DESIGN CONCEPT FOR A MODULAR IN-VACUUM HALL PROBE MAPPER FOR USE WITH CPMU CONVERTIBLE IN-VACUUM UNDULATORS OF VARYING MAGNETIC LENGTH

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Abstract

Both In-Vacuum Undulators (IVU) and Cryogenic Permanent Magnet Undulators (CPMU), each important to third generation light sources, are best characterized in their operating environment. To create a precision field map of an IVU/CPMU (IVU hereafter), an In-Vacuum Magnetic Measurement (IVMM) System is proposed. Point-by-point measurement of field and trajectory error informs corrective tuning.

A novel design concept for a universal IVMM System has been developed and explored. The IVMM seals to the rectangular UHV-flange of the IVU and shares its common vacuum space. Moreover, a modular design permits a wide range of IVU of varying magnetic length to be mapped with a single IVMM, and is thus cost effective when multiple IVU of varying configurations are planned. Here we review aspects of the modular IVMM design concept.

INTRODUCTION

IVU designed to produce well defined periodic magnetic fields act as high-brightness, tunable, narrow-band photon sources whose performance is dependent on field quality. To precisely characterize undulators, we must map their fields in the lab at operating conditions. Each functions at UHV pressure; the IVU at ambient temperature, and the CPMU from 150K (NdFeB) to as low as 40K (PrFeB magnets). Fortunately, in the lab, these operating conditons can be closely simulated with rough insulating vacuum (<10-4 Torr). The IVMM design must be compatible with these environments while affording minimal thermal, electromagnetic and mechanical "crosstalk".

IVU THERMAL ENVIRONMENT

The optimal longitudinal temperature gradient for IVU is less than 0.5 K/m to avoid deterioration of spectral characteristic. Further, due to the strong dependence of remanance on cryogenic temperature (Fig. 2) a uniform temperature is critical for CPMU operation.

An insertion device design which affords operation at room temperature but can be easily convertable to CPMU technology has been developed (Fig. 1). A cooling circuit design (Fig. 5) permits flow of water through integral cooling channels and, with some minor conversion, of liquid nitrogen in the case of CPMU. This cooling system design allows metered cooling through multiple valved circuits to account for realistic non-uniform heating of the magnet core.

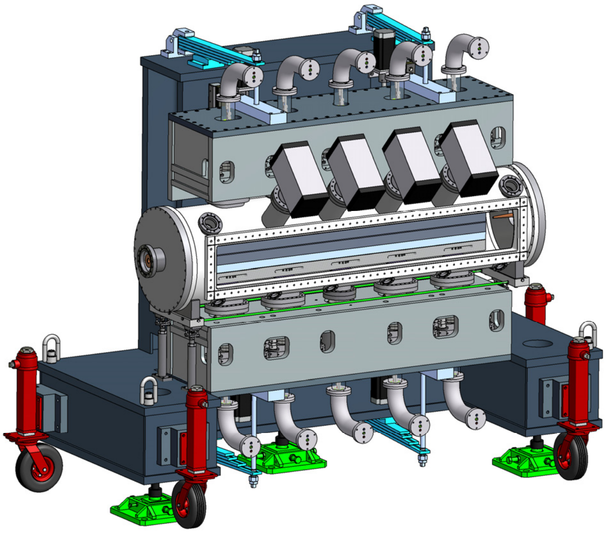

Figure 1: Conceptual design for CPMU convertible IVU.

A finite difference code was written to perform steady and transient thermal analyses (FDA) of IVU/CPMU configurations while varying several independent design parameters. A schematic of the analyzed 3D network is given in Fig. 3. The code was used to compare the expected temperature distribution of a hypothetical "standard" approach (brazed tubing without metering) and the current proposed IVU design. The heat load distribution assumed in the simulation is shown in Fig. 4. with inlet cooling water flow distribution as shown in Fig. 6. The resultant temperature profiles for each case are compared in Fig. 7.

Included in the FDA are the affects of:

- Forced Convection to Cross-Flow in Water Cooling Channels (outer flowing upstream, inner flowing downstream).
- Heat Load Conduction to ambient through the Structural Post from the Magnet Core.
- Heat Load Conducted to the end of the Magnet Core through the Flexible Transition induced by beam loss and resistive heating.

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*Work supported by U.S. DOE
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- Uniform or Non-Uniform Beam Power Deposition to Magnet Core.
- Contact Resistance at all interfaces (calculated as a function of material, surface finish, contact pressure due to bolt torque).
- Radiation from Vacuum Containment/Thermal Shielding System to CPMU Magnet Core.

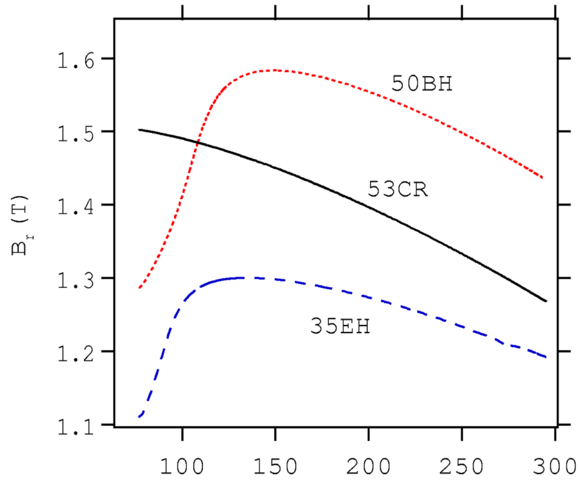
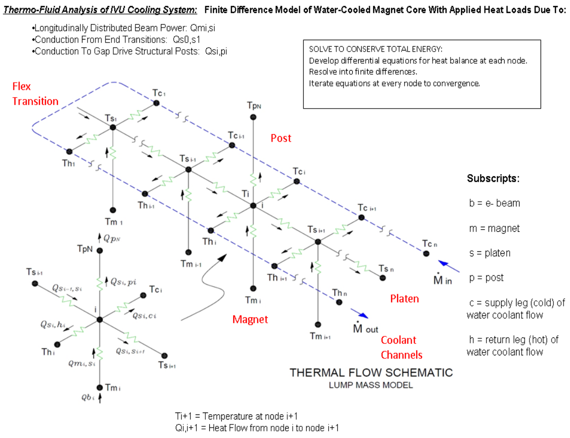


Figure 2: Temperature dependence of magnetic remanance for some rare earth PMs.



Thermo-Fluid Analysis of IVU Cooling System: **Finite Difference Model of Water-Cooled Magnet Core With Applied Heat Loads Due To:**

- Longitudinally Distributed Beam Power: Qmi,si
- Conduction From End Transitions: Qs0,s1
- Conduction To Gap Drive Structural Posts: Qsi,pi

SOLVE TO CONSERVE TOTAL ENERGY:
Develop differential equations for heat balance at each node.
Resolve into finite differences.
Iterate equations at every node to convergence.

Subscripts:

b = e- beam
m = magnet
s = platen
p = post
c = supply leg (cold) of water coolant flow
h = return leg (hot) of water coolant flow

Ti+1 = Temperature at node i+1
Qi,i+1 = Heat Flow from node i to node i+1

Figure 3: Schematic of FDA of thermal performance.

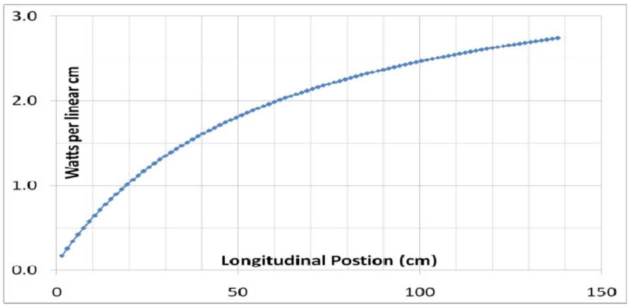


Figure 4: Logarithmic heating from SR plus beam loss. (applied in addition to 5W end load due to flex transition).

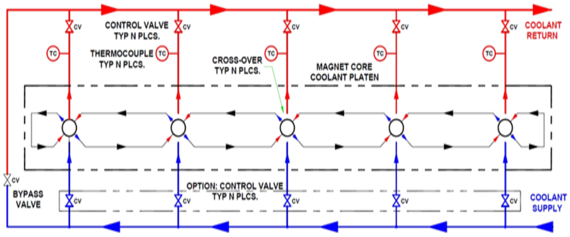


Figure 5: Coolant cross-flow distribution manifold.

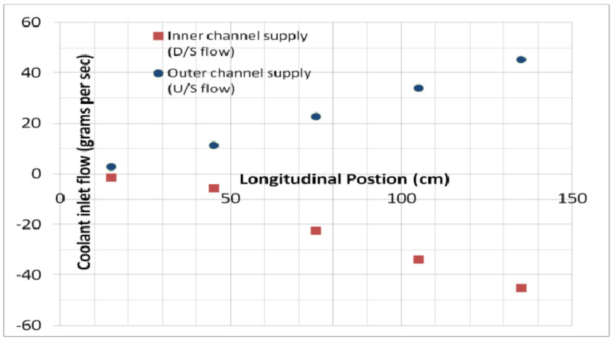


Figure 6: Optimized coolant flow inlet distribution.

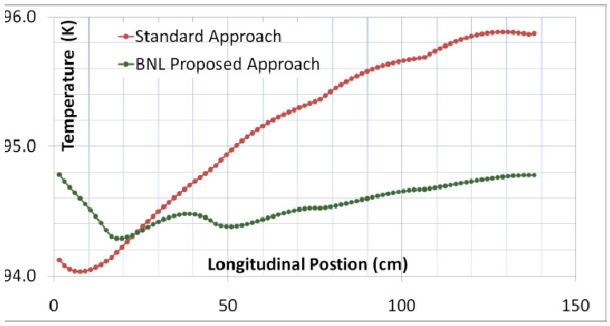


Figure 7: Comparison of magnet temperature variation along beam axis for "standard" vs. proposed approach.

THE IVU/IVMM INTERFACE

Figure 8 shows the section view of the IVMM as viewed along the electron beam axis (Z). The Hall probe is retracted from the gap (or extended as shown phantom) in the lateral direction (X). To measure off the mid-plane the probe moves vertically within the narrow limits of the IVU gap opening (Y). To the stiff structural base of the IVMM mount two motorized stages, first X then Y, each outside of the vacuum containment. These stacked stages actuate a stiff monolithic beam having several cantilevered stanchions each extending through the ID of a re-entrant bellows assembly. These circular bellows provide the mechanical feed-through for both degrees of freedom: displacement. The small Y-travel is afforded by bellows offset. The X-travel, which can exceed the pole width, is afforded by axial bellows.

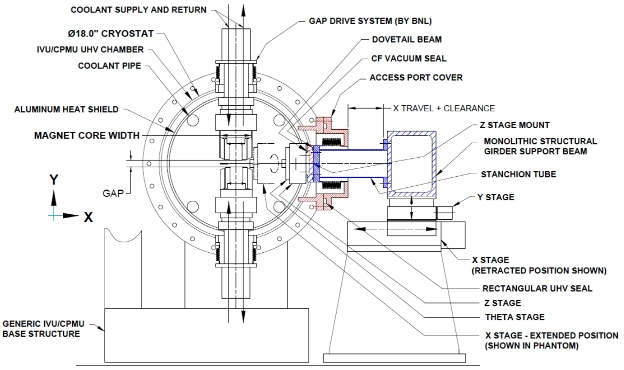


Figure 8: Cross-sectional view of the IVMM

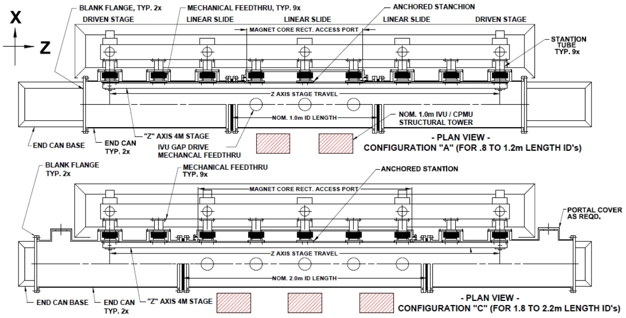


Figure 9: Incremental adaptation for In-Vacuum Undulators of Varying Magnetic Length.

Each stanchion joins the weld neck on a blank CF flange. The CF vacuum seal encircles an internal through-bolt pattern that mates to the fixed halve of a dove tail assembly. The moveable companion halve of the dovetail is in turn fixed to a long-travel linear stage aligned with the Z-axis. The Z-stage carries a rotary stage to invert the Hall probe to negate earth's field. To execute a survey at given (X,Y) coordinates redundant Z-passes with opposite probe orientations are averaged. The dovetails permit thermal contraction in Z of the long-travel stage. Figure 9 shows an anchored centermost stanchion to balance frictional load upon thermal contraction.

Deflections from the significant external pressure loadin attributable to each bellows assembly, which is absent in truge operation and therefore artificial to lab characterizations, may be negated by implementation of a pressure-compensating mechanical feed-through with design as depicted in Fig. 10.

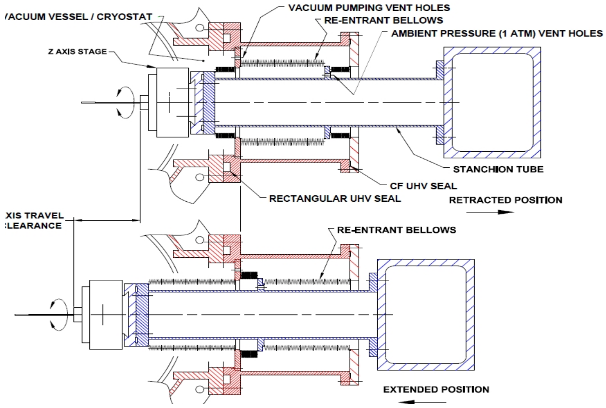


Figure 10: Pressure-compensating mechanical feed-thru.

Beamline and ring lattice demands commonly require IVU of varying length. To accommodate these device lengths the IVMM utilizes a pair of "end cans" with integral vacuum ports that receive those stanchions that fall outside the span of the rectangular UHV flange of the IVU. Those outer stanchions continue to provide support for the full fixed length Z-stage, while travel of the probe is kept symmetric about the midpoint and restricted to be equal to the IVU magnetic length. By sliding in increments equal to the span between stanchions, each "end can" on its Z-guide rail atop its stand, the IVMM can be reconfigured to accommodate progressively longer IVU. Large interconnecting bellows at each interface between IVU and "end can" afford adjustability so that a range of lengths is surveyed with each configuration.

CONCLUSION

With proper foresight in IVU design, an infinite (albeit discontinuous) range of source devices for a full synchrotron ring are characterized and optimized at true operating conditions using a single precision In-Vacuum Magnet Measurement System.

REFERENCE

[1] T. Tanabe, et. al., "Status of ID Development at the NSLS2 & Future Plans", PAC11, NY, NY,THOBS4.