# CALCULATIONS AND OBSERVATIONS OF THE LONGITUDINAL INSTABILITY CAUSED BY THE FERRITE INDUCTORS AT THE LOS ALAMOS PROTON STORAGE RING (PSR) *

C. Beltran†, Indiana University, Bloomington, IN, USA
A. A. Browman and R. J. Macek, LANL, Los Alamos, NM, USA

*Abstract*

The frequency dependence of the complex permeability of the ferrite (at room temperature and $125°C$) used in the inductors at PSR has been determined by comparing the $S_{11}$ parameters from a jig containing ferrite and a MAFIA [1] (a program package for the computation of electromagnetic fields) simulation of the jig. Both the frequency response and the longitudinal impedance of the inductive inserts were obtained by simulating the inductor cavity in MAFIA using the ferrite properties from the aforementioned fit. Experimental observations of the longitudinal instability caused by the ferrite inductors at room temperature in a bunched coasting beam have been made. Comparisons of observed and simulated growth times, resonant frequencies, and width of the instability will be discussed.

## LONGITUDINAL INSTABILITY

Three inductive inserts [2], consisting of 30 “cores” each, were installed in the PSR in the late ’90’s to compensate the space charge effect in the beam. A core is a cylindrically shaped ferrite, with thickness of one inch, inner diameter of 5 inches, and an outer diameter of 8 inches. A large longitudinal instability was noticed at approximately 75 MHz, that was devastating to the beam (see Fig. 1).

It was proposed by Popovic [3] that heating the ferrite would eliminate the instability. The three inserts were removed, and replaced by two inserts that were capable of being heated. The heating proposal was then tested and verified in the PSR. How the properties of the ferrite change during heating to cure this instability is the focus of this paper.

## COMPLEX PERMEABILITY

The complex permeability, denoted by $\mu = \mu' + i\mu''$ is a function of frequency. To uncover the frequency dependence, a comparison was made of the measured $S_{11}$ parameters done by Browman [4] of a jig containing a sample core of the ferrite used in PSR to a MAFIA simulation. The jig was designed to maximize the sensitivity to the magnetic properties of the ferrite.

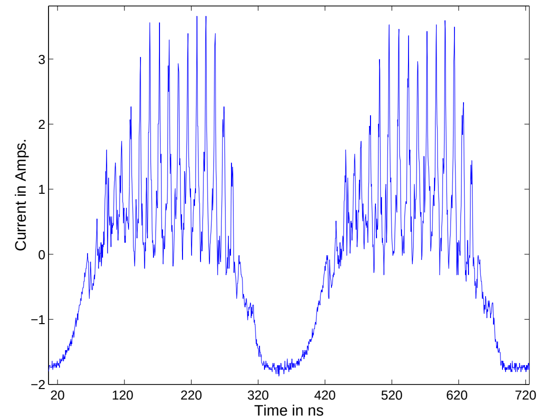


Figure 1: Longitudinal instability caused by the inductive inserts at room temperature.

To find the frequency dependence of the complex permeability of the ferrite, the jig was simulated in MAFIA. Values of $\mu'$ and $\mu''$ were selected for the simulated ferrite at a particular frequency. The $S_{11}$ parameters at that frequency were then calculated and compared to the experimental $S_{11}$ parameters at that frequency. The $\mu$’s were then adjusted accordingly, until an agreement of better then 1% was achieved. The relative permittivity, $\epsilon_r$, of the ferrite was assumed to be constant at 13.

This was done for data sets at both room temperature and $125°C$. The frequency dependence of the complex permeability for the two temperatures is displayed in Fig. 2.

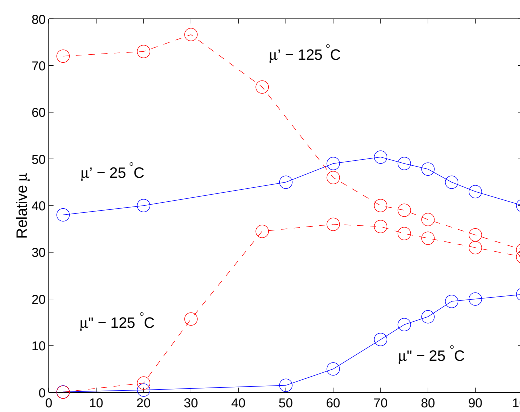


Figure 2: Complex permeability as a function of frequency for both room temperature and $125°C$.

* Work conducted at the Los Alamos National Laboratory, which is operated by the University of California for the United States Department of Energy under contract w-7405-ENG-36.
† National Physical Science Consortium (NPSC) Fellow, Los Alamos National Laboratory, with support from DOE DE-FG02-92ER40747 and NSF PHY-0140251: cbeltran@lanl.gov

## IMPEDANCE

An inductor cavity was simulated in MAFIA using the aforementioned ferrite properties to calculate the impedance resulting from the ferrite inductors. This was done for both room temperature and $125°C$. Fig. 3 is a plot of the real part of the longitudinal impedance for one inductor cavity at room temperature and $125°C$.

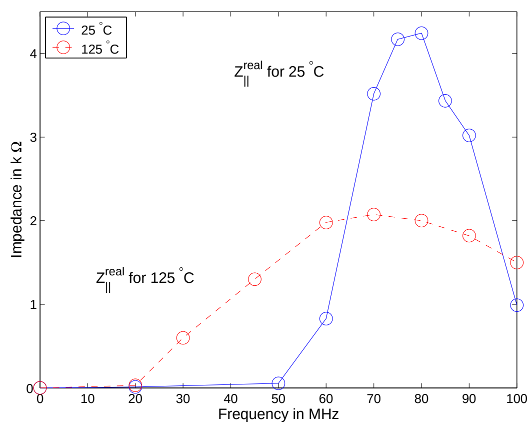


Figure 3: Real longitudinal impedance for one inductive insert at room temperature and $125°C$.

Notice the change in height and width of the impedance. Similarly, the imaginary part of the impedance also changes when the ferrite is heated (see Fig. 4).

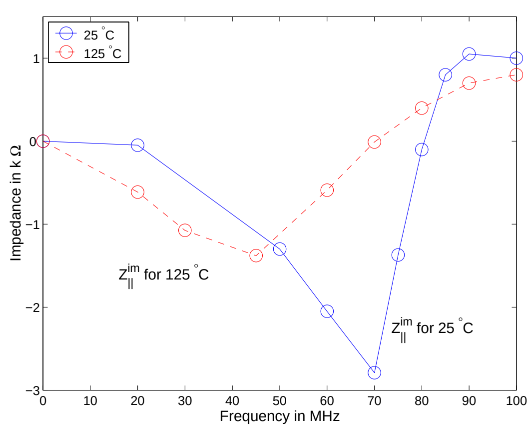


Figure 4: Imaginary longitudinal impedance for one inductive insert at room temperature and $125°C$.

## ESME SIMULATION

A PSR bunched coasting beam with a bunch length of $250ns$, $650nC$ of charge, and the impedance of three inductive inserts at room temperature was simulated in ESME [5] (a longitudinal multiparticle tracking code). The momentum distribution used in the ESME simulation was the sum of two gaussians, with 66% in the $\frac{\Delta p}{p}|_{wide} = 6.9 \times 10^{-3}$ and 34% in the $\frac{\Delta p}{p}|_{narrow} = 2.8 \times 10^{-3}$. This momentum distribution was chosen to best fit the wire scanner measurements of the incoming linac beam.

### *Growth Time*

The growth time of the longitudinal instability for the experimental data, as well as the ESME simulation were derived from the turn by turn growth of the amplitude of the summed powers of the harmonics around the resonance of the instability. Fig. 5 shows the evolution of the growth for the experiment and ESME simulation. For this simulation, a user routine was added to ESME which produced a continuous sequence of intensity vs. time histograms for each turn.

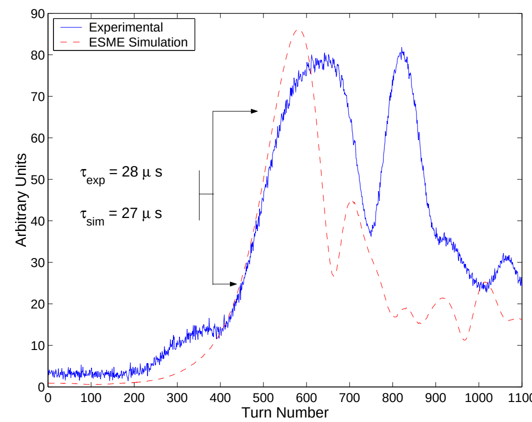


Figure 5: Experimental and ESME growth of the longitudinal instability at room temperature.

The experiment has a growth time of $28\mu s$, and the ESME simulation has a growth time of $27\mu s$.

### *Power Spectral Density (PSD)*

The Q for both the experiment and ESME simulation is defined as the peak frequency ($\omega_p$) of the PSD divided by the full width at half max ($\Gamma$) of the PSD.

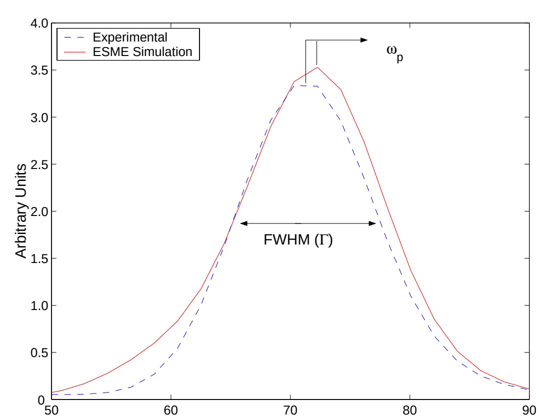


Figure 6: Experimental and ESME PSD for room temperature.

From Fig. 6, $Q_{exp} = \frac{\omega_p}{\Gamma}|_{exp} = \frac{71MHz}{14MHz} = 5.1$. The PSD for the ESME simulation is just slightly different, with $\omega_p = 72MHz$ and $\Gamma = 15MHz$, giving $Q_{sim} = 4.8$.

## TIME MODE EVOLUTION

An interesting way to look at the data is with the time mode evolution plot. The x-coordinate represents the time within the bunch and the y-coordinate is the turn number. The color represents the amplitude of the current, with blue being low and red being high. Fig. 7 is the time mode evolution of the experimental data.

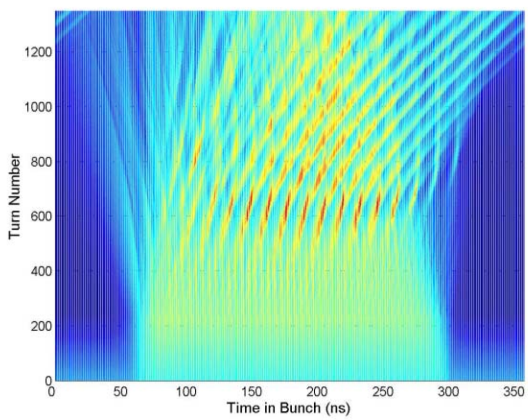


Figure 7: Experimental time mode evolution at room temperature (color).

From this type of a plot, one can see the microbunching and energy loss in the beam due to the impedance. The time mode evolution plot of the ESME simulation (Fig.8) is very similar to the experimental plot.

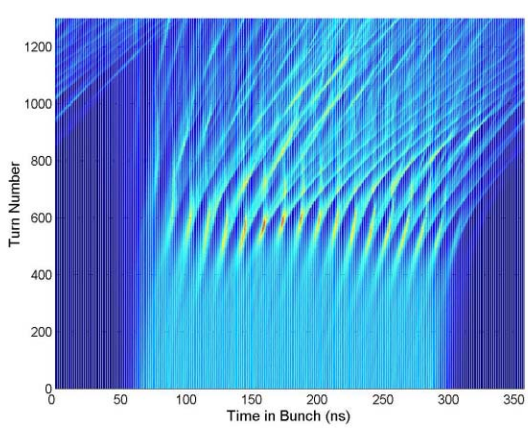


Figure 8: ESME time mode evolution at room temperature (color).

## HEATING THE FERRITE

Because of the instability caused by the 3 inductive inserts, they were removed, and two inserts with heating capability were installed. When the ferrite was heated to $125°C$ the longitudinal instability was cured, while maintaining the desired space charge compensation.

As shown in Fig. 3, heating the ferrite to $125°C$ reduces the maximum height of the impedance by a factor of two, and also broadens the impedance by a factor of two. An ESME simulation with the impedance of two heated inductive inserts also shows an elimination of the longitudinal instability.

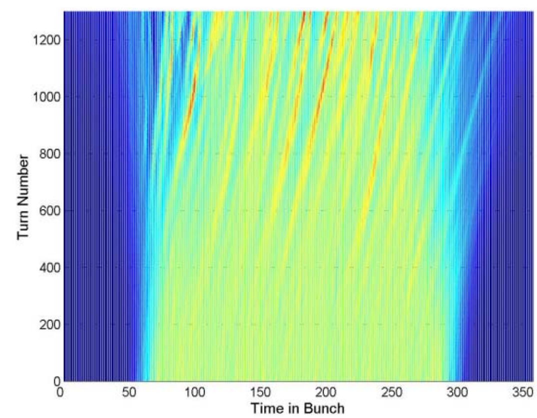


Figure 9: ESME time mode evolution for two inductors at $125°C$ (color).

## ACKNOWLEDGMENTS

The authors acknowledge many useful discussions with Tai-Sen Wang, Larry Rybarcyk, Sergey Kurennoy, Frank Krawczyk, Pat Colestock, and S. Y. Lee and informative correspondence with Dave Wildman, Bill Ng, and James Griffin. We are especially grateful to James MacLachlan for the unrestricted use of his ESME code. One of us, Chris Beltran, would like to thank his thesis advisor S.Y. Lee for his support.

## REFERENCES

[1] CST, "MAFIA Manual 4.00", http://www.cst.de, January 1997.

[2] M. Plum et al., "Experimental study of passive compensation of space charge at the Los Alamos National Laboratory Proton Storage Ring", PRST-AB V.2, 064201, June 1999.

[3] K. Y. Ng, "Physics of Collective Beam Instabilities", Fermilab-Conf-00/142-T, Ch 5.7.3, June 2000.

[4] A. Browman, Memo to R. Macek (macek57), April 2001 http://lansce2−serv.atdiv.lanl.gov/browman/CY2001/

[5] J. A. MacLachlan, J. Ostiguy, "User's Guide to ESME 2002", February 2002.