Fermilab-TM-2195

Tevatron Stripline Turn by Turn Data Showing Differential Head-Tail Positions

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INTRODUCTION

Vic Scarpine recently collected turn by turn data from the vertical wideband stripline in the Tevatron during proton injection for store 1841. The data file name is “PHT004.txt”. The single bunch intensity was roughly 200e9. The chromaticity was set to ‘+6’ horizontal and ‘–2’ vertical to induce instability. The data shown represents an extreme condition that shortly preceded losses leading to an abort.

A Yokogawa DL 7200 oscilloscope was used to measure A-B and A+B simultaneously from the 1 meter long stripline. The scope has an analogue bandwidth of 500MHz with a 2 GHz sample rate. On each of the 2048 turns taken, 200 samples were saved. Vic Scarpine assembled some movie files from the same data that revealed intriguing variations in the A-B signals.

The Excel data file contains 2048 turns of A+B followed by 2048 turns of A-B. The 200 samples taken on each turn is placed on one line in the file. Beam was injected at line 14 for A+B and line 2062 for A-B. Eight consecutive turns of data are examined starting at 1490 turns after injection (lines 1504-11 for A+B and 3552-9 for A-B).

STRIPLINE DETECTOR

The stripline detector has 1 meter long plates that are about 60° wide. The measured position gain is 0.648 db/mm.

$$pos = \frac{1}{.648}\,20\log\frac{A}{B} \approx \frac{1}{.648}\,20\frac{1}{1.1415}\,\frac{A-B}{A+B}$$
$$= 27.0\,\frac{A-B}{A+B} \qquad [mm]$$

The oscilloscope gains were set to 200mV/div for A+B and 10mV/div for A-B channels.

$$pos = 27.0\,\frac{10mV}{200mV}\,\frac{A-B}{A+B} \qquad \textit{for } A-B \textit{ and } A+B \textit{ in raw counts}$$
$$= 5.4\,\frac{A-B}{A+B} \quad [mm]$$

The stripline detector output is the sum of a positive image of the beam produced at the upstream end and a negative image of the beam from the downstream end. The images are separated by twice the plate length divided by the velocity (6.67nsec). At Tevatron energies, the beam velocity and the signal propagation velocity are very close to the speed of light. The sum produces a zero in the output when the plate is ½ wavelength long (146MHz). The frequency response of an ideal stripline is provided below. For frequencies below 500MHz the response is very close to an ideal stripline.

$$\frac{Vout}{Ibeam} = \frac{60}{360}\frac{50\Omega}{2}\left[\cos\omega\left(t-\frac{l}{c}\right)-\cos\omega\left(t+\frac{l}{c}\right)\right]$$

$$= \frac{60}{360}\frac{50\Omega}{2}\,2\sin\omega\frac{l}{c}\sin\omega t$$

$$= \frac{60}{360}\frac{50\Omega}{2}\,2\sin\pi\frac{f}{f_O}\sin\omega t \qquad for\;\; f_O = \frac{c}{2l} = 146MHz$$

DISCUSSION

The data clearly shows a head-tail instability that seems to be dominated by low frequency (<60MHz). The character of Figure 6 even suggests a 1/f dependence on the amplitude of the motion. Presumably the driving impedance is at low frequency. Possibilities include losses in the stainless steel vacuum tube and the laminations in lambertson magnets.

The head and tail oscillates at the betatron frequency. The fact that the pattern repeats every 7 turns simply suggests that 7 times the tune is near an integer. A fractional tune of 0.4286 satisfies this condition.

There is no discernable coherent synchrotron oscillation component in any of the data. The synchrotron frequency is typically 85 Hz at injection (625 turns).

If the betatron amplitude grows faster than head-tail mixing at the synchrotron frequency, one might expect the tail of the bunch to undergo larger oscillations than the head. The data shown in Figures 1 through 6 was taken well after the instability started and after synchrotron mixing has occurred. Similar data shown in Figures 7 and 8 indicates the amplitude of the oscillation is about the same in the head and tail even while the instability grows. Apparently, the head-tail growth rate is slow enough that significant mixing from synchrotron oscillations occurs.

MEASUREMENTS

A+B and A-B

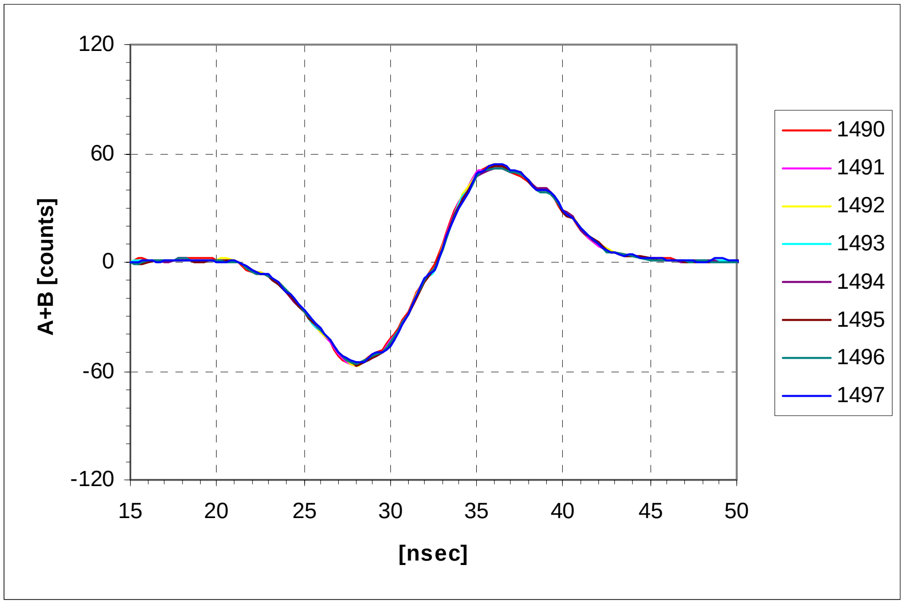


Figure 1. A+B in raw counts for all 8 turns of data. Clearly the intensity and bunch shape are very stable with no evidence of synchrotron oscillation.

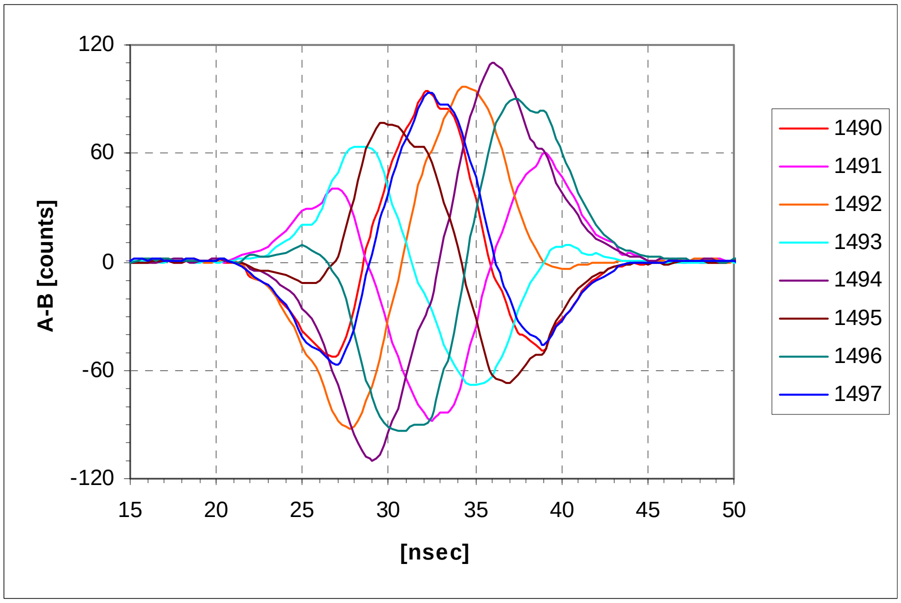


Figure 2. A-B in raw counts for the same turns used in Figure 1. The first and last turn have nearly identical shape. The pattern repeats every 7 turns.

INTRA BUNCH POSITION

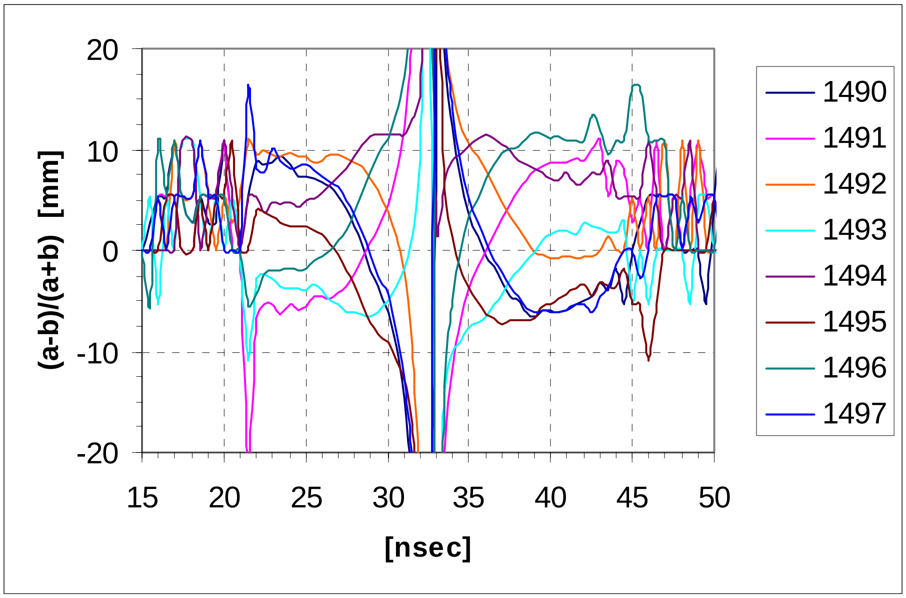


Figure 3. (A-B)/(A+B) scaled to mm for the same 8 turns shown in Figure 2. The large transient at the center occurs where A+B is near zero.

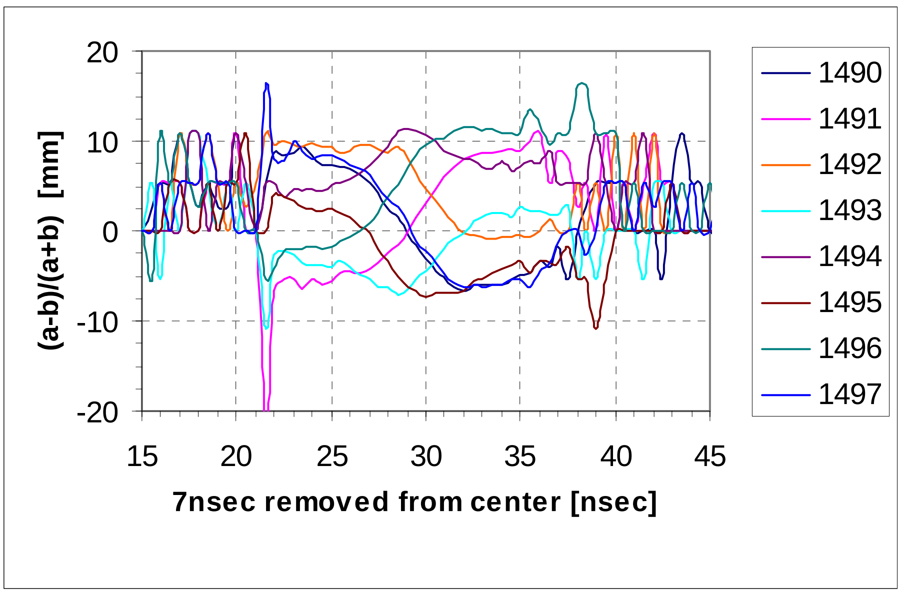


Figure 4. This plot is the same as Figure 3 but with 7nsec (2*plate length) removed from the center of the beam signal. Note how the first and last turns have nearly the same position.

FREQUENCY DEPENDANCE

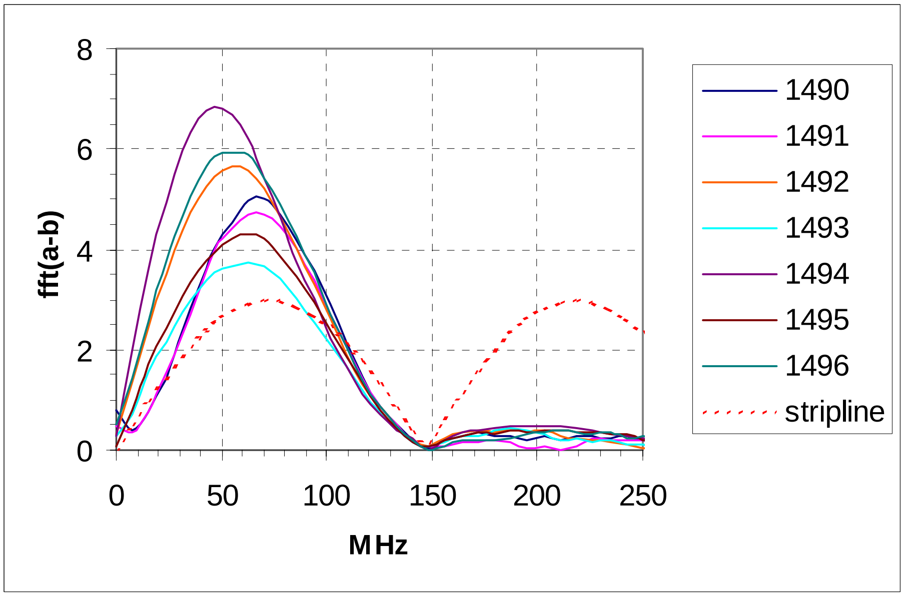


Figure 5. The FFT of 7 turns of the data. The 200 point records were zero extended to 256 samples. The dotted trace shows the frequency response of the stripline detector.

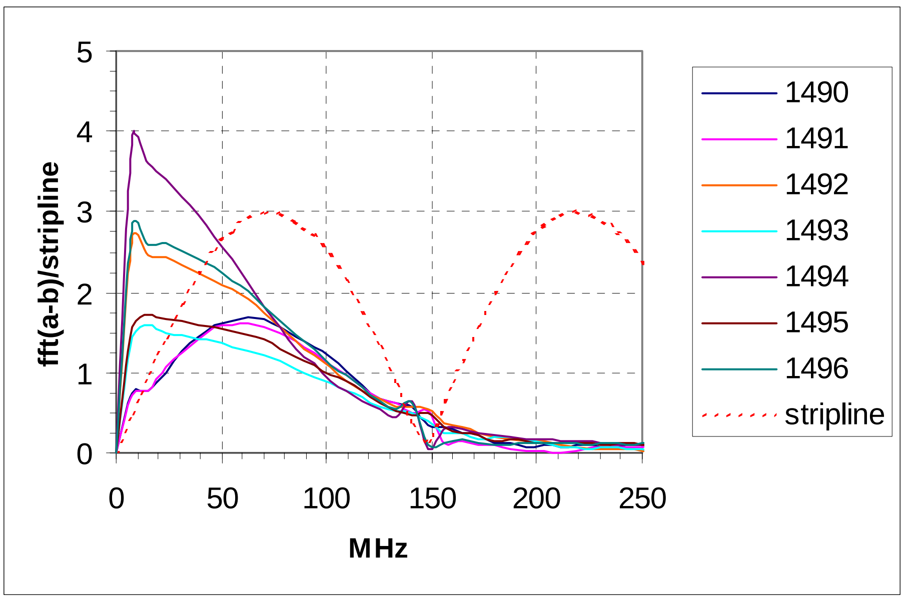


Figure 6. The FFT of the 7 turns of data normalized with the stripline frequency response.

TIME EVOLUTION OF THE POSITION AMPLITUDE

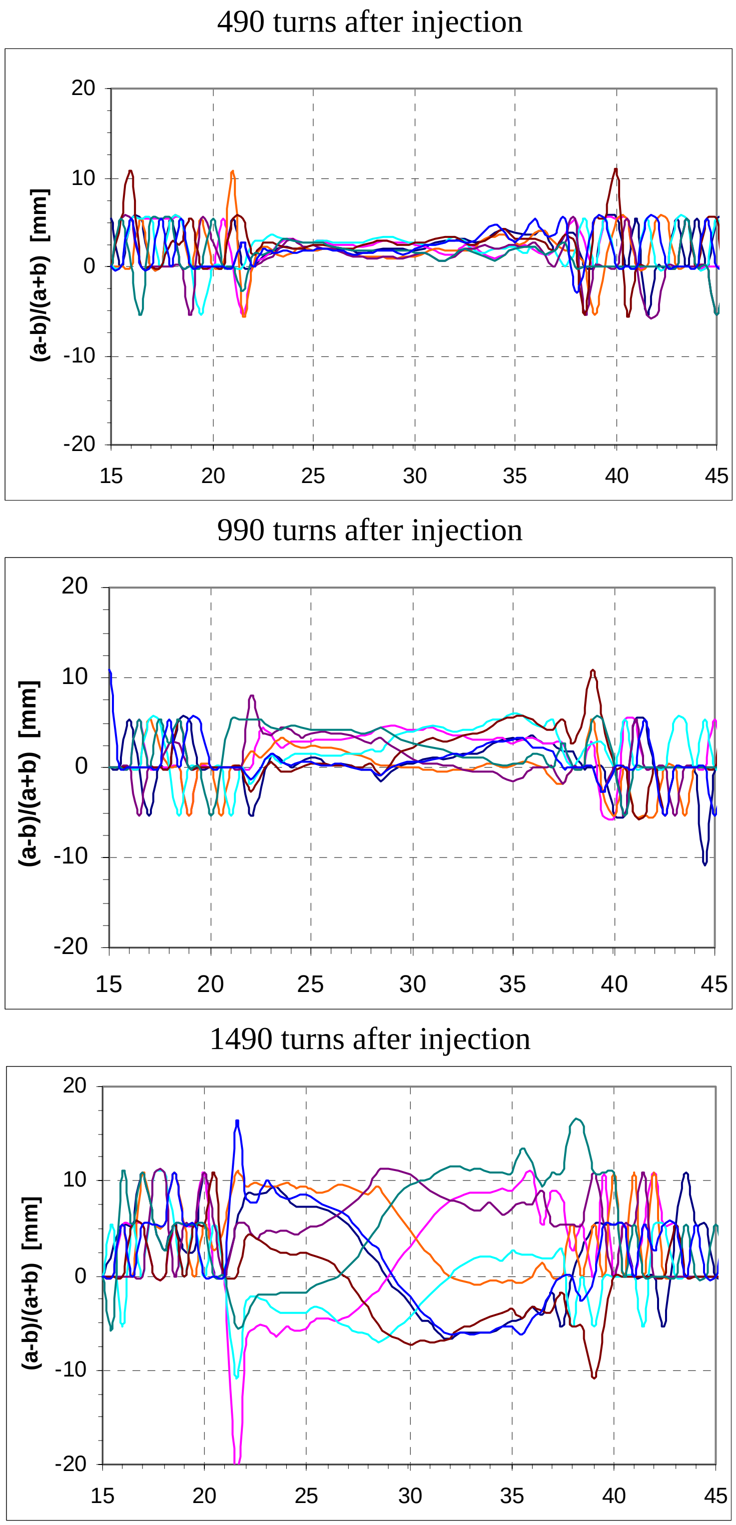
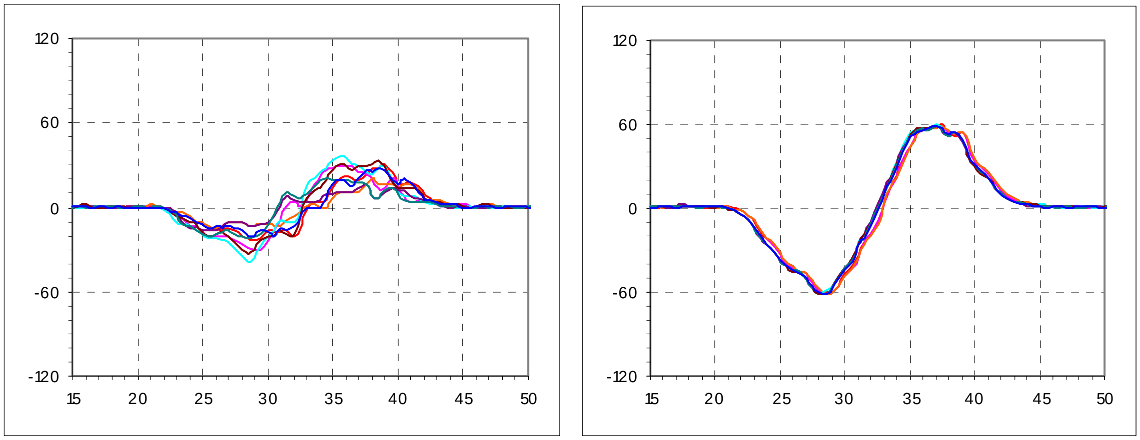


Figure 7. Progression of the ‘head-tail’ instability. The graphs show the position for 8 consecutive turns at 490, 590, and 1490 turns after injection.

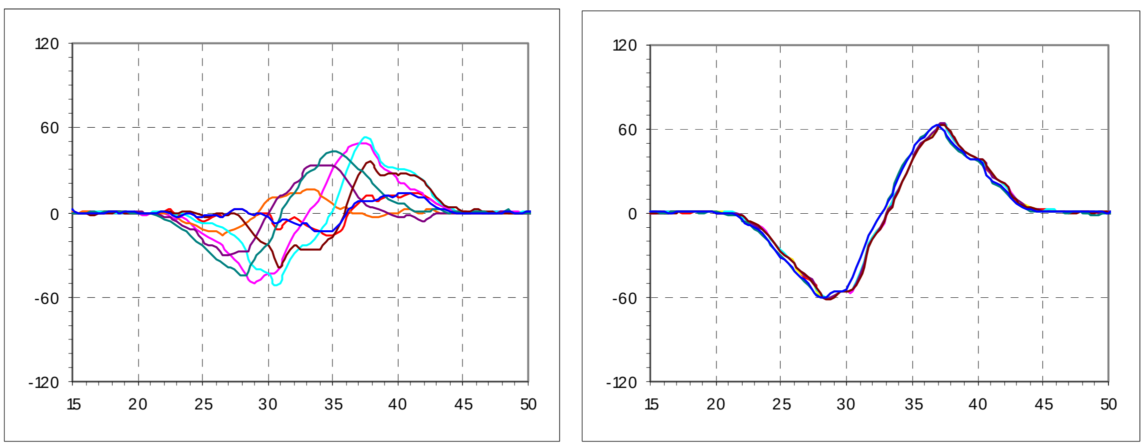
TIME EVOLUTION OF A-B AND A+B

A-B **A+B**

490 turns after injection



990 turns after injection



1490 turns after injection

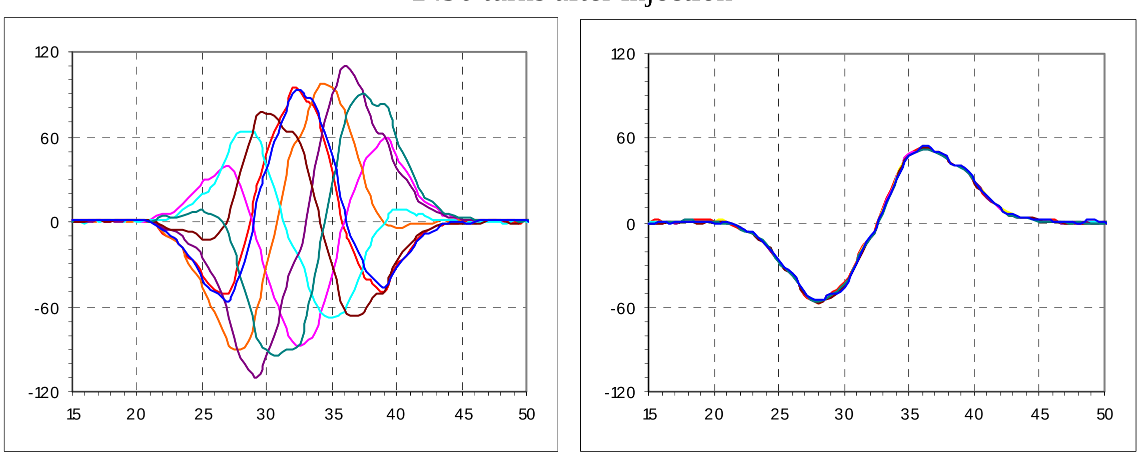


Figure 8. Progression of the ‘head-tail’ instability. The graphs show A-B on the left and A+B on the right for 8 consecutive turns at 490, 590, and 1490 turns after injection.

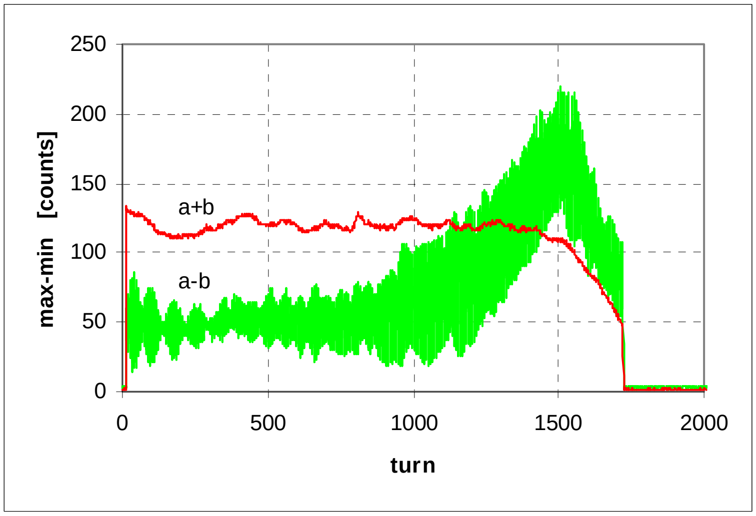


Figure 9. Max-Min from every turn for a-b and a+b. Beam is injected at turn 14, losses start at about turn 1500, and an abort occurs on turn 1720.

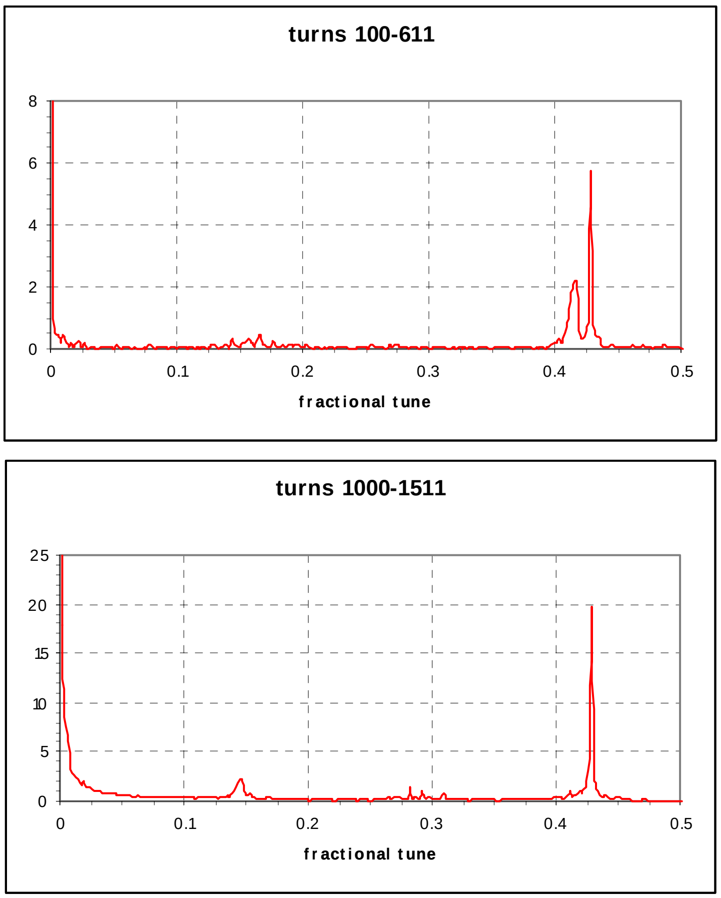


Figure 10. FFT of turns 100 to 611 and turns 1000 to 511 indicating fractional tune. In the upper plot, the vertical tune is 0.572 (at 0.429) and the horizontal tune is 0.583 (at 0.417). The presence of the horizontal tune on the vertical detector suggests some coupling is present. In the lower plot, the signal at 0.145 is very near the 2nd harmonic of the vertical tune (2x0.572).