BEAM LOADING EFFECTS ON PHASE SCAN FOR SUPERCONDUCTING CAVITIES *

D. Jeon#, S. Kim, Y. Zhang, S. Henderson, ORNL, Oak Ridge, TN37831, U.S.A.

Abstract

When the beam passes through superconducting cavities, it excites beam induced field in the cavities. A systematic study was performed to study these beam loading effects with $\beta < 1$ beam for $\beta = 0.81$ superconducting cavities of the SNS linac. The analysis indicates that the induced field level is quite close to the estimation and its effect on the beam dynamics is consistent with the model.

INTRODUCTION

The Spallation Neutron Source (SNS) accelerator system is designed to accelerate intense proton beams to energy of 1-GeV, delivering more than 1.4 MW (upgradeable to 2 MW) of beam power to the neutron production target [1]. The peak current in the linac is 38mA and the macropulse average current is 26mA due to chopping. The linac consists of a warm linac accelerating H^- beam to 186MeV and a superconducting linac accelerating beam to 1GeV. The superconducting linac consists of two parts. One part has 11 cryomodules each of that have three β=0.61 cavities and the other 12 cryomodules each of that have four β=0.81 cavities.

One technique to determine the rf set-point of superconducting cavities is based on the phase scan technique, making a 360° scan of cavity rf field phase and recording the beam arrival time at the downstream Beam Phase Monitors (BPMs). There could be unpowered cavities between the cavity being scanned and BPMs.

For the superconducting linac, beam loading effect is an important factor for tuning the linac and the low level rf control. When a charge passes through a cavity, it can excite modes. The excited modes can be monopole modes, dipole modes etc. A charge q passing through a cavity induces voltage V_q for a monopole mode with mode frequency ω_n and shunt impedance R/Q where V_q is given in Eq. 1 [2]. This induced voltage can decelerate/accelerate beam and affects the beam arrival time at the downstream beam line elements.

$$V_q = \mp \frac{q\omega_n}{2} R/Q \exp(i\omega_n t - \frac{\omega_n t}{2Q}) \qquad (1)$$

In this paper, we consider only monopole modes and their effect on energy loss and the phase scan technique. We first compare the induced field level from simulation with that from measurement. Then we compare the beam arrival time at the downstream BPMs.

* SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy.

#jeond@ornl.gov

BEAM LOADING EFFECT

Beam loading effects were studied with a $\beta < 1$ beam for the SNS Superconducting Linac (SCL) during the commissioning. We checked the validity of the shunt impedance formula of various modes for a $\beta < 1$ beam [2,3]. Eq. 2 shows the shunt impedance of the monopole mode.

$$R/Q(\beta) = \frac{\left|\int_0^l e^{-i\omega_n z/c\beta} E_z dz\right|^2}{\omega_n U} \qquad (2)$$

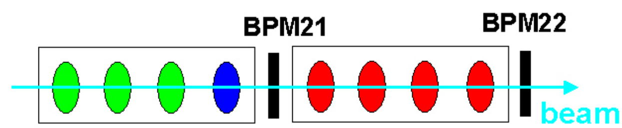

Figure 1: Schematic drawing of Phase Scan

Figure 1 shows the schematic drawing of the phase scan for a β=0.81 cavity. The cavity being scanned is rf powered (blue cavity) and cavities upstream of the BPMs are off (red). As the beam passes through the unpowered cavities, it excites induced field in the cavities. When the frequency of turned-off cavities are not detuned, that is 805MHz, a train of beam bunches coherently builds up field in the cavity and decelerates beam, delaying beam arrival time at downstream BPMs.

Induced voltage comparison

To this end, we recorded the rf signal from the pickup probe of the superconducting cavity as a beam bunch train goes by. Then the induced field level in the cavity is recorded and compared with the simulation.

Figure 2 shows the beam current profile of the 200µs used for the study. The peak current is 18mA. The design peak current is 38mA. Figure 3 displays the induced field level during the 200µs from the pickup probe for the four unpowered cavities 22a to 22d in the cryomodule 22. Table I summarizes the measured and simulated voltage drop in MV for the four cavities in the cryomodule 22. The simulation results agree with the measurement results within 2% except the cavity 22c where the difference is 5.3%. This relatively large difference might stem from the difference in the rf based calibration and beam based calibration of the rf field level in the cavity. The variation in the measured induced voltage drop is due to different loaded Q values of each cavity.

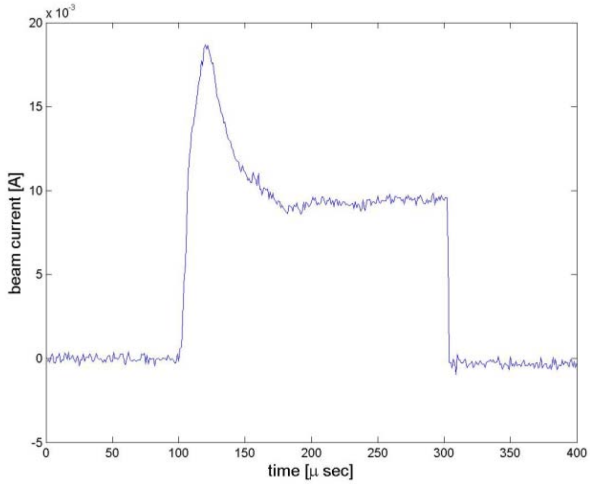

Figure 2: Beam current [A] profile of the 200µsec beam used for the measurement.

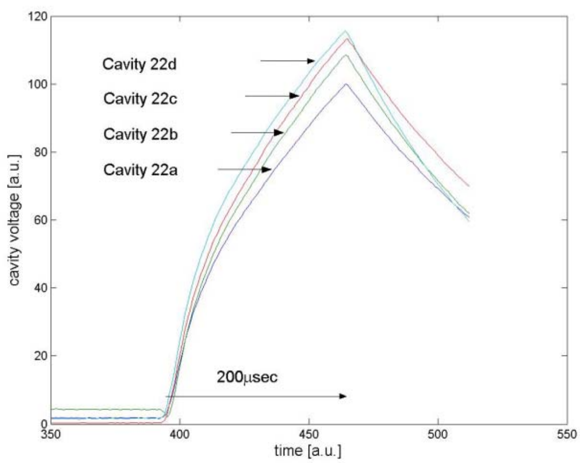

Figure 3: Plots of induced field from the pickup probe for cavities 22a to 22d.

Table 1: Induced field

Cavity	Measurement	Simulation	Ratio
22a	1.890 MV	1.886 MV	0.998
22b	1.838 MV	1.850 MV	1.007
22c	1.940 MV	1.837 MV	0.947
22d	1.760 MV	1.786 MV	1.015

Beam loading effects on Phase scan

The voltage drop across the cavity decelerates the beam and leads to the delay in the beam arrival time at the downstream BPMs. This effect was measured using two different pulse length 20µs and 200 µs. As displayed in Fig. 4, the later beam arrives, the greater the induced voltage drop is.

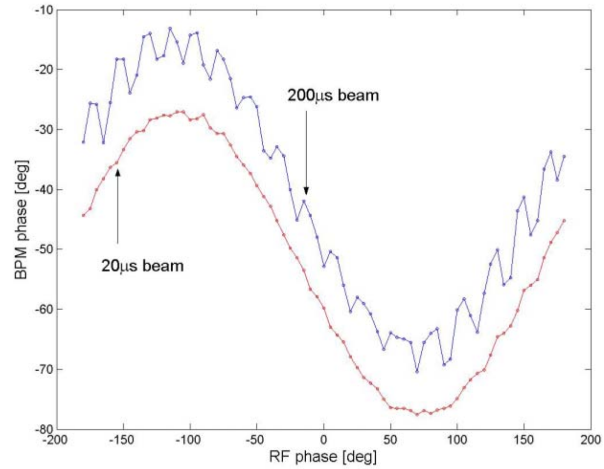

Figure 4: Plots of phase scan for two different beams

For the 200µs beam, the beam arrives at the BPM23 11.37° (10.72° according to simulation) later and at BPM24 18.08° (17.45° according to simulation) later. For the 45µs beam, the beam arrives at the BPM23 2.2° (2.1° according to simulation) later and at BPM24 3.6° (3.4° according to simulation) later. The measurement data agree well with the simulation results.

CONCLUSION

This study validated the shunt impedance formula for a $\beta < 1$ beam and validated the phase scan algorithm under heavy beam loading. As a result of these measurements, the phase scan procedure is done at 20µs and < 20mA beam when the beam induced cavity voltage is minimal.

REFERENCES

[1] J. Wei et al, Proceedings of the 2001 Part. Accel. Conf. (Chicago, 2001), p. 319.
[2] H. Padamsee et al, *RF Superconductivity for Accelerators*, John Wiley & Sons, Inc., 1998.
[3] S. Kim et al, Nucl. Instr. And Meth. A, **492** (2002) 1; D. Jeon et al, Nucl. Instr. And Meth. A, **495** (2002) 85.