HOM MEASUREMENTS WITH BEAM AT THE CORNELL INJECTOR CRYOMODULE*

S. Posen†, M. Liepe, CLASSE, Ithaca, NY

Abstract

The Cornell ERL injector prototype [1] is undergoing commissioning and testing for running unprecedented currents in an electron cw injector. This paper discusses preliminary measurements of HOMs in the injector prototype's superconducting RF cryomodule. These include HOM spectra up to 30 GHz measured via small antennae located at the HOM beam line absorbers between the SRF cavities. The spectra are compared at different beam currents and repetition rates. The shape of the spectra are compared to ABCI simulations of the loss factor spectrum of the cryomodule beam line. The total HOM power dissipated in the HOM loads was also measured with beam on, which allowed for an estimate of the loss factor. This measurement was accomplished via temperature sensors on the loads, calibrated to input power by heaters on the loads.

INTRODUCTION

At Cornell University, an accelerator designed to sustain a 100 mA electron beam cw is being commissioned as an injector to an Energy Recovery Linac (ERL). The beam is generated by a DC photogun, compressed with a buncher cavity, and then accelerated to 5.5-15.5 MeV by five two-cell 1.3 GHz superconducting cavities contained in the injector cryomodule (ICM). The short bunch length (<1 mm) and high current generate significant power in undesirable higher order modes (HOMs) up to tens of GHz, which is intercepted in HOM beam line absorbers located between SRF cavities [2]. The layout of the ICM beam line can be seen in Fig. 1 (next page). The strong HOM power generated in the ICM provides a unique opportunity to perform experimental HOM studies. This paper presents observations of the effect of varying beam parameters on HOM excitation in the cryomodule. The results are preliminary, meant to show the feasibility of the measurement methods at beam parameters not yet at the design specification.

MEASUREMENT

The HOM absorbing system of the ICM consists of six HOM loads placed between between subsequent cavities and at either end of the cavity string. The HOM loads, depicted in Fig. 2, absorb power in RF-lossy absorber tiles which are cooled with 80 K high pressure helium gas. The loads each have 8 pickups installed near the tiles, as well as thermometers and resistive heaters outside the beam line.

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† sep93@cornell.edu

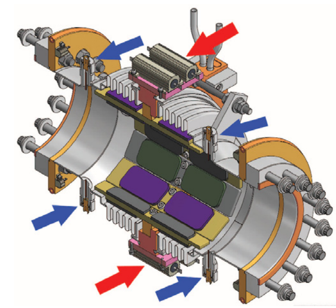

Figure 2: Cut-away view of HOM absorber section with RF probes (blue) and calibration heaters (red) indicated.

HOM spectra were obtained by connecting a spectrum analyzer to one of these pickups and measuring incident power over frequencies from 0-50 GHz. A typical scan requires several minutes of uniform beam and has a resolution of approximately 50 kHz. The coupling stregth of the pickup used and the losses in the RF cables inside the cryomodule could not be measured directly, so they were estimated by measuring transmission loss between pickups on opposite sides of an HOM load and then dividing by two. As an example, a spectrum measured at 2.0±0.1 mA and 50 MHz bunch repetition rate is shown in Fig. 3. The integrated spectrum is plotted on the same graph, illustrating the contribution to total HOM power at different frequencies.

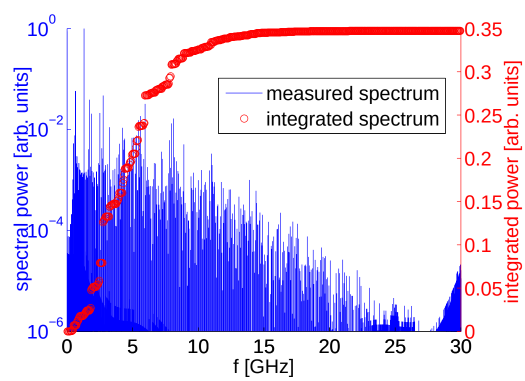

Figure 3: HOM spectrum measured at one of the HOM loads. The integrated spectrum is plotted on the secondary axis. Above 30 GHz only noise is measurable.

Observe that HOMs with frequency >15 GHz contribute negligibly to the total power and that certain stronger modes cause large jumps in the integrated spectrum. However, there are no very strong lines present in the spectrum, which one would expect to see in the case of a resonant excitation of an HOM with higher Q. This shows excellent

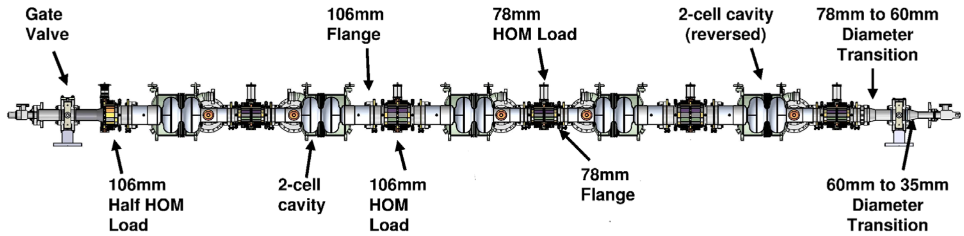

Figure 1: Layout of the ICM beam line.

damping of all monopole HOMs in the ICM beam line up to 30 GHz with typical Q's in the few 1000 range.

VARIATION WITH BEAM PARAMETERS

The single bunch loss spectrum is defined by

$$\frac{dP}{d\omega} = \frac{dk_{||}}{d\omega} qI = \frac{dk_{||}}{d\omega} \frac{I^2}{f_{rep}} \tag{1}$$

where ω is the frequency, P is the HOM power, I is the current, q is the bunch charge, f_{rep} is the bunch repitition rate, and $k_{||}$ is the longitudinal loss factor. $dk_{||}/d\omega$ can be calculated from simulation codes like ABCI [3].

From Eq. 1, the HOM power should depend quadratically on the beam current for fixed bunch repetition rate. This is confirmed experimentally by the integrated HOM spectrum data shown in Fig. 4, in which the HOM spectrum excited by a 1.3$\pm$0.1 mA beam is normalized to the spectrum of the 2.0$\pm$0.1 mA beam presented in Fig. 3 and plotted on the same graph. The two curves follow each other very closely as expected for an unchanged bunch length. Small differences in the plots may be explained by small current variations during data taking.

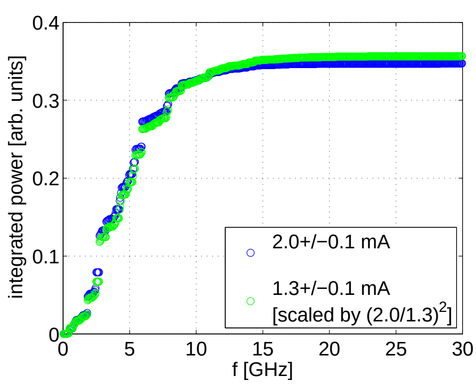

Figure 4: Scaled integrated HOM spectra showing that the shape stays constant with changing beam current.

The HOM spectrum was also measured at different bunch repetition rates. For the spectrum presented in Fig. 3, a 50 MHz laser was used in the photogun. When a 1.3 GHz laser is used instead, the spectral power distribution has fewer lines, corresponding to more widely spaced frequencies of the beam harmonics, as shown in Fig. 5. For proper comparison, the data are scaled by I^2 as before.

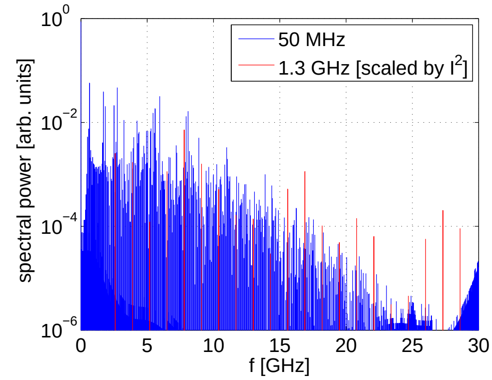

Figure 5: Scaled HOM spectra for different repetition rates.

The low frequency lines seem to match up closely between the two lasers, which indicates that the expected scaling is shown. At higher frequency, the 1.3 GHz laser spectrum has strong spectral lines out much further than the 50 MHz laser. This suggests that the bunch length decreased in the weeks between the 50 MHz measurement and the 1.3 GHz measurement.

The scaled integrated spectra are compared in Fig. 6. The plots follow each other quite closely, taking into account the uncertainty in beam current, differences in bunch length, and potential resonant excitation of modes. This again shows that the expected scaling is followed.

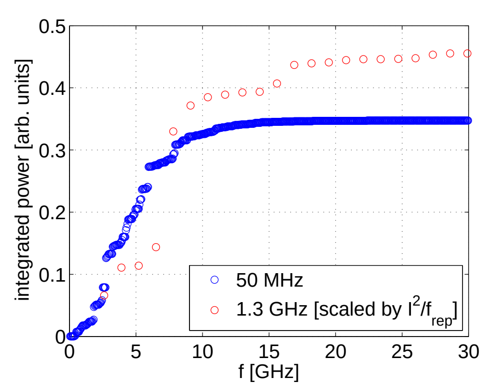

Figure 6: Scaled integrated HOM spectra for different repetition rates. The 1.3 GHz spectrum is dominated by the line at 7.8 GHz.

COMPARISON TO SIMULATION

The measured HOM spectra can be compared to simulations of $dk_{||}/d\omega$ from ABCI, as the measured spectrum should be proportional to the simulated one. Data were generated with bunch length and amplitude as free variables. This was done for both the 50 MHz laser and the 1.3 GHz laser measurements as shown in Fig. 7. The 1.3 GHz data shows spectral lines up to very high frequencies, but because the network analyzer was limited to 40 GHz, the calibrated data is limited to below that frequency.

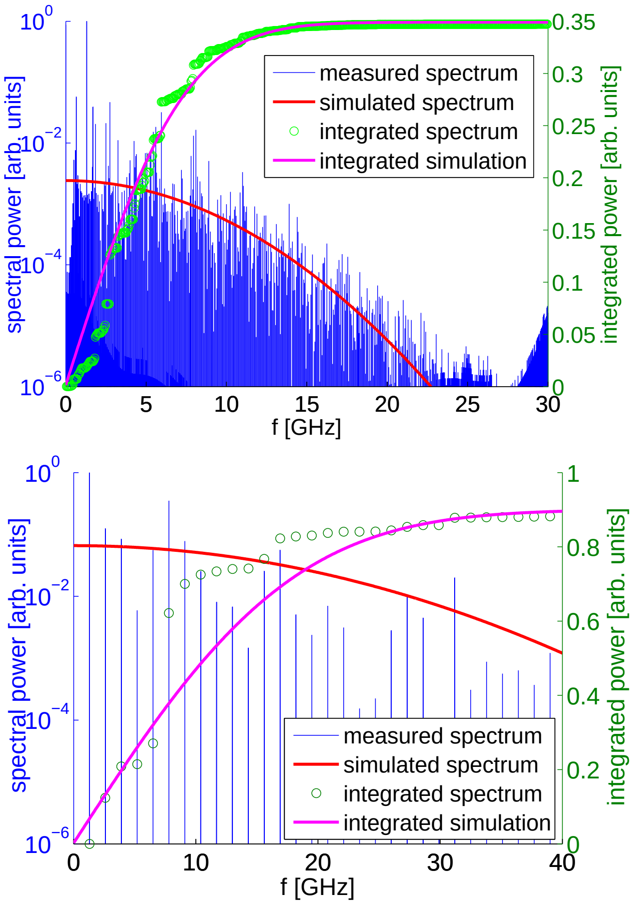

Figure 7: Measured HOM spectra using 50 MHz (top) and 1.3 GHz (bottom) lasers with data from ABCI simulations.

HOM HEATING

At a beam current of 100 mA, the HOM loads should each absorb 40 W, causing a significant temperature increase to be read by the thermometers on them. Even at lower currents, some signal is measurable. With 20 mA, a temperature increase of 0.15±0.10 K was recorded (electronic noise caused this uncertainty). Using the heaters on the loads as a calibrated power signal, this measurement was found to correspond to absorbed HOM power of approximately 0.5 W per load. It is estimated that 50% of the power is absorbed in the HOM loads and the rest propagates out of the ICM beam pipes at the two module ends.

For the measured bunch charge of 15.4 pC, the total HOM power generated gives an estimate of the total loss factor of the ICM beam line of approximately 19 V/pC. From ABCI simulation results shown in Fig. 8 [4], such a loss factor can be attributed to a bunch with length of order 1 mm, as expected.

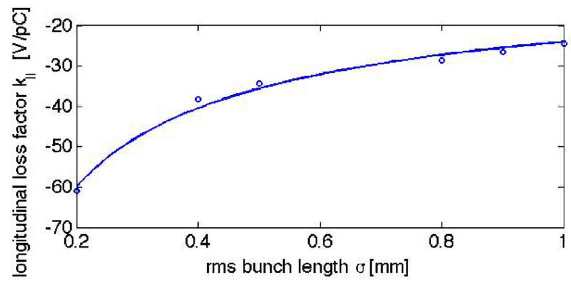

Figure 8: Loss factor at various bunch lengths from ABCI simulations. From [4].

CONCLUSIONS

The HOM spectra measured show the theoretically expected behavior with varying beam current and repetition rate. More significant to assuring proper operation at higher currents, these spectra show that there are no weakly damped resonant modes excited by the beam.

Measurements of heating of the HOM loads were used to give an estimate of the cavity beam line loss factor, which is in good agreement with the loss factor calculated by numerical wakefield simulations. The HOM spectra also produce a useful non-destructive way to measure bunch length during high current beam operation. The HOM heating measurements also showed that the temperature increase of the loads at one-fifth of the design current was quite small. There is much more HOM power interception capacity, which will easily enable running at full 100 mA.

REFERENCES

[1] J. Crittenden et al. "Developments for Cornell's X-Ray ERL," PAC'09, Vancouver, Canada, (2009).

[2] V. Shemelin et al. "Status of HOM Load for the Cornell ERL Injector," EPAC'06, Edinburgh, Scotland (2006).

[3] Chin, Yong Ho. "Users Guide for ABCI Version 9.4," 2005.

[4] M. Liepe and R. Wolf. "Wake Fields in the Cornell ERL Injector," SRF'09, Berlin, Germany (2009).