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Title: CSR for drift

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1 CSR for drift

1D-CSR wakefunction can now be used for the drift element by defining its attribute WAKEF = FS_CSR_WAKE. In order to calculate the CSR effect correctly, the drift has to follow a bending magnet whose CSR calculation is also turned on.

Example:

```
bend1: SBEND, ANGLE = bend_angle,
                   E1 = 0, E2 = 0,
                   FMAPFN = "1DPROFILE1-DEFAULT",
                   ELEMEDGE = drift_before_bend,
                   DESIGNENERGY = bend_energy,
                   L = bend_length,
                   WAKEF = FS_CSR_WAKE;

drift1: DRIFT, L=0.4, ELEMEDGE = drift_before_bend +
               bend_length, WAKEF = FS_CSR_WAKE;
```

2 Benchmark

The OPAL dipoles all have fringe fields. When comparisons are done between OPAL and ELEGANT [1] for example, one needs to appropriately set the FINT attribute of the bending magnet in ELEGANT in order to represent the field correctly. Although ELEGANT tracks in the $(x, x', y, y', s, \delta)$ phase space, where $\delta = \frac{\Delta p}{p_0}$ and p_0 is the momentum of the reference particle, the watch point output beam distributions from the ELEGANT are list in $(x, x', y, y', t, \beta\gamma)$. If one wants to compare ELEGANT watch point output distribution to OPAL, unit conversion needs to be performed, i.e.

$$\begin{aligned} P_x &= x'\beta\gamma, \\ P_y &= y'\beta\gamma, \\ s &= (\bar{t} - t)\beta c. \end{aligned}$$

To benchmark the CSR effect, we set up a simple beamline with 0.1m drift + 30 degree sbend + 0.4m drift. When the CSR effect is turn off, Fig. 1 shows that the normalized emittances calculated using both OPAL and ELEGANT agree. The emittance values from OPAL are obtained from the *.stat* file, while for ELEGANT, the transverse emittances are obtained from the sigma output file (enx, and eny), the longitudinal emittance is calculated using the watch point beam distribution output.

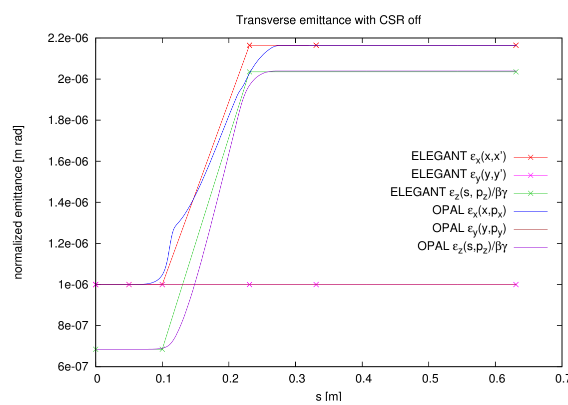

Figure 1: Comparison of the trace space using ELEGANT and OPAL

When CSR calculations are enabled for both the bending magnet and the following drift, Fig. 2 shows the average δ or $\frac{\Delta p}{p}$ change along the beam line, and Fig. 3 compares the normalized transverse and longitudinal emittances obtained by these two codes. The average $\frac{\Delta p}{p}$ can be found in the centroid output file (Cdelta) from ELEGANT, while in OPAL, one can calculate it using $\frac{\Delta p}{p} = \frac{1}{\beta^2}\frac{\Delta \overline{E}}{\overline{E}+mc^2}$, where $\Delta \overline{E}$ is the average kinetic energy from the *.stat* output file. In the drift space following the bending magnet, the CSR effects are calculated using Stupakov's algorithm with the same setting in both codes. The average fractional momentum change $\frac{\Delta p}{p}$ and the lon-

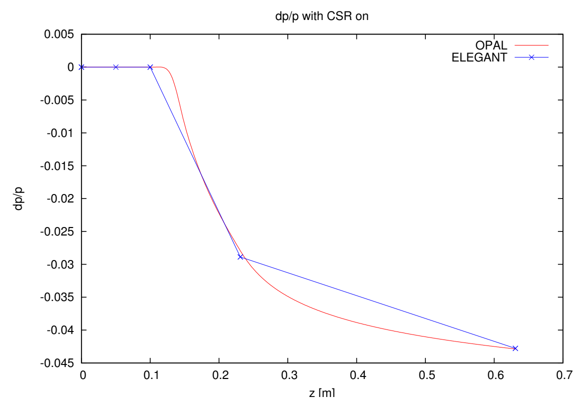

Figure 2: $\frac{\Delta p}{p}$ in Elegant and OPAL

gitudinal emittance show good agreements between these codes. However, they produce different horizontal emittances as indicated in Fig. 3.

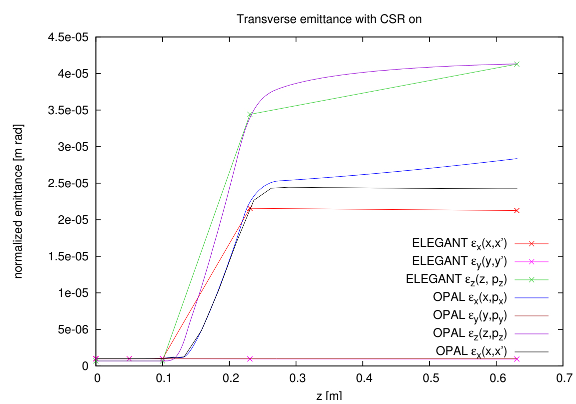

Figure 3: Transverse emittances in ELEGANT and OPAL

One important effect to notice is that in the drift space following the bending magnet, the normalized emittance $\epsilon_x(x, P_x)$ output by OPAL keeps increasing while the trace-like emittance $\epsilon_x(x, x')$ calculated by ELEGANT does not. This can be explained by the fact that with a relatively large energy spread (about 3% at the end of the dipole due to CSR), **an correlation** between transverse position and energy can build up in a drift thereby induce emittance growth. However, this effect can only be observed in the normalized emittance calculated with $\epsilon_x(x, P_x) = \sqrt{< x^2 >< P_x^2 > - < xP_x >^2}$ where $P_x = \beta\gamma x'$, not the trace-like emittance which is calculated as $\epsilon_x(x, x') =$

$\beta\gamma\sqrt{< x^2 >< x'^2 > - < xx' >^2}$ [2]. In Fig. 3, a trace-like horizontal emittance is also calcualted for the OPAL output beam distributions. Like the ELEGANT result, this trace-like emittance doesn't grow in the drift. However, their differences come from the ELEGANT's lack of CSR effect in the fringe field region.

3 Parallel Version

There was a problem with the CSR calcualtion when it is run in parallel. The simulation would hang indefinitely without any error message. Now the problem is fixed. As long as the field solver is parallelized in the longitudinal direction, the simulation runs well, otherwise, a segmentation fault will appear (because the CSR routine needs to calculate line density in the longitudinal direction).

4 Regression Test

A regression test of the CSR routine called "CSRBendDrift" is added to the regression tests. It can also be used as an example on how to enable the CSR functionality in the dipoles and drifts.

References

[1] M. Borland, "Elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation", Advanced Photon Source LS-287, September 2000.

[2] K. Floettmann, PRSTAB, 6, 034202 (2003)