TOP-UP SAFETY SIMULATIONS FOR THE ALBA STORAGE RING

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Abstract

The potential hazards introduced by injecting into the ALBA storage ring with front end shutters open are determined through particle tracking simulations. The method is based on the possible overlap between phase space of forwards and backwards tracking between the straight section downstream the front end and the beamline. Realistic magnetic field, trajectory, aperture and energy errors are taken into account. Scenarios that could bring an injected beam of electrons passing through an open beamline front end are identified. The interlocks required to prevent such situations from arising are discussed.

SIMULATION PROCEDURE

Presently, ALBA has six insertion device beamlines and one dipole beamline. The method used for the safety simulations follows that used for the first time at SPEAR3 [1] and then adopted by other light sources [2]. In this, only a small section of the storage ring between the straight section upstream of the dipole and the respective beamline front ends is considered. The basic procedure is to track all possible particle trajectories forwards from the start of the ID straight to the beginning of the first bending magnet, and all possible trajectories from each beamline back to the start of the same bending magnet. The resulting phase-space distributions can then be compared at this location to see whether they overlap for any realistic error scenario.

Tracking Code

The motion of particles at very large amplitudes is considered, in particular in the case of the bending magnets and the fields roll-off of the quadrupoles and sextupoles, whose profile data were previously generated using a finite element analysis code. New pass methods developed at Diamond for the Accelerator Toolbox code [2, 3] were modified for tracking through the ALBA gradient bending magnets.

Defenition of Particle Phase Spaces

The physical apertures of the ID straight section and beamline front ends define the region of phase-space to use when generating distributions of particles to track. For the straight sections the limiting apertures are tapers at each end (ID beamlines) or the vacuum chamber aperture (dipole beamline), and for the front ends the limits are given by the second fixed mask and the movable mask apertures close to the shield wall.

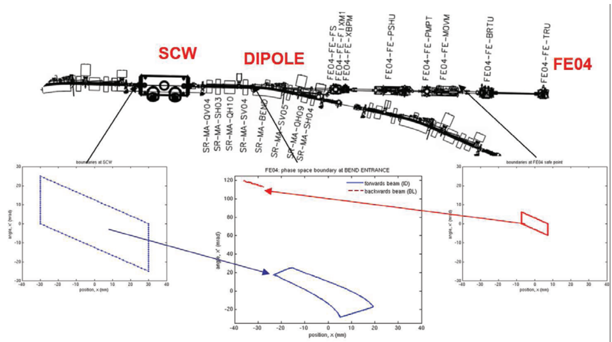

Figure 1: Section of the storage ring used for the tracking studies in the case of an ID beamline. Initial phase-space coordinates for the forwards tracked beam (bottom left), for the back tracked beam (bottom right) and final distributions (bottom centre) are shown: in this example the two distributions do not overlap, indicating a safe situation.

Error Scenarios

To retain lattice independence for the results of the tracking studies, all magnet strengths were varied across the full range allowable by the power supplies, and no specific setpoint was assumed. Magnet strength variations were therefore scanned in all possible combinations. Energy mismatch between the injected and stored beam could occur due to booster extraction timing errors, booster magnet strength errors or simply by a scaling down of all storage ring magnet strengths. For the simulations a limit of 15% energy error has been placed on the injected beam as the booster power supplies are rated to give a maximum energy of 3.45 GeV.

ID BEAMLINES

The present six ID beamlines have the same layout: the ID is installed in a medium straight section of the ALBA lattice and the layout of the BL04 front end is shown in Fig. 1 as an example. The electrons exiting the ID travel through two quadrupoles and two sextupoles before entering the bending magnet where the beam line front end is aligned tangent to the entrance point. The acceptances for all the present insertion device beamlines are shown in Fig. 2. An aperture boundary enclosing all FE apertures has been defined enlarging by 20% the second mask aperture of FE22: if top-up can be shown to be safe here, then all other beamlines must also be safe.

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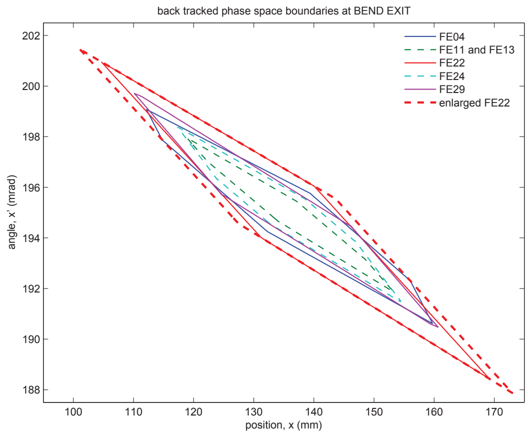

Figure 2: The phase space boundaries enclosing all possible trajectories for each of the ALBA ID beamlines compared at the dipole exit. Positions and angles are stated with respect to the stored beam centre line.

Injected beam Energy Error

Figure 3 shows the results of varying the energy -2.5% to +15%. The phase space boundaries are brought closer together with increasing injected beam energy. As can be seen, there is a large degree of separation between the phase spaces tracked from the ID straight section and beamline at the entrance of the dipole over this range of energies.

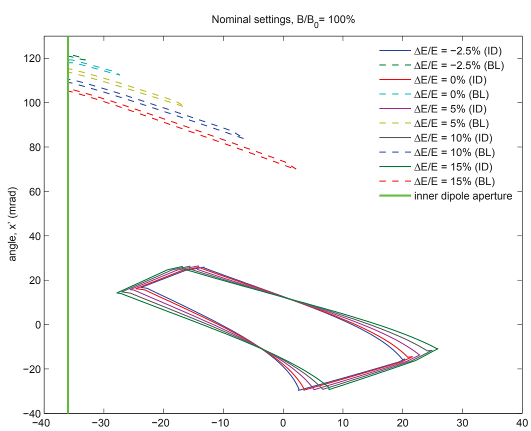

Figure 3: ID beamlines: phase space boundaries at the entrance to the bending for different degrees of energy offset.

Single Dipole failure

Figure 4 shows that the magnet that has the strongest effect on the particle trajectories is the bending magnet, and clearly if this magnet were switched off the electrons travelling forwards from the ID straight section would pass straight down the beamline at 11.25° with respect to the stored beam centre orbit. The phase space boundaries from the ID straight section and beam-line begin to overlap once the bending magnet strength has fallen to 20% of nominal. This situation is not a cause for concern, since simulations have demonstrated it is not possible to store beam with a single dipole at 93% of nominal or below, and the stored beam interlock would inhibit injection.

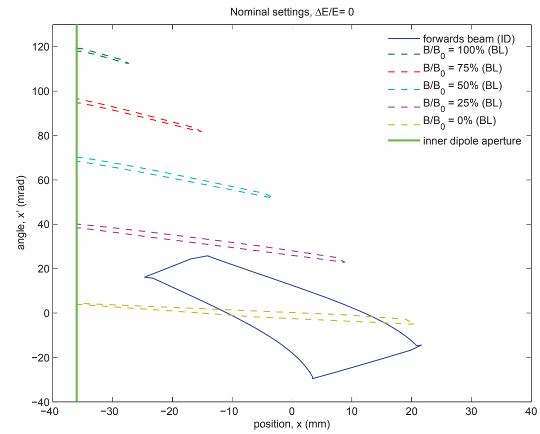

Figure 4: ID beamlines: phase space boundaries at the entrance to the bending for different degrees of dipole failure.

Worst Case Combining Events

Strengths of quadrupoles, sextupoles and dipole correctors were varied in combination across the stated ranges. No error combination where beams overlap was found. The situation where the forwards and backwards tracked beams are brought to the closest distance occurs at energy offsets of +15%, dipole field at 93% of nominal value, two quadrupole off and one at maximum strength (Fig. 5). In this condition the distance between the two phase space boundaries is still larger than 20 mrad.

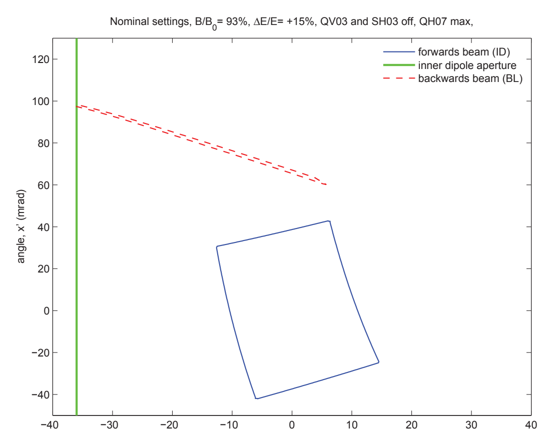

Figure 5: ID beamlines: phase space boundaries at the entrance to the bending magnet in the worst combination of errors.

DIPOLE BEAMLINE

In the dipole beamline the radiation is produced by the first dipole installed downstream of a long straight section of the ALBA lattice. The electrons exiting the straight travel through three quadrupoles and two sextupoles before entering the bending magnet where the beam line front end is aligned at an angle of 4.6° with respect to the stored beam centre orbit. The front end beam pipe interferes with the roll-off field of three sextupoles and three quadrupoles.

Injected beam Energy Error

As for the ID beamlines, the first error scenario considered was for an energy mismatch between the injected and stored beam energies by -15% to +15%. Over this range of energies, the degree of separation between the two distributions is very large being the backwards tracked beam always outside of the dipole aperture.

Single Dipole failure

In this beamline, if this magnet drops to 60% of nominal, electrons travelling forwards would exit the bending parallel to the X-ray beam at 4.6°, but the position would be 30 mm apart because the alignment does not coincide (Fig. 6). This means that at least a second combined error is needed to overlap the two distributions. In addition to this, as in the ID case, in realistic accident scenarios single dipole failures are limited to 93% of nominal where the stored beam interlock would inhibit injection.

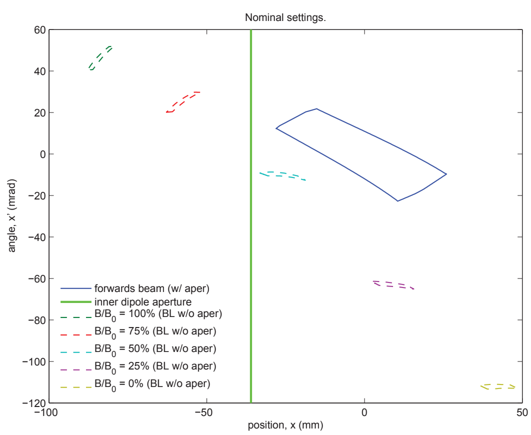

Figure 6: Dipole beamline: phase space boundaries at the entrance to the bending magnet for different degrees of dipole failure.

Worst Case Combining Events

Strengths of quadrupoles, sextupoles and dipole correctors were varied in combination across the stated ranges. Not only no error combination where beams overlap was found, but no situation where the backwards tracked beam is not lost through the dipole vacuum chamber was found. The situation where the forwards and backwards tracked beams are brought to the closest distance is shown in Fig. 7. This occurs at injected beam energy offsets of +15%, dipole field at 93% of nominal value and two sextupoles off and one sextupole at maximum strength. In this condition the distance between the two phase space boundaries is still larger than 15 mrad and 15 mm.

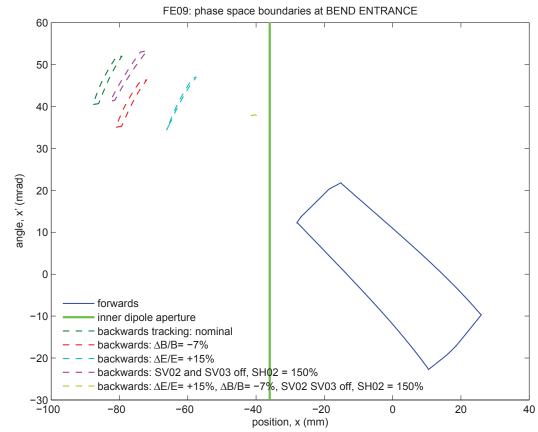

Figure 7: Dipole beamline: phase space boundaries at the entrance to the bending magnet in the worst combination of errors.

CONCLUSIONS

One interlock already implemented in ALBA is the stored beam interlock, where top-up injection is inhibited if the stored beam current drops below a pre-determined threshold, as the absence of stored beam indicates a possible fault in the storage ring.

At ALBA it has been demonstrated that neither a single error nor more combined events would be sufficient to lead to a top-up accident, even in the absence of interlocks. The one exception to this statement is in the case of the ID beamlines for a single dipole to be below 20% of nominal strength with all other dipoles at full field. For this last case the stored beam interlock already guarantees that a single dipole field can not be below 7% of nominal value.

The method chosen to investigate the possibility of a top-up accident occurring has proven to be an effective one. Monitoring the behaviour of the phase-space boundaries gives a good intuitive feel for the consequences of a particular type of magnet failure and as such it has proved unnecessary to simulate every single setting for each magnet of the storage ring.

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REFERENCES

[1] X. Huang, "Tracking study for top-off safety validation at SSRL", NIM-A 635, 2011.

[2] I. Martin, "Top-up Safety Simulations for the Diamond Storage Ring", Proceedings of IPAC2008, Genoa, Italy.

[3] A. Terebilo, SLAC-PUB-8732, 2001.

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