CARE AND FEEDING OF THE OSCILLATION OVERTHRUSTER

Dave McGinnis

March 17, 2006

INTRODUCTION

The Oscillation Overthruster is an auto-tune program used for controlling the 120 GeV proton beam in the P1,P2 and AP1 beam lines and the secondary 8 GeV beam in the AP2 line for antiproton production. The program is substantially different from most of the other beamline auto-tune programs used at Fermilab because it uses singular value decomposition[1] to compute the trim corrections. Singular value decomposition cleanly handles over-constrained or under-constrained problems so any combination of trims and BPMs can be used. In addition, because of non-ideal spacing of correction elements and BPMs, normal inversion of square beamline correction matrices can result in poorly constrained trim solutions. Singular value decomposition provides a natural way to reject nearly singular solutions.

Another difference between the Oscillation Overthruster and other auto-tune programs is that trims in the 120 GeV line affect the orbit in the 8 GeV AP2 line. The Oscillation Overthruster incorporates some of the 120 GeV trims in the AP2 8 GeV correction matrix.

PROGRAM OPERATIONAL MODES

The main application page is shown in Figure 1. A number of save-restore features have been added to the main TV window. On entry into the program, the program records the initial settings of the trim magnets in the 120 GeV and AP2 line into memory. If the operator does not like the trim settings that the program sent out, it may restore the settings to the initial values by interrupting on the "**Help me! Mr. Wizard!**" button. If the operator likes the trim solution that the program has found, the initial values of the trim settings may be overwritten by interrupting on the "**I Like it!**" button. However, the program will not remember these overwritten values once the program is terminated.

The program has three operational modes that can be selected from the main application page. These modes are:

- <u>Just Looking</u> This mode observes the orbit and computes the correction needed but does not send the trim corrections to the control system
- <u>Ask Me</u> This mode observes the orbit and computes the trim corrections but asks the operator to choose whether or not to send the trim corrections to the control system at each iteration.
- <u>Trust Me</u> This mode observes the orbit, computes the trim corrections, and automatically sends the trim corrections to the control system at each iteration. To protect against two instances of the program running at the same time making corrections, the programs sets a lock as shown in Figure 2. This lock is a database device A:OSCCNS. The value of A:OSCCNS is the console number that is running the program in the "Trust Me" mode. If no console is running in the "Trust Me" mode, the value of A:OSCCNS is zero and the lock is released. If the

[1] Numerical Recipes in C++

program crashes, the lock will not be released. Setting A:OSCCNS to zero will manually release the lock.

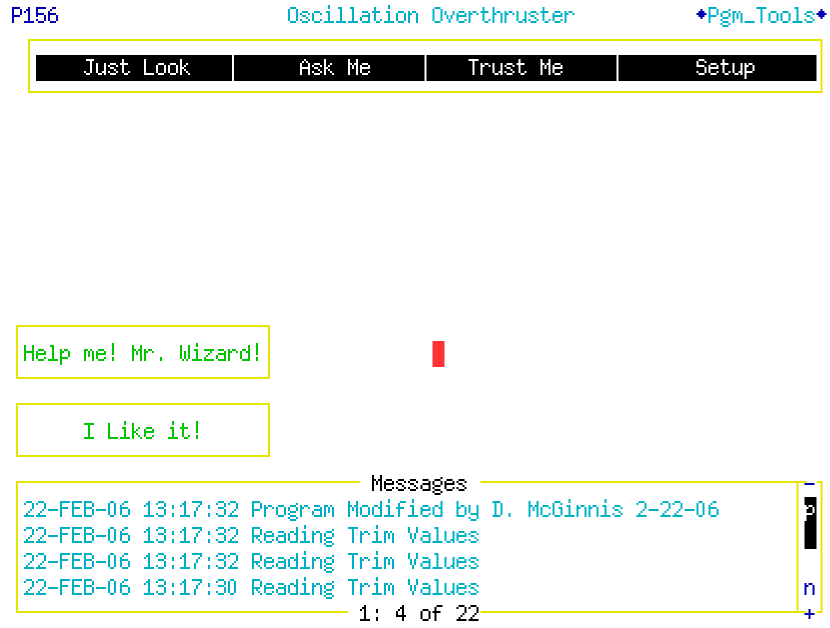

Figure 1. Main window of the Oscillation Overthruster application

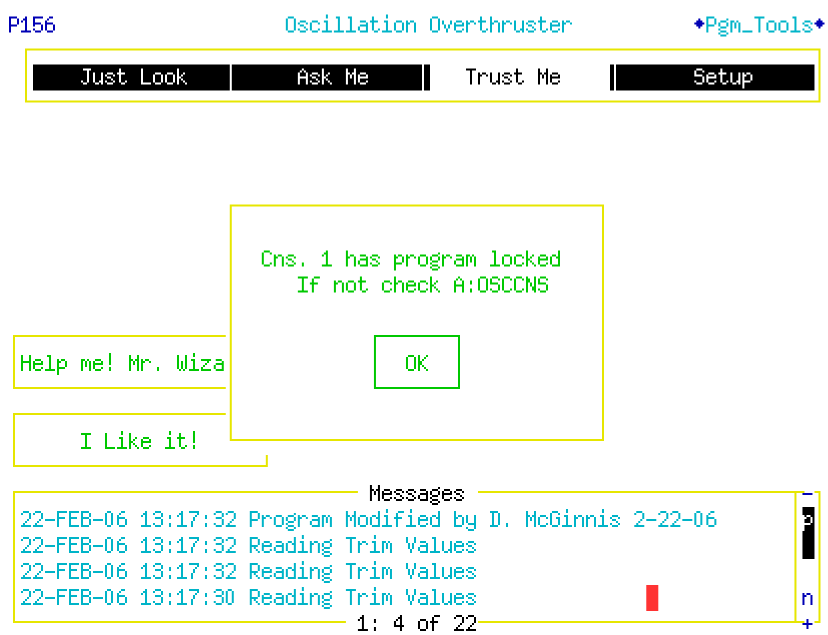

Figure 2. The “Trust Me” mode locked.

The program runs in a continuous loop. It first measures the BPM trajectory of the 120 GeV proton line. Once it finishes measuring the 120 GeV trajectory, it computes the trim corrections for the 120 GeV line. The program then moves to measuring the BPM trajectory of the 8 GeV AP2 line. Before the program decides to correct the AP2 line, it looks at the last two unmasked BPMS in both planes of the 120 GeV line. If the absolute values of these BPMs are below the “BPM Lck Max” value (which can be changed in the

Setup menu), the program considers the 120 GeV line in tolerance (locked-in) and will compute the AP2 corrections described in the “AP2 8 GeV” Setup. If the absolute values of these BPMs are above the “BPM Lck Max” value, the program considers the 120 GeV line out of tolerance (not locked-in) and will compute the AP2 corrections described in the “AP2 8 GeV Easy” setup. The “AP2 8 GeV Easy” setup typically has a much reduced set of trims unmasked so that the AP2 line will not diverge will the 120 GeV line is locking in. After the BPM trajectory of the AP2 line is measured, it computes the AP2 trim corrections using the appropriate AP2 setup and begins the next round of 120 GeV BPM measurements.

The graphics display of the program has four screens as shown in Figure 3. The left screens are for the horizontal plane and the right screens are for vertical. The bottom screens show the BPM orbit of the beam line that is currently being measured. The blue markers (shown in Figure 3) show the BPMs that are masked-out (masked-out means not used in the calculation of the trim correction). The program will acquire a number of BPM trajectories and show each trajectory on the plot. Once the program has achieved the specified number of trajectories, it displays the average of the trajectories in a thick magenta trace (not shown in Figure 3). Once the average trace has been found, the trim corrections will be computed. The top screens show the results of the trim corrections. The traces shown on the top screens are the average measured BPM trajectory (green), the trim correction (blue in Figure 3 but yellow on the computer screen), the computed <u>negative</u> trajectory that the trim correction would produce (magenta), and the <u>computed</u> left-over orbit after the trim correction is applied (red). While the program is computing the trim corrections, it begins measuring the BPM trajectory of the other transfer line.

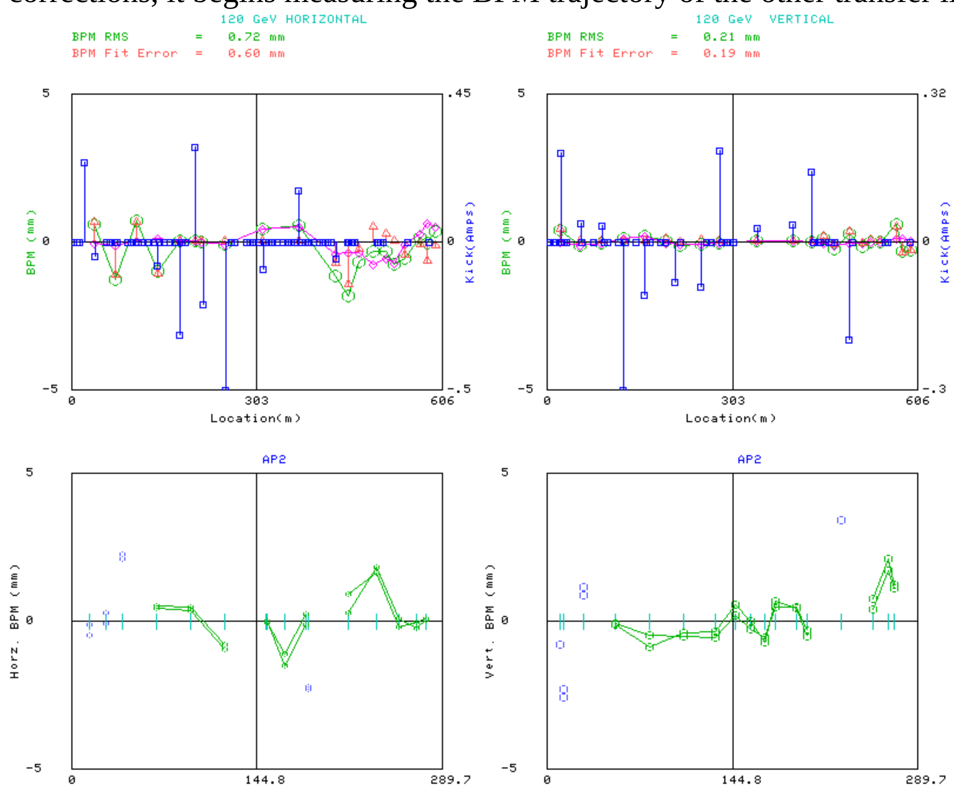

Figure 3. Graphics Screen for the Oscillation Overthruster

PROGRAM SETUP

The program setup menu is activated from the menu item on the upper right hand corner. There are different setups for the 120 GeV line and the AP2 line which are selected from the sub-menu of the Setup menu. The setup for a beam line is shown in Figure 4.

- The **Event Wait** setting is the maximum number of seconds the program will wait for a Pbar injection event ($81). If the program has to wait longer the specified number of seconds, it will flag the event as bad. Also before entering the BPM measurement iteration, the program will check if there has been any non-antiproton production Main Injector Reset events ($20, $21,$2A,$2B,$2E) that have occurred in a time interval more recent than the **Event Wait** time. If a non-antiproton production event has occurred more recent than the **Event Wait** time, it will flag the event as bad.
- The **Averages** setting is the number of BPM trajectories to measure and average during each iteration.
- The **Reset Pulse** setting is the number of events that the program must wait after an event has been flagged as bad. An event can be flagged if the program has waited too long as specified by the **Event Wait** time or if there has been no beam on the event.
- The **Reg. Count** setting is the number of iterations that will be done in a row before moving onto the next beam line. An iteration is defined as a BPM measurement and trim correction. This setting can be used to weight the amount one beam line is corrected over the other beam line. If the **Reg. Count** is set to zero, the beam line will not be measured or corrected.
- The **Ref. Orbit** setting is the index of the APX Line application (P143) BPM file that the program will use to as a reference orbit. P143 can be used to edit this orbit.
- The **SVD TOL.** setting is the singular value tolerance[2] that is used to rate trim solutions. Setting this value to a high number will provide a solution that is well behaved (an example of a poorly behaved solution would be to have neighboring trims set to opposite but nearly equal values). However, a well-behaved solution might be limited in its ability to correct the orbit.
- The **BPM Scale** setting is BPM plot limits for the graphics.
- The **BPM Max Cor** setting. If the BPM rms value (shown on the top panels of Figure 3) is larger than this value, the program will assume something has gone wrong upstream of the beam line and not send out trim corrections. The BPM rms value is the standard deviation of the difference between the measured BPM trajectory and the reference trajectory.
- The **BPM Min Cor** setting is the minimum difference between BPM rms value and the BPM fit error before the program will send out a trim correction. The BPM fit error number is the standard deviation of the difference between the measured BPM trajectory and the negative of the trajectory provided by the trim solution. (The BPM fit error is shown as the red lines in the top panels of Figure 3.)

[2] Numerical Recipes

- The **BPM Lck Max** setting is used to decide which AP2 setup to use. Only the 120 GeV setup needs for this value to be defined. While running, the program looks at the last two unmasked BPMS in both planes of the 120 GeV line. If the absolute values of these BPMs are below the "BPM Lck Max" value, the program considers the 120 GeV line in tolerance (locked-in) and will compute the AP2 corrections described in the "AP2 8 GeV" Setup. If the absolute values of these BPMs are above the "BPM Lck Max" value, the program considers the 120 GeV line out of tolerance (not locked-in) and will compute the AP2 corrections described in the "AP2 8 GeV Easy" setup. The "AP2 8 GeV Easy" setup typically has a much reduced set of trims unmasked so that the AP2 line will not diverge will the 120 GeV line is locking in.
- The **Trim % Cor** setting is the percentage amount of the trim solution calculated and shown in the top panels of Figure 3 that will be sent out to the trims. A value of 100% will mean that the full amount of the trim correction will be sent out. A value of 0% will mean that no changes to the trims will be sent out.
- The **BPM Masks** line is a sub-menu that will open a panel to edit which BPMs will be included in the calculations for the trim corrections. The BPM plane can be toggled by interrupting on the right hand side of the line. Interrupting on the left hand side of the line will cause the BPM mask sub-menu to appear. The BPM mask sub-menu is shown in Figure 4. Interrupting on the BPM name will cause the mask status to toggle. If the BPM name is in red, the BPM is masked, if it is in green it is unmasked and will be used in the trim correction calculation. The BPM sigma is used in the BPM trim excitation matrix. The BPM trim excitation matrix is relates the orbit trajectory to trim kicks and is used to calculate the trim changes needed to obtain a desired orbit.

  $$\frac{BPM_i}{\sigma_i} = \sum_j \frac{M_{i,j}}{\sigma_i} I_j$$

  The column **j** of the matrix **M** is the BPM trajectory that results from a 1 ampere change in trim **j**. Adjusting the BPM sigma will determine the weight of the BPM in the trim calculation. A low value for sigma will make the BPM value very important in the calculation. Setting the BPM sigma to a very large number is the same as masking the BPM off. The BPM value is the last value of the BPM measurement for that BPM. Changing the BPM value will do nothing for the trim correction calculation. Clicking outside the BPM sub-menu window will cause the window to close.
- The **Trim Masks** line is a sub-menu that will open a panel to edit which trims will be included in the calculations for the trim corrections as shown Figure 5. The trim plane can be toggled by interrupting on the right hand side of the line. Interrupting on the left hand side of the line will cause the trim mask sub-menu to appear. The trim mask sub-menu is shown in Figure 5. Interrupting on the trim name will cause the mask status to toggle. If the trim name is in red, the trim is masked, if it is in yellow (blue as shown in Figure 5) it is unmasked and will be used in the trim correction calculation. The trim value is the last value of the trim setting used for that trim. Changing the trim value will do nothing for the trim

correction calculation. Clicking outside the trim sub-menu window will cause the window to close.

- Interrupting on the **Save Setup** entry will save the setup settings including the BPM and trim masks for both planes for only the selected beamline in the database. When the program is re-entered it recalls the settings saved in the database file. If the settings are not saved, the program will use the changed settings on display but not remember any changes when the program is re-entered.

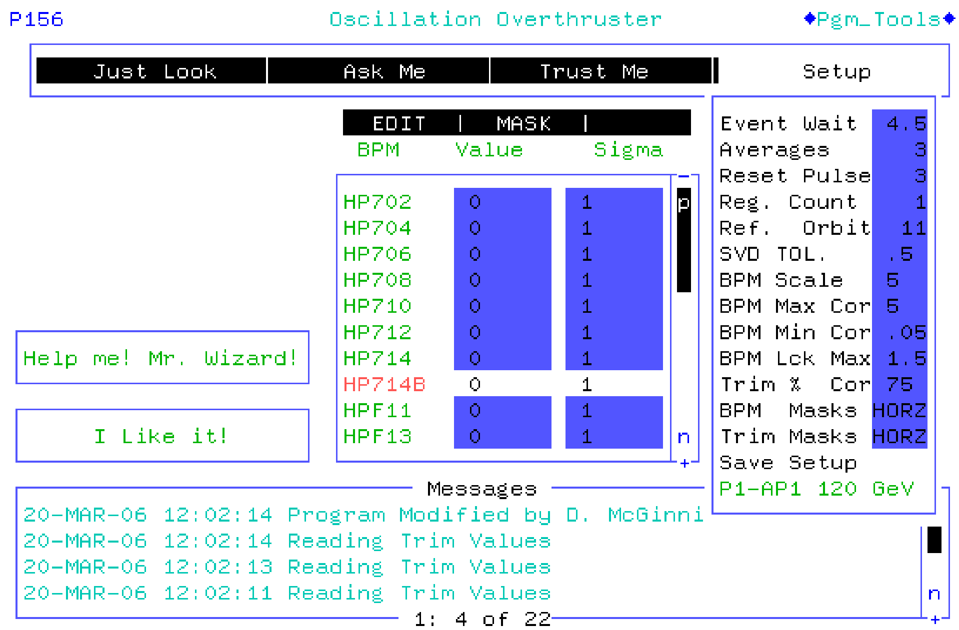

Figure 4. Setup menu including BPM mask sub-menu.

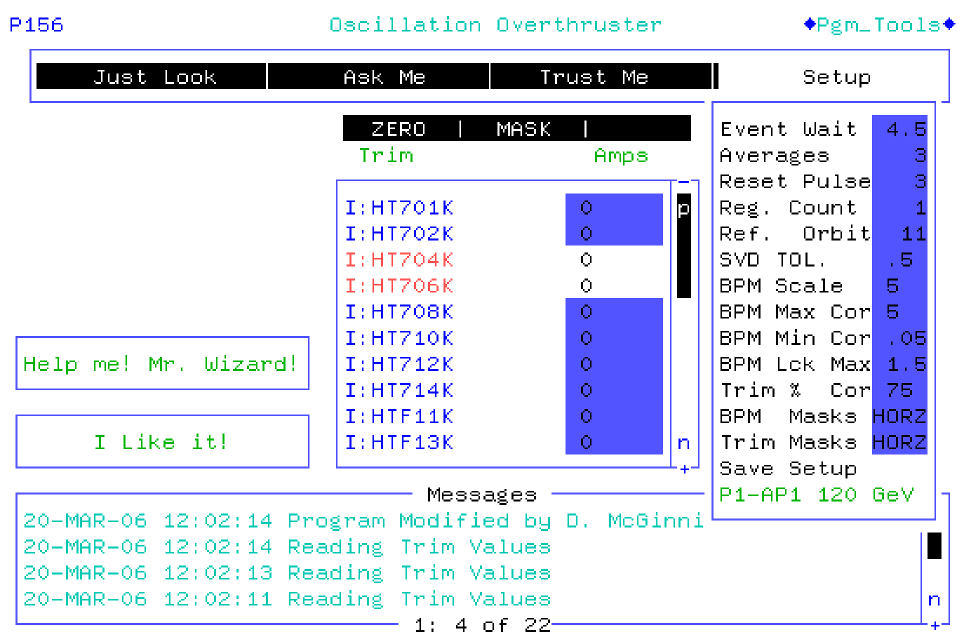

Figure 5. Setup Menu including trim mask sub-menu.

EDITING THE BPM-TRIM EXCITATION MATRIX

To edit the BPM-Trim excitation matrix, the user should be an expert on how the APX Line application (P143) program works. The number of experts on this program is vanishingly small. The BPM trim excitation matrix relates the orbit trajectory to trim kicks and is used to calculate the trim changes needed to obtain a desired orbit.

$$\frac{BPM_i}{\sigma_i} = \sum_j \frac{M_{i,j}}{\sigma_i} I_j$$

The column **j** of the matrix **M** is the BPM trajectory that results from a 1 ampere change in trim **j**. The matrix is initially calculated from the MAD lattice of the selected beamline in the APX Line application (P143). The APX Line application (P143) stores this matrix in the HORZ_BPM_TRIM_MATRIX.DAT and VERT_BPM_TRIM_MATRIX.DAT files in the appropriate beamline directory. The Oscillation Overthruster application reads these matrix files during program initialization.

However, using P143, single columns of this matrices can be replaced by actual measured BPM trajectories. In this way the BPM response in a beamline to a trim that is physically not in the beamline can be computed from experimental data. A good example of this is the BPM response of the AP2 line to the trim M:H107ST.

The trim must be contained in the APX Line application MAD lattice file for the particular beam line. If the trim does not physically exist in the beam line, the trim can be designated as MAD marker in the MAD lattice at the beginning of the beamline. The name of the MAD marker for the trim and the ACNET control system must also be contained in the XXX_TRIM_STRENGTH_BLI.DAT file in the appropriate beamline directory.

To edit the matrix using measured BPM data and P143, first the measured difference orbit for the trim excitation must be read into P143 under the <u>**Correct Orbit**</u> menu. Then with <u>both</u> the EDIT BPMS and EDIT TRIMS in the NORM mode, the EDIT TRIMS sub-menu is selected for the appropriate plane. In this sub-menu, all the trims are masked except for the trim that was used to excite the BPMs. In the **Amps** column, the difference in trim current between the excited BPM trajectory and the reference BPM trajectory is entered. Under the CALC sub-submenu, selecting the **Publ**. (Publish) menu item will overwrite the matrix column with the BPM trajectory divided by the trim excitation for the given plane.

The new matrix can be checked be re-entering the beamline so that the matrix is read into P143 again. Then, the difference orbit for the trim excitation must be read into P143 under the <u>**Correct Orbit**</u> menu. Then with <u>both</u> the EDIT BPMS and EDIT TRIMS in the <u>***MEAS***</u> mode, the EDIT TRIMS sub-menu is selected for the appropriate plane. In this sub-menu, all the trims are masked except for the trim that was used to excite the BPMs. The trim value is calculated under the CALC sub-submenu and selecting **Correct** menu item. The trim value calculated will be the <u>negative</u> of the difference in trim current between the excited BPM trajectory and the reference BPM trajectory and the trajectory fit will be identical to the difference trajectory.