LIGHTING THE WAY FOR IMPROVED SYNCHROTRON VACUUM CHAMBERS AT RADIASOFT

RadiaSoft and Argonne National Laboratory are working together to enhance the brightness in synchrotrons. They created a user-friendly simulation tool to streamline the design of synchrotron vacuum chambers, advancing particle accelerator research in the process.

By **BRIDGET PAULUS**

A SYNCHROTRON LIGHT SOURCE is a type of particle accelerator used for scientific research across a wide variety of disciplines. A beam of electrons is accelerated to an extremely high (ultrarelativistic) speed using an accelerator chain composed of a linear accelerator (LINAC) and a circular booster synchrotron. Once injected into the storage ring, the beam is directed in a circular orbit by powerful magnets, causing the release of X-ray radiation tangential to the curved trajectory of the electrons. The energy lost to the radiation must be restored each revolution with radiofrequency cavities placed along the ring. Many beamlines branch off from the synchrotron, each containing a unique sequence of optical elements that modify the X-rays in accordance with the requirements of a given experiment and sample.

The radiation from synchrotrons enables scientists to peer into different materials and chemical processes, acting as a "super microscope". For instance, synchrotrons can be used to examine the internal structure of crystals, nondestructively test archaeological findings (like ancient pottery), and study complex proteins. However, while the research may vary, one requirement is the same in every case: The beam needs to be as intense as possible.

To foster more advanced research, many facilities are planning to enhance the brightness of synchrotron beams, and the Advanced Photon Source (Figure 1) at Argonne National Laboratory (ANL) is no exception. However, accomplishing this task is quite challenging. Nicholas Goldring of RadiaSoft LLC, a company that designs particle accelerators using simulation, describes the process of improving an accelerator as an "inherently multiphysics problem," since the device involves vacuum science, magnetic fields, heat, and particle motion. Even optimizing individual parts can be difficult. For instance, the vacuum chambers, which the electron beam travels through, involve complex phenomena that all interact with and affect each other, making for a long and complex development process.

To create a design tool for vacuum chambers that can account for all of their effects, RadiaSoft and ANL teamed up, with support from the United States Department of Energy. Using the COMSOL® software, the group developed a comprehensive multiphysics model of a synchrotron vacuum chamber. Adding another step to their modeling workflow, the researchers created an easy-to-use graphical interface for the model, a simulation application, which they distribute to particle accelerator facilities around the world.

» *MODELING THE MULTIPHYSICS OF VACUUM CHAMBERS*

VACUUM CHAMBERS (Figure 2) are critical to a particle accelerator's effectiveness. According to Goldring, the chambers must maintain a pressure in the nanotorr region to let the electron beam propagate unimpeded. Higher pressure means there are too many gas particles, which causes scattering and leads to beam loss. Accurately

Figure 1. The Advanced Photon Source (APS), a synchrotron at Argonne National Laboratory.

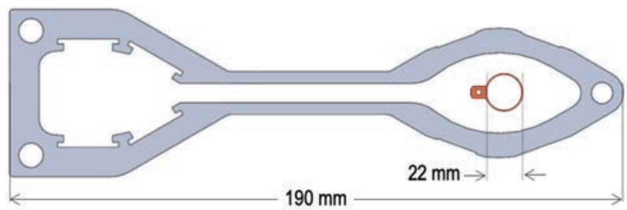

Figure 2. Cross section of a 2D axisymmetric vacuum chamber geometry. This design is used for the APS and needs to be downsized from 190 mm to 22 mm for an upgrade.

accounting for these scenarios and effects like high temperatures, synchrotron radiation, outgassing, and desorption can get complicated — especially when all of these phenomena affect each other.

To develop vacuum chambers, particle accelerator engineers often rely on simulation software. However, Goldring pointed out that the traditional tools are highly specialized and typically simulate only one physical process. Plus, since these software packages also tend to have very little (if any) documentation, there is a steep learning curve for actually using them, creating a siloed work environment: One engineer excels in running ray tracing analyses, another specializes in gas flow and pressure calculations, and so on. Each engineer tests specific changes in the design, passing the results back and forth for every iteration.

For a streamlined process, RadiaSoft turned to COMSOL Multiphysics® and the add-on Ray Optics Module and Molecular Flow Module. "COMSOL drew our interest due to its multiphysics capabilities. It can solve all of the important calculations that a vacuum engineer will need to perform in a simpler manner," says Goldring. He added that obscure and complex simulations can be done more easily and all in one place.

Goldring says that compared to other software, COMSOL Multiphysics offers additional benefits, including better data analysis tools, solver types, and more. "What is nice about COMSOL is that we can model multiple gas species at a time," says Goldring about molecular flow simulations. Standard accelerator simulation software can typically only simulate one species at a time. Plus, it is possible to replicate the functionality of other specialized software in COMSOL and get results that are just as accurate. Goldring compared results from a variety of models to analogous models created with software dedicated to free molecular flow in vacuum chambers and found good agreement between the two.

THE POWER OF PARTICLE ACCELERATOR SIMULATION APPLICATIONS

RADIASOFT AND ANL used the Application Builder in COMSOL Multiphysics to add a user-friendly interface to their vacuum chamber model, making it easier to analyze how the propagation of synchrotron radiation affects the design. By creating an application, "people do not have to go into the model itself to figure out how to set up the ray tracing, which is complicated," says Goldring. Instead, they can just define where the beam starts and what the magnets look like; import a CAD geometry; and find the pressure, temperature, and more.

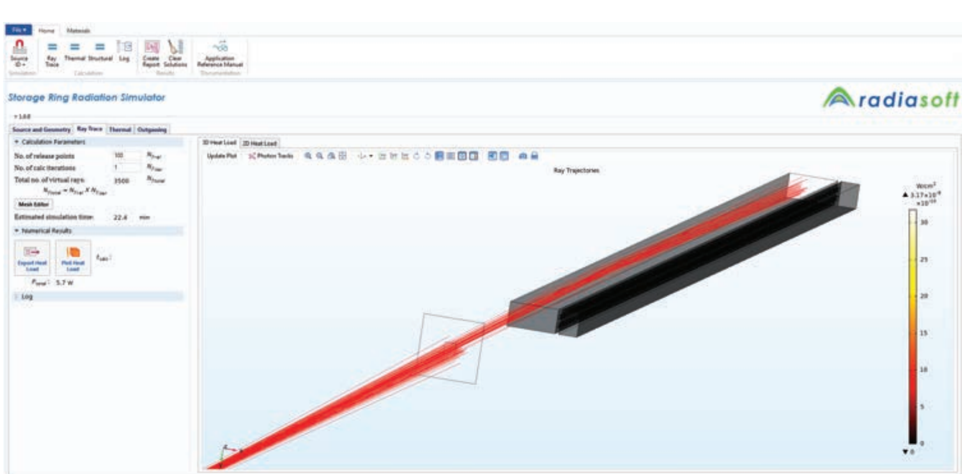

Figure 3. Simulation application of synchrotron radiation ray tracing in a vacuum chamber.

The simulation application (Figure 3) solves a true multiphysics problem: analyzing the propagation of synchrotron radiation using ray optics simulation, then observing the effect of outgassing on the vacuum chamber pressure as X-rays hit the chamber walls. Application users can define parameters such as the electron beam source, the beam's energy and arc length, and the strength of the dipole magnets. After the user clicks Compute, the application visualizes the rays' path and power as well as the temperature in the chamber. For particle accelerator engineers, these results provide valuable insight into the radiation power distribution of the high-energy beam at different points, enabling them to examine how the distribution changes as the beam travels within the synchrotron.

The application can also be used to determine the amount of desorption from the walls of a vacuum chamber. (Figure 4) In the chamber, the high-energy particle beam produces synchrotron radiation that hits the chamber walls, causing gas molecules to be kicked out, thus altering the pressure within the vacuum. However, maintaining the vacuum pressure is critical to the lifetime of the beam. To avoid disabling the beam, it is important to know just how much gas leaves the walls to enter the chamber.

The simulation application (Figure 4) makes this calculation simple, determining the desorbed gas for various

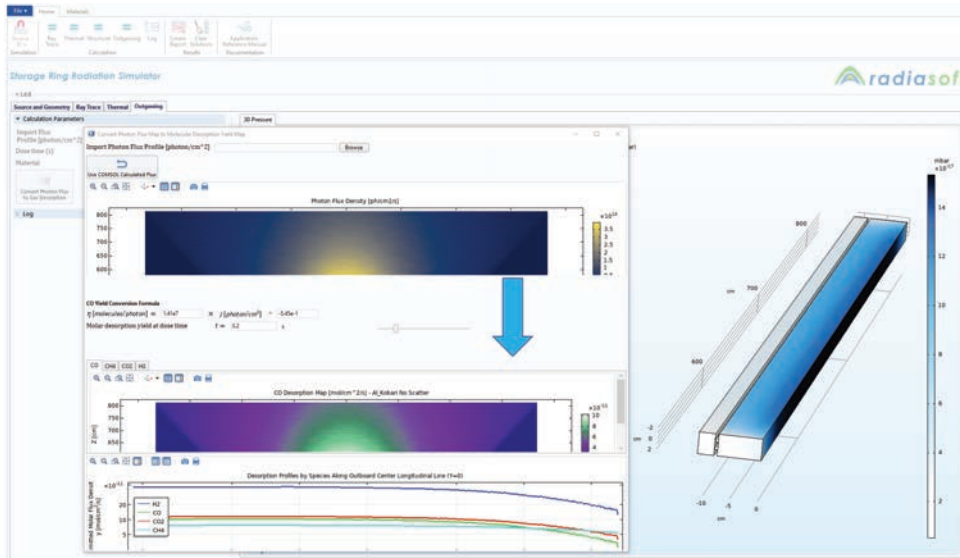

Figure 4. Simulation application for calculating gas desorption and pressure.

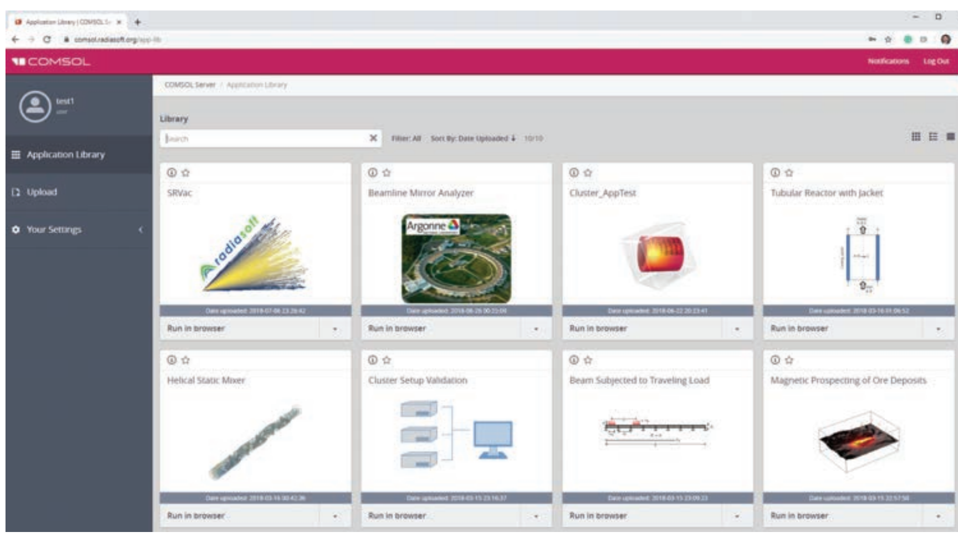

Figure 5. RadiaSoft's applications in their instance of COMSOL Server™.

species by combining a ray tracing simulation with equations that convert the photon flux density into the accumulated number of rays on the wall. This incident energy flux is then used to set boundary conditions in a free molecular flow simulation to predict the density and pressure of outgassed molecules in the chamber. As Goldring says: "The tool lets people import the flux profile and then autocomputes how much gas gets out according to that and material properties." Simulation applications can also include multiple gas species simultaneously.

PROMOTING COLLABORATION AND GETTING FEEDBACK

AFTER BUILDING A SIMULATION APPLICATION, Goldring distributed it to other people involved in the project using the COMSOL Server™ product (Figure 5). According to Paula Messamer of RadiaSoft, creating and deploying an application can make the design process for vacuum chambers much more collaborative and efficient. "The application allows people with lower levels of expertise to get answers to questions without going back to the engineer who created the code and without having to go through the steep learning curve," she says, adding: "Essentially, it is like a calculator."

Deploying applications also allows RadiaSoft to get feedback from those in the field, enabling them to customize the application's interface to meet the needs of users. Goldring mentions that the application is not only being tested by those at ANL but also at other particle accelerator facilities around the world.

PLANS FOR FURTHER IMPROVING THE VACUUM CHAMBER SIMULATION APPLICATION

IN THE FUTURE, Goldring plans to improve the application to include import functionality of arbitrary geometries, which would make it even easier for users to test and optimize different vacuum chamber designs. Further, RadiaSoft wants to generalize the application to accommodate different types of existing and future particle accelerators.

By deploying simulation applications, the teams at RadiaSoft and ANL are giving engineers a specialized tool for improving vacuum chambers, enabling a more efficient design and optimization process. This, in turn, allows for better-performing particle accelerators while facilitating further cutting-edge research and imaging.