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, minimize undesirable 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 these 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 impedance 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 crotch 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 as large 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.

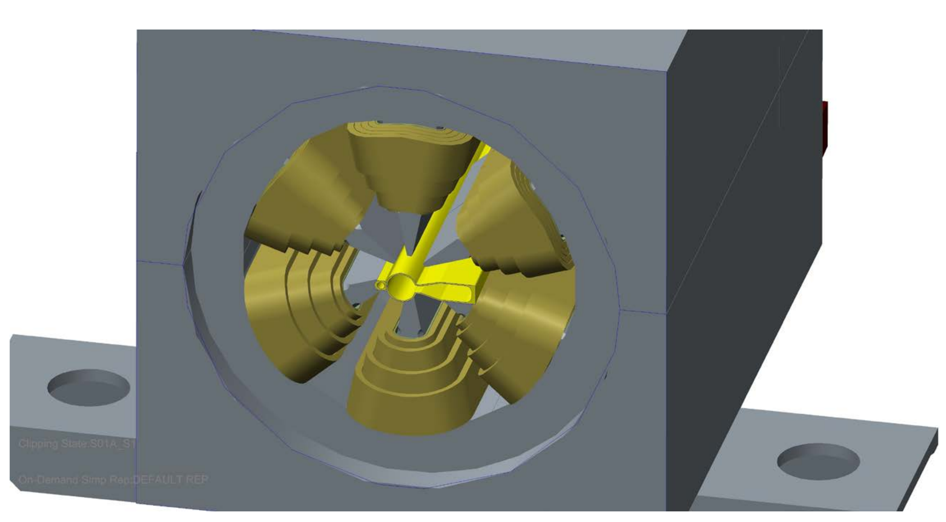

Figure 1: Cross section where chamber must accommodate both particle and user x-ray beams.

Our Solution: Parameterize A Simplified "Dummy" CAD Model on a Small Set of Key Parameters

It would be counterproductive to parameterize every design detail of an accelerator vacuum system at the top-most assembly level, so we choose parameters that we expect will evolve with time and ones that, when changed, will have the greatest impact. For our work these include: the particle beam trajectory, the longitudinal sizes and locations of magnets, locations of extracted x-ray beams, and locations of key components like beam position monitors and some photon absorbers. To efficiently and effectively direct the global design, we have developed a process by which a top-level "dummy" CAD model is generated based on a small set of key parameters. The dummy model contains enough detail for use in generating top-level layout drawings and ray traces, and also serves as a template for the more detailed models required to generate fabrication drawings. Creo software (formerly Pro/Engineer) has been used to generate our parameterized CAD models and layouts [2].

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 "tier 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.

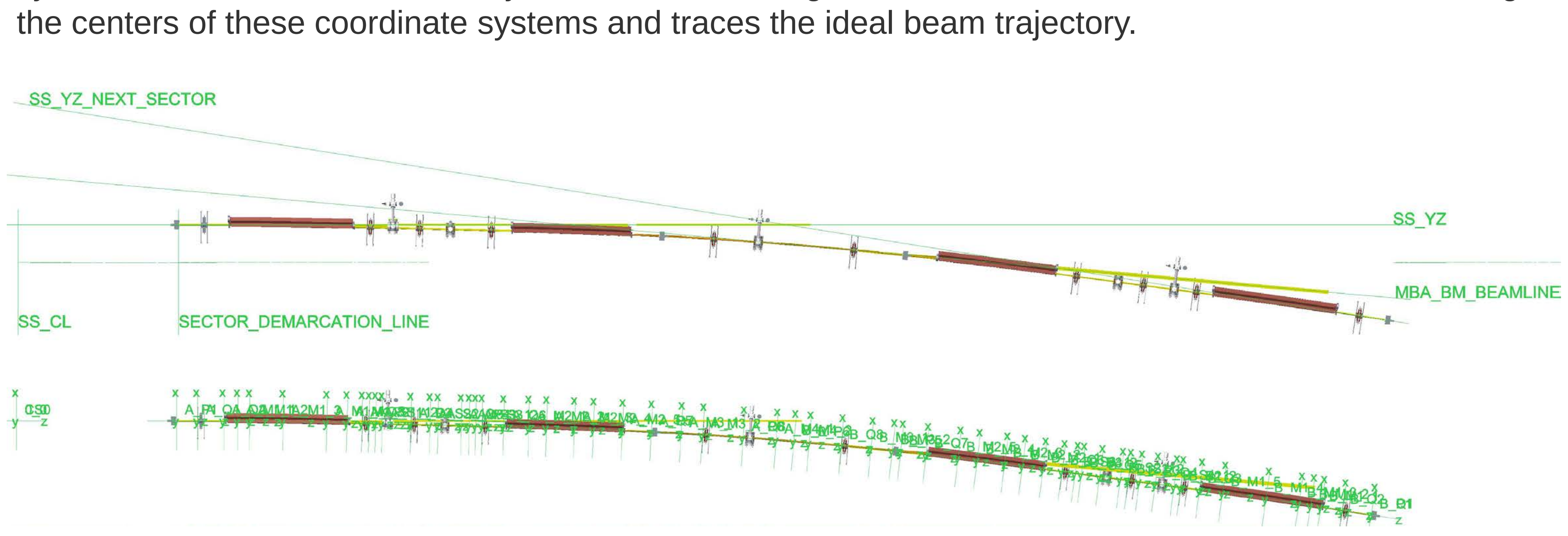

Figure 2: Skeleton model datum planes and coordinate system array.

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

Rather than designing a large number of individual components and iterating on the many individual designs to achieve proper fit in the assembly, we found that it can be much more efficient to start with a simplified "dummy" model that fits by default because it is derived directly from the datum set described above. This dummy model can then be used as a basis for top-level layouts and as a template for the more detailed models required to create fabrication drawings. We found that this not only improved the efficiency of our workflow but also kept the computing requirements of the top-level models and layouts within the capabilities of our workstations.

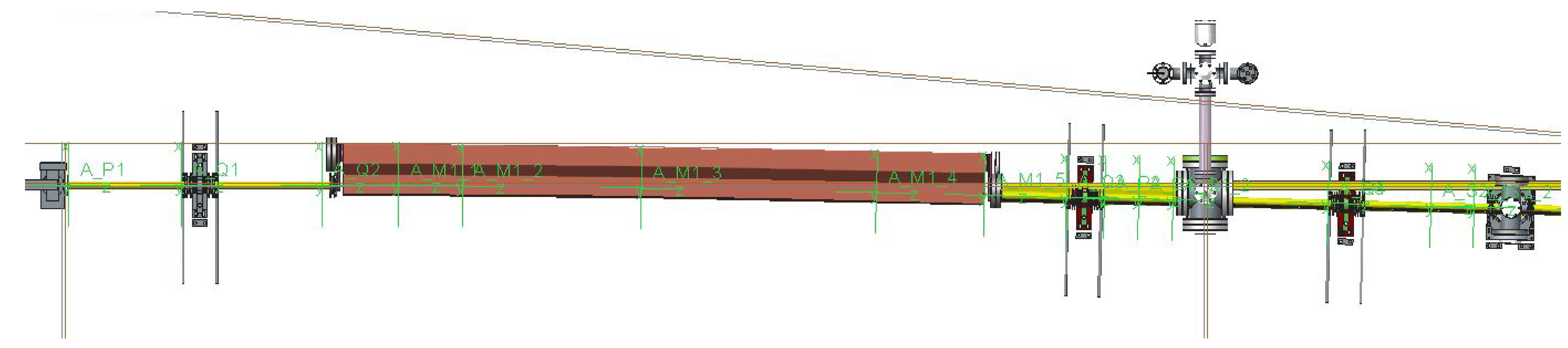

Figure 3: A simplified top-level "dummy" model built on skeleton model datums.

Step 3: Generate Bending Magnet Radiation Ray Traces

The location and distribution of bending magnet radiation "fans" are a consequence of the particle beam trajectory alone. Because the particle beam trajectory is precisely described in the skeleton model, the bending magnet radiation fans can be readily generated. Surfaces from the parameterized dummy model are used to terminate the bending magnet rays. Because the rays and dummy model are both generated using geometry in the skeleton model, updating the skeleton (to reflect a new lattice iteration, for example) will automatically update the cast rays and their intersection with the vacuum system surfaces. Corrections to the ray trace model are occasionally necessary when the manner that a ray is intercepted by the vacuum hardware changes, for example when a difference in geometry causes a ray to be no longer intercepted on a photon absorber but instead by a chamber wall. Figure 4 is an excerpt from a ray trace layout generated from the parameterized model.

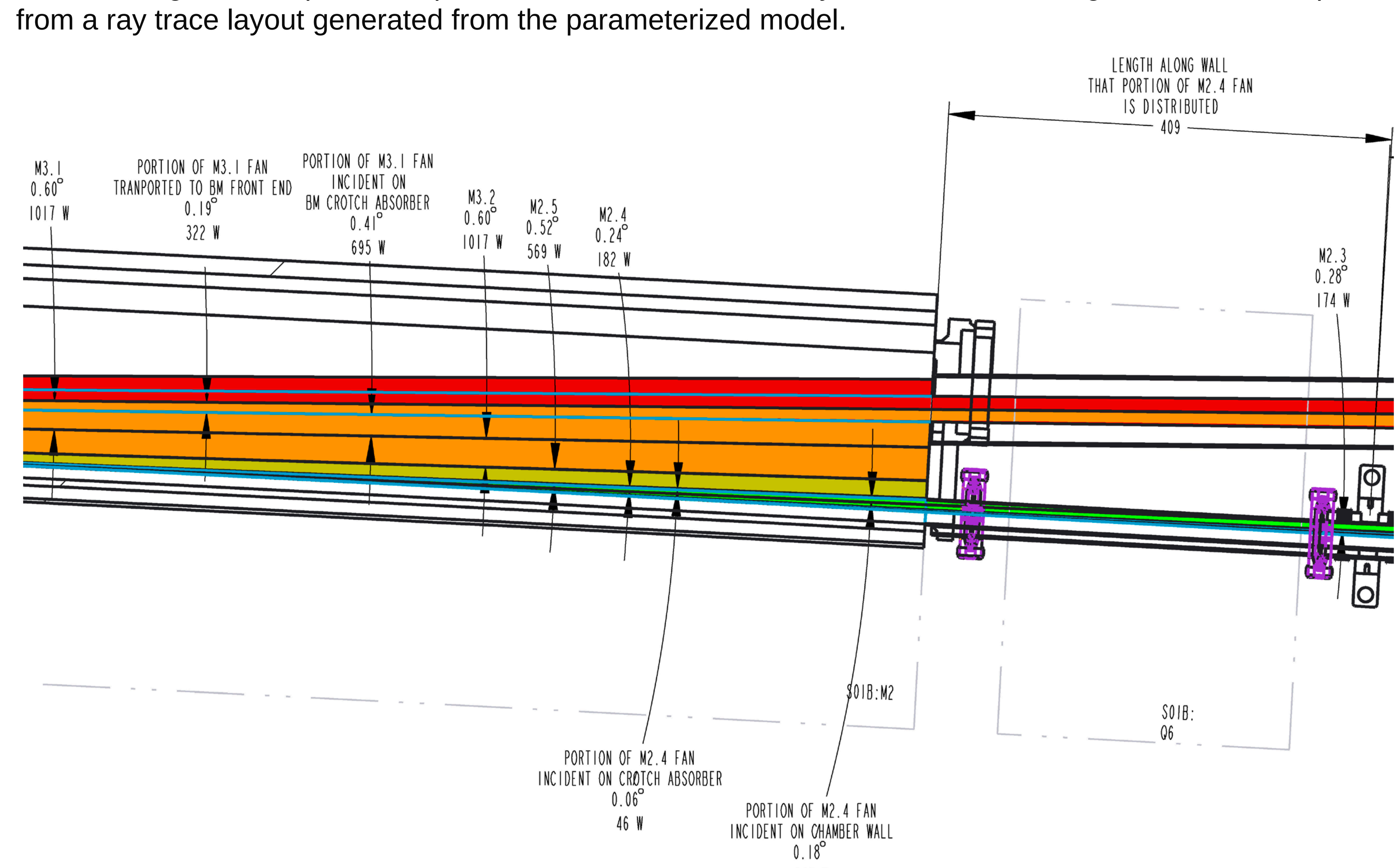

Figure 4: Excerpt from radiation ray trace layout generated with the parameterized CAD model.

Step 4: Explore Design Options and Optimization

A fully-parameterized top-level assembly model also gives the engineer a set of "knobs" which can be easily adjusted to fine-tune the global design. An example of doing this for the APS-U storage ring vacuum system design is shown in Figure 5 below. In this case the width of a vacuum chamber cross section is adjusted to evaluate the feasibility of extracting x-ray beams through the side of the chamber versus through a flange on the end.

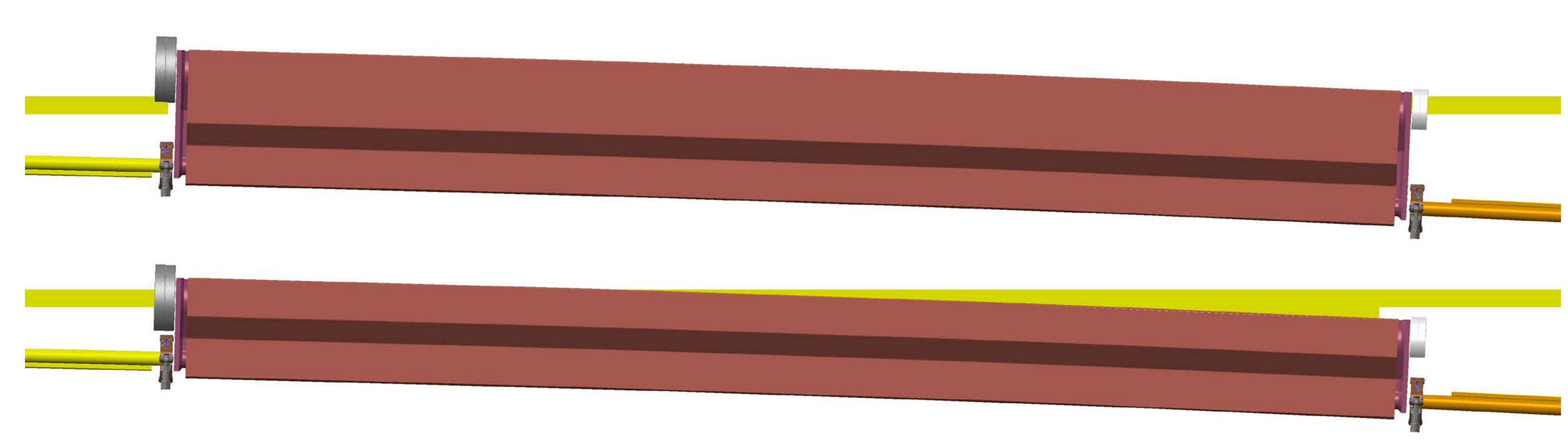

Figure 5: Size of a vacuum chamber is adjusted to identify the optimal solution for x-ray extraction.

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

[1] B. Stillwell, B. Brajuskovic, H. Cease, D. Fallin, J. Noonan, and M. O'Neill, "Conceptual Design of a Storage Ring Vacuum System Compatible with Implementation of a Seven Bend Achromat Lattice at the APS," IPAC '14, Dresden, 2014, p. 1554 (2011); http://www.JACoW.org

[2] http://www.ptc.com/product/creo