Fast Excitation Variable Period Wiggler*

A. van Steenbergen, J. Gallardo, T. Romano, M. Woodle
National Synchrotron Light Source and Physics Department
Brookhaven National Laboratory
Upton, New York 11973

Abstract

The design of an easily stackable, variable period length, fast excitation driven wiggler, making use of geometrically alternating substacks of Vanadium Permandur ferromagnetic laminations, interspaced with conductive, non magnetic, laminations which act as eddy current induced "field reflectors", is discussed and experimental results obtained with short wiggler models are presented.

I. INTRODUCTION

As part of the program of Inverse Free Electron Laser (IFEL) Accelerator Development [1-4], the development of planar wigglers with high K magnitude has been pursued. The IFEL accelerator, as parameterized, makes use of a quasi-sinusoidal magnetic field, with constant maximum field magnitude, and varying wiggler period length, as shown in Fig. 1. Related to the beam injection energy into this accelerator, this period length may vary from a few cm's in length to tenth of cm's. Such a structure could be constructed using presently known techniques employing permanent magnet material. It would, however, be very high in cost because of the nonrepeat feature of the wiggler period length. The use of conventional dc electromagnetic excitation of the wiggler, by means of a multiplicity of individual pole coils, is excluded for the objective of a high field wiggler because of the small value of the period length at beam injection for a typical set of IFEL accelerator parameters. Hence, for the present objective, a new design approach has been pursued, which makes use of easily stackable, geometrically alternating substacks of identical ferromagnetic material (VaP) laminations, which is driven in a fast excitation mode and which makes use of interleaving of conductive, non magnetic, laminations, which act as eddy current induced "field reflectors" [5,6]. In the following, the design approach is given, and experimental results, obtained with short model wigglers, are presented.

II. TECHNICAL APPROACH AND EXPERIMENTAL RESULTS

For the ferromagnetic laminations for this wiggler design a number of basic configurations have been studied by means of two dimensional mesh computations (POISSON) and by means of actual short wiggler model measurements. The adopted configuration is shown in Fig. 2. The laminations are assembled in substacks, and stacked, separated by non-magnetic material laminations. Four straight current conductors, in parallel to the axis of the composite assembly and interconnected only at the ends of the total assembly, constitute the single current excitation loop for the wiggler, permitting ease of stack assembly, compression of the stacks by simple tie rods, and ready adoption of either constant period length or sequentially varying period length.

Initial experimental results obtained with short wiggler models, without conductive material interleaving, indicated expected behavior of maximum on axis field magnitude when varying the period length towards smaller values. It also showed, however, that for these configurations the required field magnitude of B = 12.5 kG. could not be obtained, with a gap value of 4 mm, for a period length of less than approximately 5 cm.

Subsequent to those early trials of a fast excitation driven wiggler, the use of eddy current induced "field reflectors" in the laminated wiggler core, was initiated. This is illustrated in Fig. 3. This led to dramatic enhancement of maximum on axis field magnitude, for a specific wiggler period length and gap value, as shown by the experimental data given in Fig. 4. Field saturation is evident in these results for higher excitation current values. The onset of field saturation is clearly discernible with the onset of distortion of the magnetic measurement probe voltage versus time display. The field value corresponding to the onset of saturation, for a sequence of model measurements with different period length values, was obtained, both for the case of wiggler models without field reflection and with field reflection. This is summarized in Fig. 5. As is evident from these results the specification of 12.5 kG., for a 2.9 cm period length wiggler, with gap value of 4 mm, can readily be met for the fast excitation wiggler with field reflection.

It is of interest to compare the achievable B(max) vs (λ_o/g) for this wiggler, with the permanent magnet "driven" wigglers, such as the classical Halbach hybrid $SaCo_5$-VaP wiggler and the "pure" $SaCo_5$ permanent magnet wiggler. This is shown in Fig. 6. Clearly, the fast excitation wiggler, as presently executed, compares favorably, in terms of B vs λ_o/g behavior, with state of the art hybrid wigglers.

The median plane field versus wiggler longitudinal coordinate was also measured for a number of wiggler models. An example of this, with tapered period length, and a nominal

*This work was performed under the auspices of the U.S. Department of Energy.

0-7803-0135-8/91$01.00 ©IEEE

λ_o = 28.5 mm., is shown in Fig. 7. In this case also, the harmonic content (harmonic and non-sinusoidal content) of the central section of the wiggler models was measured and found to be acceptably small.

III. SUMMARY AND CONCLUSIONS

It is evident from the foregoing that fast excitation driven, laminated Vanadium-Permandur wigglers or undulators, with periodic interleaving of conductive "field reflectors", can provide state of the art (in terms of B(max) vs λ_o/g) wigglers or undulators, which may be optimum for specific applications, such as, for example, the IFEL accelerator module, for which a tapered period length is required.

It is worthwhile to note that similar maximum field on axis versus λ_o/g enhancement as achieved here for the fast excitation wiggler, should be obtainable for a dc electromagnetic wiggler or permanent magnet wiggler with the periodic interleaving ($\lambda_o/2$ separation) of superconducting field exclusion sheets*. The possible maximum enhancement achievable in this case is given by the limiting value of $B_{max}=B_s/\cosh\zeta$ with $\zeta = (\pi g/\lambda_o)$ [7], i.e. making use of periodic superconducting "field reflectors" could, for example, for the case of a λ_o/g value = 3, yield a factor of two enhancement in the wiggler B_{max} versus λ_o/g value, when compared with a room temperature hybrid $SaCo_5$-VaP.

Taking advantage of inherent symmetry, the fast excitation, Cu sheet interlaced, undulator/wiggler can be constructed in the form of a passive septum bounded periodic magnet [5]. As such, it may find also application as a small gap, large number of periods, undulator in conjunction with a storage ring without the need for a bypass configuration.

IV. REFERENCES

[1] C. Pellegrini, P. Sprangle, W. Zakowicz, Intern. Conf. on He Accelerators, 1983.

[2] E. Courant, C. Pellegrini, W. Zakowicz, Phys. Rev. A 32, 1985.

[3] E. Courant, J. Sandweiss, BNL Report 38915.

[4] A. van Steenbergen, in Exp. Progr., ATF, BNL 42664, 1988; and "IFEL Accelerator Demonstration Stage," ATF, BNL 43702, 1989.

[5] A. van Steenbergen, J. Gallardo, T. Romano, M. Woodle, "Fast Excitation Wiggler Development," Proc. Workshop 1 Angstrom FEL, Sag Harbor, NY, 1990, Editor J. Gallardo, p.79, BNL 52273.

[6] A. van Steenbergen, Patent Application 368618, June 1989 (issued August 1990).

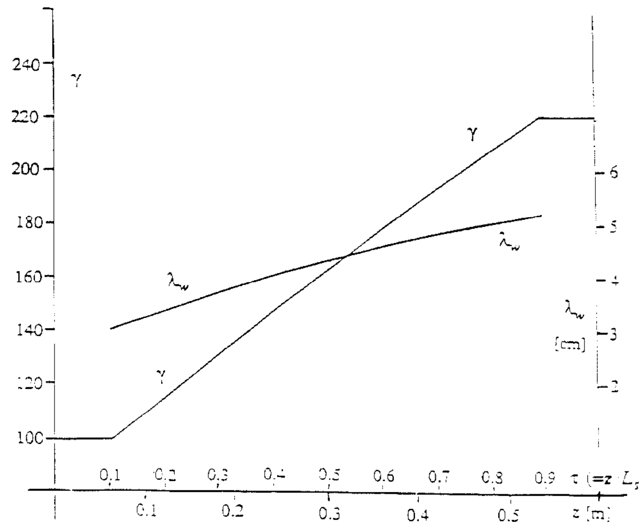
[7] K. Halbach, priv. comm., Workshop 1 Angstrom FEL, April, 1990.

*Note added in proof: The suggested use of periodic located superconducting laminations in a dc electromagnetic wiggler is mentioned by R. Tatchyn, et al. in the Proc. Workshop "PEP as a Synchrotron Radiation Source", SSRL, p. 229, Oct. 1987.22

IFEL ACCELERATOR DEMONSTRATION STAGE*
γ vs z; λ_w vs z
[B = constant accelerator, B_{max}(wiggler) = 1.25 T.]
[Dielectric coated guide laser transport, α = 0.05 m^{-1}]

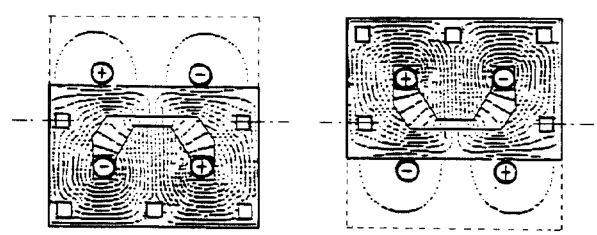
$$[\gamma_z^{4/3} = 1.8\ 10^3\ \tau L_s \exp(-\alpha\tau L_s) + \gamma_0^{4/3}]$$

Fig. 1



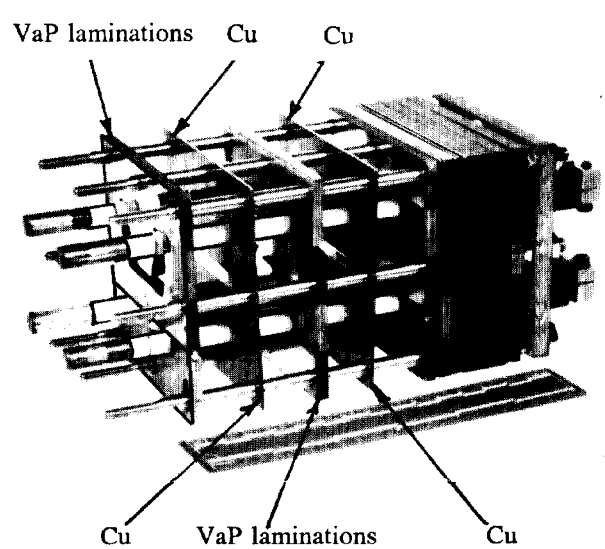
Computed 2D Field Distribution (Excit.current 10 kA)

Fig. 2



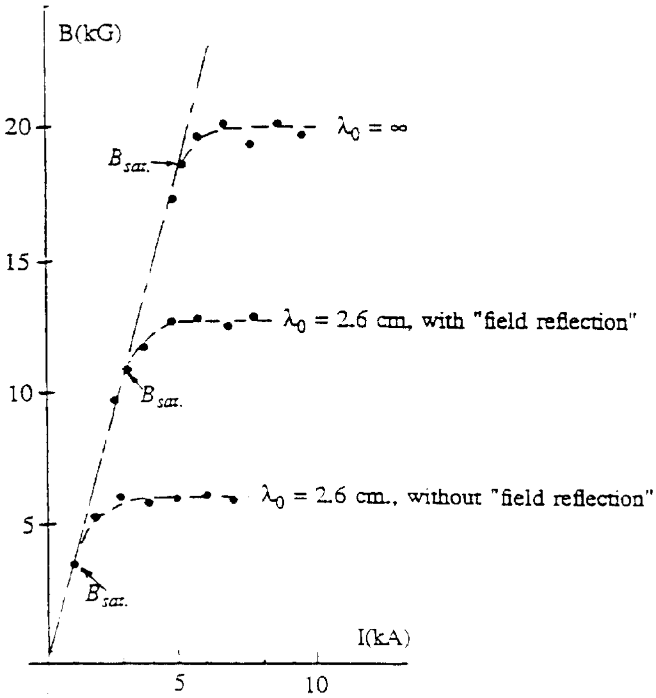
Fast Excitation Variable Period Wiggler

Fig. 3



FAST EXCITATION WIGGLER, B vs I

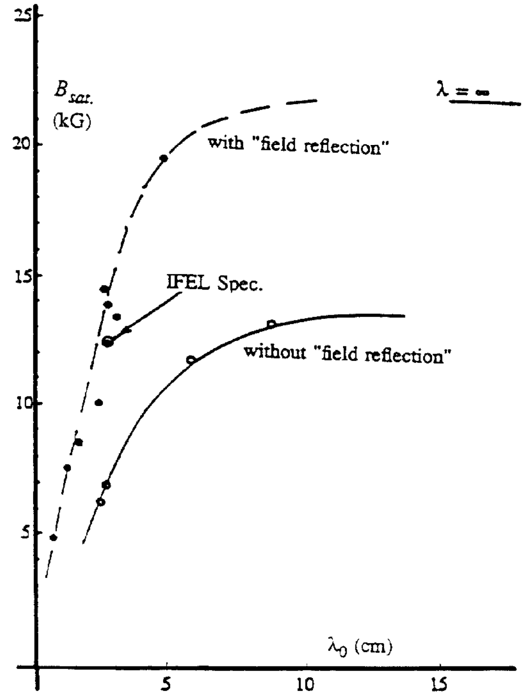
Fig. 4



FAST EXCITATION WIGGLER, $B_{sat.}$ vs λ_0

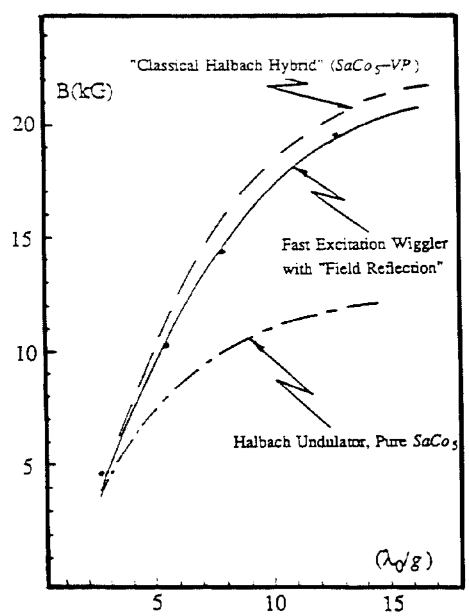
(Gap = 4.0 mm)

Fig. 5



PULSED EXCITATION WIGGLER

Fig. 6

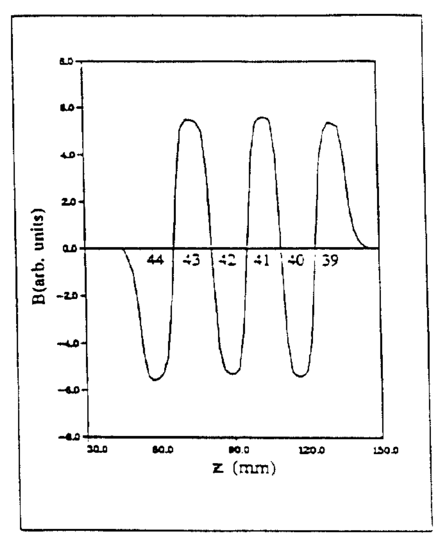


Relative Performance B(max) vs (λ_0/g) for a Permanent Magnet Hybrid ($SaCo_5$–VP), a "pure" $SaCo_5$ Undulator and the Fast Excitation Wiggler with Field Reflection

FAST EXCITATION WIGGLER, B vs z

[With Field Reflection]

Fig. 7



Tapered Period Length Wiggler

I = 4.8 kA; B(max) = 14.85 kG; K(w) = 4.0

$\lambda_0(42)$ = 28.5 mm (Cu = 3.6 mm, d(lam) = 0.254 mm)