from the pulsed magnet system in the booster. A first cut at horizontal beam steering was completed just prior to beam shutoff August 10, 2009. Tests will be resumed in October. In the vertical plane the baseline orbit is much closer to BPM centers (no dispersion component) and the response matrix data looks plausible. Vertical steering tests will also commence in October, 2009.

Appendix I: Middle Layer Functions

Orbit Measurement:	\machine\SPEAR3\getltbx, getltby, getltbs
Response Measurement:	\applications\LTB\measLTBresp
Configuration Get/Save:	\ machine\SPEAR3\getltbconfig \machine\SPEAR3\saveltb
Orbit folder:	\machine\spear3data\<LowEmittance>\LTB
Response Matrix folder:	\machine\spear3data\LowEmittance\Response\LTB

Appendix II: LTB PV’s

```
bpmxpv=['LTB-BPM01:X'; 'LTB-BPM02:X'; 'LTB-BPM03:X'; 'LTB-BPM04:X'; 'LTB-BPM05:X'];

bpmypv=['LTB-BPM01:Y'; 'LTB-BPM02:Y'; 'LTB-BPM03:Y'; 'LTB-BPM04:Y'; 'LTB-BPM05:Y'];

bpmspv=['LTB-BPM01:S'; 'LTB-BPM02:S'; 'LTB-BPM03:S'; 'LTB-BPM04:S'; 'LTB-BPM05:S'];

corxpv={'inj:LIN_CORR2H.CURR_AS'; 'inj:LIN_CORR4H.CURR_AS';'inj:LTB_B1TRIM.CURR_AS';
'inj:LTB_CORR2H.CURR_AS'; 'inj:LTB_Q4TRIM.CURR_AS';'inj:LTB_B2TRIM.CURR_AS';
'inj:LTB_Q5TRIM.CURR_AS'; 'inj:LTB_B3TRIM.CURR_AS';};

corypv={'inj:LIN_CORR1V.CURR_AS'; 'inj:LIN_CORR3V.CURR_AS'; 'inj:LTB_CORR1V.CURR_AS';
'inj:LTB_CORR3V.CURR_AS'; 'inj:LTB_CORR4V.CURR_AS'; 'inj:LTB_CORR5V.CURR_AS';};

bends and quads
'inj:LTB_B1.CURR_AS’
'inj:LTB_B2.CURR_AS'
'inj:LTB_B3.CURR_AS'
'inj:LTB_Q1F.CURR_AS'
'inj:LTB_Q2F.CURR_AS'
'inj:LTB_Q3D.CURR_AS'
'inj:LTB_Q4F.CURR_AS'
'inj:LTB_Q5F.CURR_AS'
'inj:LTB_Q6D.CURR_AS'
```

Appendix III: Response Matrix Structure

LTBResponse(1,1)=

Units, UnitsString, GeV, TimeStamp, ModulationMethod
WaitFlag, ExtraDelay
DataDescriptor, CreatedBy, OperationalMode, FileName
Monitor: [1x1 struct]
    FamilyName, DeviceList, Status, Field, Mode
    UnitsString, DataDescriptor, CreatedBy, TimeStamp
    Data: [5x1 double] %initial orbit
    SumData: [5x1 double] %initial sum
    QData: 0.2560
Actuator: [1x1 struct] (note: PV names not included)
    FamilyName, DeviceList, Status, Field (Setpoint), Mode
    UnitsString, DataDescriptor, CreatedBy, TimeStamp
    Data: {8x1 cell} %initial settings
Monitor1: [5x8 double]
    orbits (columns) for each of 8 negative kicks
Monitor2: [5x8 double]
    orbits (columns) for each of 8 negative kicks
Data: [5x8 double] %mm/ampere
    raw response matrix in mm/ampere
ActuatorDelta
    corrector kicks in ampere