

CONSIDERATIONS AND IMPROVED WORKFLOW FOR SIMULATION OF DISSIPATED POWER FROM WAKE LOSSES

A. F. D. Morgan, G. Rehm
Diamond Light Source, Oxfordshire, UK

Abstract

At Diamond quite some effort has gone into simulating and understanding the dissipation of energy into structures induced by wake losses. Due to changes in the core simulation code we use, it is now possible to extract the dissipated energy information directly from the simulation rather than inferring it from other parts of the simulation output which was, by necessity, our previous method. Various modelled geometries will be used to illustrate the improved approach. Also we will discuss the considerations needed when constructing the model geometries in order to get the most representative results from the simulation.

BASIC WORKFLOW

One of the core principles of our approach is that there should be one core geometry file for each geometry. This can mean some added complexity in the file, but it ensures all the simulations are using the same geometry, and also allows entire simulation sets to be re run for validation. The outline of the approach is shown in Fig. 1

As we are now able to obtain material losses directly from the simulation, only one simulation is required, rather than the $N+1$ simulations for N materials required by our previous method [1,2]. This gives a large saving in both time and complexity. More importantly it also allows us to remove the assumption that material changes have only a small perturbative effect on the fields in the structure, something we know to be untrue for many of the structures we have studied. Another benefit is that we can now directly compare the total energy lost from the beam to the total energy accounted for from port emission and material heating, giving us an additional valuable check on the self consistency of the simulation.

In order to enable this approach we use a software framework around the core modelling software. The framework (implemented in MatLab [3]) takes the core geometry description and adds any simulation specific information, before running the simulation (CST PS in the past [4], now GdfidL [5]), gathering the results and generating an initial report. As part of the geometry file is programmatically generated it is possible to sweep model parameters (providing the parameters have been set up in the original geometry file). Usually the sweeps involve geometry parameters, however, we have also found it useful to sweep meshing parameters to validate that the model is represented in enough detail to capture all of the resonances and fine structure.

In order to compare the different simulation types, and also to evaluate the effects of geometric changes, we have written high level analysis software in MatLab. This extracts

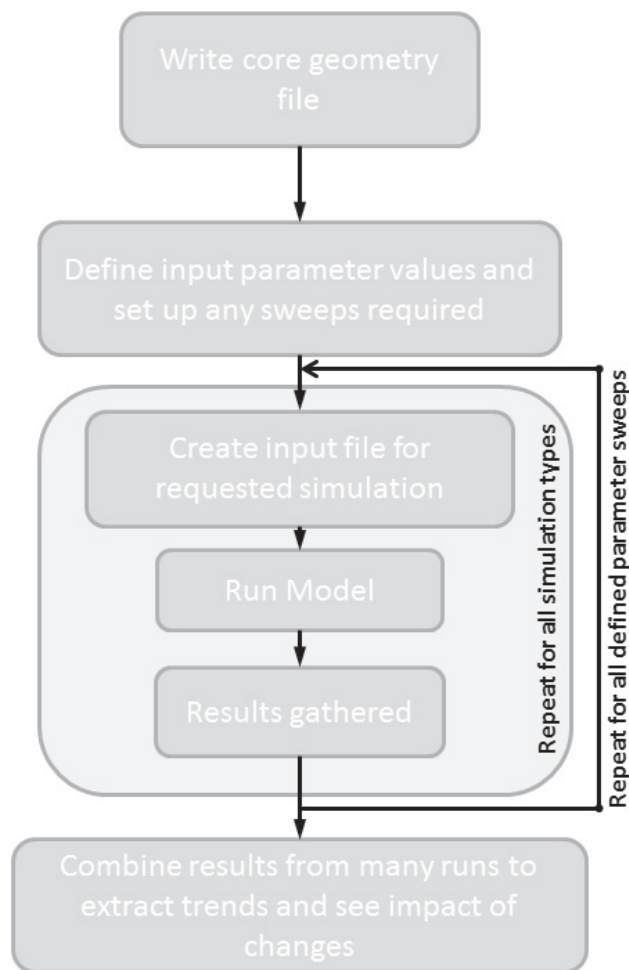


Figure 1: Basic workflow of the simulation process.

information from the output data of the simulations, and combines results in order to help us extract trends and to pull out the more important information for further study. This work is ongoing as we are often finding new ways to combine and look at the data in order to investigate a new aspect of the structures' behaviour.

Currently, this high level analysis is mainly used to track changes in behaviour in S-parameters or energy losses during design studies. In the latter stages of such studies we can perform sensitivity analysis, in order to help define mechanical tolerancing for manufacture. As well as design work, this sort of analysis can be used to improve our understanding of existing devices. It is also useful to validate that

new versions of the simulation code behave in the expected fashion.

MORE DETAILS OF A SINGLE RUN

In order to get an as complete picture as possible, we use three different simulation modes.

A wake simulation is used to assess wake potentials and wake impedances, as well as energy loss into the structure, and potential disturbances upstream and downstream caused by energy re emission. As described in previous publications this simulation type can be used as a basis to investigate sensitivity to changes in beam and machine conditions [1]. For our purposes, a wake model comprises of a structure with a line charge passing through it representing the beam. There are ports at the beam entry and beam exit, as well as any pick ups (e.g. coaxial outputs from striplines or beam position monitors).

From this simulation we capture energy loss into materials, signals emitted from the ports, and a map of energy deposited into the structure, which helps identify hot spots. Because of the long range nature of the wake potential, we have a correspondingly high resolution wake impedance which gives a clearer picture of structural resonances. When combined with the loss map and the eigenmode results it has the potential to let us identify which mode is causing which effect, and if it is a problem for operation.

An S-parameter simulation excites a single port with a broadband signal. By monitoring the output of the ports, and by repeating the excitation for each port a full S-parameter matrix can be built up. This type of model is useful to assess signal coupling and changes of output due to geometry changes. However its main benefit is to predict signals which can later be measured on the physical device. This being the case, in the simulation we only excite signal ports.

A lossy eigenmode simulation enables us to visualise the modes in the structure, and, depending on the structure being investigated, find the shunt impedance and the Q factors for the modes present in the model. For cavity type structures the shunt impedance helps specify the size of the drive amplifiers required to drive it.

CONSIDERATIONS ABOUT MODEL CONSTRUCTION

Wake Simulation

On top of the usual considerations of using a suitably fine mesh in order to faithfully reproduce the desired geometry, with a suitable time step to describe the input beam, and whether symmetry planes can be used. Additional considerations need to be taken into account. We require a long wake simulation as we require to account for all the energy injected into the simulation by the beam. This implies that we need to wait for the energy in the structure to either couple out of the ports or be absorbed by the materials of the structure.

One of the checks we perform is measuring what fraction of energy lost from the beam is accounted for at the end of the simulation. If it is less than all then we will need to run the simulation for longer. If the accounting returns more than that lost from the beam then there must be an unphysical process in the simulation. A major consideration arises from the behaviour of the ports. Currently the ports cannot distinguish signals arising from a transmitting mode and that from an evanescent mode. Accounting for the former is correct as power is leaving the structure, however, the fields associated with the evanescent modes do not leave the structure. If these evanescent signals touch the port boundary it adds to the account of power leaving the structure which leads to false accounting of the port contribution.

By adding extensions to all ports this reduces the contribution of the evanescent modes to the port signals. Initially we added lossless pipes, but found that with lossy pipes the same effect could be had for a smaller model. Steel was chosen as it is the material used for our vacuum pipes and thus was representative of the installed environment of the machine.

One does not want to capture the output signal due to the original beam signal. Ideally each port can have a capture delay set so that signals are only analysed after the input line charge has fully passed through the port.

Eigenmode Simulation

Currently, the eigenmode simulations return many longitudinal modes which can not exist in the real structure, (ideally it should be possible to match up the resonances between eigenmode and wake solvers). This is due to the need for all pipes and ports to be closed for this type of simulation. A capability to have ports in an eigenmode simulation would mean that the reported modes should be just ones which are present in the physical device and will be a focus for further development.

CHECKING RESULTS FOR SELF CONSISTENCY

In order to build confidence that what is returned by the simulation is a good representation of the real behaviour, we apply many checks to the data to make sure that the results are self consistent and do not violate any physical laws, conservation of energy for example.

The initial check is, whether all the energy has been accounted for. If not, generally the simulation has not run long enough. The aim is to get as close as possible to 100% within a reasonable simulation time. If more than 100% of the input energy is accounted for, this indicates that there is unphysical behaviour in the simulation. Figure 2 shows the energy accounting for a set of button pickups. Most of the energy is accounted for, and in this case the vast majority of the energy is coupled out of the structure through the ports.

In order to determine if the simulation has stabilised we look at several results, as illustrated in Fig. 3. The top graph shows the cumulative sum of the energy out of all

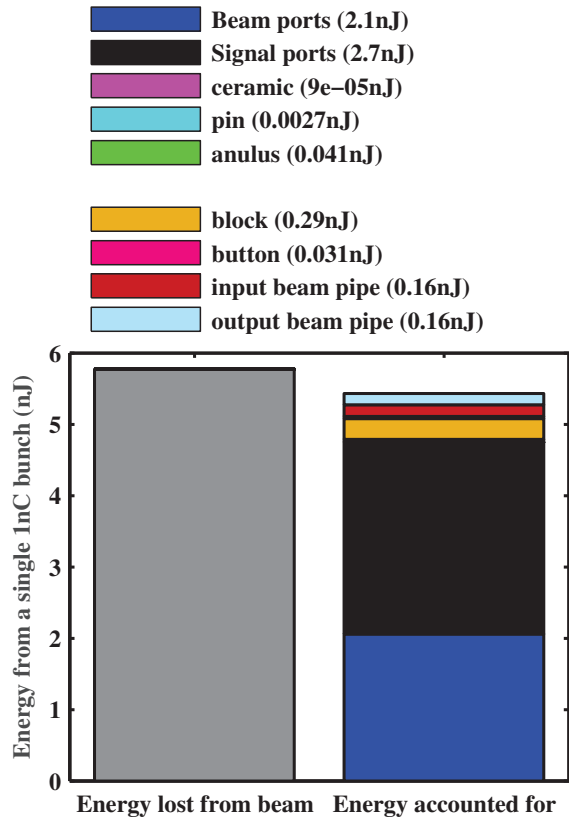


Figure 2: Energy accounting for a beam position monitor button.

ports, so a horizontal line means that the signals out of the ports have decayed away, and no further energy will be emitted. The middle graph shows the cumulative sum of all the energy deposited in the different materials in the structure. The lower graph shows the ring down of the wake potential. Often the wake potential will not ring down fully within the simulation time due to high Q resonators in the structure. This introduces errors into any frequency domain analysis such as calculating the wake impedance. How much of a problem this is will depend on the details of the model under scrutiny. Figure 4 illustrates the effects of truncating the time domain wake potential for a button block.

One type of simulation artifact is a resonator which does not decay, and so would ring on for ever. In this case, the simulation will never fully stabilise and the energy from the ports will eventually exceed the total energy put into the structure by the beam.

Once we are satisfied that we have a simulation which has a long enough wake and stabilises well, we move on to more detailed checks.

So far all the checking has been done in the time domain. This next set moves into the frequency domain. As the simulations are all based on linear equations, then there can be no energy transfer between frequencies. Thus if any

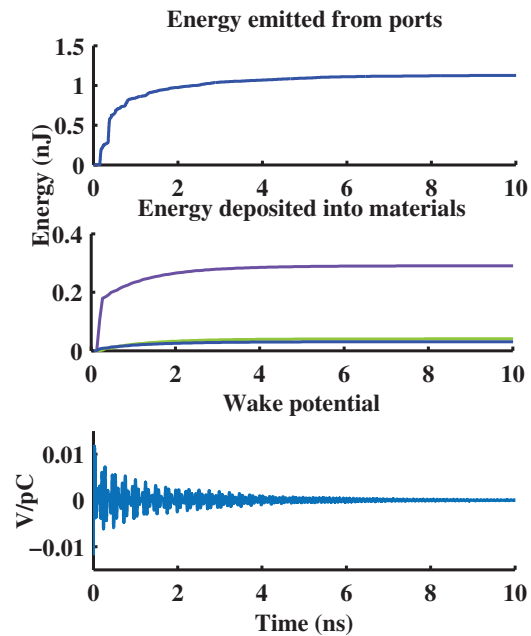


Figure 3: Typical results for a stable model.

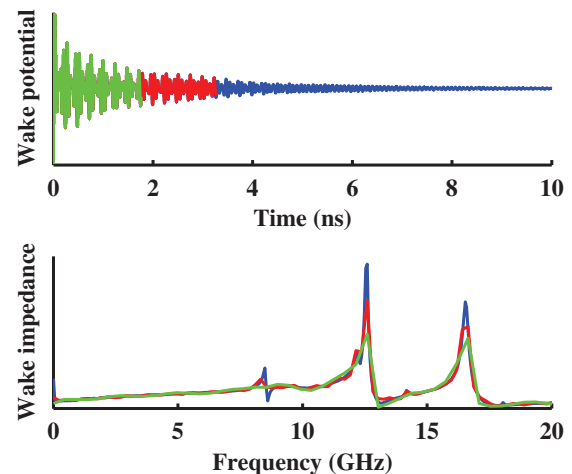


Figure 4: The effects of truncating the wake potential.

frequency has more energy coming out of the ports than was put into the structure, it indicates there is a problem which needs further investigation.

If the discrepancy occurs at a waveguide cutoff of a port, it usually indicates that the simulation is struggling to correctly represent the signal so close to the threshold. In terms of the energy accounting it often has negligible impact due to the sharpness of the resonance. More generally it usually means that either, the port is seeing the fields from evanescent modes, which do not leave the structure or too short a wake has been used causing the time signal to be truncated. Figure 5 shows an example of this. Around 9.6 GHz, the energy from the ports exceeds that deposited by the bunch.

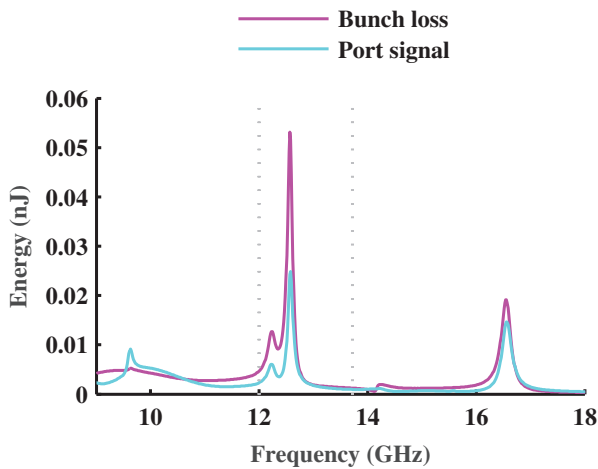


Figure 5: Frequency domain signals emitted from ports and deposited by beam.

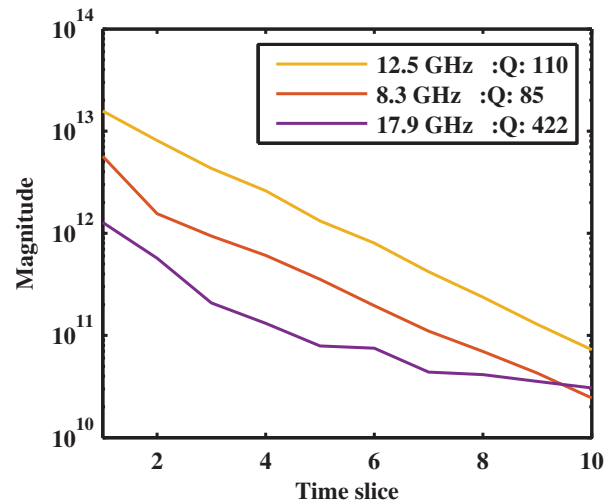


Figure 7: The decay of resonance peaks in a button structure.

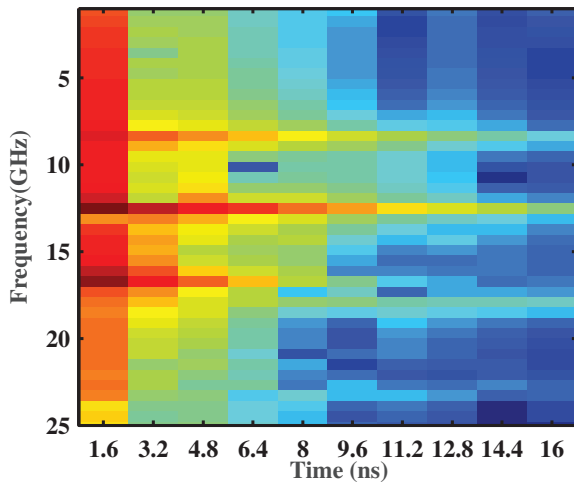


Figure 6: Spectrogram of the wake potential.

Although we have run the simulation long enough for it to stabilise in the time domain, there is still the question of how accurately the resonances in the structure are represented. In order to check this we run the frequency domain processing on a series of increasingly truncated wake potentials. If the Q values obtained for the resonances do not change if additional wake length is added then they are properly represented.

A related check is to separate the wake potential data into chunks of time, and then fourier transform each chunk. This gives a time evolution of the spectrum, and from this one can calculate the decay rate and thus the Q of the resonances. Resonances with extremely high Qs are most likely artifacts but certainly bear further investigation as they could be trapped modes in the structure.

Figures 6 and 7 show a typical result from a button pickup. Figure 6 show the spectrogram of the wake potential. Each

collum is the spectrum of 1.6ns of time. three high Q resonances can be seen at 8.3 GHz, 12.5 GHz and 17.9 GHz. An initially strong but fast decaying resonance can be seen at approximately 16 GHz.

Figure 7 shows the trend of the three highest Q resonances in the simulation. The 8.3 GHz and 12.5 GHz lines show the expected exponential decay. However the 17.9 GHz line levels off. This probably indicates the numerical noise floor of the simulation, but a longer simulation could be run in order to see if the other lines also level off when they reach that magnitude.

CONCLUSION

We have described the workflow used in order to investigate many long wake behaviours of the various structures for the Diamond accelerator.

We have also shown how developments in the core simulation code are allowing us to develop new more robust ways of investigation energy losses.

Further work on integrating the output of the wake and eigenmode solvers is expected to improve our understanding of which field patterns contribute to undesired outcomes. Allowing for more targeted solutions.

REFERENCES

- [1] A. F. D. Morgan G. Rehm, *Quantifying dissipated power from wake field losses in diagnostic structures*, IBIC 2013.
- [2] A. F. D. Morgan G. Rehm, *Finding the distribution of wake field induced losses in diagnostics structures for realistic machine conditions*, ICFA mini-workshop on Electromagnetic wake fields and impedances in particle accelerators 2014.
- [3] Mathworks, www.mathworks.com
- [4] Computer simulation technology, www.cst.com
- [5] GdfidL, www.gdfidl.de