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USING DRIVE RODS IN INDUCTIONS CELLS TO REDUCE THE BEAM BREAK UP INSTABILITY *

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Abstract

The beam breakup instability is an effect that must be heavily suppressed for optimum operation of high current induction accelerators. The RF modes generated inside the induction cells can deflect or degrade subsequent beam traversing the cell. Significant effort has been invested in minimizing the effect over several decades. One mechanism that is known to reduce the transverse impedance, the main observable experimentally which directly relates to the BBU amplitude, is to introduce ferrites to absorb the fields. Another, less investigated mechanism, is to disturb the modes symmetry by inserting the drive rods at the proper locations in the cell. This paper will show that the drive rods can dramatically reduce the transverse impedance and will show that simulations are maturing towards predicting this effect.

INTRODUCTION

Linear Induction Accelerators (LIAs) have the capability to accelerate enormous currents up to tens of MeV. Previously constructed LIAs have accelerated up to 100 kA of electron beam to energies near 50 MeV [1]. The uses for these devices are diverse such as: radiography, heavy ion fusion, and beam plasma studies. There are two flavors of LIA: core and coreless. Several of each type of have been constructed and each has their own pros and cons. Currently, a new conceptual design for a multi-pulse core-type LIA, called Scorpius, is being developed to have beam quality for use in flash radiography. Beam instabilities, such as the Beam Breakup instability (BBU), can have detrimental effect on the overall spot size on the target.

BBU is generated when the beam is off center of the axis and travels past an aperture, such as an accelerating cavity or cell. This sets up RF modes that proceed to ring in the cavity. These modes will then produce electric and magnetic fields that will further displace the beam. The TE modes are of little consequence as the magnetic field and electric fields will effectively cancel, as shown by the Panofsky-Wenzel theorem [2]. The dominate transverse mode is therefore the TM_{11} mode.

To quantify how large the RF modes are, the transverse impedance of the accelerating cell can be measured using a two-wire approach [3] and modelled with software such as AMOS [4] and CST Studio - Wakefield [5]. The BBU amplitude growth (Γ) can then be calculated as

$$\Gamma \propto N * I * Z_{\perp}/B \qquad (1)$$

where N is the number of gaps, I is the current, B is the magnetic field, and $Z_{\perp}$ is the transverse impedance of the cell. To reduce the BBU, one either must increase the magnetic field – leading to higher corkscrew motion, reduce the number of gaps – higher voltage cells, or decrease the current – requires higher voltage to achieve same dose for radiography. Larger voltage cells require larger gaps to hold of the voltage pulse, which in turn have larger transverse impedance. Figure 1 shows how the peak impedance is dependent on the gap size compared to the beam pipe radius.

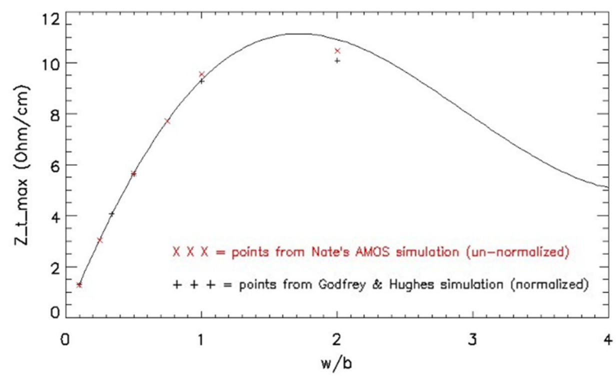

Figure 1: Plot of the theoretical peak impedance for a pillbox cavity with a gap width of w and a beampipe radius of b according to Briggs for the TM_{11} modes [6]. This plot also shows the simulated data points by Hughes and Godfrey and those produced by the authors with AMOS. All three are in close agreement. Plot produced by Carl Ekdahl [7].

One common method to reduce the $Z_{\perp}$ is to insert ferrites into various locations in the cells to damp out these modes. However, these ferrite locations may interfere with or increase risk to the design of the cell. This paper will focus on cell designs and how they are powered, the drive rods, can be used to effectively provide the same reduction in $Z_{\perp}$ on the largest modes of the cell if properly designed.

CELL DESIGNS

Two cell designs are shown in Figure 2. These cells are simple cells that generally mimic the conditions traditionally placed on LIA cells. Cell A is a push-pull cell, or where the one side is -V and the other +V. It contains a center channel that leads to two ferrite cores flanking each side. Four drive rods are positioned on the step on the tab of material covering the ferrite core. The positions of the drive rods are shown in Figure 2 for Cell B. Cell A's drive rods are positioned similarly but each half of the cell has 4 rods (total of 8 for the cell) azimuthally separated from each other by 90 degrees about the beampipe.

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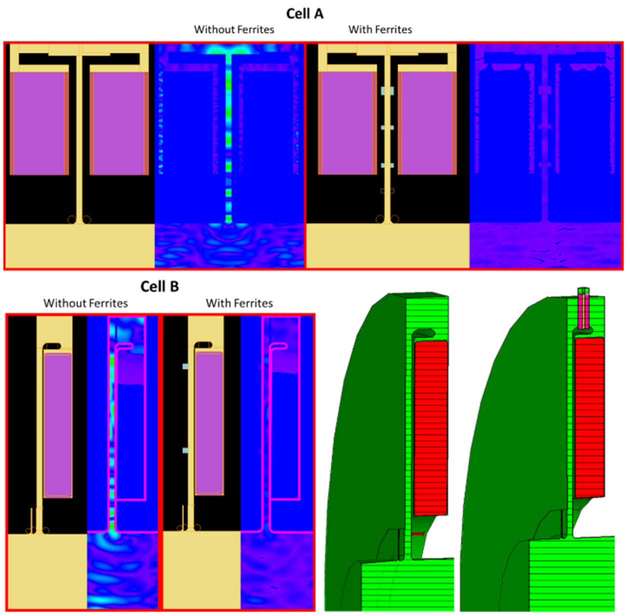

Figure 2: The two cell designs studied are presented in each of their configurations: no ferrites (left) and with ferrites (right). Each configuration also has the H_ϕ plot adjacent to it on the right. These plots show the substantial decrease in field when the ferrites are located in the gap. This illustrates that the drive rods should have little to no effect when the ferrites are in the gap. The lower right image indicates the position and how the drive rods are inserted in to each of the cells.

To demonstrate the effect of the ferrite damping, a set of concentric rings made of the core ferrite can be placed on the sides of the central gap in each cell design shown in Figure 2. All the ferrites damp out the RF modes, some better than others based upon their μ″, but the rings were placed at strategic locations for supressing the modes based upon their field distributions.

The Cell B is a more typical -V to ground design. It also has a vertical channel that connects to the ferrite core. The 4 drive rods are still located on the tab above the core and separated by 90 degrees as in Cell A.

SIMULATIONS

These two cells were simulated in both AMOS and CST. AMOS is a 2.5 D cylindrically symmetric code that provides the TM_{1m0} modes and their impedance in Ω/m. AMOS has been benchmarked against measured data for several cell designs over the past two decades and has good agreement. Using AMOS, these two cells were then optimized to reduce their impedance by placing the ferrites at strategic locations. These locations are where the H_ϕ fields' magnitude was the strongest in the channel. The H_ϕ plots for the two cells with and without their ferrite rings are shown in Fig 2 adjacent to their cell designs. The AMOS simulations computed the transverse impedance for the dominate TM_{11} mode for both cell types and w/o ferrites but not drive rods. These results with CST are shown in Fig. 3 and Fig 4. The AMOS results are shown in Figure 5

For the simulations with drive rods, CST Studio was utilized to add four 50 Ω ports to the cells. CST Wakefield solver was used to calculate the total transverse impedance of the cell, which is in Ω. The effect of the 50 Ohm port being added to each cell configuration is shown in Fig. 3 and Fig 4. Figures 3 and 4 show the results from CST in Ω/m as the impedance was divided by the offset of the beam from the axis. This provides a good comparison to AMOS but has an elevated background generated from the other modes.

It is important to do both the AMOS simulation and the CST simulation as neither can provide all the information. AMOS is quick but axisymmetric, CST requires significant computational time but does not immediately report the TM_{11} modes which is critically important as the TM_{11} mode structure is the quantity that is physically measured in the fabricated cavity.

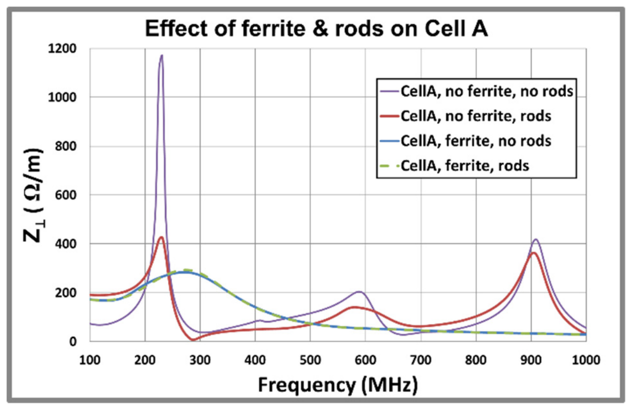

Figure 3: Plot of the $Z_\perp$ for Cell A as modelled in CST. The insertion of the drive rods significantly decreases the impedance of the lowest frequency peak but has little effect on the higher frequencies. The ferrites supress the field significantly across all frequencies such that the field effectively never reach the drive rods, hence no effect on the impedance when the ferrites are present.

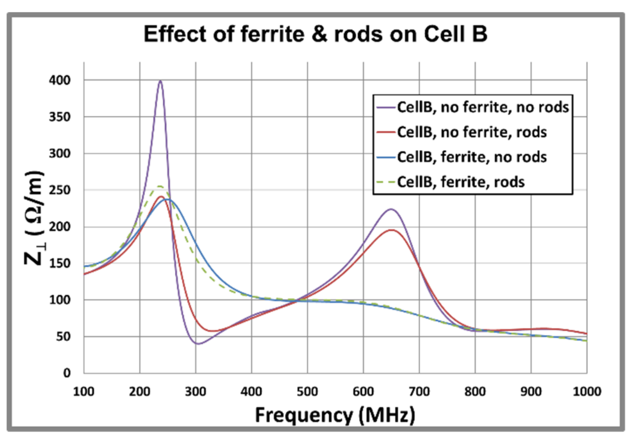

Figure 4: Plot of the $Z_\perp$ for Cell B as modelled in CST. Cell B responds in the same manner as Cell A. The difference is Cell B's higher frequency peak is significantly stronger due to the cell design and might require ferrites for suppression.

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Modal Decomposition

The $Z_\perp$ generated by CST is from all modes. This output is not comparable to AMOS or to direct measurements of the fabricated cell as the twin leads are set off center to produce a TM_{11} mode. As shown in Fig. 5, the magnitude of the peaks for Cell B are comparable, however CST impedance at every frequency is higher than AMOS. This has been shown to be due to the inclusion of other asymmetric modes in addition to the TM_{11} mode. In order to obtain a more precise comparison, we will be performing a modal decomposition of the fields from CST. These simulations are currently underway.

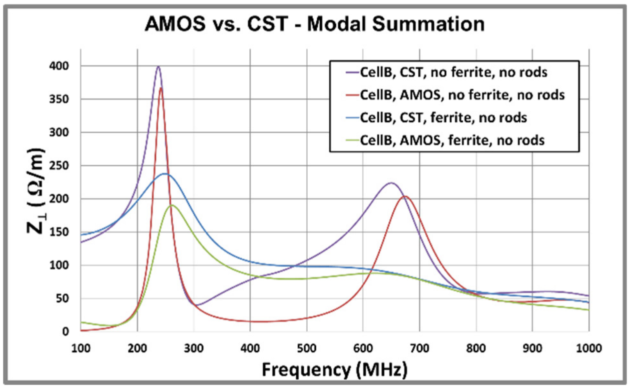

Figure 5: Comparison of CST to AMOS simulations for Cell B. The CST simulations have all modes included whereas AMOS only shows TM_{11}.

Measurements

Using the twin lead method developed by Fawley and Briggs [3], Cell B was constructed and measured. The measurements, shown in Fig. 6, illustrate that the $Z_\perp$ is reduced as predicted by AMOS and CST. The AMOS simulation and the measurement with no rods, no ferrite configuration for Cell B is very close in shape and magnitude. The CST simulation is slightly higher and broader as is expected from the additional modes. The measured reduction is more significant than the model predicts. The modal decomposition should provide a better prediction as a direct comparison of the TM11 modes in the simulation and measurement can be made in each case.

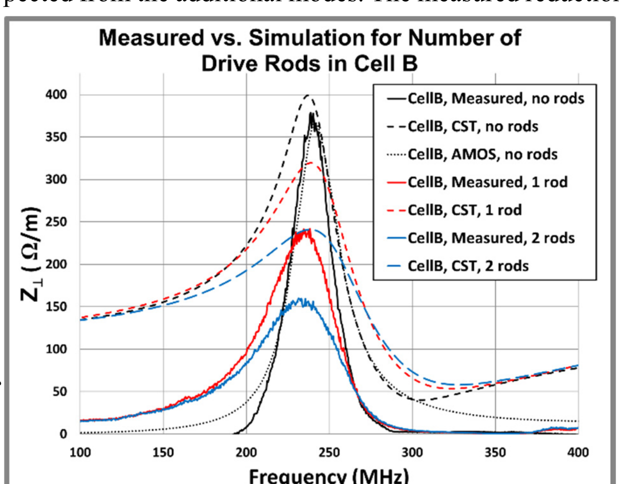

Figure 6: Plot showing the effect of the drive rods compared to CST and AMOS simulations, as well as the effect of the number of rods.

The setup was also simulated and measured with various numbers of drive rods and orientation with respect to each other and horizontal plane (0 deg). The twin leads were set at 90 and 270 degrees. Table 1 shows the reduction in $Z_\perp$ for each case. The case of two rods aligned with the twin leads has the greatest effect as the mode is most disrupted, however the two rotated 90 degrees has minimal impact on $Z_\perp$. Using more rods should disrupt the fields more and also reduce multipole focusing on the beam caused by the drive rods insertion into the cell.

Table 1: Drive Rod Position vs. Measured $Z_\perp$ reduction

# of rods	Magnitude Ω/m	Separation deg.	Location Hor. 0 deg.	%
2	160	180	90, 270	41
3	164	90	0, 90, 270	42
4	181	90	0, 90, 180, 270	47
1	242	-	90	63
3	245	90	0, 90, 180	63
2	257	90	90, 180	67
2	363	180	0, 180	94
1	367	-	180	95
0	386	-	-	100

CONCLUSIONS

The results of this study show that an adequately designed cell which has a single low frequency mode will have a minimal $Z_\perp$ if drive rods are placed in location of high H_ϕ magnitude. If higher frequency modes exist, ferrites can be placed at large H_ϕ magnitude location near the gap region to effectively damp the higher order terms completely.

This study has also showed that simulations using AMOS and CST are moving closer to predicting fabricated cells and additional effort to get one to one comparison by performing modal decomposition. Additionally, Cell B is currently being altered to allow for the ferrite concentric rings to be added. This configuration will be compared to the results presented.

Lastly, the number of drive rods does have a non-trivial impact on the transverse impedance. Thus, any design should strive to have a high count of drive rods to minimize the impedance and any focusing effects on the beamline. Further studies on these topics are underway.

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