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STUDY FOR ALTERNATIVE CAVITY WALL AND INDUCTIVE INSERT MATERIAL

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Abstract

The goal of this work was to develop a solution to the problem of longitudinal beam instability. Beam instability has been a significant problem with storage rings' performance for many decades. The proton storage ring (PSR) at the Los Alamos Neutron Science Center (LANSCE) is no exception. To mitigate the instability, it was found that ferrite inductive inserts can be used to bunch the protons that are diverging due to the electron background. The PSR was the first storage ring to successfully use inductive inserts to mitigate the longitudinal instability with normal production beams. However, years later new machine upgrades facilitate shorter, more intense beams to meet the needs of researchers. The ferrite inserts used to reduce the transverse instabilities induce a microwave instability with the shorter more intense proton beam. Finemet was proposed as a replacement for the PSR Toshiba ferrite inserts because of its very stable magnet flux density. Yet in Japan, J-PARC has found complications with its use. This study investigates alternative magnetic materials for inductive inserts in particle beam storage rings, including the necessary engineering for maintaining the ideal temperature during operation.

INTRODUCTION

Proton beam targets are great sources of charged and neutral π-beams that enable experiments on dark matter, sterile neutrino oscillations and, precision measurements of coherent nucleus scattering neutrinos [1, 2]. These are well encompassed on the DOE HEP high intensity frontier (HIF) goals [3], through an intense program of accelerator produced dark matter and sterile neutrino searches [4]. The Los Alamos National Laboratory (LANL), through the Lujan neutron scattering center at LANSCE, can contribute to the DOE HIF efforts by transforming the LANSCE-Proton Storage Ring (PSR) into the highest instantaneous power proton beam source in the world. The Lujan neutron scattering center at LANSCE consists of an 800-MeV, short-pulse, 100-kW proton source and spallation neutron source where exotic searches are on-going together with the Coherent CAPTAIN Mills (CCM) 10 ton, liquid argon detector [5].

The integration of fast timing coincidence of the proton beam and the CCM detector is used to identify signals of interest and efficiently reject the background noise. The current beam pulse width is 300 ns with intensity of 2.9×10^{13} protons per bunch at a 20 Hz.

Planned upgrades to the PSR are underway to compress the beam bunch width down to 30 ns while maintaining the current beam intensity. This will result in an order of magnitude increase in the delivered instantaneous power. This increase in power, together with improved background noise rejection techniques would result in a CCM signal-to-background increase of 100 as well as sensitivity increase of an order of magnitude in dark matter and sterile neutrino searches.

Short Pulse PSR Upgrade

Researching low-loss beam bunches with pulse width less than 100 ns is hardly trivial. Such effort involves leveraging both theoretical and experimental studies for reaching improved timing, higher average and peak currents, and shorter pulses in the PSR [6, 7]. THE PSR instabilities are driven by the beam's interaction with electron clouds generated along the ring [8]. Initial experiments have shown active damping of the beam instabilities by means of an analog vertical feedback system [9, 10] and by use of heated ferrites. Figure 1 shows the suppression of microwave instability by heating the ferrite insert loads. The temperature change lowers the $Q-$factor of the ferromagnetic material as it approaches the Curie temperature.

Use of a material insert with different complex permeability and impedance could reduce the effects of microwave instability. In KEK for example, Finemet has been used as a replacement in their storage ring [11].

The instability induced by the inserts mostly comes from the complex permeability of the Toshiba ferrites, where $\mu = \mu' + i\mu''$. The real component, μ', should be sufficient to build up the necessary inductance at the ring's base frequency to dampen the beam space-charge effects. Yet, the complex component, μ'', should not rise or fall significantly at the bunch frequencies associated to the ring harmonics. It is also important to select a material that would not build up charge inside the pipe as the beam is accumulated.

FERRITE INDUCTIVE INSERTS

Toshiba ferrite loads are currently used at the PSR to mitigate the microwave instability in the proton beams. These

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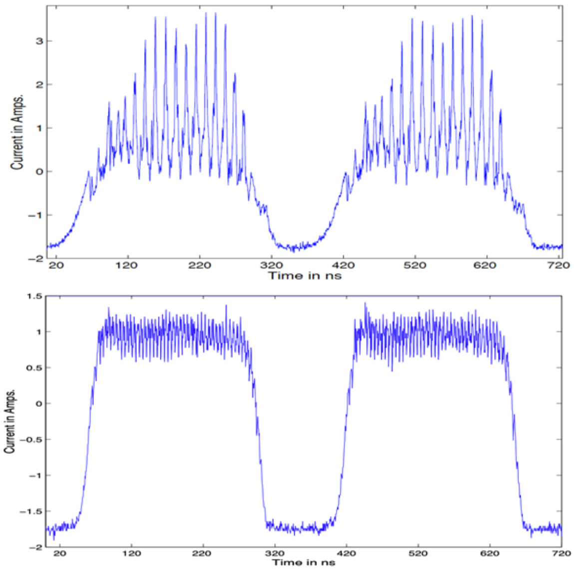

Figure 1: Two 300 ns beam pulses showing instability peaks (top). By heating the ferrite inductive inserts, the microwave instability is reduced (bottom).

can be placed at different locations around the ring replacing sections of the beam pipe. For a charged bunch of particles travelling around the accelerator, an image charge is created in the beam pipe so that the boundary conditions are satisfied at the beam pipe surface. When the beam traverses a region where a ferrite load is inserted, the discontinuity on the material produces a broadband wakefield, which can be tailored to counteract the build-up of microwave instabilities in the beam. Wakefields in a circular ring can also be treated as impedances in the frequency space.

Simulation Studies on Ferrite Loads

Using CST Microwave studio, a single ring ferrite and a 100-inch long ferrite were simulated with the help of Wakefield solver. These simulations were done for Toshiba and other ferrites by using their values of μ' and μ''. The variation of the magnetic permeability of these materials at different frequencies were fed to CST. A Gaussian longitudinal 1-nC beam was used to determine the wakefield and impedances. The impedances obtained through these CST MWS were used as an input for the computational simulation of microwave instability in proton storage ring (PSR) through ELEGANT software. The impedances obtained through the CST simulations would be verified through experimental measurement. Figure 2 shows for example a single ring ferrite insert and a 100-inch long insert of currently used Toshiba ferrite. Figure 3 shows the resulting ELEGANT simulation instabilities for short-pulse mode.

Measurement of Alternate Ferrites

There were two sources of materials for this study- standard stock supply from the National Magnetics Group, Inc. (NMG) and the LANL material science group. So far, the

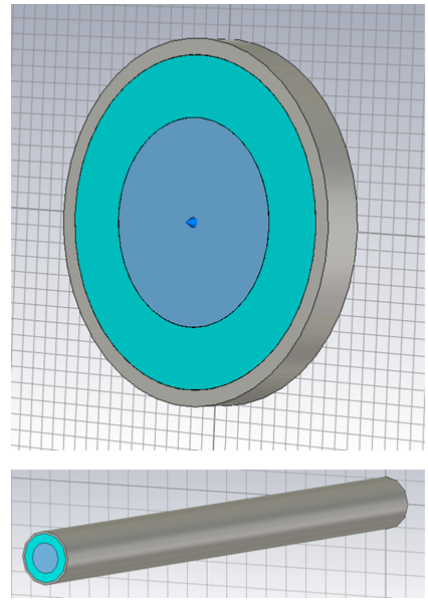

Figure 2: CST Microwave Studio Simulation of a single ferrite insert ring (top) and a 100 in long ferrite cavity mimicking the existing insert at the PSR (bottom).

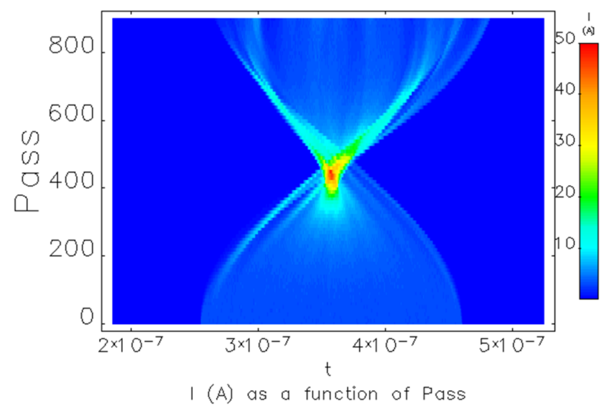

Figure 3: Simulated beam instabilities with ELEGANT.

samples from NMG have proven similar to the Toshiba ferrite currently being used in the PSR. However, their M3 sample has not yet arrived for study. The initial NMG report shows a significantly reduced complex component for permeability at the frequency of PSR instability.

The LANL material science group is nearing completion of their first samples. They offer ferrites such as NiO, ZnO, and Fe_2O_3 with their new fabrication process. The first sample to be measured will be a nano-nickel-zinc oxide refined with nickel-zinc ferrite. Their processing method applies a hot press to achieve a void-free structure with a reduced grain-growth factor. This is expected to have a significantly reduced complex permeability measurement at higher frequencies.

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CONCLUSIONS

In this study, we have been able to successfully simulate the complex S-parameters of the ferrite materials with a strong agreement with the measurements. Figure 4 shows the measured fields (solid lines) compared with the CST simulated model. Using the model shown in Fig. 2, we were able to generate impedances for the PSR model to use for its reproduction of beam instabilities. The models successfully reproduced the beam structure for normal production and short-pulse modes. The initial samples of new materials from the National Magnetic Group, Inc. show promise, but still have to much gain in their complex permeability in the sensitive region. New samples will arrive from both NMG and LANL's material science team shortly after this report.

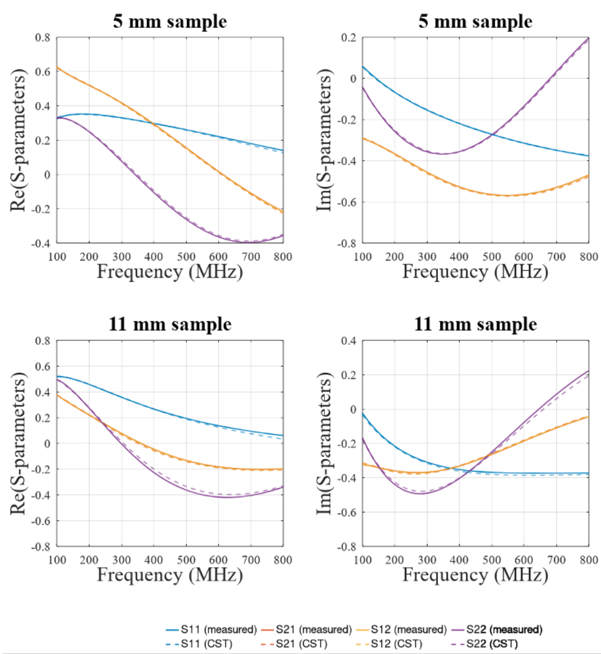

Figure 4: S-Parameters, measured field (solid lines) compared with CST simulated model.

It has been determined that the multi-layer nanocrystalline materials, such as finemet and Vitroperm, would not be ideal for the PSR. While they may help with the beam stability at the higher frequencies, they could produce new resonances at the lower frequencies, due to overcompensation to space-charge effects. Additionally, it has been shown that finemet has issues with outgassing and needs to be isolated from the beam vacuum [12].

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