EXPERIMENTS WITH A DC WIRE IN RHIC*

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Abstract

A DC wire has been installed in RHIC to explore the long-range beam-beam effect, and test its compensation. We report on experiments that measure the effect of the wire's electro-magnetic field on the beam's orbit, tune and lifetime, and show some accompanying simulations.

INTRODUCTION

Long-range beam-beam effects are expected to have a significant effect on the LHC performance [1], and wires were proposed to mitigate the long-range effect [2]. The effect of a wire on the beam was tested in the SPS [3]. In these experiments the beam lifetime was significantly smaller than in a typical hadron collider. A partial compensation of the long-range beam-beam effect with wires was also tested in DAΦNE [4].

In 2006, a wire was installed in both the Blue and Yellow rings to test its effect on the beam under various conditions including head-on collisions, and to attempt the compensation of a single long-range interaction [5]. The beam lifetime in RHIC is much longer than the beam lifetime in the SPS experiments. Experiments exploring the wires effect on 100 GeV/nucleon gold beams were carried out in 2007. An attempt to compensate a long-range interaction with proton beams is planned for next year. Proton beams have beam-beam parameters about three times larger than gold beams, and no proton beams were available in RHIC this year.

EXPERIMENTS

The experiments explored the effect of the wire on the gold beam. The relevant beam and wire parameter are shown in Tab. 1. In the experiments the following parameters were varied: wire current, wire position, tunes, and chromaticities. Two experiments were done (Tab. 2 and 3). The main observables are orbit, tune, and beam loss rate.

The orbit and tune changes can be calculated analytically. The orbit change is proportional to $1/d$, and the tune change is proportional to $1/d^2$, where d is the distance between the wire and the beam. Fig. 1 shows the vertical orbit change in the Blue and Yellow rings for both 5 A and 50 A wire currents in the second experiment, and comparisons with calculations. A similar good agreement of tune and orbit changes with theory was observed in the other experiments. Due to coupling the tunes may not follow the calculated changes, as was seen in the first experiment. Orbit and tune changes are generally correctable, but orbit and tune changes of pacman bunches, which see a different

Table 1: RHIC parameters for experiments with Au beams.

quantity	unit	Blue	Yellow
beam energy E	GeV/n	100	
rigidity $(B\rho)$	Tm	831.8	
number of bunches	...	23	
max. wire current I_{max}	A	50	
wire length L	m	2.5	
distance IP6 to wire ctr.	m	40.92	
position range d	mm	0...65	−65...0
β_x at wire location	m	1091	350
β_y at wire location	m	378	1067
ripple $\Delta I/I$ (at 50 A)	10^{-4}	< 1.7	

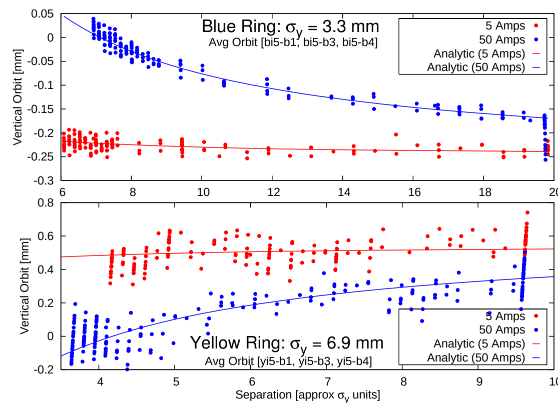

Figure 1: Vertical orbit change (average of 3 BPMs near wire) as a function of vertical distance, in Blue and Yellow ring for experiment 2 (May 9, 2007).

Table 2: Experiment 1, Fill 8609, April 25, 2007.

quantity	unit	Blue	Yellow
init. avg. bunch intensity	10^9	1.00	1.08
beam loss rate w/o wire	%/h	1.0	1.6
init. ver. emittance ϵ_n	mm.mrad	23	38
ver. rms beam size at wire	mm	3.7	7.9
hor. tune Q_x	...	28.234	28.228
ver. tune Q_y	...	28.226	29.235
chromaticities (ξ_x, ξ_y)	...	$(+2, +2)$	
harmonic number h	...	2520	
gap voltage V_{gap}	MV	3.5	

number of long-range beam-beam interactions than nominal bunches, can lead to different beam lifetimes for these.

The main observable of nonlinear effects is the beam loss rate. Fig. 2 shows the beam loss rate as a function of the wire distance, in both rings, for 5 A and 50 A. Note that the beam size in the Yellow ring is larger than in the Blue ring (Tab. 1). While in the Blue ring the loss rate is clearly dependent on both the wire current and the distance be-

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Table 3: Experiment 2, Fill 8727, May 9, 2007.

quantity	unit	Blue	Yellow
init. avg. bunch intensity	10^9	0.75	0.78
beam loss rate w/o wire	%/h	2.5	1.5
init. ver. emittance ϵ_n	mm.mrad	18	29
ver rms beam size at wire	mm	3.3	6.9
horizontal tune Q_x	...	28.220	28.232
vertical tune Q_y	...	29.231	29.228
chromaticities (ξ_x, ξ_y)	...	$(+2, +2)$	
harmonic number h	...	360	
gap voltage V_{gap}	MV	0.3	

tween the beam and the wire, the Yellow ring loss rate is only weakly dependent on the wire current. In both rings the 50 A scan was done after the 5 A scan, and it is possible that in the Yellow ring certain amplitude ranges were cleared already in the 5 A scan.

Fig. 3 shows the Blue and Yellow beam loss rate as a function of the wire current, at a fixed wire location. Here too, the Blue beam shows a clear parameter dependence while the Yellow beam does not.

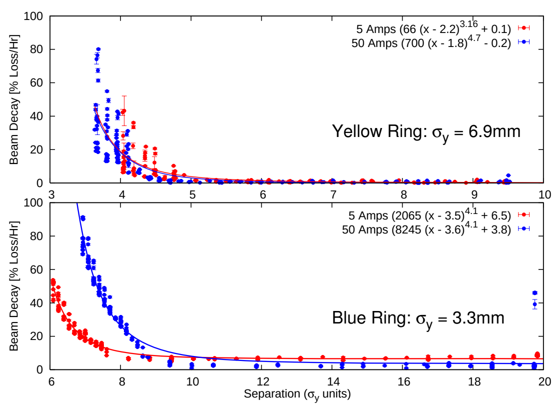

Figure 2: Beam loss rate as a function of vertical distance, in Yellow and Blue ring for experiment 2. The solid lines are power law fits to the respective data.

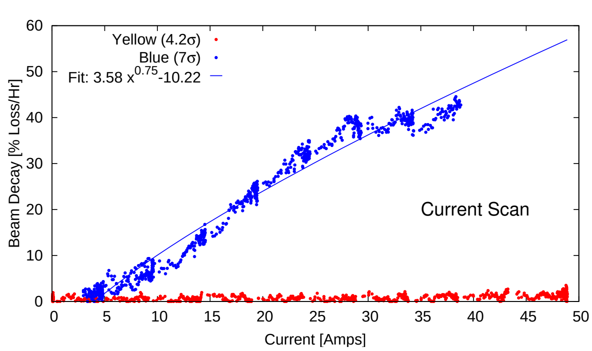

Figure 3: Blue and Yellow beam loss rates as a function of wire current during experiment 2. The Blue wire is fixed at +23 mm, the Yellow wire at -29 mm.

Fig. 4 shows the beam loss rate as a function of the chromaticity (top), and as a function of the wire current at the maximum chromaticity. The loss rate can be enhanced with large chromaticity settings. This may be a mechanism to enhance the effect of a single long-range beam-beam interaction in RHIC. Only one long-range interaction can be compensated, and the effect is rather small compared to the LHC. Such a test is planned for next year with proton beams.

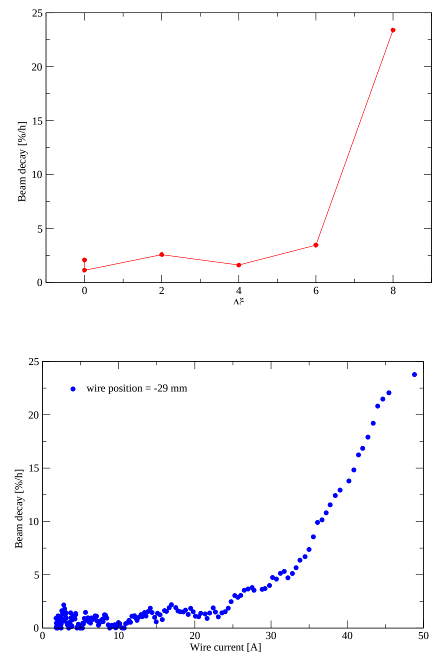

Figure 4: Yellow beam loss rate as a function of vertical chromaticity change (top) with the wire at fixed position -29 mm, and Yellow beam loss rate as a function of wire current at the maximum chromaticity setting (bottom). For the data in the latter plot the wire current was gradually turned off.

SIMULATIONS

Work has began to compare the experimental observation with simulations. A principal problem in this comparison is that the best observable in the experiment, the beam loss rate, can be observed in simulations only with difficulties. Other simulation observables such as the dynamic aperture, amplitude dependent diffusion coefficients, or emittance growth, are not easily obtainable experimentally. Our first effort is therefore to find parametric dependencies in the simulation observables for wire current and distance.

For example, Fig. 5 shows the calculated emittance growth over 10^5 turns for 5 A and 50 A wire current [6]. The code BeamBeam3D with 90k particles was used for this calculation. While the emittance growth for 5 A wire current is small, for 50 A wire current the dependence of the emittance growth rate on the distance between wire and beam can be established.

In another example, Fig. 6 shows calculated vertical escape times using the code BBSIM [7]. Here too, a clear dependence on both the wire current and the separation be-

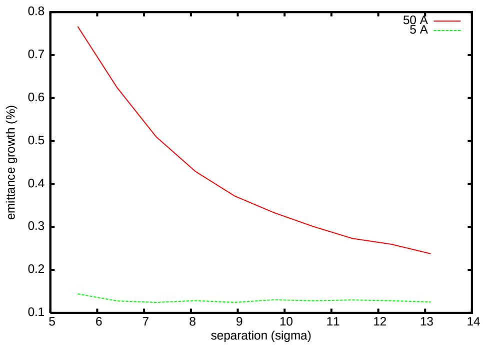

Figure 5: Blue emittance growth in percent over 10^5 turns for 5 A and 50 A wire current.

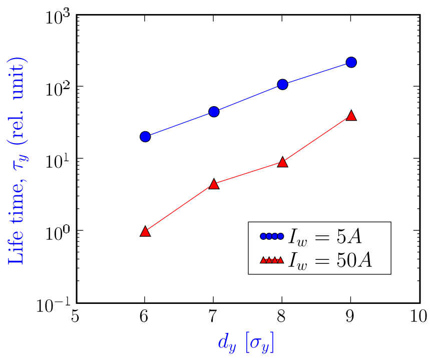

Figure 6: Vertical escape time τ_y, calculated from the diffusion coefficient D_y,s as a function of separation for 5 A and 50 A wire current, and normalized by the lifetime τ_y for 6 σ separation and 50 A current.

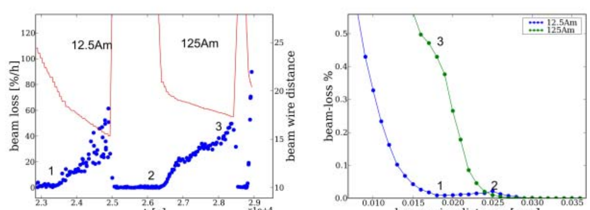

Figure 7: Left: Experimentally observed beam loss for a distance scan with 5 A and 50 A. Right: Simulations find the same onset of beam loss indicated by 1 for the 12.5 Am. The onset of beam loss in the 125 Am case is shifted in the experiment to lower distances as the beam done right after the 12.5 Am case. The label 3 indicates a resonance which is found in both, experiment and simulation, at the same d-value.

tween the wire and the beam is found. For constant wire current, at 50 A, the lifetime at 6 σ is about 40 times smaller than at 9 σ. At 5 A, the lifetime at 6 σ is about 10 times smaller than at 9 σ. For constant separation at 6 σ, at 50 A, the lifetime is about 20 times smaller than at 5 A. BBTrack simulations Fig. show good agreement on finding the onset of beam loss and identify the major resonances observed experimentally.

Fig. shows a comparison of measured loss rates as a function of wire distance, for two wire strength, with calcu-

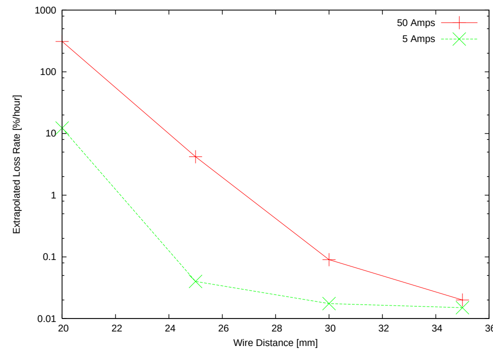

Figure 8: Loss rate as a function of wire distance for 5 A and 50 A wire current, calculated with PLIBB, for the Blue beam in experiment 2 [8].

lated loss rates. Although absolute values of loss rates are different, a qualitative change in the loss rate is observed in both experiment and simulation at three different location [1].

Simulations have also started with the code PLIBB [8]. Fig. shows calculated losses for the Blue beam during experiment 2, for 5 A and 50 A wire current. 10^5 particles are tracked over typically 18k turns (corresponding to 0.2 s real time). Note that the losses in Fig. 2 start at about 9 σ_y, corresponding to 30 mm.

SUMMARY

The effect of a DC wire on the RHIC gold beam at 100 GeV/nucleon has beam measued. The measured orbit and tune changes are calculable in most cases, and are also reproduced in simulations. The beam loss rate has been measured as a function of wire current, wire position, tune, and chromaticity. Work started to find the parameter dependence of wire current, wire position, tune and chromaticity on observable in simulations. These include dynamic apertures, beam lifetimes, amplitude dependent diffusion coefficients, and emittance growth rates. So far a number of features of the experiments could be reproduced.

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