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# INTRABEAM SCATTERING STUDIES FOR THE ILC DAMPING RINGS USING A NEW MATLAB CODE[*]

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## Abstract

A new code to calculate the effects of intrabeam scattering (IBS) has been developed in MATLAB [1] based on the approximation suggested by K. Bane [2]. It interfaces with the Accelerator Toolbox [3] but can also read in lattice functions from other codes. The code has been benchmarked against results from other codes for the ATF [4] that use this approximation or do the calculation in a different way. The new code has been used to calculate the emittance growth due to intrabeam scattering for the lattices currently proposed for the ILC Damping Rings, as IBS is a concern, especially for the electron ring. A description of the code and its user interface, as well as results for the Damping Rings, will be presented.

## INTRODUCTION

For the Positron Damping Rings of the ILC Intra Beam Scattering (IBS) is a concern but, as the damping times are small, believed to be manageable. However, for the electron ring, it may be advantageous to relax damping times by reducing the number of wigglers. In that case IBS becomes more significant and potentially a limiting effect on the performance.

The study presented here was done based on a proposed six kilometer lattice for the Damping Ring, the OCS lattice. The regular OCS lattice is for the positron ring, therefore has a short damping time. It was modified (see below) to have a longer damping time by using fewer wigglers. IBS calculations were done for lattices with different numbers of wiggler cells.

The IBS calculations were done using a new code written in MATLAB and based on the approximation suggested by K. Bane [2]. He suggests a simplified model of IBS, valid for high energy storage rings. In [2] results using this approximation for the ATF are compared to the Bjorken-Mtingwa and the Modified Piwinski solution and are in good agreement.

## IMPLEMENTATION

### Algorithm

To calculate accurate growth rates, one needs to integrate the growth rates (which depend on the lattice functions) along the ring. This is accomplished by creating a vector

of values of the growth rate at all elements. As those points are not equidistant in $s$, the functions need to be interpolated for the integration. This is done using the MATLAB command pchip which calculates a piecewise cubic hermite interpolating polynomial [5]. The numerical integration is done using the MATLAB command quad which uses an adaptive Simpson quadrature method [5].

The calculations are usually done on an ideal lattice, i.e. no vertical dispersion, $\mathcal{H}_y = 0$. This is not really desirable, therefore the code offers the possibility to define a constant value for $\mathcal{H}_y$ along the whole ring.

### User Interface

There are two versions of the code. The first defines all the required parameters in the code, the second has a user-friendly interactive routine asking the user to input the parameters one by one. The Twiss parameters can be read in from a file which contains the relevant parameters in columns in the following order: $s$, $\beta_x$, $\alpha_x$, $\eta_x$, $\eta'_x$, $\beta_y$, $\alpha_y$, $\eta_y$, $\eta'_y$. If the lattice is available for usage with the Accelerator Toolbox, one can load the lattice and the code will calculate the Twiss parameters using the AT routines and data structures. To make sure the lattice was read in correctly three plots are generated, one showing the $\beta$-functions, one showing the dispersion and one showing the $\mathcal{H}$-functions (the ones that will be used by the IBS calculation).

The code also writes the following parameters on the screen at the start of the calculation: $\mathcal{H}_y$ at the very first element in the lattice, the coupling constant $\kappa$ and the initial vertical emittance $\varepsilon_{y0}$.

After each step the following quantities are written to the screen: Step number, growth rates in all three planes, $\varepsilon_x$, $\varepsilon_y$, the bunch length and the energy spread.

Up to forty iterations are performed to find the equilibrium emittance with IBS. Fewer iterations are done if the last ones calculated and the new ones differ by less than 0.1% in all planes. For the cases shown here typically between twenty and thirty iterations were necessary.

After finding the equilibrium emittances three plots are generated to show the convergence. The x-axis for all these plots is the iteration number. Plots are generated for $\varepsilon_x$, $\varepsilon_y$ and one showing both the bunch length and the energy spread.

### Comparison with Other Codes

To benchmark the new code, IBS calculations for the ATF storage ring were made to compare them to the results

in [4]. The IBS growth rates calculated using the different methods are given in Table 1.

Table 1: IBS growth rates for the ATF [4].

| method | $1/T_p$ | $1/T_x$ | $1/T_y$ |
|---|---|---|---|
| complete theory | 390 | 267 | 9.10 |
| Bane | 435 | 291 | ... |
| CIMP | 449 | 298 | 7.47 |
| Mathematica code used in [4] | 442 | 293 | 18 |
| this method | 440 | 288 | 18 |

The growth rates as a function of $s$ were calculated with the same input parameters using the new code and the code used in [4]. Figure 1 shows a comparison of the longitudinal growth rates. Results for the transverse growth rates look similar. We also compared equilibrium emittances for this case and reached similar values.
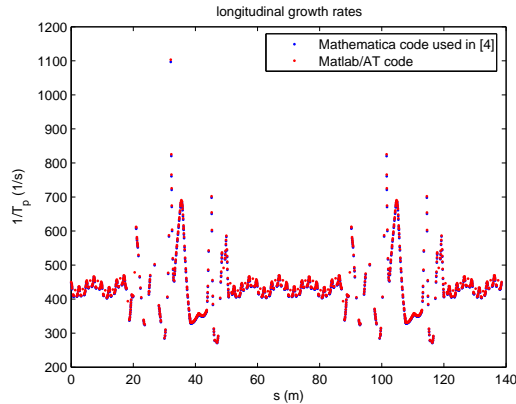


Figure 1: Comparison of the longitudinal growth rates for the ATF between the code used here and the one used in [4].

## RESULTS FOR THE DAMPING RINGS

### The Modified OCS Lattice

The OCS lattice is the present working model for the ILC damping rings. Some parameters of the lattice are given below in Table 3. The version used here is the one from November 2005. As the general parameters have not changed significantly since then we do not assume that the newer versions will yield significantly different results. The lattice has ten wiggler sections each containing four wigglers.

As the injected electron beam is significantly smaller than the positron beam, the electron ring will need less damping. This can be achieved by having fewer wiggler magnets in the ring. To achieve this, the wiggler cell of the lattice was modified to have the same Twiss parameters at the ends without the wiggler magnets while keeping the phase advance over the cell constant. This was done by rematching the cell varying the strength of the quadrupoles in the center of the line. Both wiggler cells are shown in Fig. 2.

Table 2: Damping times and emittances for different numbers of wiggler cells.

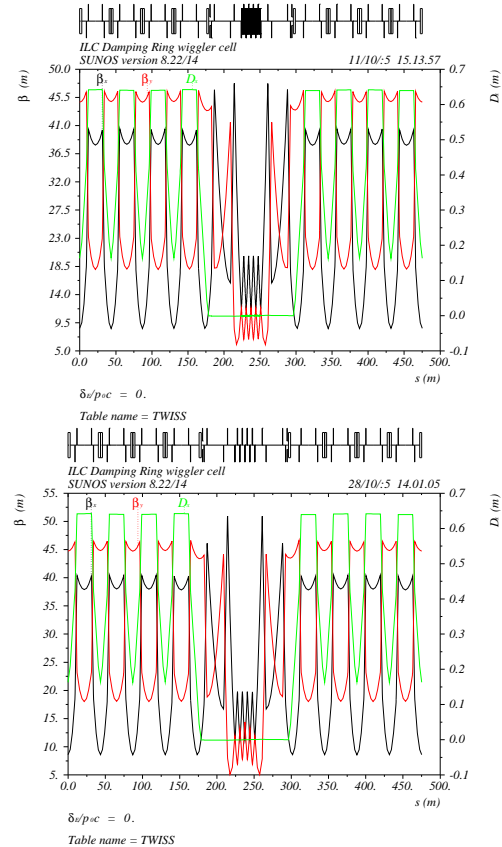| wiggler cells | no wiggler cells | $\tau_x$ [ms] | $\varepsilon_x$ [pm rad] |
|---|---|---|---|
| 0 | 10 | 303.11 | 2370 |
| 1 | 9 | 133.63 | 1280 |
| 2 | 8 | 85.705 | 969 |
| 3 | 7 | 63.083 | 823 |
| 4 | 6 | 49.909 | 738 |
| 5 | 5 | 41.287 | 682 |
| 6 | 4 | 35.205 | 643 |
| 7 | 3 | 30.685 | 614 |
| 8 | 2 | 27.193 | 591 |
| 9 | 1 | 24.415 | 573 |
| 10 | 0 | 22.157 | 552 |



Figure 2: Wiggler cell in the OCS lattice with the wigglers (top) and rematched without the wigglers (bottom).

One can now replace a number of regular wiggler cells with no wiggler cells to adjust the damping time and equilibrium emittance. For the studies here the order of cells in the lattice does not make a difference. In a real machine there will probably be additional constraints on which cell to place where (e.g. symmetry arguments). Table 2 gives damping times and emittances for several possible configurations without taking IBS into account.

A damping time of about 50 ms is desirable for the elec-

Table 3: Results for the OCS lattice for a bunch length of 6.0 mm and an average vertical dispersion of 2.2 mm (except the last column which is for $\langle \eta_y \rangle = 2.5$ mm.

| # of wigglers | | 10 | 8 | 6 | 4 | 4 |
|---|---|---|---|---|---|---|
| without IBS | $\varepsilon_{nat}$ | 552 pm | 584 pm | 634 pm | 733 pm | 733 pm |
| | $\varepsilon_{y0}$ | 1.5 pm | 1.4 pm | 1.3 pm | 1.2 pm | 1.5 pm |
| | $H_y$ | $2.2580 \times 10^{-7}$ | $2.1496 \times 10^{-7}$ | $2.0387 \times 10^{-7}$ | $1.9496 \times 10^{-7}$ | $2.5175 \times 10^{-7}$ |
| | rf voltage | 19.269 MV | 18.267 MV | 17.246 MV | 15.993 MV | 15.993 MV |
| | $\sigma_{\delta 0}$ | $1.2918 \times 10^{-3}$ | $1.2817 \times 10^{-3}$ | $1.2655 \times 10^{-3}$ | $1.2352 \times 10^{-3}$ | $1.2352 \times 10^{-3}$ |
| | $\sigma_{s0}$ | 6.0173 mm | 6.0178 mm | 6.0166 mm | 6.0199 mm | 6.0199 mm |
| with IBS | $\varepsilon_x$ | 698 pm | 768 pm | 881 pm | 1057 pm | 1007 pm |
| | $\varepsilon_y$ | 1.67 pm | 1.42 pm | 1.40 pm | 1.33 pm | 1.72 pm |
| | $\sigma_\delta$ | $1.31274 \times 10^{-3}$ | $1.30631 \times 10^{-3}$ | $1.19426 \times 10^{-3}$ | $1.27169 \times 10^{-3}$ | $1.26827 \times 10^{-3}$ |
| | $\sigma_s$ | 6.11484 mm | 6.13334 pm | 6.15335 mm | 6.19772 mm | 6.18108 mm |

Table 4: Results for the OCS lattice for different bunch populations using the same parameters as in the other 10 wiggler cases.

| $N_0$ | $1 \times 10^{10}$ | $2 \times 10^{10}$ | $4 \times 10^{10}$ |
|---|---|---|---|
| $\varepsilon_x$[pm] | 637 | 698 | 814 |
| $\varepsilon_y$[pm] | 1.61 | 1.67 | 1.80 |
| $\sigma_\delta$[$\times 10^{-3}$] | 1.30572 | 1.31274 | 1.32638 |
| $\sigma_s$[mm] | 6.08214 | 6.11484 | 6.17839 |

tron ring (based on the ratio of injected to extracted emittance and the storage time), however the horizontal emittance needs to stay below 800 pm rad, which is the case without IBS, but might not be the case with IBS.

Increasing the beam energy to mitigate the effects of IBS is not a possibility because of limits on the longitudinal emittance determined by downstream systems.

### Results of IBS calculations

The IBS calculations are done for a number of different configurations. They are summarized in Table 3. All calculations assume a constant value for $\mathcal{H}_y$ based on an rms dispersion. The coupling constant $\kappa$ is then chosen such that

$$\kappa \varepsilon_0 + 2\mathcal{H}_y \sigma_s^2 = \varepsilon_{y0} \tag{1}$$

The value for the ten wiggler cell ring (the positron ring) is based on a dispersion of 2.2 mm which gives a vertical emittance of 1.5 pm. The other cases were either calculated with the same rms dispersion or with a different one such that the vertical emittance was 1.5 pm (As the $\beta$-functions in the no wiggler cell are slightly different from the ones in the regular cell, the $\mathcal{H}$-functions are slightly different).

We also calculated the emittances for different currents for the positron ring case (10 wiggler cells). The results are given in Table 4. The nominal case is $2 \cdot 10^{10}$ particles. A bunch population of $1 \cdot 10^{10}$ particles is under discussion for the "low-Q" option which would then use twice as many bunches.

As for the ATF the growth rates using K. Bane's approximation are about 10% larger than the ones calculated using the full formalism, calculations were also done including a fudge factor of 0.9 on the growth rates. With this fudge factor included the equilibrium emittances for the positron damping ring (first column of Table 3) are $\varepsilon_x = 721$ pm, $\varepsilon_y = 1.69$ pm, $\sigma_\delta = 1.3145 \times 10^{-3}$ and $\sigma_s = 6.12302$ mm.

## CONCLUSION

The new code has been used for studies of the ATF storage ring and the ILC damping rings and for the ATF gives results comparable to other calculations. The calculations for the ILC damping rings show that IBS in the positron ring should be manageable. For the electron ring a damping ring with six wiggler sections will have emittances that are small enough to be viable. Five wiggler sections should also work. Four wiggler sections, although yielding the desired 50 ms damping time might have a slightly too large horizontal emittance.

## REFERENCES

[1] MATLAB is a registered trademark of The MathWorks, Inc.

[2] K. Bane, in Proceedings of EPAC2002, p.1443.

[3] A. Terebilo, Accelerator Toolbox for MATLAB, SLAC-PUB-8732 and www-ssrl.slac.stanford.edu/at/.

[4] K. Kubo et al., Intrabeam Scattering Formulas for High Energy Beams, Physical Review Special Topics AB.8.081001 (2005).

[5] Matlab [1], The Language of Technical Computing, Programming, Version 7.