Interaction of in-vacuum undulators with electron beam

Kai Tian, February 19th , 2019



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Outline

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- Introduction
 - IVU induced beam instabilities
 - Ridge waveguide structure of an IVU
- Characterization: CBI and HOM modes
 - Beam based measurement
 - RF cold test
 - Simulations
- Simulation study
 - Setup
 - Results
- In-situ RF cold tests of the dampers
- Other Approaches
- Summary

An electron beam and an IVU interact through wakefields.

- Short range wakefields (Single bunch effects)
 - Being considered in structure design (current sheets, flexible transitions);
 - Well studied for theory, measurement, and simulations.
- Long range wakefields (Multi-bunch effects): Topic of this talk
 - Trapped HOM modes;
 - Recently observed in multiple facilities; controlled by BxB feedback system



Abnormal IVU gap dependence TC reading in SPEAR3

Trapped HOM modes in an ALS IVU Collaborated with E. Wallen and S. Santis

Ridge Waveguide Structure of an IVU

- Ridge waveguide type structure
 - Cut off frequency of a ridge wave guide decreases with the gap
 - The IVU chamber can support low frequency modes



- Similar problems happened to APS*
 - The regular beam chamber has ridge waveguide structure;
 - "Rogue" HOM modes corrupted BPM signals;
 - Remedy: ceramic dampers at the narrow gap.



Characterization **Beam based : Grow-damp measurement**

- Beam condition
 - 500mA uniform filled beam in all buckets
 - Vertical chromaticity = 0
- Grow-damp measurement
 - Varying BL15 ID gap at 10um/step
 - Exponential fits of the amplitude growth of the dominating mode
 - Two series of instabilities are found
- Trapped RF modes in the chamber
 - Two modes induce 2 series of instability modes
 - HOM resonant freq. = CBI mode freq.?





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Gap (mm)	Mode index	CBI Mode freq. (MHz)	Q
6.85	156	199.51	456
7.15	157	200.86	444
7.45	158	202.12	446
7.36	118	150.84	237

Gap=6.85mm, Evolution of Modes

Characterization S21 measurement with 2 antennas (no e-beam)

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Port 2

- Two single loop antennas were installed in port 1 and 2
 - Loop size: as large as possible -

Port 1

Three modes were found, all below 200MHz.







Mode #	f _{meas} (MHz)	Q _L (meas.)
1	108.5	16
2	148.17	173
3	199.45	390
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Characterization RF code tests, beam based measurements, and simulations SLAC

- Resonant frequency of mode #3 at various pole gaps from 6.82mm to 10mm agrees with the CBI mode frequency.
- Eigenmode calculations of the IVU chamber up to 6 GHz indicate that modes #2 and #3 have the largest transverse coupling impedances.



CBIs are caused by base band modes

Simulation Setup

- Simulation Software
 - Omega3P from ACE3P suite: Eigen-mode solver
 - Cubit: model creation and meshing
 - Paraview: Visualization of simulation results
 - Cubit and Paraview run on PC and Omega3P on NERSC clusters (typically 5 nodes 160 cores)
- Creation of simulation model
 - A simple but realistic model for simulations
 - Model the structure that can significantly affect the frequency and geometry factor of the resonant mode.
 - Neglect subtle details that contribute only slightly to the surface loss (Q₀) that can be scaled







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Simulation model in CUBIT



Simulation Comparing with S21 measurement



Modes #1,2,3 can be identified in the simulation but with some discrepancies.

- Mode frequencies: good agreement; ~10% difference
- Quality factors: large difference; 1-2 orders of magnitude
 - Q₀ in simulation and Q_L in S21 measurement
 - Q₀ depends on the power loss on the surface and can be reduced by a factor of 2-3 with more tedious efforts
- Transverse impedance Z_T
 - Modes #2 and #3 stand out
 - Absolute values are not accurate due to the uncertainty of Q_L

Simulation Field Distribution of HOM #3







E field

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B field

B field Note I-beam supports

Simulation Damping performance



Neomax was able to include our design of the ferrite brackets into the new BL17 ID



Courtesy of Neomax Engineering Co.

Damping performance of the Ferrite Brackets



- Great damping performance across all frequency range
 - > two orders of magnitude from simulation results of bare ID
 - > one order of magnitude from S21 cold-test measurements of bare ID

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Compare with BL17 ID S21 measurement



- BL17 ID measurement
 - Same cold test setup as with the BL15 ID S21 measurement
 - Observe the same three trapped modes at roughly the same frequencies
 - Compared with BL15 ID, modes #2 and #3 are damped by > 1 order of magnitude, roughly agree with simulation results (24 pairs of ferrites in design; 22 pairs actually installed)

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Other Approach (1) Mode Curtains

- GOAL: increase frequency and reduce $(R/Q)_{tr}$
- They work best when
 - Both transitions and magnet arrays are covered
 - The curtains should attach to the structure tightly
- Ineffective at SPEAR3: 40mm gap between the ID jaws and the outboard curtain due to the SR fan







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Other Approach (2) Multi-turn Loop Antenna

- Goal: increase the coupling impedance by increase effective area
- Simulation results were not positive
 - Single loop: broad band
 - Multi-turn loop: narrow band
- Tests were abandoned.









With extensive efforts in beam based characterization, RF tests, and numerical simulations, we believe that we have a clear understanding of the source of the instabilities. Ferrite dampers are a very effective and simple solution to the problem in SPEAR3 and should also work for other facilities.

There are some interesting topics worth further efforts:

- High fidelity simulations with more accurate models in both time domain and frequency domain;
- Direct measurement of the transverse impedance (Beam based/bench RF);
- Other effects of these trapped modes

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With the concerns of impedances in future LERs, it will be definitely beneficial to address these questions.

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Thank you for your attention