Leveraging Parametric Computer-Aided Design for Efficient Optimization of a Storage Ring Vacuum System Design for the APS Upgrade*

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Abstract

Design of a vacuum system for a synchrotron light source must meet certain performance criteria, minimum acceptable beam effects, accommodate co-located systems, minimize required installation and maintenance time, and do so at a minimum cost. Recent diffraction-limited storage ring lattice schemes are ever more demanding of vacuum systems as they generally rely on stronger focusing fields which are most directly provided by positioning magnet poles closer to the particle beam. Vacuum chambers cannot be made arbitrarily small since beam impendence and other deleterious effects generally scale exponentially with reduction in the chamber aperture. To make the best use of the available space inside the magnets, an integrated design approach is clearly warranted. A conceptual design for the storage ring vacuum system has been recently described [1]. We also wish to share our experience leveraging parametric computer aided design (CAD) in a manner that allows rapid iteration and optimization of global vacuum system characteristics in response to changes in the designs of interfacing systems. In doing so, we not only improve the efficiency of our own effort, but we also help those responsible for the interfacing systems by promptly relaying the impact of their design changes on the vacuum system.

The Problem: How to Efficiently Manage a Demanding Set of Constantly-Evolving Constraints

In addition to providing a suitable vacuum environment for the particle beam, a storage ring vacuum system must satisfy a number of other interface requirements. Interfacing systems include magnets, diagnostics, insertion device vacuum chambers, beamline front ends, and the extracted x-ray beams themselves. By far, the largest number of constraints on the vacuum system are imposed by the magnet system. In many areas, space inside the magnets is so limited that little more than simple tube will fit inside. X-ray extraction can be particularly tricky. A cross section through the integrated CAD model upstream of a stretcher absorber where the chamber must accommodate both particle and user x-ray beams is shown in Figure 1.

Particularly at the early stages of an accelerator design project, the designs of the various interfacing systems may evolve rapidly, and major changes to the vacuum system design are often required to accommodate the evolution of these systems. To wait until the designs of other systems are complete before initiating the vacuum system design is to miss an opportunity to influence the designs of those other systems in a way that might greatly improve the performance of the machine as a whole. Commercial CAD software offers the means of large-scale design integration, but allowing designs of an assembly to change and as complex as a storage ring vacuum system to be determined automatically by the designs of other interacting systems is not commonly done because of the fragile logic in the CAD model that is likely to result.

Step 1: Establish the Skeleton Model

The “skeleton” part is built on a small, non-redundant set of datums which are identical from sector to sector and which can be easily mapped to survey references at each sector location. In doing so we utilize an ideal set of references which nonetheless can be considered “real” considering that the alignment error associated with placing a given component relative to these datums can be directly calculated. For our design this set of “her one” datums consists of a vertical axis at the storage ring center, the horizontal beam plane, and the vertical plane that passes through the storage ring center axis and bisects the insertion device beamline. For convenience, a second tier of datums is generated relative to the first tier. These include the vertical planes of the insertion device and bending magnet beams and the planes that separate straight sections used for insertion devices and rf cavities from the storage ring “arc” which contains the primary lattice magnets. Added to this is a series of local coordinate system references which mark key locations in the magnet lattice. A datum curve is created connecting the centers of these coordinate systems and traces the ideal beam trajectory.

Step 2: Create the Dummy Model with a Small Set of Simplified Elements Located and Sized According to the Skeleton Model

Step 3: Generate Bending Magnet Radiation Ray Traces

Step 4: Explore Design Options and Optimization

Figure 3: A simplified “dummy” model built on skeleton model datums.

Figure 4: Excerpt from radiation ray trace layout generated with the parameterized CAD model.

Summary

An effective and efficient process has been developed which utilizes a simplified, yet fundamentally parameterized, CAD model of a storage ring vacuum system that serves as an effective basis for top-level layouts and ray traces, as a template for more detailed component models, and as a means to quickly understand the implications of design changes in other closely-interfacing systems.

REFERENCES


Figure 2: Skeleton model datum planes and coordinate system array.

Figure 5: Size of a vacuum chamber is adjusted to identify the optimal solution for x-ray extraction.

Figure 6: Excerpt from radiation ray trace layout generated with the parameterized CAD model.