SPL RF Frequency Choice: Cavity Scaling Considerations (Summary)

When simply scaling a 700 MHz cavity and its HOM coupler(s) to 1400 MHz the longitudinal impedance per length $Z_{\parallel}/L$ grows by a factor 2 and the transverse (dipole) impedance per length $Z_{\perp}/L$ by a factor 4. The beam breakup threshold current I_{th} scales as the inverse of $Z_{\perp}/L$, about *independent of the frequency at which* the impedance peaks, i.e. to be dangerous a mode needs not to be close to a main machine line (here multiples of 350 MHz).

This simple geometrical scaling requires twice the number of cavities, couplers, tuners, electronic crates, ... roughly doubling the price of the bare accelerator in this frequency range[1]; doubling the number of cells per cavity is a way to about recover the initial price. This has the immediate ramification that the same HOM couplers have to damp twice the field energy hence Q_{ext} and with it $Z_{\perp}/L$ increased by a factor 2 for *all* modes and I_{th} decreases in total by a factor 8 compared to the 700 MHz case.

On top of this *guaranteed* Q_{ext}-increase there exist two additional causes for a *further* increase, which are difficult to estimate due to the multitude of different HOMs and the inevitable end-cell and fabrication scatter[2] problem.

The first cause is modes that are not flat in field profile but have a considerably lower field in the end-cells – which have to exist even in perfect cavities. Only the end-cell field (in fact its square) couples to the HOM couplers on the beam tubes[3]. For regular pass-bands such modes have ‘scaled-equivalents’ with Q_{ext} up to a factor 4 higher than for flat modes, i.e. I_{th} may decrease in total by factor 32 compared to the 700 MHz case if such an ‘unflat’ mode is the limiting factor. Deformed pass-bands – as happen for higher HOMs – may even have higher factors.

The end-cells are perturbed in frequency by the presence of the beam-tubes. This effect is corrected for the accelerating mode in the design phase but HOMs have to accept this – for them not corrected – end-cell shape. Therefore there can exist families of HOMs that have two modes excited nearly exclusively in one of the end-cells while the other N-2 modes in the family have nearly no end-cell field, called trapped modes. This effect may even be enhanced due to cell-frequency scatter from fabrication. It can be shown that the sensitivity to relative cell frequency scatter is 2 to 4 times more significant for cavities with twice the number of cells. In total this effect gives a further increase of $Z_{\perp}/L$ of the corresponding mode, decreasing I_{th} by the same factor if this mode is the limiting factor.

To avoid over-power problem on the HOM couplers, modes with higher (R/Q) have to be sufficiently far away from the machine-lines at multiples of 350 MHz. Since the beam spectrum remains invariant under the examined scaling, lines are twice as dense at 1400 MHz but this should not present a significant problem due to the sparseness of the machine lines.

An absolute conclusion, especially on the threshold current, can only come from a simulation including the cavity HOM frequency scatter and the intended bunch pattern(s) as done for SNS[4] in assuming $Q_{ext} \leq 1 \cdot 10^8$ for all modes for 6-cell cavities at 800 MHz. Assuming double beam current for SPL, similar f-scatter and bunch pattern, we conclude that (for the *very worst case*) if on the 700 MHz cavities a Q_{ext} of about $2 \cdot 10^5$ can be guaranteed for ***all*** HOMs one might go to 1400 MHz with twice the cell number with the same security factor as for SNS.

---

[1] Ph. Bernard, E. Chiaveri and J. T. : “Technical and Financial Implications of the frequency choice for a sc. accelerator section”, Jan. 1996 (unpublished).

[2] The scatter problem might be avoided by complete cavities being produced from large solid and well annealed Nb slabs on a numercically controlled lathe; but it would not be affordable anymore.

[3] Putting coupling ports directly on the cells will limit the obtainable gradient (field enhancement) and carry the risk of multipactor as learned by the 500 MHz 5-cell cavity test.

[4] R. Sundelin, D. J. Kim and Marc Doleans, “SNS HOM damping requirements via bunch tracking”, Proc. PAC 2001, Chicago.