

Development of alternative method for Booster TBT data Analysis

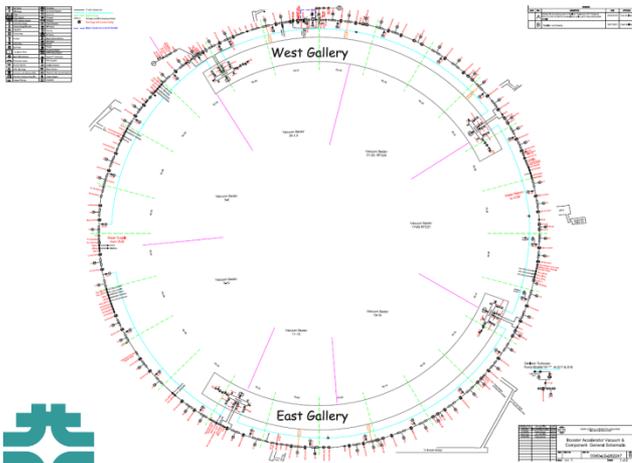
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FNAL/APC

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Fermilab Booster BPMs

- The Fermilab Booster - 474 m long machine accelerating protons from 0.4 to 8 GeV kinetic energy in 33 ms (about 22000 turns);
- B38 - Booster console application for analyzing the Turn-by-Turn (TBT) beam position measured by Beam Position Monitors (BPMs);
- 48 Booster BPMs measure both horizontal and vertical beam position.



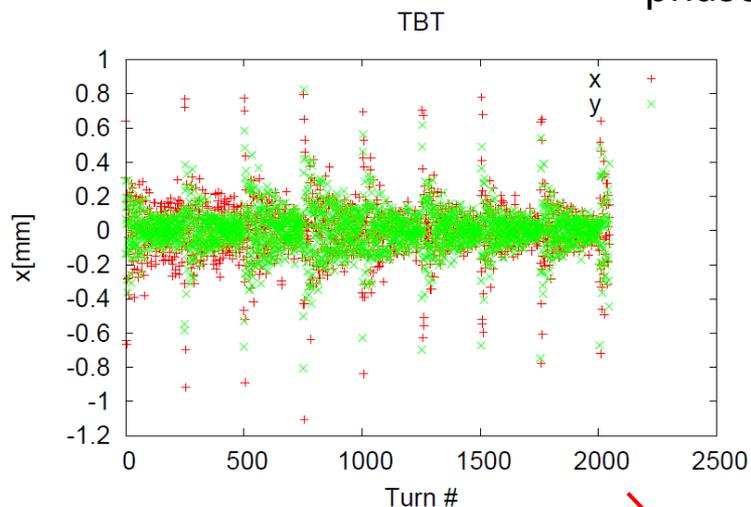
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B38 BOOSTER TURN BY TURN
File Tune Peak Meas Other actions Turn Calc options
Action
FREEZE DATA FT CONTOUR PLOT
UNFREEZE DATA BPM COMB FT CONTOUR PLOT INIT GRAPHICS CURSOR
READ MULTIPLE BPM FT REPEAT CONTOUR PLOT DELETE GRAPHICS CURSOR
READ MULTIPLE BPM OPTIONS FT CONTOUR PLOT OPTIONS
PLOT MULTIPLE BPM ADD TO SUM FT SPECTRA
PLOT BPM2 VS BPM1 REPEAT SUM FT SPECTRA
BPM2 VS BPM1 PLOT OPTIONS DISPLAY SUM FT PEAKS
TURN BY TURN BPM PLOT SUM FT SPECTRA OPTIONS
REPEAT TBT BPM PLOT RESET SUM FT SPECTRA
TBT BPM PLOT OPTIONS AUTO DAQ SUM FT SPECTRA
COMPUTE COUPLING
PLOT TBT DISPLAY DISPLAY COUPLING COEFF
REPEAT TBT DISPLAY PLOT COUPLING COEFF
TBT DISPLAY OPTIONS DISPLAY COUPLING THISS
TBT DISPLAY OPTIONS FILE COMPUTE COUPLING OPTIONS
PING ANALYSIS COMPUTE CHROMATICITY
PING STRENGTH ANALYSIS DISPLAY CHROMATICITY
PING ANALYSIS OPTIONS CHROMATICITY OPTIONS
PING STRENGTH OPTIONS
FT COMBINE BPM OPTIONS
PLOT FOURIER TRANSFORM
PLOT REPEAT FT
FT PLOT OPTIONS
DAQ Status
Micro 24 ON
Micro 6 ON
Micro 12 ON
Micro 15 ON
Micro 18 ON
Micro 21 ON
DIGITIZE ON EVENT
DIGITIZE ON EVENT 17
Messages
Booster Turn by Turn Started
Tune Peak Meas Options FILE RECORD 1 READ SUCCESSFULLY
    
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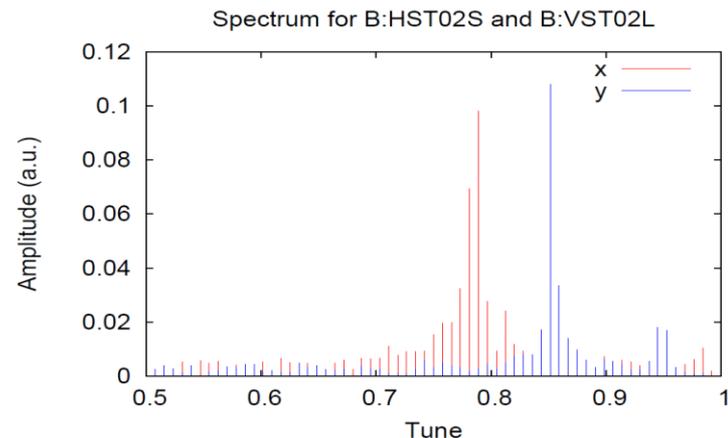


Continuous Fourier Transformation for TBT data

To decrease noise data from all BPMs were summed with according theoretical phase shifts for each BPM.

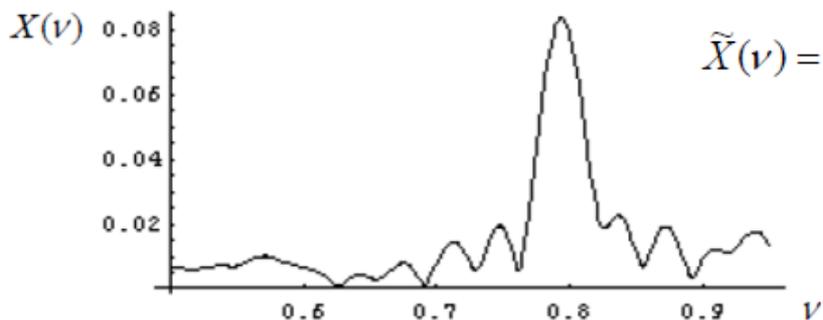


F.F.T.



*fast decrement – small number of turns available

“C.F.T.”



$$\tilde{X}(\nu) = \frac{1}{N} \sum_{n=1}^N e^{-2\pi i \nu (n-1)} \sum_k w_k x_n^{(k)} e^{-i\varphi_x^{(k)} - i s_k (\nu - Q_{x0})}$$

$$\tilde{x}_n = \sum_k w_k x_n^{(k)} \exp[-i\varphi_x^{(k)}]$$

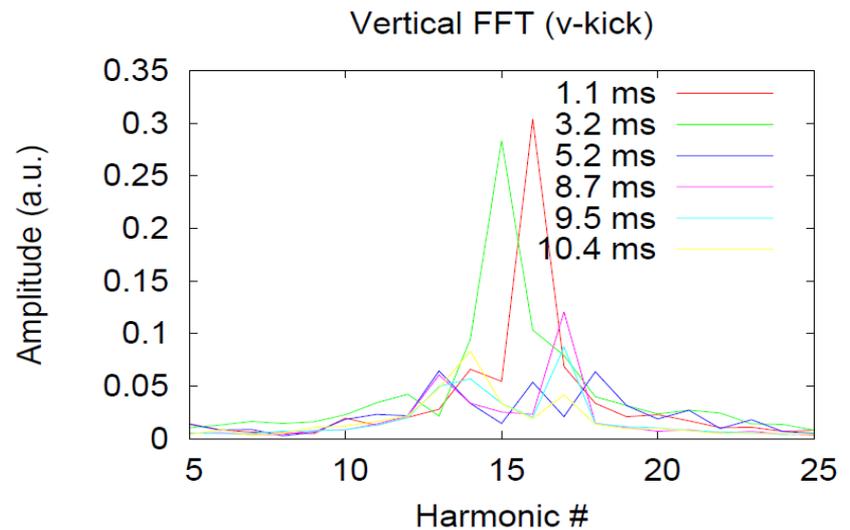
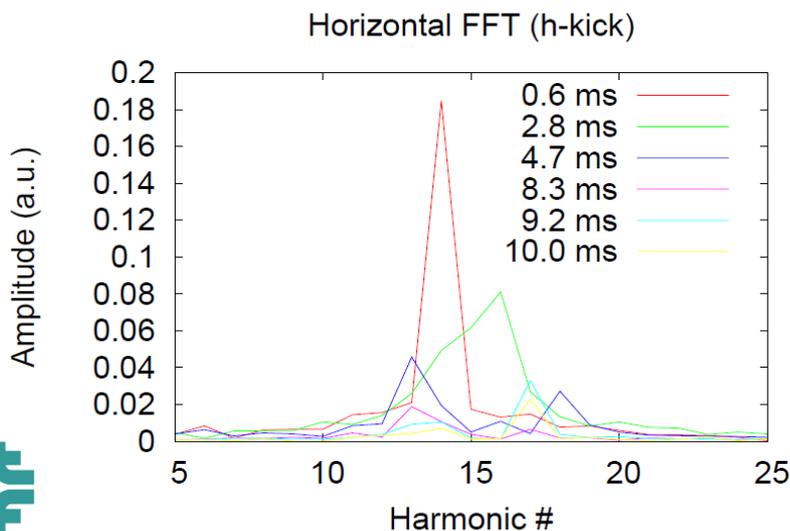
$$\varphi_x^{(k)} = \varphi_{x0}^{(k)} + s_k (\nu - Q_{x0})$$



Problems

- In the presence of coupling both transverse mode peaks are present in the spectra of oscillations;
- Existing algorithm may fail to identify tunes correctly in case of strong coupling, BPM noise or when the mode with lowest damping rate dominates the spectra of oscillations in both planes.

Example of a problematic point: which are the tunes at 9.5 ms?



New algorithm for tune identification

An alternative algorithm with **real fit parameters** for TBT data analysis which should improve tune identification has been proposed:

$$F_n^x \sim a_x e^{ig(v_x, \varphi_x, d_x, n)} + b_y e^{ig(v_y, \psi_y, d_y, n)}$$

$$F_n^y \sim a_y e^{ig(v_y, \varphi_y, d_y, n)} + b_x e^{ig(v_x, \psi_x, d_x, n)}$$

where $g = (2\pi n\nu + \varphi) + i * nd$ or $g = (2\pi n\nu + \psi) + i * nd$

The values of the variable parameters is found by minimizing the function:

$$F_n = [\Re(F_n^x - \tilde{x}_n)]^2 + [\Im(F_n^x - \tilde{x}_n)]^2 + \frac{a_{x0}^2}{a_{y0}^2} \{ \Re[F_n^y - \tilde{y}_n]^2 + \Im[F_n^y - \tilde{y}_n]^2 \}$$



Main Goals

- Write a C++ routine resorting to a suitable minimization package for performing the fit;
- Embed it into B38.

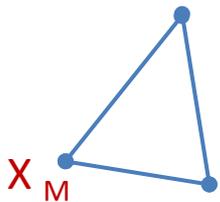
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Z9 BOOSTER TURN BY TURN Pgm_Tools
file Tune Peak Meas other actions Turn Calc options
Action
FREEZE DATA FT CONTOUR PLOT
UNFREEZE DATA BPM COMB FT CONTOUR PLOT INIT GRAPHICS CURSOR
READ MULTIPLE BPM FT REPEAT CONTOUR PLOT
READ MULTIPLE BPM OPTIONS FT CONTOUR PLOT OPTIONS DELETE GRAPHICS CURSOR
PLOT MULTIPLE BPM ADD TO SUM FT SPECTRA
REPEAT MULTIPLE BPM REOPTIONS REPLOTTING SUM FT SPECTRA
PLOT BPM2 VS BPM1 DISPLAY SUM FT PEAKS
BPM2 VS BPM1 PLOT OPTIONS SUM FT SPECTRA OPTIONS
TURN BY TURN BPM PLOT REPEAT SUM FT SPECTRA
REPEAT TBT BPM PLOT AUTO DAQ SUM FT SPECTRA
TBT BPM PLOT OPTI RPOS == 0 Tunes
PLOT TBT DISPLAY Compute Chromaticity
REPEAT TBT DISPLAY Plot Tunes
TBT DISPLAY OPTIO Edit Tunes
TBT DISPLAY OPTIO Reselect one Tune
PING ANALYSIS 1 Ping Close Tune Algorithm Analysis
PING ANALYSIS 1 Ping 2 decaying cos fit Analysis
PING ANALYSIS Utility (Copies)
PING STRENGTH ANA
PING ANALYSIS OPTIONS DIGITIZE ON EVENT
PING STRENGTH OPTIONS DIGITIZE ON EVENT
FT COMBINE BPM OPTIONS
PLOT FOURIER TRANSFORM
PLOT REPEAT FT
FT PLOT OPTIONS
Messages
102 BPM's IMPORTED
102 BPM's IMPORTED
102 BPM's IMPORTED
1:3 of 7
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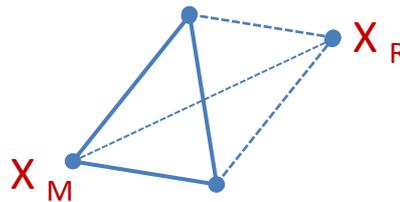
Nelder-Mead algorithm

- Simplex-method
- Does not use gradients
- Applied to noisy and nonsmooth functions

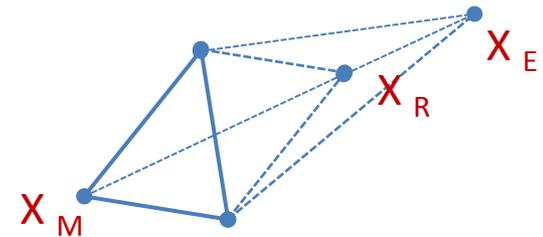
Simplex deformations:



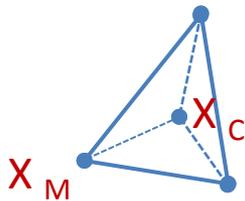
Initial



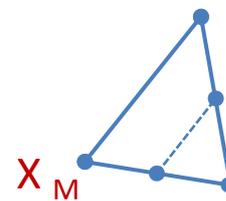
Reflection



Expansion



Contraction



Multi-Contraction



Variables constraining

Till beam is stable:

$$\Phi_{x,y}, \psi_{x,y} \in [-\pi, \pi];$$

$$v_{x,y} \in [0.5, 1];$$

$$a_{x,y}, b_{x,y} > 0;$$

$$d_{x,y} > 0$$

```
Estimate of minimizing value X*:  
ax      10.3967  
bx      9.06848  
d_x     0.0160238  
qx      0.839712  
phi_x   1.57997  
psi_x   3.14116  
ay      5.68827  
by      7.44748  
d_y     1.23872  
qy      1.85984  
phi_y   -0.119833  
psi_y   -12.7483  
  
F(X*) = 5505.65  
  
Number of iterations = 14616  
Number of restarts = 13  
  
Tune qy is not in range!  
New tune qy = 0.859838  
  
Phase psiy is not in a range!  
New phase psiy = -0.181885
```



Return **INFINITY** value when parameters are out of range – leads to excess of iterations;



After a minimum is found, the variables are moved to the wished range of values. This is done for clarity purposes, being yet suitable for the tunes.



Stability of algorithm

- Starting point is obtained from CFT;
- Method non-sensitive for deviation from starting point:
 - Amplitudes 30%,
 - Phases 40%,
 - Decrements 100%,
 - Tunes 30%;
- For deviation from starting point more than is noted above tunes values are changed to 0.2% and 1.7% for ν_x and ν_y respectively.



Conclusions

- Suitable algorithm for function minimization was found;
- Algorithm was realized and tested in off-line program;
- Tests showed that algorithm is stable for initial point deviation;
- Got familiar with MECCA (Fermilab procedure for compiling and administrating machine applications) and ACNET (Fermilab Accelerator Control System). Write a subroutine for B38 based on this algorithm (in progress).

