An Empircal Study of HOM Frequencies

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Abstract

A study in the late 1980's by Ron Sundelin measured the statistics of cavities constructed for use in SNL. This work examined the spread of frequencies for each of the resonant modes of the cavity, as well as the measured differences from those predicted by simulation. A measurement in 2006–7 of the cavities installed at SNS approximately confirmed the empirical rules developed in the original study.

The unpublished status of these studies means that data must be collated from various sources. This document is an attempt to summarise the results.

1 Introduction

In the late 1980's, Ron Sundelin studied a series of SCRF cavities in order to understand the statistics of the distribution of the resonant frequencies of the cavities, as well as to quantify the difference between the frequencies measured in the cavities and those predicted by simulation codes.

In 2006–7, studies of SCRF cavities installed at SNS demonstrated that the empirical rules developed in the earlier study were approximately correct, and therefore of viability beyond the exact cavities studied.

Unfortunately, this study does not appear to have been published anywhere, despite having been referred to in several publications and presentations [1, 2].

This document is an effort to summarise the results of his studies.

2 Background

As explained in [3], the effect of the HOMs on the beam dynamics depends critcally on whether or not the frequency of the mode coincides with a significant line in the Fourier spectrum of the beam.

It is, therefore, of considerable importance to identify the frequency spectrum of the cavities as installed on the machine.

Due to manufacturing errors, the cavities will have to go through a tuning procedure after installation in the linac. This procedure is designed so as to move the fundamental (π–mode) to the correct frequency, with no regard for its effect on the parameters of the HOMs.

Thus, it is possible that a mode found to lie far from a machine line, may be shifted, either by manufacturing errors, or by the tuning procedure, to a frequency that allows it to cause significant degradation to the quality of the beam.

Sundelin's study gave direct measurements of the statistics of the frequency shifts for a significant, although currently unknown, number of cavities.

3 Centroid frequency

The shift of the centroid frequency from that expected from eigenfrequency calculations is an indication of the common set of differences between the measured cavities, and the 'perfect' cavity geometry used in the simulation.

Sundelin identified two different regions of interest. One was the distribution of the centroids for the fundamental passband, while the second group of measurements was for the remainder of the spectrum (the "higher modes").

3.1 Fundamental passband

For the four non-π-modes in the fundamental passband, Sundelin found the following rule:

$$\left| \frac{f_{meas} - f_{sim}}{f_{sim}} \cdot \frac{f_\pi - f_{sim}}{f_\pi} \right| \leq 0.027 \tag{1}$$

This is equivalent to a statement that the fractional error of the centroid of these modes is less than or equal to 2.7% of the fractional difference of the simulated frequency from that of the π-mode.

That the size of the shift of the centroid frequency is dependent on the difference in frequency from the fundamental mode makes intuitive sense since the cavity tuning procedure is designed to perform best for the fundamental field.

3.2 Higher modes

For modes in higher passbands, the empirical rule was found to be simpler:

$$\left| \frac{f_{meas} - f_{sim}}{f_{sim}} \right| \leq 0.0038 \tag{2}$$

4 Frequency spread

The frequency spread, σ, of the measured HOMs is an indication of the differences between each manufactured & tuned cavity, rather than any differences with the simulated geometry.

The empircal rule found for this quantity is very similar to that shown in sub-section 3.1.

$$\sigma = 1.09 \times 10^{-3} \cdot |f_n - f_0| \tag{3}$$

As in sub-section 3.1, this rule reflects the fact that modes whose frequency, f_n, lies closer to that of the fundamental, f_0, will have tighter constraints on their frequency spread.

5 Summary

That the expected frequencies of these modes are vital in determining how dangerous they are to the operation of ESS means that the empircal rules summarised here provide very important input to the necessary beam dynamics simulations.

References

[1] M. Doleans, D. Jeon, S. Kim, and R. Sundelin, "SNS HOM Damping Requirements via Bunch Tracking," pp. 1984–1986, 2001.

[2] S. Kim, "HOM Experiences at the SNS SCL." SPL HOM Workshop, June 2009.

[3] M. Schuh, F. Gerigk, J. Tuckmantel, and C. P. Welsch, "Influence of higher order modes on the beam stability in the high power superconducting proton linac," *Phys.Rev.ST Accel.Beams*, vol. 14, p. 051001, 2011.