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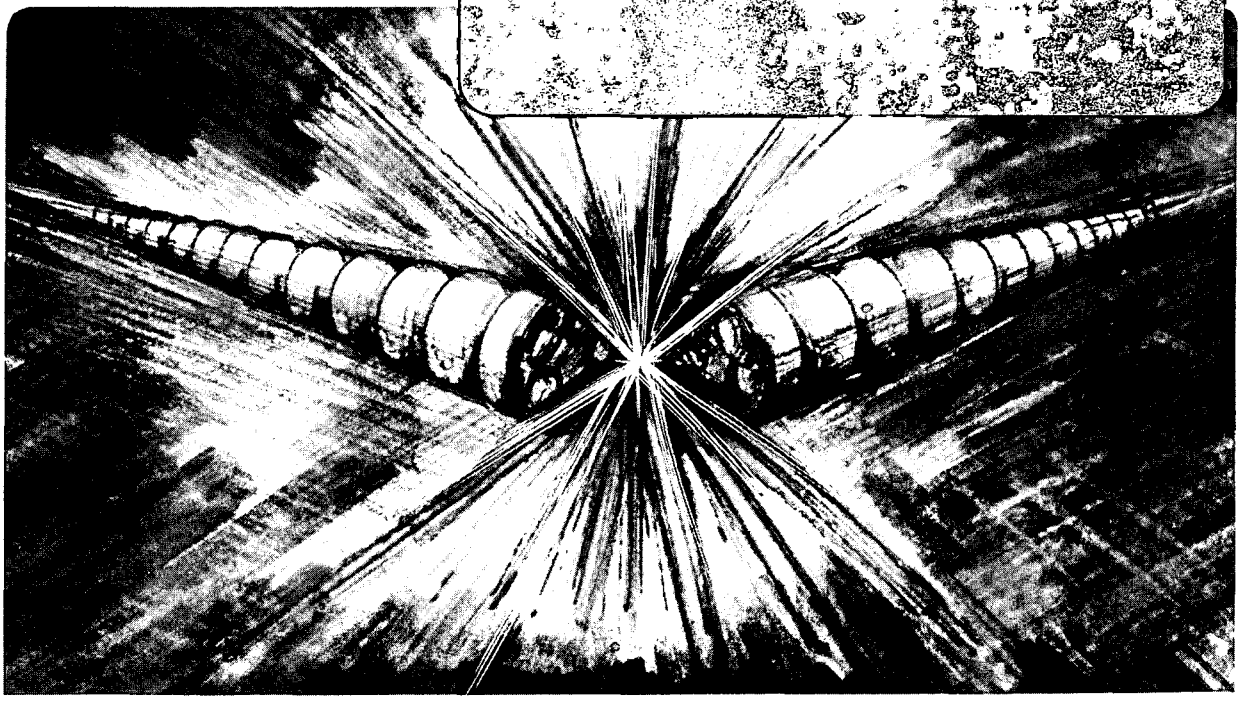

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CSEM-STEEL HYBRID WIGGLER/UNDULATOR MAGNETIC FIELD STUDIES*

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Summary

Current design of permanent magnet wiggler/undulators use either pure charge sheet equivalent material (CSEM) or the CSEM-Steel hybrid configuration. Hybrid configurations offer higher field strength at small gaps, field distributions dominated by the pole surfaces and pole tuning. Nominal performance of the hybrid is generally predicted using a 2-D magnetic design code neglecting transverse geometry.

Magnetic measurements are presented showing transverse configuration influence on performance, from a combination of models using CSEMs, REC (H_c = 9.2 kOe) and NdFe (H_c = 10.7 kOe), different pole widths and end configurations. Results show peak field improvement using NdFe in place of REC in identical models, gap peak field decrease with pole width decrease (all results less than computed 2-D fields), transverse gap field distributions, and importance of CSEM material overhanging the poles in the transverse direction for highest gap fields.

Introduction

Presently there is considerable interest in magnetic structures for insertion devices (wigglers/undulators) used in electron storage rings to provide both enhanced and quasi monochromatic synchrotron radiation and for free electron lasers generating coherent radiation.[1]

Permanent magnet structures are particularly attractive for these applications because of their inherent simplicity and are often the only design alternative with short period lengths (< 30 cm). With short periods normal conducting electromagnetic structures become design limited by coil heat transfer; superconducting electromagnetic structures suffer from complexity and become current density design limited.[2]

Current design of permanent magnet structures use either the pure charge sheet equivalent material (CSEM) or the CSEM - steel hybrid configuration. Advantages of the CSEM-steel hybrid configuration when compared to the pure CSEM configuration are:

1. The achievable field strength for small gap to period length (g/λ) ratios is considerably higher.
2. The field distribution is dominated by the shape of the pole surfaces, making the field strength and distribution much less dependent on the CSEM material properties.
3. The peak field at each pole can be tuned with variable flux shunts at each pole.

Computational Procedures

The computer code PANDIRA[3] performs the two dimensional modeling of magnet components. PANDIRA accounts for nonlinear permeability and the anisotropy of permanent magnet materials. Calculations have shown excellent agreement with measured results where the 2-D assumptions are appropriate; i.e. where the magnet pole is sufficiently wide. Fig. 1a shows a wiggler cross section, cut along the beam axis. Fig. 1b shows the cross section geometry as modeled with PANDIRA, where symmetries are used to minimize the model size.

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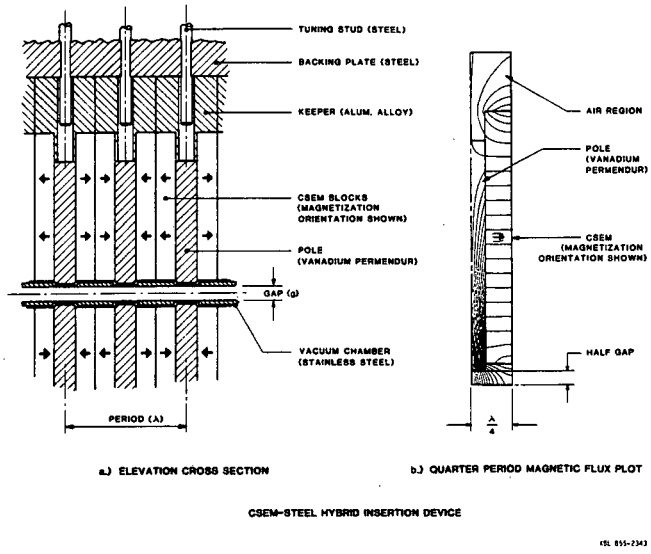


Figure 1

Validity limits of the 2-D assumption for wiggler/undulator (w/u) assemblies was a primary motivation for the study reported here. Fig. 3 compares the measured values of central field for pole assemblies of several widths, with the results from a 2-D PANDIRA model, which has infinite pole width. As expected, agreement increases with increasing pole width.

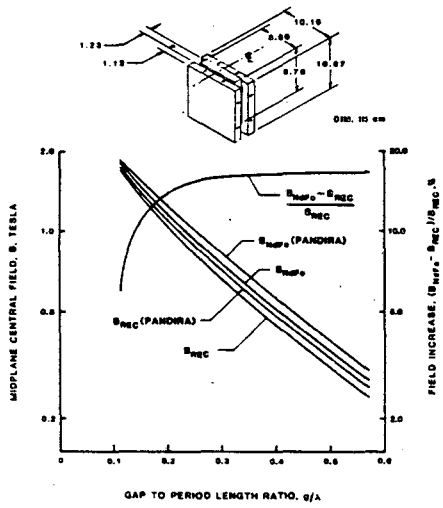
However, better agreement can be obtained between theory and measurement than is suggested in Fig. 3, by augmenting the computer modeling with other analytical procedures. In considering the 3-D features of w/u assemblies and relating them to analytical procedures, the effects which contribute to the scalar potential value on the pole surface are separated from the effects which influence the resulting magnetic field distribution due to that scalar potential value. The method can accurately predict pole surface scalar potential value but is limited in relating the scalar potential value to central field value for narrow poles.

Determining the pole surface scalar potential involves the calculation of magnetic flux through the various surfaces of the pole that are ignored in the 2-D analysis of the configuration shown in Fig 1b. These calculations may use either analytical models or POISSON[3] runs. The combination of computer and analytical techniques is a pseudo 3-D analysis that amounts to the integration of 2-D field effects over all pole surfaces. All the significant contributions to the total flux into the pole are accounted for. This determines the pole surface scalar potential value. (Flux through 3-D pole corners is not accounted for; however, this effect is generally very small). The predicted central field value is obtained by comparing the calculated scalar potential value to the 2-D scalar potential and the corresponding central field value from the 2-D PANDIRA analysis. It is assumed that the ratio of central field and scalar potential remains the same for the actual 3-D pole assembly. This assumption does not take into account the diminution of the transverse field due to finite pole width; a theoretical/analytical procedure is currently under development to account for this effect. These techniques will be described in detail in a paper to be published.

Model Tests

To determine experimentally the influence of transverse width and configuration on performance of the CSEM-Steel hybrid magnetic structure, a number of single pole assemblies were fabricated, each inserted into a steel test fixture and measured magnetically.[4] Pole material was either Vanadium Permendur or steel and the active material was either Rare Earth Cobalt (REC) or Neodymium Iron (NdFe). The test fixture simulated the effect of adjacent poles by providing Neumann boundary conditions at appropriate symmetry planes. Mid pole - midplane gap field measurements were made transversely with a Hall probe.

To determine the field improvement of NdFe when compared to REC, NdFe blocks (H_c = 10.7 kOe) were substituted for REC (H_c = 9.2 kOe) in a pole assembly designed for optimum performance with REC material.[5] The increase in peak field is shown for various g/λ ratios in Fig. 2. At large g/λ ratios the full 16% increase in the H_c results in a 16% increase in gap field. As the g/λ ratio decreases field increase is less due to pole saturation.

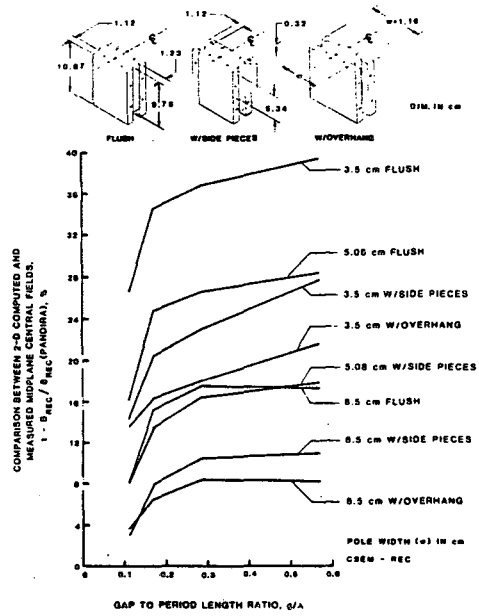


FIELD COMPARISON BETWEEN NdFe AND REC IN A CSEM-STEEL HYBRID CONFIGURATION

Figure 2

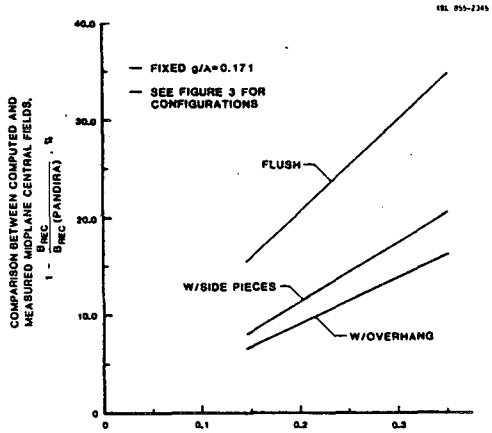
To examine the effect of finite pole width on peak field, tests, using three different pole widths in conjunction with three different transverse end configurations of CSEM (REC) were carried out and results are shown in figures 3 and 4. Figure 3 shows the difference between the computed peak field, using 2-D modeling (PANDIRA) and the measured peak field, which is normalized with the computed peak field, as a function of the g/λ ratio. In all cases the measured field is less (from 3-39% less) than the computed field because of the finite width. Also shown are that the differences are less for small g/λ ratios where the width to pole gap ratio increases. (The PANDIRA computed peak fields used correspond to the computed REC case shown in Figure 2.) Not shown on Figure 3 is the case where an 8.5 cm steel pole with flush REC was substituted for the Vanadium Permendur pole. The steel pole configuration gave only 0.8% less field at a g/λ ratio of 0.57, but 5.4% less field at a g/λ ratio of 0.114.

Figure 4 is a slice out of Figure 3 at a g/λ ratio of 0.171. Shown clearly is when pole thickness-width ratio decreases the difference between the measured peak field and the computed peak field decreases. Also demonstrated is the importance of the transverse end configuration. Of the configurations tested; highest peak fields were produced in the configuration where the blocks extend beyond/overhang the pole in all the transverse dimension except toward the midplane.



COMPARISON BETWEEN 2-D COMPUTED AND MEASURED MIDPLANE CENTRAL FIELDS IN CSEM-STEEL HYBRID CONFIGURATIONS

Figure 3



COMPARISON BETWEEN 2-D COMPUTED AND MEASURED FIELDS FOR VARIOUS POLE THICKNESS TO WIDTH RATIOS IN CSEM-STEEL HYBRID CONFIGURATIONS

Figure 4

To see how transverse field quality is influenced by pole width and transverse end configuration, transverse field profiles were measured for combinations of pole widths and transverse end configurations at various g/λ ratios. Figures 5 and 6 show field quality (expressed as the difference between the measured central gap field and the measured gap field away from the pole center normalized with the central gap field) as a function of pole overhang (normalized in half-gaps). Figure 5 shows results for a g/λ ratio of 0.171 and for configurations with 8.5 cm pole widths. The three different configurations with the Vanadium Permendur pole give very similar curves which indicate that the transverse field profile is dominated by the ferromagnetic pole. The less permeable steel pole requires a greater pole overhang to produce the same field quality than the Vanadium Permendur pole cases. Figures 6a, 6b & 6c show field quality for three different g/λ ratios for the flush configuration with three different pole widths. The data indicates that for a given field quality, the

required pole overhang decreases with increased g/λ and decreases with pole width. Good field aperture width is given by pole width less twice the required pole overhang.

Design Example

Recently, the magnetic design was completed for the LLNL Beam Line VIII Wiggler; a 15 period variable gap wiggler with a 12.85 cm period length.[6] Design criteria includes a gap field greater than 1.24 Teslas at a 21 mm gap (g/λ = 0.163) and a 3% field tolerance for the 2.4 cm aperture over a peak gap field range from 0.01 Teslas to 1.24 Teslas.

The test data[4] was used to estimate the magnetic structure dimension. NdFe was selected as the active material for its higher field strength and estimated lower unit cost. Pole material is Vanadium Permendur. Final configuration was based on the 2-D and pseudo 3-D analysis which was verified with a scaled model. The final magnetic structure configuration is shown in Figure 7 along with the magnetic measurements from the 7 cm period scaled model. For a 21 mm gap (g/λ = 0.163) a peak field of 1.39 Teslas was measured, the pseudo 3-D analysis computed 1.45 Teslas, a 4% difference which shows that the computations and measurements compare well. With the 3% field tolerance on the peak field, a minimum good field aperture of 2.9 cm is obtained; for a 2% field tolerance the good field aperture is 2.2 cm.

Acknowledgement

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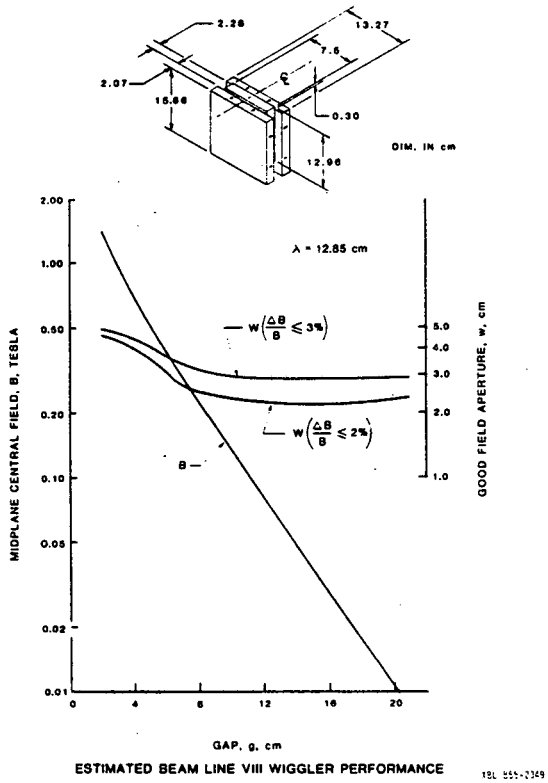
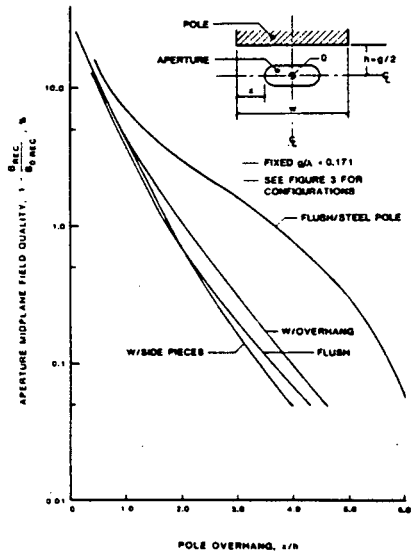
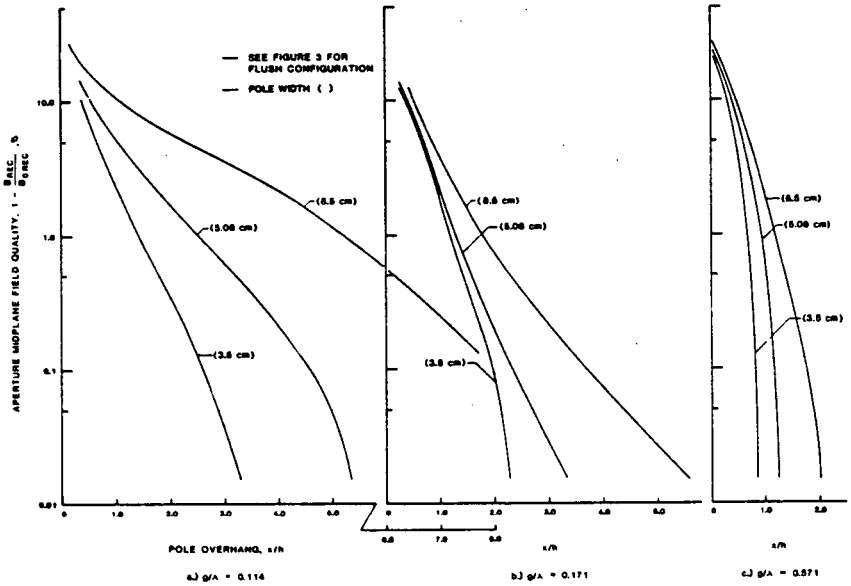


Figure 7



FIELD QUALITY AS A FUNCTION OF POLE OVERHANG FOR 8.5 cm WIDE POLE CSEM-STEEL HYBRID CONFIGURATIONS

Figure 5



FIELD QUALITY AS A FUNCTION OF POLE OVERHANG FOR DIFFERENT WIDTH FLUSH CSEM-STEEL HYBRID CONFIGURATIONS

Figure 6

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