EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN – A&B DEPARTMENT

AB-Note-2004-064 MD

Study of a New Working Point for the CERN PS Booster

**M. Benedikt, A. Blas, C. Carli, M. Chanel, H. Fiebiger, A. Findlay,
K. Hanke, J.-L. Sanchez-Alvarez, J. Tan, P. Urschütz**

Abstract

This paper reports on experiments with a new working point for the CERN PS Booster (PSB), performed during a dedicated machine development (MD) session following the 2003 run. For the experiments, we have set up the PSB with $(Q_h = 4.17, Q_v = 4.23)$, and compensated only the $2Q_v = 9$ resonance. We compare the performance of the PSB to the one using operational settings $(Q_h = 4.17, Q_v = 5.23)$. We have studied the performance using ISOLDE and LHC type beams. Furthermore, we have measured the strength of some of the resonance driving terms.

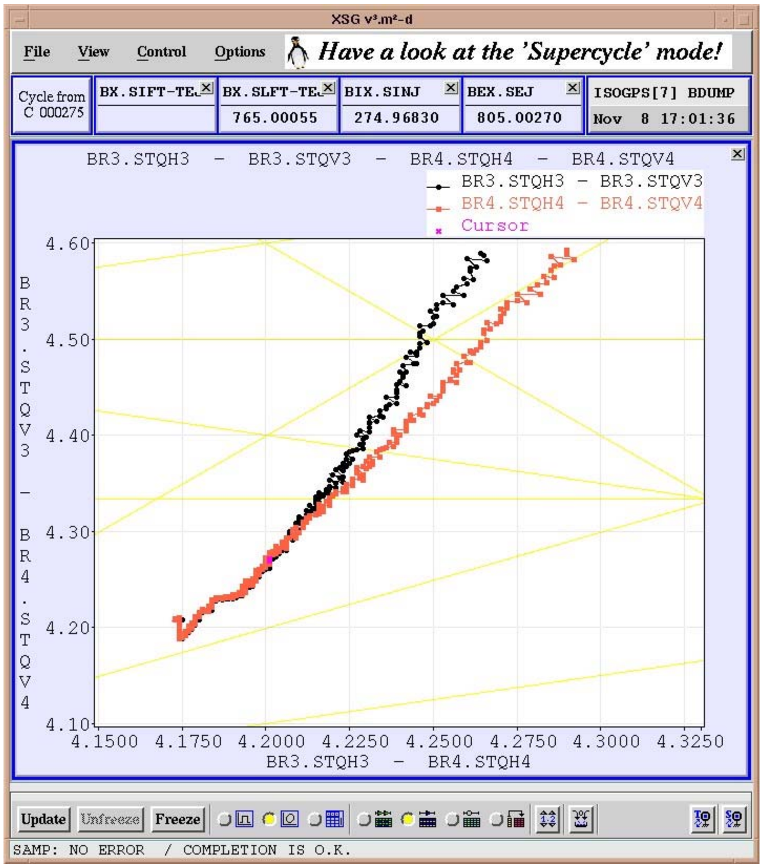
Geneva, Switzerland

September 8, 2004

1 Introduction

The operational optics of the CERN PS Booster (PSB) features a working point with split tunes ($Q_h = 4.17, Q_v = 5.23$ at extraction and up to $Q_h = 4.28, Q_v = 5.60$ at injection of high intensity beams), where the $2Q_v = 11$, $3Q_v = 16$, $2Q_h + Q_v = 14$ and $Q_h + 2Q_v = 15$ resonances are compensated. In order to possibly reduce the effect of resonances, we have set up the PSB with non-split tunes ($Q_h = 4.17, Q_v = 4.23$ at extraction).

The advantage of the new, low-working point optics can be seen from the tune diagram shown in Figure 1. There is no systematic resonance. The working lines for rings 3 and 4 are shown together with low order resonance lines. The beam is injected with a "zero intensity" tune corresponding to the upper right end of the working line. Due to the high Laslett tune spread, the tunes of individual particles cover a large area between this "zero intensity" tune and integer.



SAMP: NO ERROR / COMPLETION IS O.K.

Figure 1: Dynamic new working point. No systematic resonance is crossed. Only $2Q_v = 9$, $3Q_v = 13$, $2Q_v + Q_h = 13$ and $Q_v + 2Q_h = 13$ are crossed.

Figure 2 shows the β-function for one cell of the Booster lattice for both old and new optics. One notes that the vertical β-function is smoother than for the old optics.

We have measured the performance for two different types of beams: ISOLDE and LHC. Furthermore, we have determined the strength of the resonance driving terms for the bare (uncorrected) machine. In the following sections, the measurement results are reported.

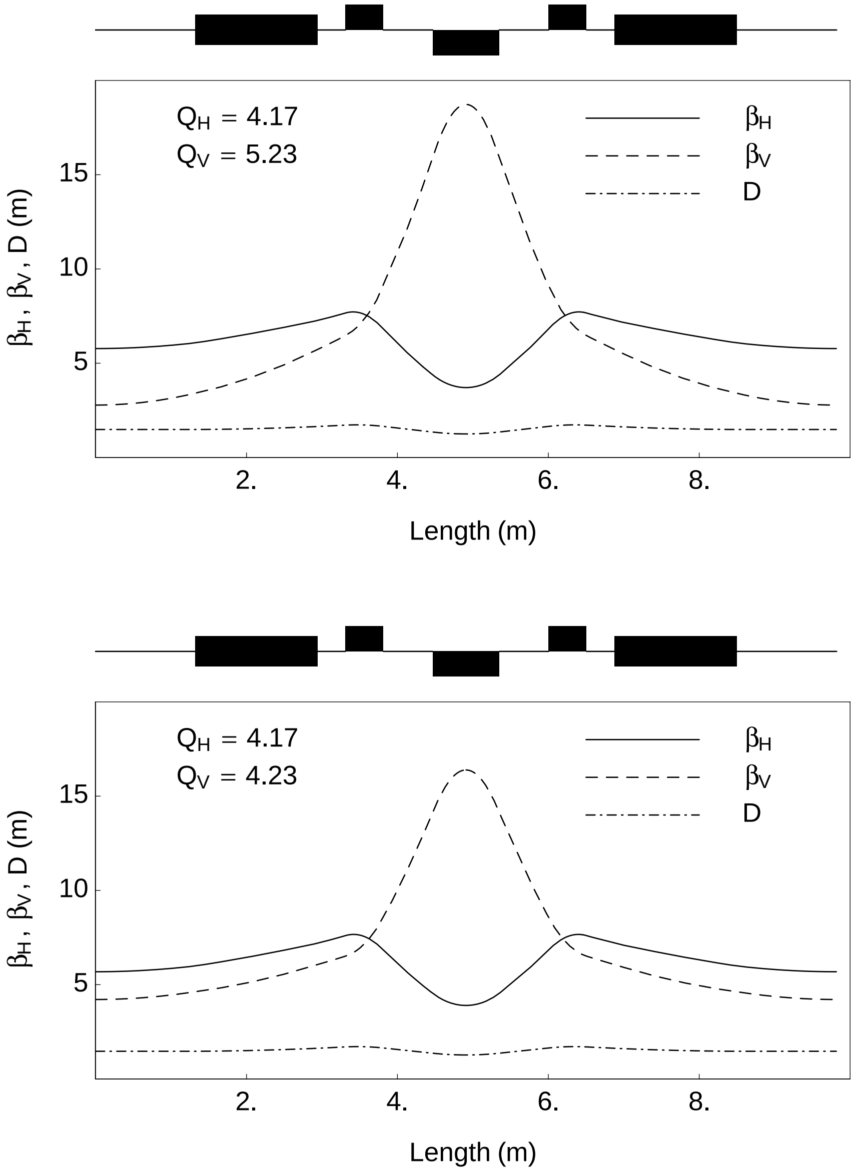


Figure 2: β-functions for one cell of the Booster lattice for old (upper figure) and new working point (lower figure). The vertical β-function is smoother for the new optics. The β-functions for the horizontal plane and the dispersion function are nearly identical for both optics. The smooth behavior of the vertical β-function results in an increase of the Laslett tune spread for given intensities and emittances and, thus, is not expected to improve performance.

2 ISOLDE Beam

We have taken reference measurements with the ISOLDE beam for both the old and new working point. Figure 3 shows the tune diagram for the $(Q_h = 4.17, Q_v = 5.23)$ optics. The dynamic working point varies from the top right (injection) to the bottom left (extraction), with a fast variation right after injection where the tune shifts and spreads are large (working area), and slowly after wards. As can be seen from Figure 3, several resonances have to be crossed. Crossing the resonances results in a drop of intensity. Figure 4 shows the intensity versus Q_v for a low-intensity beam (one turn injected) with this optics. The drop of intensity when crossing the resonances is clearly visible. Figure 5 shows the same graph for the new working point optics. Here, the curve of intensity versus Q_v is much smoother.

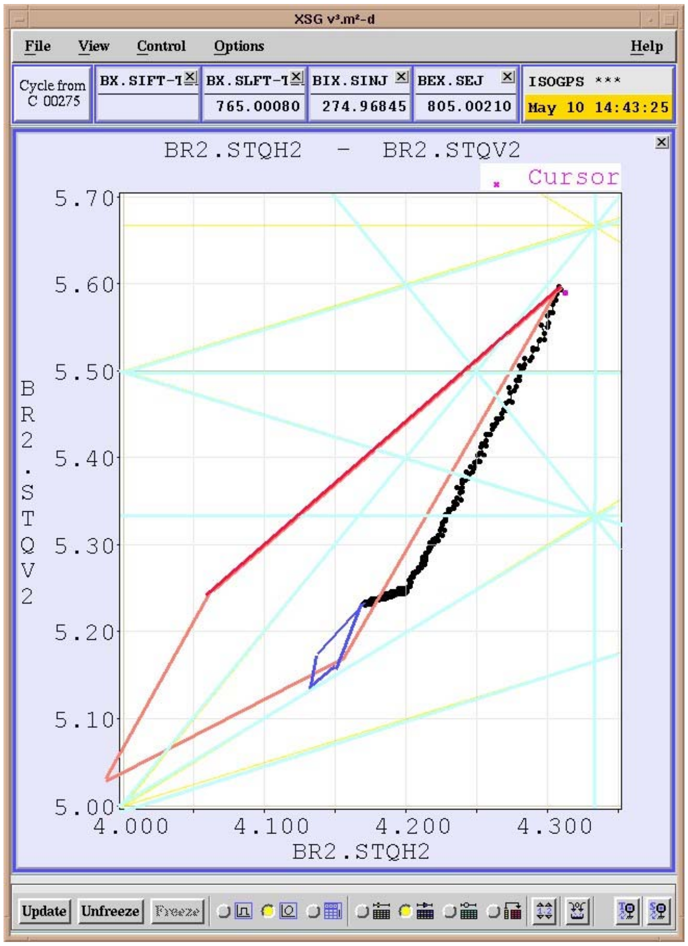
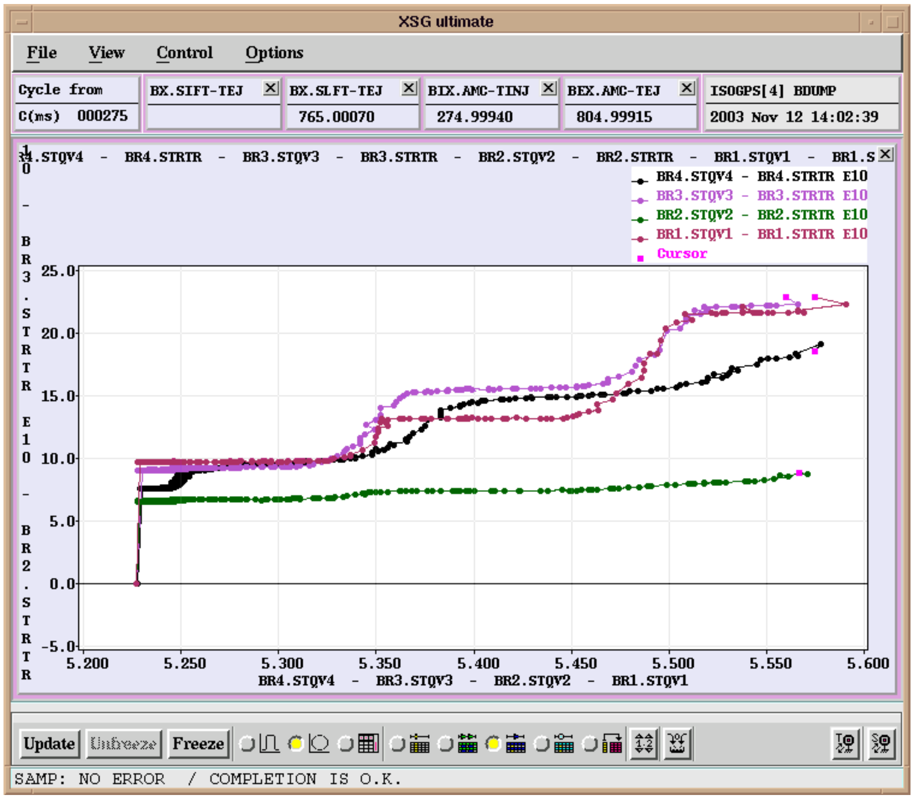

Cycle from C 00275
BX.SIFT-1
BX.SLFT-1 765.00080
BIX.SINJ 274.96845
BEX.SEJ 805.00210
ISOGPS *** May 10 14:43:25

Figure 3: Tune diagram for $(Q_h = 4.17, Q_v = 5.23)$ optics. The resonances $2Q_v = 11$, $3Q_v = 16$, $2Q_h + Q_v = 14$ and $Q_h + 2Q_v = 15$ are compensated at low energy, $Q_h - Q_v = -1$ is excited at injection.

We have measured the injection and acceleration efficiency as well as the transverse emittances for an ISOLDE beam with both old and new working point. Table 1 gives the number of protons at different stages of the cycle for both settings. The (non-normalised) transverse emittances are given in Table 2.

It is worth noticing, that the performance for both working points is comparable (Table 1), but that the total losses after injection in the PSB are higher in case of the new working point.



Cycle from C(ms) 000275

BX.SIFT-TEJ

BX.SLFT-TEJ 765.00070

BIX.AMC-TINJ 274.99940

BEX.AMC-TEJ 804.99915

ISOGPS[4] BDUMP 2003 Nov 12 14:02:39

SAMP: NO ERROR / COMPLETION IS O.K.

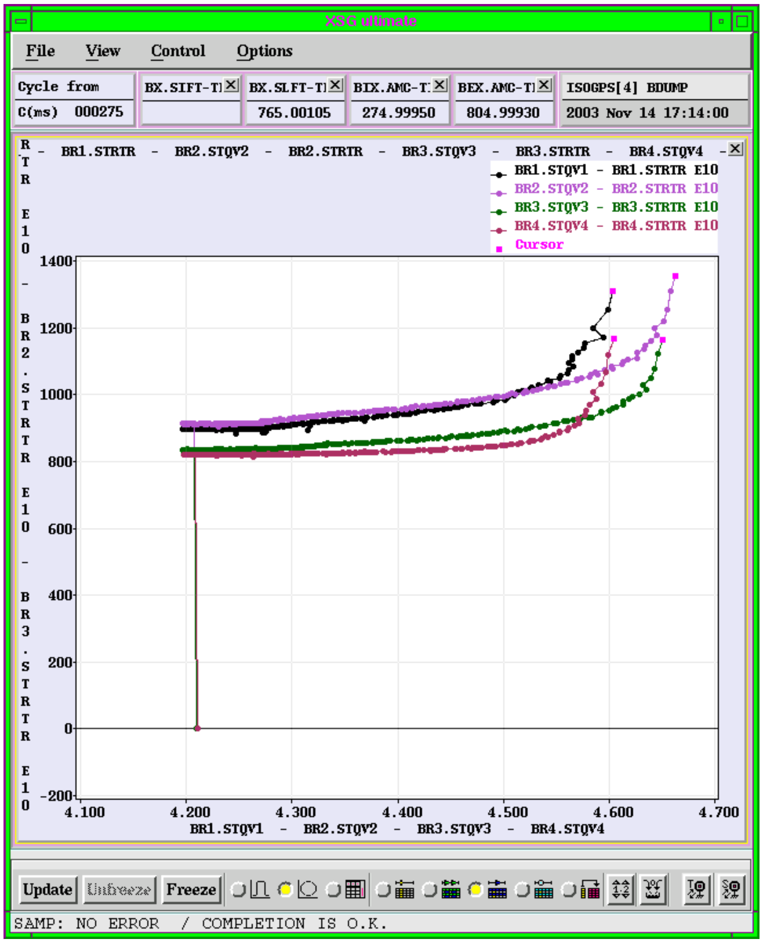
Figure 4: Intensity versus vertical tune for one turn injected and old working point optics. The drop of intensity when passing a resonance is clearly visible. The major sources of beam loss are the resonances $3Q_v = 16$ and $2Q_v = 11$.

	old working point		new working point	
	protons/cycle [10^{10}]	efficiency [%]	protons/cycle [10^{10}]	efficiency [%]
BI-TRA20	8864		8864	
injection	4569	52	5030	57
20 ms after injection	3580	78	3924	78
accelerated	3358	94 (38*)	3497	89 (39*)

Table 1: Efficiency of ISOLDE beam with old and new working point. Figures with (*) refer to the overall efficiency.

	old working point	new working point
ε_h (2σ) [π mm mrad]	25	20
ε_v (2σ) [π mm mrad]	14	15

Table 2: Transverse emittance of ISOLDE beam for an intensity of about 3000 $\times 10^{10}$ protons/cycle (all rings) with old and new working point.



Cycle from	BX.SIFT-TI	BX.SLFT-TI	BIX.AMC-T:	BEX.AMC-TI	ISOGPS[4] BDUMP
C(ms) 000275		765.00105	274.99950	804.99930	2003 Nov 14 17:14:00

```
SAMP: NO ERROR  / COMPLETION IS O.K.
```

Figure 5: Intensity versus vertical tune for ISOLDE beam with new working point optics.

3 LHC Type Beam

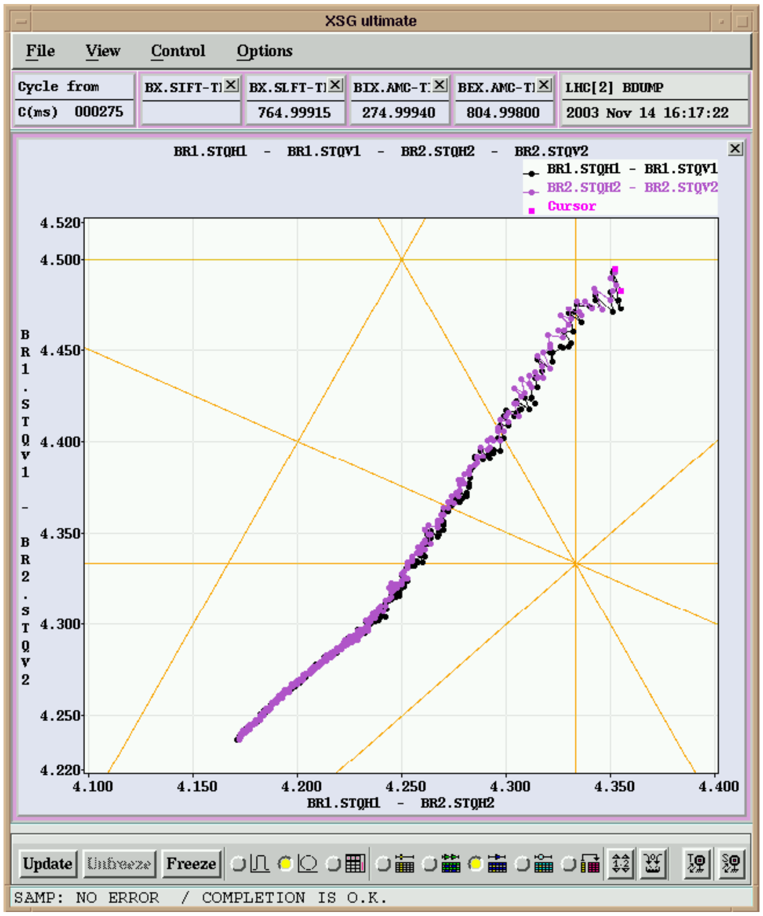
As a second beam, we have optimised and measured an LHC type beam with the new working point. In a first step, we have aimed at achieving "nominal" LHC beam parameters, i.e. an intensity of more than 160×10^{10} protons per bunch and ring with a normalised, 1σ emittance of less than 2.5π mm mrad (the requirement is, that $\varepsilon_{h(normalised,1\sigma)}+\varepsilon_{v(normalised,1\sigma)} \leq 5.0$). In a second step, we have increased the intensity to more than 210×10^{10} protons per ring and cycle. This intensity is smaller than the one for the "ultimate LHC beam". It has been chosen such that (i) nominal emittance may be reachable and (ii) it is significantly larger than "nominal". The optimisation needed relatively little effort on transverse parameters, but significant adjustments of the beam control system.

Table 3 summarises the achieved emittances for the given intensities. Note, that for the case of the "ultimate" LHC beam, only two rings were optimised due to a lack of time. One notes, that the transverse emittances for nominal LHC intensity are well within specifications. With the lower vertical tune, the emittances tend to be more equal (whereas with the higher operational vertical tune, the horizontal emittances are significantly larger than the vertical ones). The emittances measured after optimisation with the higher intensity are slightly larger than nominal. It is worth mentioning that, optimising for small emittances with a given intensity, we have been forced to program an unusually high horizontal tune.

The computed working line (from currents delivered by various power supplies) for this case is shown in Fig. 6. It is unclear whether this horizontal tune at injection (above the $3Q_h$=13 resonance) is an artefact (due to limitations of the machine model used to program and acquire the working line) or reality.

	nominal		higher	
	ε_h	ε_v	ε_h	ε_v
ring 1	2.55	2.32	2.81	2.52
ring 2	2.41	2.11	2.80	2.52
ring 3	2.82	2.41		
ring 4	2.59	2.19		

Table 3: Emittance (normalised, 1σ) for nominal LHC intensity (160×10^{10}) and higher intensity (210×10^{10}).



Cycle from C(ms) 000275

BX.SIFT-TI

BX.SLFT-TI 764.99915

BIX.AMC-T 274.99940

BEX.AMC-TI 804.99800

LHC[2] BDUMP 2003 Nov 14 16:17:22

SAMP: NO ERROR / COMPLETION IS O.K.

Figure 6: Dynamic working point for the high intensity LHC beam with the new settings.

4 Resonances

Modern methods allow to extract resonance excitation terms from turn-by-turn position data of a beam executing coherent oscillations. For this a new multi-turn acquisition system was installed in the PSB, allowing data taking over more than 2000 turns [1], [2]. Due to the lack of a proper kicker, the resonance studies were limited to injection energy (50 MeV). Furthermore, measurements were only done in ring 1 of the Booster.

The new working point leads to the positive fact that only non-systematic resonances have to be considered, hence beam intensity and brightness should be increased. For the comparison of the two working points the vertical second and third order resonances $2Q_v = 11$ and $3Q_v = 16$ respectively $2Q_v = 9$ and $3Q_v = 13$ were treated. Figure 7 shows the Fourier spectra for tune values close to $2Q_v = 11$ respectively $2Q_v = 9$ resonance condition. The corresponding resonance spectral line, indicated with (0/-1), is clearly smaller in case of the new working point. The $3Q_v = 16$ resonance is systematic, hence less excitation of the third order resonance for the new working point is expected. The corresponding spectral lines (0/-2) in Figure 8 clearly indicate the weaker excitation of the $3Q_v = 13$ resonance from the bare machine.

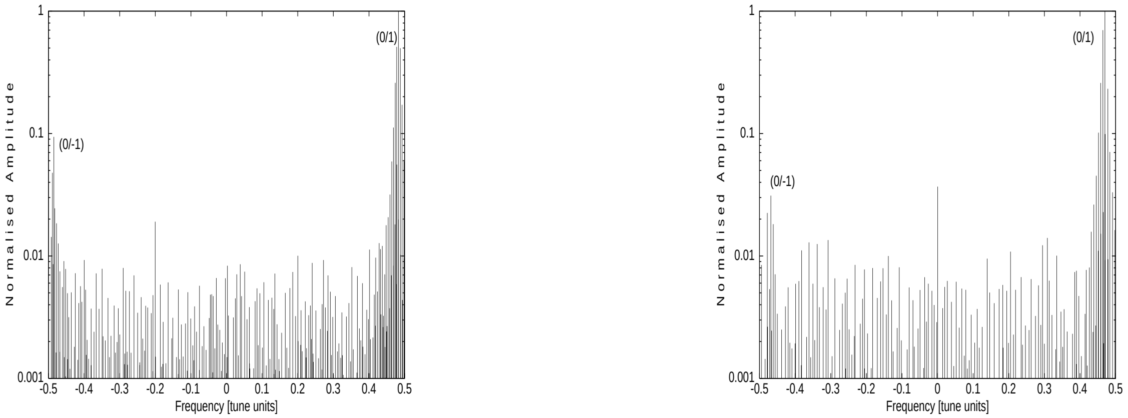


Figure 7: Fourier spectra for tunes close to $2Q_v = 11$ (left) respectively $2Q_v = 9$ (right) resonance condition obtained from bare machine measurements.

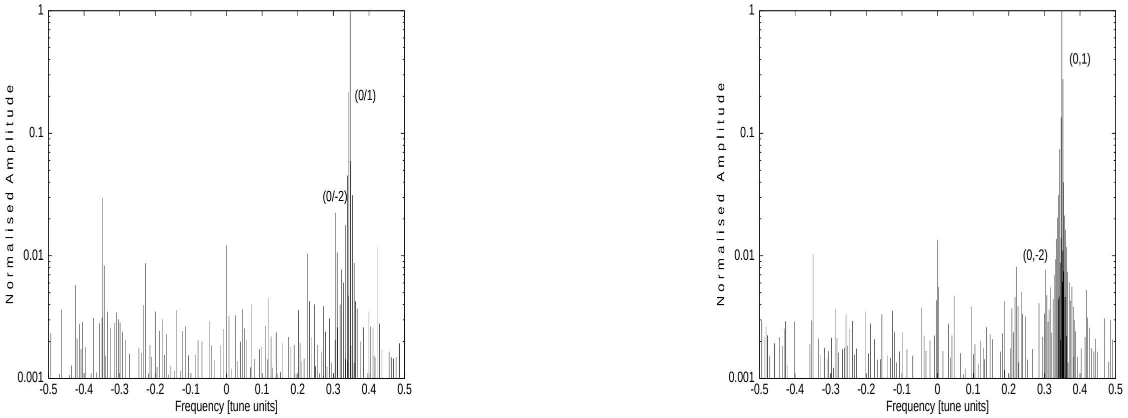


Figure 8: Fourier spectra for tunes close to $3Q_v = 16$ (left) respectively $3Q_v = 13$ (right) resonance condition obtained from bare machine measurements.

Table 4 compares the measured strength of the resonance driving terms for the old and new working point. For the uncorrected machine the resonance strengths are roughly a factor 2 respectively a factor 4 smaller for the new working point. Table 5 summarises the calculated compensation currents for these

Driving Term	**Resonance considered**	**Old WP**	**New WP**
h_{0020}	$2Q_v = 11$ resp. $2Q_v = 9$	$7.0 \pm 0.4 \cdot 10^{-3}$	$3.2 \pm 0.1 \cdot 10^{-3}$
h_{0030}	$3Q_v = 16$ resp. $3Q_v = 13$	$9.0 \pm 0.6 \cdot 10^{-3} mm^{-\frac{1}{2}}$	$2.2 \pm 0.4 \cdot 10^{-3} mm^{-\frac{1}{2}}$

Table 4: Comparison of the resonance strength for the old and new working point

Comp. Elements	**Old WP**	**New WP**
QNO412L3	+6.3A	-1.4A
QNO816L3	-2.8A	-2.7A
XSK2L4	-12.3A	0.0A
XSK9L1	+15.3A	+31.0A

Table 5: Comparison of the compensation currents for the old and new working point

two resonances. The XSK2L4 skew sextupole is located in a high β_v region and therefore roughly 10 times stronger than the XSK9L1. The above mentioned currents are the calculated ones. Similar settings were found when performing trial and error measurements by minimising beam losses. Considering just the results of the measurements done so far, the lower working point is definitely favorable.

5 Conclusions

We find, that the lower working point is attractive, as the same performance as for the high working point was achieved without difficulties, and even without full optimisation of the compensations for all relevant resonances. The major work for 2004 will be the resonance compensation. Work remains also to be done on the re-matching of the transfer line to the measurement line and ISOLDE, re-calculation of matrices for x, x', y, y' at extraction, re-calculation of the matrices for the ejection line trajectory correction and Q-strips.

References

[1] P.Urschütz, *Measurement and Compensation of Second and Third Order Resonances at the CERN PS Booster*, conf.proc. EPAC 2004, Luzern (2004).

[2] P.Urschütz, M.Benedikt, C.Carli, M.Chanel, F.Schmidt, *Betatron Resonance Studies at the CERN PS Booster by Harmonic Analysis of Turn-by-turn Data*, conf.proc. EPAC 2004, Luzern (2004).