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LONGITUDINAL IMPEDANCE MODELING OF APS PARTICLE ACCUMULATOR RING WITH CST*

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Abstract

The APS-U (APS upgrade) ring plans implement a "swap out" injection scheme, which requires an injected beam of 15.6 nC single-bunch beam. The Particle Accumulator Ring (PAR), originally designed for up to 6 nC charge, must be upgraded to provide 20 nC single bunch beam. Our studies have shown that bunch length of the PAR beam, typically 300 ps at lower charge, increases to 800 ps at high charge due to longitudinal instabilities, which causes low injection efficiency of the downstream Booster ring. We completed beam impedance simulation of all the PAR vacuum components recently with CST wakefield solver [1].

3D CAD models are directly imported into CST and various techniques were explored to improve and verify the results. The results are also cross-checked with that from Gdfidl and Echo [2,3] simulation.

We identified 23 bellow- and 24 non-bellow flanges that contribute to as much as 40% of the total loss factor. We are considering upgrade options to reduce overall beam energy loss and longitudinal impedance.

Beam tracking simulation is in progress that includes the longitudinal impedance results from the CST simulations. This is not reported here.

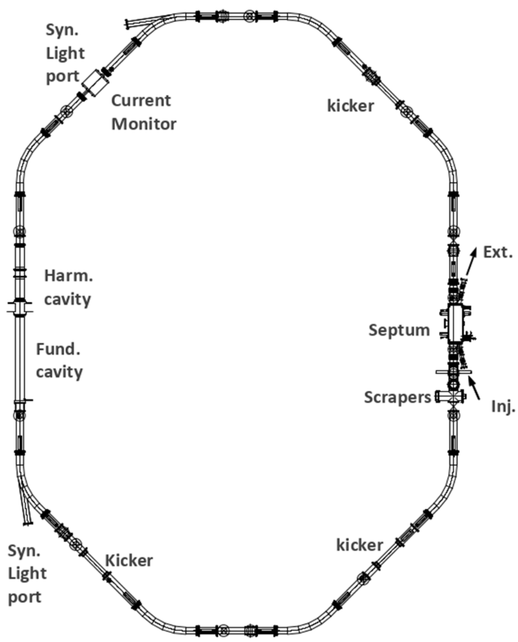

Figure 1: Layout of the PAR vacuum chamber.

INTRODUCTION

A layout of the PAR vacuum chamber is shown in Fig. 1. It consists of an injection section, an rf cavity section that houses a fundamental cavity and a 12th harmonic cavity, eight 45° bending chambers, and six straight chambers for BPMs, kickers, etc.

CST Studio Suite was selected because its ability of importing models directly from CAD models and it is available both on Windows PC and Linux workstation. Most of the simulations were performed with a bunch length of 50 ps and a total wake length of ~50 ns. The PAR beam has a bunch length of from about 300 ps to 1 ns, depending on rf settings and beam current. This selection of parameters is a compromise between desired bandwidth and frequency resolution, and computer resources and simulation time.

Table 1 is a list of all the components that are included in the simulation

LOSS FACTOR RESULTS

A 20 nC beam in the PAR loses significant amount of energy due to cavity and chamber impedance. In table 1 we listed the loss factor result from wakefield simulations. Most significant contributors are: kicker chambers, bending chambers, florescent screens and scraper chambers.

The kicker ceramic chamber has a resistive coating of 75 Ω per square, which contributed to the high loss factor. We plan to do a surface resistance measurement to confirm the specifications.

Figure 2 shows a plot of beam loss factor vs bunch length, which is computed based on the impedance results and Gaussian beam distribution. Based on this results a 20 nC PAR beam with 600ps bunch length will lose 1.32 kW of power. This must be considered in the overall power requirement of the rf system.

Loss factor measurement of the PAR are performed [4], which showed a loss factor of 160 V/nC for a 10nC with a bunch length of 1nS. Comparing with simulation there is a 16% difference. We plan to further investigate the causes of the discrepancy and revisit some components that contribute large portion of losses, such as kicker, florescent screens, and bellowed chambers.

IMPEDANCE RESULTS

Figure 3 shows the total real and imaginary longitudinal impedance of the PAR. Longitudinal beam tracking is under way with the results from these impedance results.

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Table 1: List of Components and Loss Factors

Name	Number	LossFactor	Loss %
BPM	16	0.024	3.91
Tune stripline	2	0.028	0.57
VHScraper+FL6	1	0.5303	5.40
BM chamber	6	0.292	17.84
BM+LPort	2	0.292	5.95
Kicker	3	1.192	36.41
RF1 Cav	1	0.1029	1.05
RF12 Cav	1	0.223	2.27
Curr. Monitor	1	0.4237	4.31
Septum	1	0.1204	1.23
Pump28	2	0.002	0.04
Pump22	2	0.0002	0.00
Pump19	1	0.0017	0.02
FL1+Valve	1	0.6799	6.92
FL2-5	2	0.16	3.26
FL2-4	2	0.156	3.18
Bellow27	1	0.0465	0.47
InjExtBellow	2	0.1667	3.39
Add. Bellows	1	0.145	1.48
Add. Flages	3	0.0284	2.31

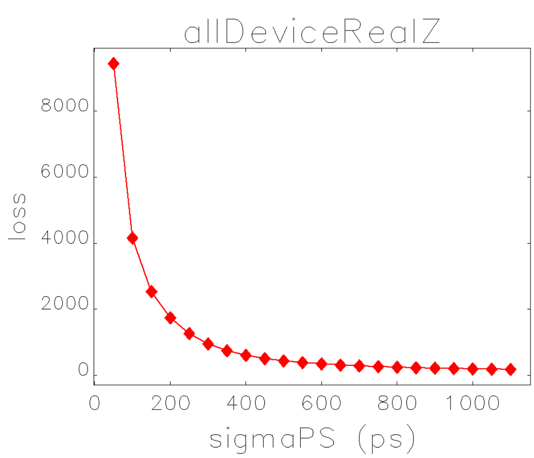

Figure 2: Energy loss of a 1 nC beam vs bunch length. At 1 ns bunch length the loss is 185 eV.

BALANCE OF BEAM LOSS ENERGY

In order to verify the validity of the simulation results we performed energy balance check. Beam losses from loss factor evaluation should equal to the sum of metal loss, residual energy in the simulation region and integral of power losses through the ports. Table 2 showed the results for a 1nC beam. Overall a few percent of a difference is achieved. For a 1 nC charged beam in the PAR this is equivalence of a difference of ~0.01 W.

CST provides port power related 1D data: (1) port signal time domain. (2) port power spectra. We found that these data do not provide consistent results. Instead we monitored 3D power flow (Poynting vector) and post-processed surface integral on port surface. This method produces a more consistent data. We also found port geometry has significant impact on port power losses. It is essential to define individual chamber component with the same vacuum chamber geometry for the beam entry and exit ports. Figure 4 shows integrated losses over time of a PAR kicker chamber.

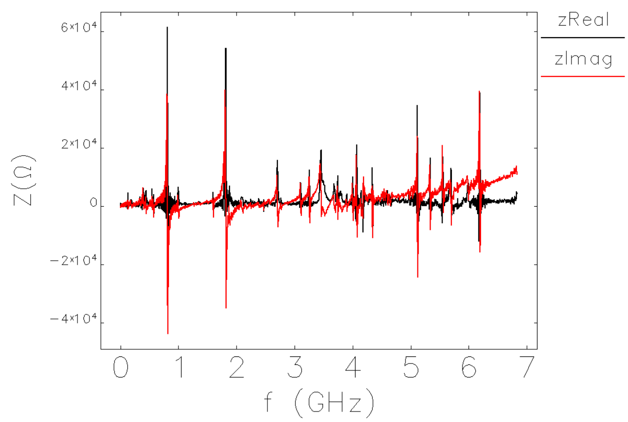

Figure 3: Real and imaginary total impedance of the PAR.

Table 2: Comparison of Beam Loss and Sum of All Energy Losses of a 1 nC Beam

Name	Beam Loss (nJ)	Port Loss (nJ)	Sum of Loss (nJ)	Difference (%)
BPM	23.97	22.76	24.004	0.14
FL1+Valve	688.9	164.6	689.11	0.03
FL2	202.4	18.75	203.18	0.39
FL3+Pump	206.2	7.04	207.4	0.58
BM+bellow	292.3	3.56	296.64	1.48
Bellow	144.7	13.6	159.06	9.92
Flange	28.4	2.17	27.92	-1.69
injExtFlange	166.7	0.221	155.821	-6.53
Scraper+FL6	530.3	13.81	531.11	0.15
Curr.monitor	423.7	13.7	423.9	0.05
Kicker	1191.7	24.1	1180.83	-0.91
Septum	120.4	8.65	120.54	0.12
RF1Cavity	102.9	4.03	112.16	9.00
RF12Cavity	222.7	98.57	223.23	0.24

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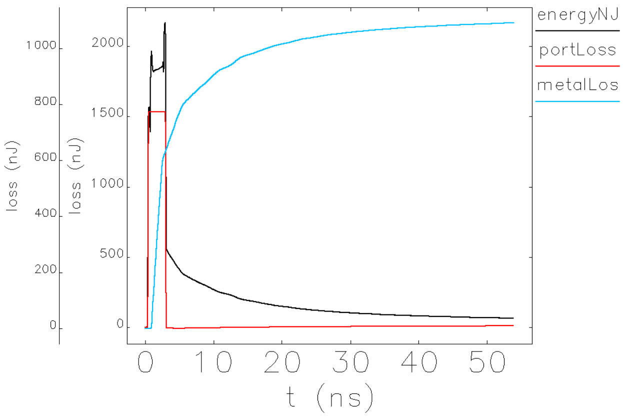

Figure 4: Stored energy and integrated metal and port losses vs time of the kicker chamber.

The short flat-top peaks represents the time when beam bunch is in the structure and the energy represents the non-radiation field that moves with the beam. The metal loss rate is basically proportional to stored energy.

STORED ENERGY PROFILE

Profile of 3D stored energy in the simulated structure provides valuable visual information, such as field leaks via metal interface, incorrectly specified material, incorrect port modes, coupling of various modes, etc. This helps improve the accuracy of the model. Figure 5 shows a cut view of the septum model and Figure 6 shows stored electric energy distribution of the septum magnet at 31 ns after beam entry.

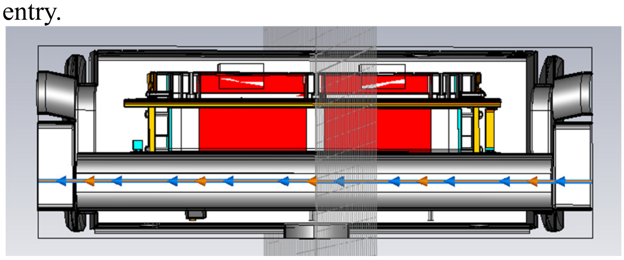

Figure 5: Cut view of PAR septum. The stored beam is indicated by arrows. Injected (from right) and extracted (to the left) are through the top beam pipes.

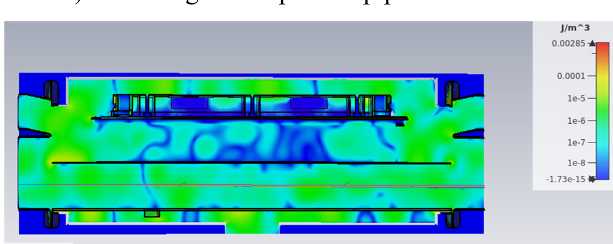

Figure 6: Electric field energy after 31 ns of beam entry. The field level is very weak.

EFFECT OF BELLOW GAPS

The PAR vacuum chamber has 23 bellow flanges. Figure 7 showed the details of a bellow flange design. The PAR bellow flanges do not have a liner. A 10mm gap exists between the connecting vacuum chambers. We scanned the gap sizes in simulation to assess the effect of the gap sizes on loss factor and impedance. Figure 8 shows the dependence of loss factor on the gap sizes of the bellow flanges.

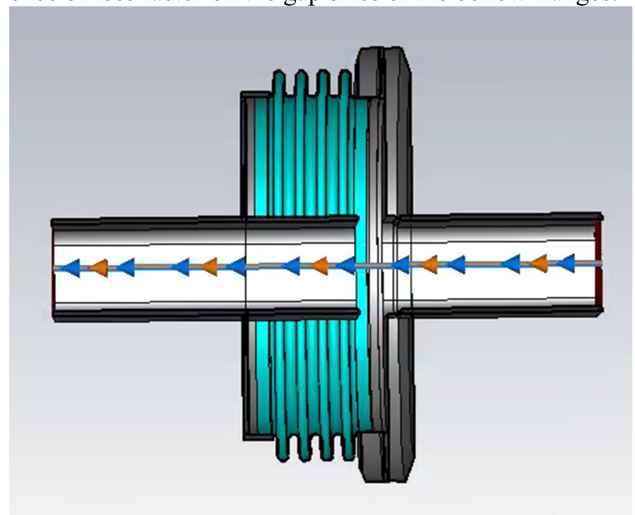

Figure 7: PAR chamber bellow flange with a 6 mm gap between the liner (left) and a right chamber.

CHAMBER IMPEDANCE UPGRADE

We have achieved a 20 nC PAR beam. But the bunch length is too long at about 1ns, which is too long for the 2.84 ns rf bucket and the booster efficiency decreases at high charge. Improving chamber impedance is one of the options to achieve shorter bunch length. Currently we are working on two areas: (1) replacing a scraper/florescent screen section with a smooth spool pipe. (2) replacing the bellow flange with a different gasket that reduces the gap size by a factor of 50% or more. We estimate that with these upgrades we can achieve a 13% reductions in overall beam loss and similar amount in impedance.

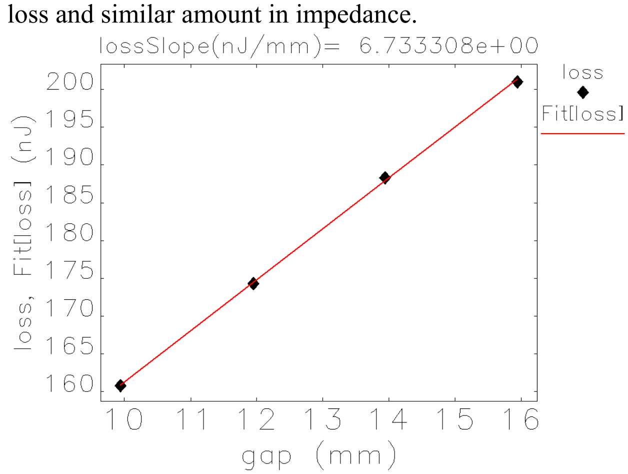

Figure 8: Loss factor gap scan result.

CONCLUSION

We completed a full-ring exact-model wakefield simulation of the PAR longitudinal impedance with CST. The results provide beam loading data for the determination of rf system upgrade. The impedance data is used for beam instability analysis. Based on the simulated results we identified a few areas for an impedance upgrade.

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