RECENT IMPROVEMENTS IN PARTICLE SIMULATION SUPPORT IN ANALYST-MP*

J. F. DeFord, B. Held, A. Nichols, AWR Corporation, Mequon, WI 53092, USA

Abstract

Recent work on the Analyst product has simplified model development, improved result visualization, and added particle simulation functionality. The Analyst user interface has been updated with a new control layout, and support for automatic session recording, variables/expressions for all inputs, and units. For the study of multipacting and dark current phenomena a new volumetric particle source has been deployed, and changes to the way secondary generations are managed has simplified the identification of multipacting resonances.

INTRODUCTION

Analyst is a finite element-based tool used for design and optimization of three-dimensional structures in microwave engineering. In development of new particle accelerators, Analyst is used on a variety of components including RF modules, feed systems, deflectors, etc. When applied to the multipacting problem, driven RF or eigenmode calculations are performed to obtain field distributions, and these are then used in a separate particle simulation to search for particle resonances.

Recent work has improved the particle tracking algorithms and emission models [1]. The current version of the code employs a statistical secondary emission model that produces from an impact a set of zero or more electrons whose count and properties are obtained from samples of random variables that collectively enforce observed secondary emission behaviour [2]. The Analyst user interface has also been updated in response to user experience in the old system. Development on the particle simulation engine has focused on changes that make it easier to identify and interpret multipacting behaviour. These changes are discussed in the following sections.

VOLUMETRIC PARTICLE SOURCING

Previous versions of Analyst used a simple primary emission model for multipacting simulation. This model emitted one or more particles from each element face that lay on the model boundary. Particles were emitted at regular intervals during the first RF period, and subsequent particle motion and deterministic secondary generation were used to identify resonances. This technique is very efficient, but it does not necessarily require fewer emissions than a volumetric launch if one is to avoid missing resonances.

In addition to supporting primary emission from surfaces, Analyst now also allows initiation of particles in the volume by emitting a specified number from each mesh element (triangle or tetrahedron) during the first RF cycle. The position, direction vector, and emission time of each particle are all randomly chosen. The initial velocity of each particle is obtained by sampling a random variable, with the number of particles emitted per element controlled by a user input, and is typically of order 10^2.

As expected, the efficiency with which resonances are identified is a function of the choice of initial velocity distribution. Robust multipacting resonances involve low energy electrons because it is primarily low energy impacts (< 5 keV) that yield multiple secondary particles. Higher energy impacts can result in single reflected or re-diffused secondary particles, but do not contribute to gain in multipacting resonances. Consequently, initiating particles with high energy is usually of little utility in identifying resonances. In the low energy regime we studied the effects of using different velocity distribution functions, including a delta function (specified value), uniform over a range of values, and Boltzmann with a peak matching the secondary emission yield peak of surface material. We concluded that these functions were largely equivalent in initiating resonances in test structures, and the simplest approach of giving all of the particles the same initial energy (in the 100s of eV) is perfectly adequate. This value is an input parameter in the software, which defaults to the peak energy of the true secondary yield curve. Note that this choice does not imply that only particles with comparable energy exist in the simulation to initiate resonances. High-field regions will accelerate particles to high energies, and subsequent interaction with cavity walls will typically scatter some of these particles into low-field areas. However, with this approach the preponderance of particles in low field regions will be in an energy range to yield true secondaries on impact with common metals, increasing the odds that a resonance will be discovered if one is supported by the geometry/field-structure.

Volumetric sourcing produces an initial cloud of particles that rapidly dissipates, primarily due to collisions with cavity walls that produce no secondary particles. What remains after a few RF cycles is predominantly secondary particles that are in a resonance (Figure 1).

MULTIPROCESSING

Particle tracking is done by secondary generation, with each generation completed before the next one is started. Between generations secondary particles are redistributed across available processors to balance the computational load. Dependence of particle populations on processor count is undesirable, even when it does not lead to

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quantitative changes to the results of interest, and such dependencies are also problematic in automated regression testing systems. To make the results independent of processor count requires the creation of a particle index that does not depend on either processor count nor processor index. This index is formed on the basis of initial emission parameters and secondary history, and is composed of a small number of 64-bit integers (generally 3 or less). The index is unique for each particle, but simple interpretations of its values as integers are not evenly distributed in the set of integers, and as such it is not suitable for use in index-based load-balancing. So for this purpose an index hash (a single integer of a specified maximum size) is created based upon the index which is approximately evenly distributed, but is not generally unique. Load balancing is then performed on the basis of this hash, which has exhibited high-quality partitions in our testing.

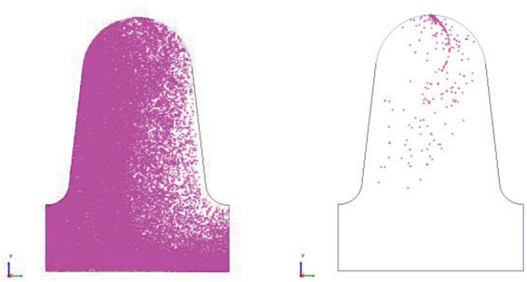

Figure 1: Particle cloud at 1 RF period (left), and after 2 RF periods (right) in 2-D RZ example. Ultimately a resonance is seen about cavity "equator" (top center of cavity).

SECONDARY DECIMATION

The number of secondary particles that are tracked at each generation is controlled via decimation. This is particularly important in highly resonant situations in which the particle growth is exponential. As with load balancing, an index hash is used for this purpose, and only particles with zero hash index are tracked. The existence of the untracked particles is accounted for in accumulated statistics, such as yield, but otherwise they are simply discarded.

MODEL CREATION AND RESULT PROCESSING

The Analyst user interface has been updated to simplify the creation and manipulation of complex geometry models. Changes include mouse-based solid construction, relative coordinate systems tied to geometric entities (for creating a solid at a location/orientation that is relative to another solid), and the aggregation of all model data in a property grid that allows rapid access and modification of model parameters (Figure 2).

Scripting is supported in the Analyst system, and is based upon the Python language. The new software automatically records the complete session in a script that can be replayed in order to reproduce the session. This recording can also be used as the basis for a user script.

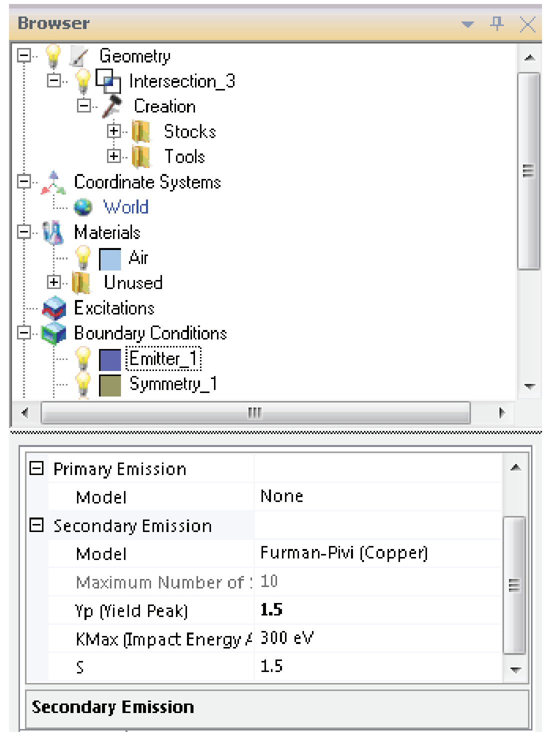

Figure 2: New model data browser in Analyst simplifies access to common elements.

Variables and expressions can now be entered in place of numeric values in all input fields. Variable definitions are collected in a single input panel for rapid access. Units are now comprehensively supported in the user-interface, and a variable has the unit of its associated expression. The expression parser observes rules associated with the use of quantities with units in expressions, so for example, it is not allowed to add a variable with unit of distance to another variable with unit of time. Moreover, values with the same unit but differing scales are handled automatically via conversion to a common scale, so for example, an expression of the form v=1m+1in is allowed and correctly evaluated.

Result visualization has been reorganized to allow simpler addition of filters to view elements (now called "annotations"). Annotations can now be created in advance of a simulation, allowing views that are updated as data become available. Previously in Analyst geometry visualization was done only in its own window, separate window from all result views. In the new system there is no distinction between the two, so geometry and result visualization can be rendered together in the same view.

As an example, we analysed an RF deflector cavity [3] (Figure 3). This structure uses a dipole mode resonant at 2.82 GHz, and the interest was to identify any multipacting bands below about 60 MV/m peak surface electric field. Figure 4 shows the mode electric field, which is a field annotation rendered together with an outline view of the original solid geometry.

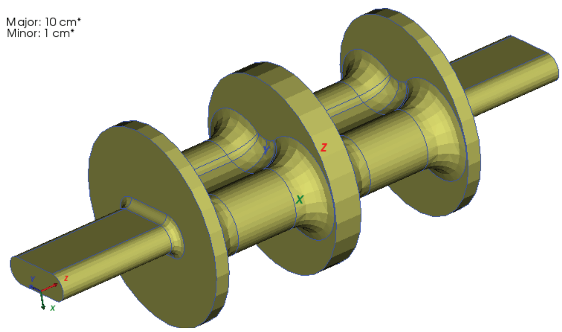

Figure 3: Deflector cavity geometry.

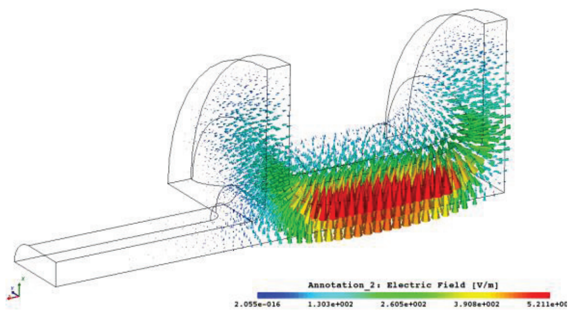

Figure 4: Electric field of mode in deflector cavity. Cavity is shown as modelled using 3 planes of symmetry. View is combination of structure and field annotations.

Running the problem at a single field level and dumping particles allows visualization of particular resonances. Particles can be rendered either as dots (their position at a particular instant in time), or as tracks that show the path of a particular particle or set of particles (Figure 5). In the deflector structure for the particular choice of secondary emission model there is a resonance near 50 MV/m in the vicinity of the connection between the beampipe and the cavity. Particles in this resonance return to the surface once every RF period as can be inferred from the individual particle statistics table that is output by Analyst.

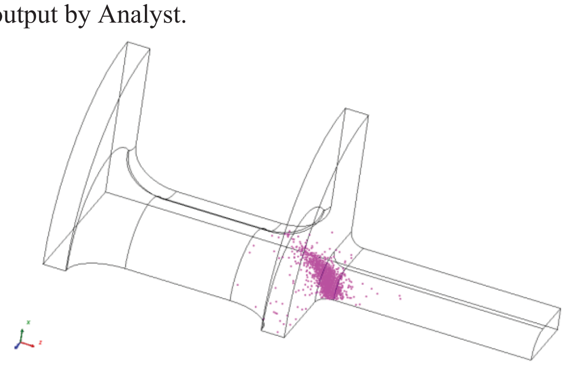

Figure 5: Particle distribution after 30 RF cycles in the multipacting band, showing accumulation of resonant particles near the fillet between cavity and beampipe.

Plots now contain one or more "measurements", which are data sources that can come from a simulation table or some other source. As with annotations, measurements are updated as data becomes available, so if a number of plots have been created and the simulation is rerun there is no need to recreate the plots as they will simply be updated with the new data when the simulation is finished. The enhanced counter function for the deflector cavity is shown in Figure 6. The particle count time history for a field level in the multipacting band is shown in Figure 7.

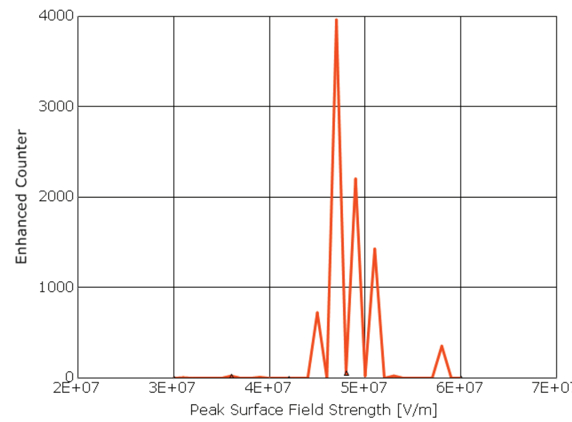

Figure 6: Enhanced counter function (number of particles surviving to 20 impacts including yield) as a function of peak surface electric field.

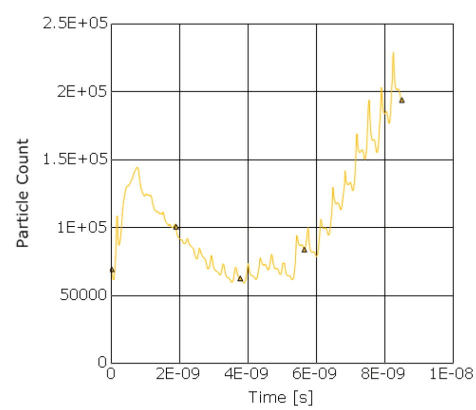

Figure 7: Particle count vs. time in deflector at 49 MV/m. Resonance is evident in late-time growth.

CONCLUSIONS

The Analyst finite-element software package has been updated, including improvements to the user-interface and particle simulation functionality. Changes in the way particles are sourced and secondary particles are managed now allows direct observation of particle count growth in resonant situations. Studies show expected multipacting resonances in test structures.

REFERENCES

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