Wire compensation: Performance, SPS MDs, pulsed system

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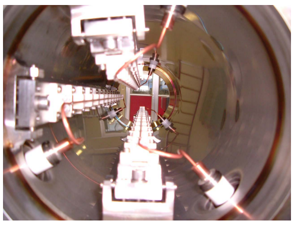
Abstract

A wire compensation (BBLR) scheme has been proposed in order to improve the long range beam-beam performance of the nominal LHC and its phase 1 and phase 2 upgrades[1]. In this paper we present experimental experience of the CERN SPS wires (BBLR) and report on progress with the RF BBLR.

SPS MDS

Two wire compensators are installed in the CERN SPS (Fig. 1). They are located at positions with about equal beta functions in the transverse planes ($\beta \approx 50$ m) and are separated by a betatron phase advance of $\Delta\Phi \approx 3°$. Each one can be powered with an integrated DC current of up to $I_{\max} \cdot l_{\text{BBLR}} = 360 Am$. While a single BBLR allows simulating long-range beam-beam interactions, as a pair they can be used to test the compensation. It must be noted that there is no-head on collision in the SPS and thus no head-on related tune spread. The situation therefore differs from the real LHC case. Still it allows us to gain experimental hints and to benchmark simulations. In the experiments, it was always attempted to correct for the linear orbit and tune changes due to the BBLR.



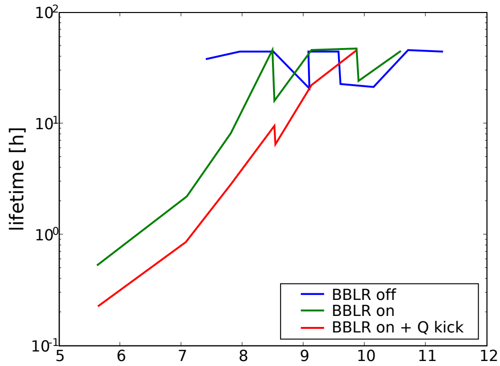
(a) BBLR 2 contains 3 wires

(b) The BBLR in the SPS tunnel

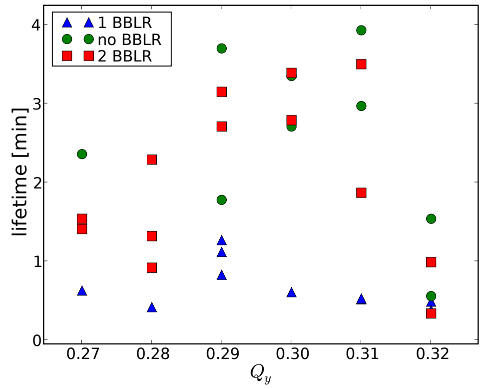
Figure 1: The SPS BBLR

Figure 2 a) shows one of the first results obtained in 2002: A beam-wire separation scan of one BBLR with a current equivalent to the integrated effect of 60 LHC long-range beam-beam interactions. The result indicates that a beam-beam separation of 9.5σ may to be acceptable. Subfigure b) shows a tune scan of the wire compensation which proves that the unperturbed beam lifetime can be restored over a wide tune range. The loss of compensation efficiency at lower tune values is not yet understood.

Figure 3 shows the compensation for various parameters of the second BBLR. The best compensation is achieved at equal BBLR strength and an offset of 1mm with respect to the position of the first BBLR, due to a difference in the β function and a assumed 0.5mm relative alignment error.

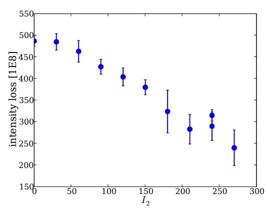


(a) Beam - wire distance scan with a wire current equivalent to the integrated effect of 60 LHC long-range beam-beam collisions.

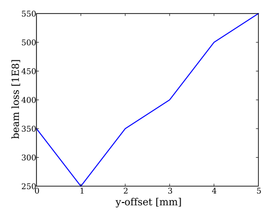


(b) Tune scan of the BBLR compensation

Figure 2: Compensation tests in the CERN SPS. Beam lifetime as a function of the beam wire distance (a) and as a function of the vertical betatron tune (b).

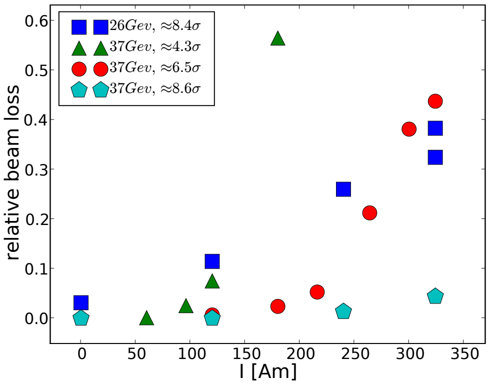


(a) Wire current scan of the compensating BBLR2

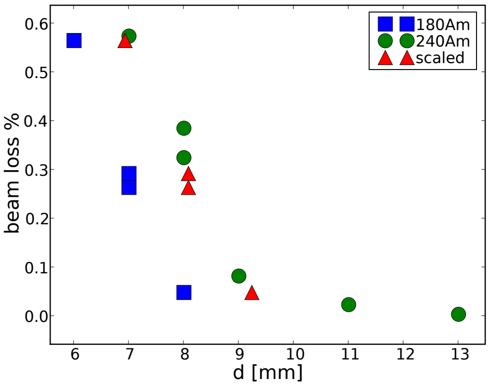


(b) Position scan of the second compensating BBLR

Figure 3: Beam loss as a function of the current and relative position of the second BBLR with respect to the first (19mm from the beam,250Am)



(a) Indication of a threshold effect.



(b) A current scaling fits the expectation

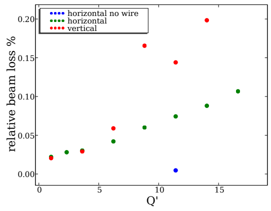
Figure 4: Beam loss over s at various beam energies, normalized beam-wire distances and excitation currents

In 2007 we had the opportunity to perform experiments at various energies (26, 37 and 55 GeV). Figure 4 a) shows the relative beam loss as a function of the BBLR current for various beam-wire separations d at two energies. There are indications for a threshold effect at 37GeV, which might be attributed to the limited geometric aperture of the SPS (the beam is cut at 4σ) or/and to the limited measurement resolution. Subfigure b) shows experimental data of a d-scan at two wire currents as well as one dataset scaled in current according to [2], which is in good agreement with the 240Am data. The scaling law requires that for an identical DA the value of $I/(n^2\epsilon)$ (where n is the normalized beam-wire separation) must be the same.

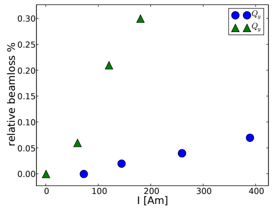
RHIC observed first hints of a strong chromaticity dependence of the beam-loss in the RHIC BBLR studies of 2007. This was followed up and confirmed in the 2007 SPS MDs (Fig. 5)

PULSED BBLR

In the nominal LHC almost half of the bunches will be PACMAN bunches - bunches at one or the other end of the bunch train that experience a reduced number of long range interactions. While a constant intermediate wire current level could improve the stability of both, the nominal and the Pacman bunches, an individually adjusted wire current could enhance the performance even further. Figure 6 illustrates this for the case of the extreme Pacman bunch, which is the bunch at the very end of each bunch train and thus does not experience any LRBB on one side of IP1 and IP5.

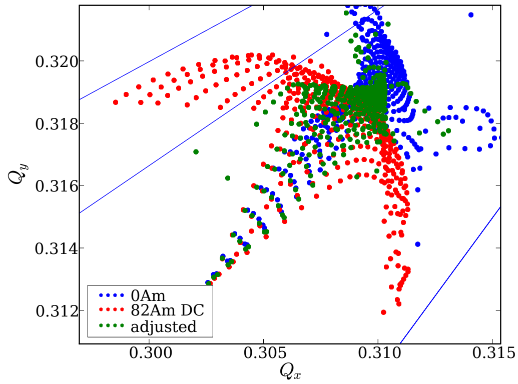


(a)

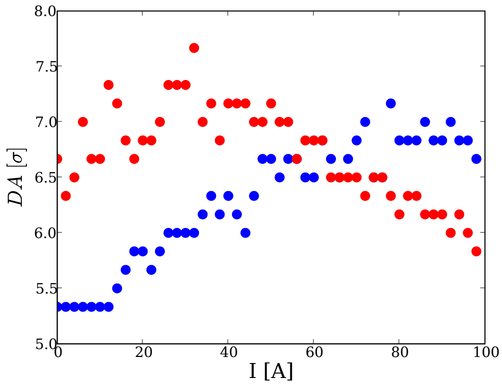


(b)

Figure 5: Chromaticity dependence observed in the SPS for d=6.6σ at 55 GeV

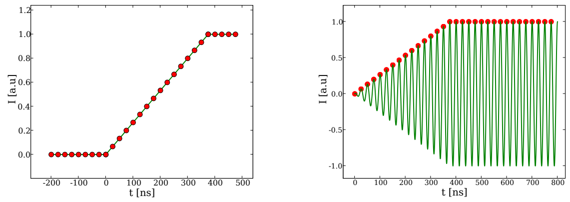


(a) Tune footprint for the extreme Pacman bunch without wire excitation, with a DC wire optimized for nominal bunches (82Am) and with a compensation adjusted to minimize the tune foot print of the extreme Pacman bunch



(b) The Dynamic Aperture (DA) for nominal bunches and the extreme Pacman bunch as a function of the compensation current

Figure 6: Motivations for adjusting the BBLR strength for PACMAN bunches



(a) Pulsed DC BBLR (b) RF-BBLR

Figure 7: Comparison of a ramped DC to a RF approach. The red dots indicate the moments when a specific current-value is required, the green line the actual current on the wire.

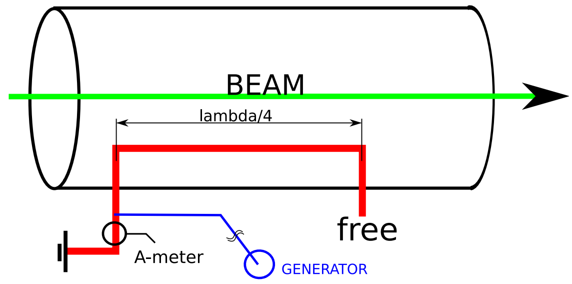
Until recently a ramped DC approach as indicated in Figure 7 a) was followed. But as this approach led to unfulfillable hardware requirements, an alternative approach - the RF-BBLR based on the idea of F. Caspers, shown in Figure 7 b) - is now pursued, where instead of creating a linear slope a pulsed RF signal is used.

The RF-BBLR is based on a $\lambda/4$ resonator as indicated in Figure 8 a). The advantages of a RF-BBLR are the following:

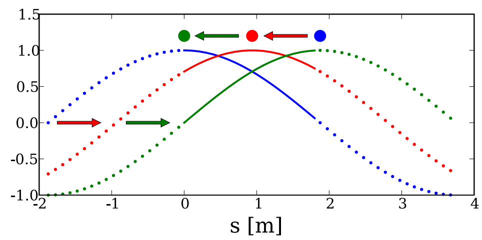
- Zero slope of the current at the moment of the LRBB encounters reduce the required timing precision.
- Required RF technology is available.
- RF fields are easier to shield
- As the waves are counterpropagating to the beam (Fig 8 b) the magnetic and electric effects add up and therefore the power requirements are reduced by a factor of 4.
- A resonating structure should very reliable and the power losses should be limited.
- The power generator can be placed on the surface with only a passive radiation hard transformer installed in the tunnel.

Any turn to turn current jitter causes emittance growth. While for a ramped DC BBLR the amplitude jitter is linearly proportional to the timing jitter, this is not the case for a RF-BBLR. Allowing a $\Delta\epsilon < 10\%$ over 20h for a linearly pulsed BBLR the amplitude noise must be kept lower than $\Delta I < 3\text{mA}$ which corresponds to $\Delta t < 0.02\text{ns}$. For a RF-BBLR this tolerance is increased to $\Delta t < 0.126\text{ns}$. This value can be further relaxed if the orbit feedback works well or if a feedback is integrated into the power generator.

First experimental prototypes have been built and tested. In Figure 9a) it can be seen that the prototype behaves like a resonator with well defined resonances. Subfigure b) shows the experimental verification of the RF-BBLR principle at low power. The response on the BBLR to an excitation by a pulsed RF-voltage is an oscillating current whose amplitude linearly increases and then saturates at a constant level.



(a) The RF BBLR is based on a resonating structure



(b) The electromagnetic waves on the wire and the beam counter-propagate

Figure 8: Schematic layout and wave propagation for the RF-BBLR

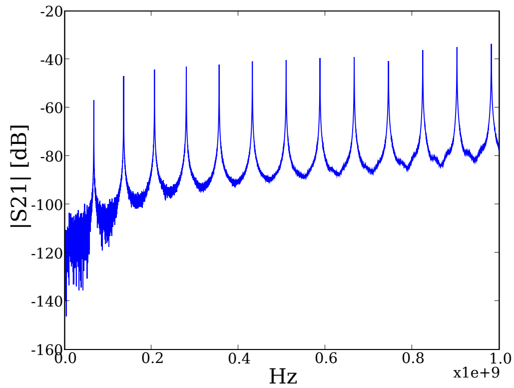
Therefore the signal reproduces the target shape shown in Fig.7. In a parallel effort, the RF-properties of the existing BBLRs installed in the SPS were characterized in terms of their interaction with the beam and their resonant behavior. Figure 10 shows a beam induced signal that refelects the bunch pattern. This beam-induced current will need to be measured and be taken care of by a feedback system. Subfigure b) shows the result of resonance measurements, where the arrows indicate the contributions from the BBLR itself and those from the connecting coaxial cable, respectively. The next steps towards a usable RF BBLR will be:

- Building a phase-noise measurement setup especially adapted for one-turn sensitivity
- Field simulations of the RF-BBLR
- Building a high power version

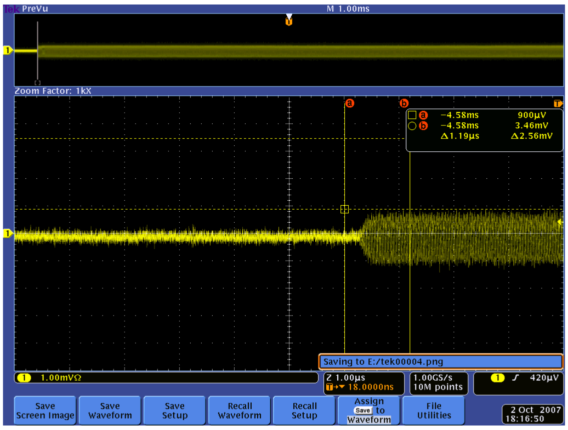
For all these actions a dedicated budget is required.

CONCLUSIONS

The SPS BBLR MDs have proven to be a valuable source of data, helping to understand the long range beam-beam interaction and its compensation. The 2007 MDs have scanned a large parameter space and in particular explored the energy scaling, the possible thresh-

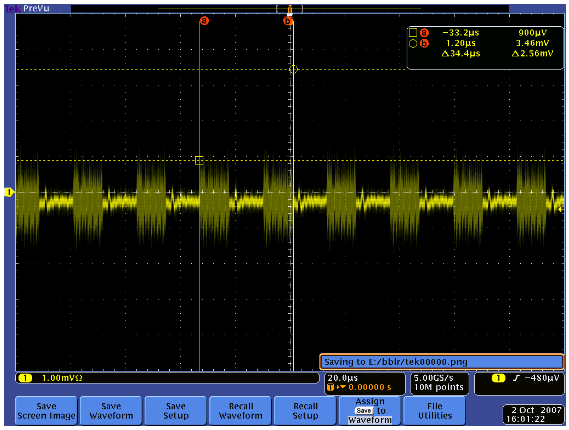


(a) Measuring the resonant structure: S11

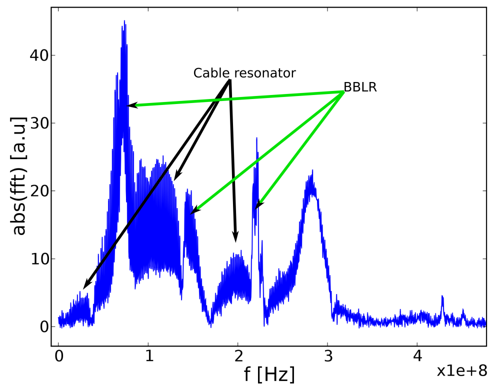


(b) Current on the BBLR as a function of time for a excitation by a pulsed RF-signal.

Figure 9: Results from the experimental RF-BBLR prototype.



(a) Signal induced in the SPS BBLR by a bunch train.



(b) Resonant structure. The contributions of the BBLR itself can be clearly separated from the effect due to the connecting cable.

Figure 10: The CERN SPS BBLRs

old behavior and its chromaticity dependence. The RF-BBLRdevelopment is rapidly advancing.

Thanks

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[2] F. Zimmermann, "Scaling of Diffusive Aperture with Wire Current“, unpublished [http://cern-ab-bblr.web.cern.ch/cern%2Dab%2Dbblr/documentation.htm], 2003