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FAST EXCITATION WIGGLER DEVELOPMENT*

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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, material laminations which act as eddy current induced "field reflectors", is discussed and experimental results obtained with short wiggler models are presented.

INTRODUCTION:

As part of the program of Inverse Free Electron Laser (IFEL) Accelerator Development (Refs'1-4), the development of planar wigglers with high K(wiggler) 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 larger period length magnitudes. Such a structure could possibly 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" (Ref.4). In the following, the design approach is given, and experimental results, obtained with short model wigglers, are presented.

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

TECHNICAL APPROACH and EXPERIMENTAL RESULTS:

For the ferromagnetic laminations for this wiggler design two basic configurations have been studied by means of two dimensional mesh computations (POISSON) and by means of actual short wiggler model measurements. These configurations are 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, as shown in Fig.3 .

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. This is shown in Fig.4, where B(max) versus I(excit.) is given, for various λ_o values. For the IFEL accelerator, a λ_o value of 2.9 cm is required at injection. The electrical parameters for the fast wiggler are given in Fig.5 .

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.6. 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.7 and Fig.8 . 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.9 . 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.10. Clearly, the fast excitation wiggler, as presently executed, compares favorably, in terms of B_o vs λ_o/g behaviour, with state of the art hybrid wigglers.

The median plane field versus wiggler longitudinal coordinate was also measured for a number of wiggler models. Two cases are shown in Fig.11 . The first case is an example of a tapered period length wiggler of nominal period length of $\lambda_o = 28.5$ mm ;

the second is an example of B vs z for a relatively short period length wiggler (λ_o = 13.8 mm). In addition, a first attempt was made to incorporate diminished end field sections in order to reduce the first and second wiggler integrals to zero. This is shown in Fig.12 . 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.

WIGGLER VARIANTS:

As evident from the field distribution given in Fig.2b, the asymmetric H structure is separable into two mirror symmetric halves. With the addition of a copper septum sheet in the symmetry plane, for the fast excitation case, an undulator-septum magnet variant of the asymmetric H structure is obtained. This is shown in Fig.13a. This septum undulator should permit the use of small magnetic gap values, when used in combination with a storage ring. In that case, the equilibrium damped beam would be "parked" by means of slow orbit deflectors, close to the septum, but externally thereof, to be deflected sequentially into the small magnetic gap of the septum unit. Repetitive excitation of this orbit perturbation would yield short (≈10 μsec, or single bunch), relatively intense (small gap, short period length, large number of periods) "bursts" of undulator radiation, for possible applications in dynamic spectroscopy. The need to preserve a practical magnitude of average beam lifetime would limit this mode of operation to a multiplicity of short duration beam traversals through the septum undulator, rather than a sustained operation with beam in the undulator. Hence, for the case of undulator utilization with minimum magnetic gap, the fast excitation character of the septum undulator, as presented here, matches the permissible mode of operation in the storage ring.

A second variant of the asymmetric H structure evolved from the realization that, related to the current conductor location in the geometrical assembly of the stacked Asymmetric H structure laminations, it proved to be possible to orientate sequential $\lambda_o/2$ lamination stacks at 90 degree rotation intervals, rather than 180 degree rotation intervals. This then, in essence, provides for a helical-like field distribution with a pitch of $2\lambda_o$, when compared with the planar wiggler version with wiggler period of λ_o. Preliminary experimental results are shown in Fig. 13b . Further study of this quasi helical wiggler is in progress.

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 $B_{\max} = B_s/\cosh\xi$ with $\xi = (\pi g/\lambda_o)$ (Ref.5), 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, as given in Fig.10 .

Superconducting field exclusion sheets, of the form and nature suggested here, can be manufactured, as evidenced by the results obtained with field exclusion cylinders used in bubble chambers. In that case , multi layers of a thin Cu–$NbSn_3$–Cu sandwich tape were employed in magnetic fields of up to 2 Tesla (Refs'6,7).

The use of the fast excitation, Cu sheet interlaced, undulator, in a septum magnet configuration, may lead to interesting applications in existing, high energy, electron storage rings, without the need for expensive bypass reconfiguration of the long straight section domain of the storage ring. Similarly, the X-Y interlaced "planar" wiggler, as indicated here, may yield the benefit of a helical undulator (in FEL or IFEL applications), without the compromise of a rather low K_w magnitude, where $K_w = 0.93\, B[T]\lambda_o[cm]$, as would be the case for a classical electromagnetic helical wiggler.

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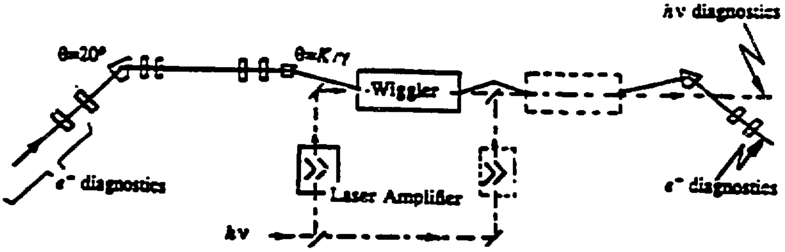
* Note added in proof: The suggested use of periodic located superconducting laminations in a dc electromagnetic wiggler is mentioned by R.Tatchyn et.al. in the Proc. Workshop "PEP as a Synchrotron Radiation Source", SSRL, p.229, Oct.1987.



IFEL Accelerator Demonstration Stage

B = Const. Accelerator (B(max) = 1.25 T.)

γ_r vs z ; λ_o vs z ($E_o(\tau=0.5) = 10^6$ MV/m)

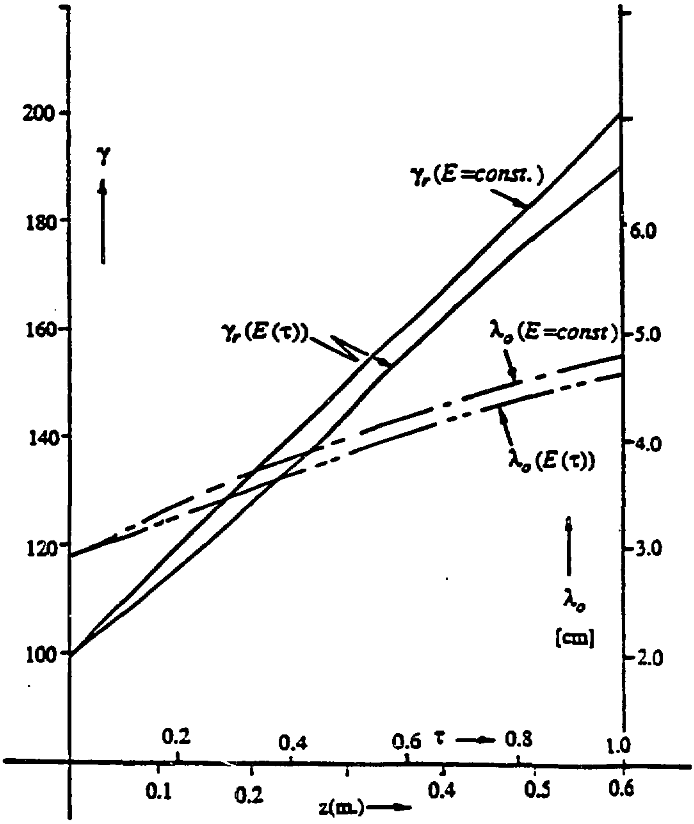


Fig.1

Pulsed Excitation Wiggler

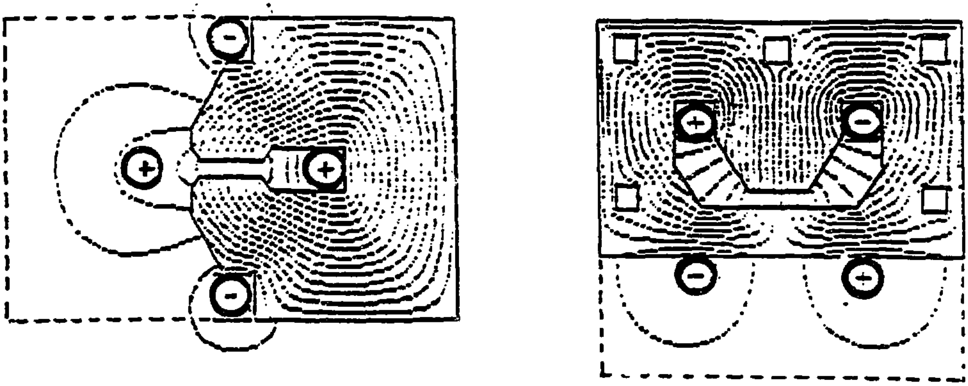


Fig.2a
Type C

Fig.2b
Asymm. H

Computed 2D Field Distribution for Wiggler Model
Type C and Wiggler Model Type Asymmetric H
(Excitation Current 10 kA)

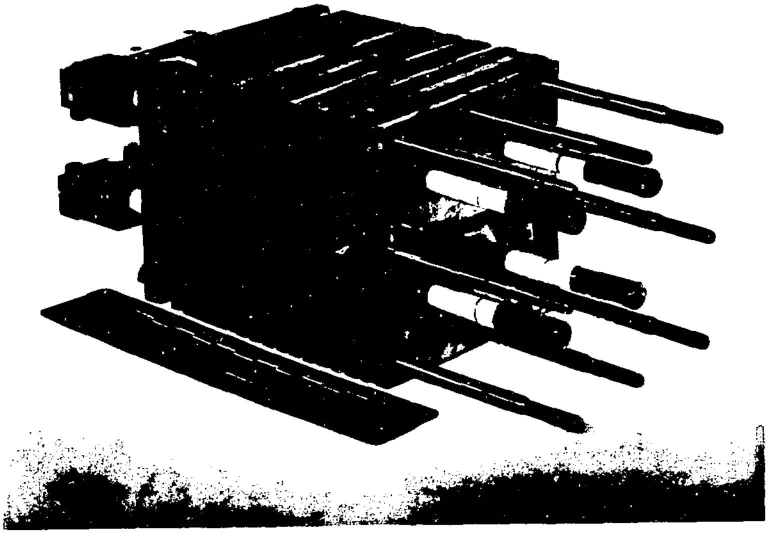
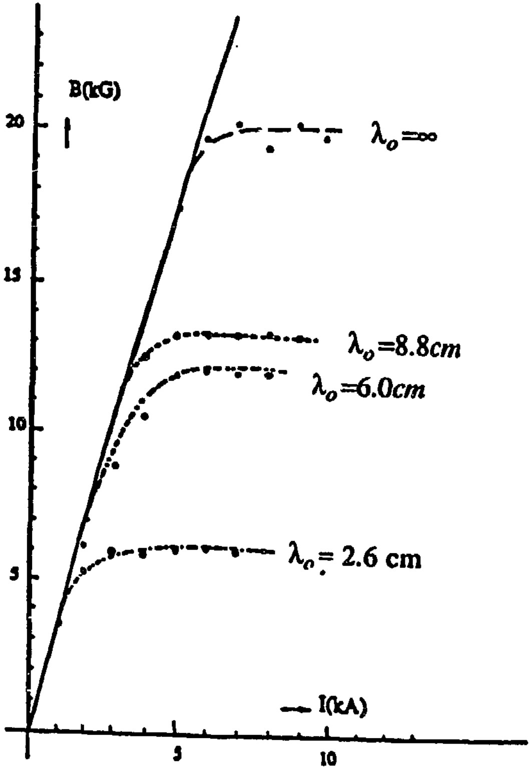


Fig.3

Fig.4

Pulsed Excitation Wiggler (Asymm.H)
B(max) vs λ_o



Pulsed Excitation Wiggler(asymm.H)

Magnet model, length (m)	0.2
Magnet gap (mm)	4
Pole width (cm)	1.4
Current (kA)	4
Resistance (Ohm)	410^{-4}
Inductance (Henry)	$1.3\ 10^{-6}$
Frequency (kHz)	1
ωL	$8.2\ 10^{-3}$
V(max) (V)	80
Laminations	Supermendur V
Thickness (mm)	0.25
δ (skindepth) (mm)	0.5

Fig.5

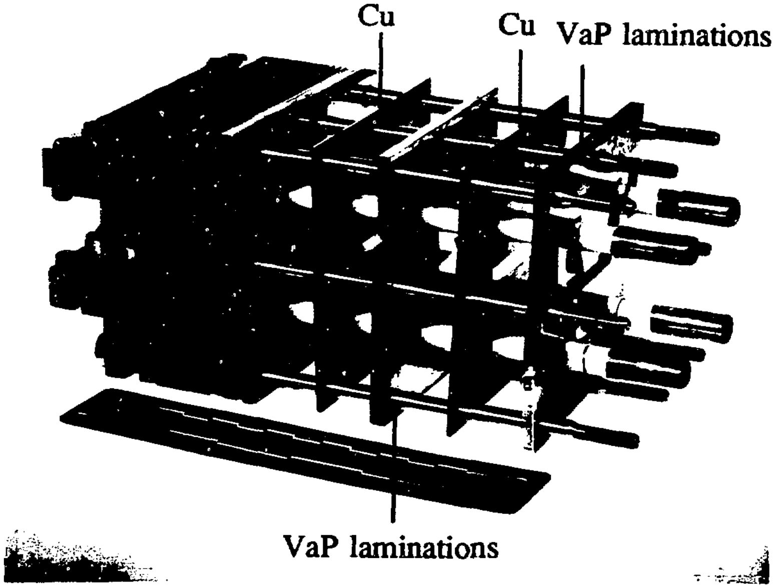


Fig.6
Pulsed Excitation Wiggler (Asymm.H), with Field Reflection

Fig.7
Pulsed Excitation Wiggler (Asymm.H)
B(max)

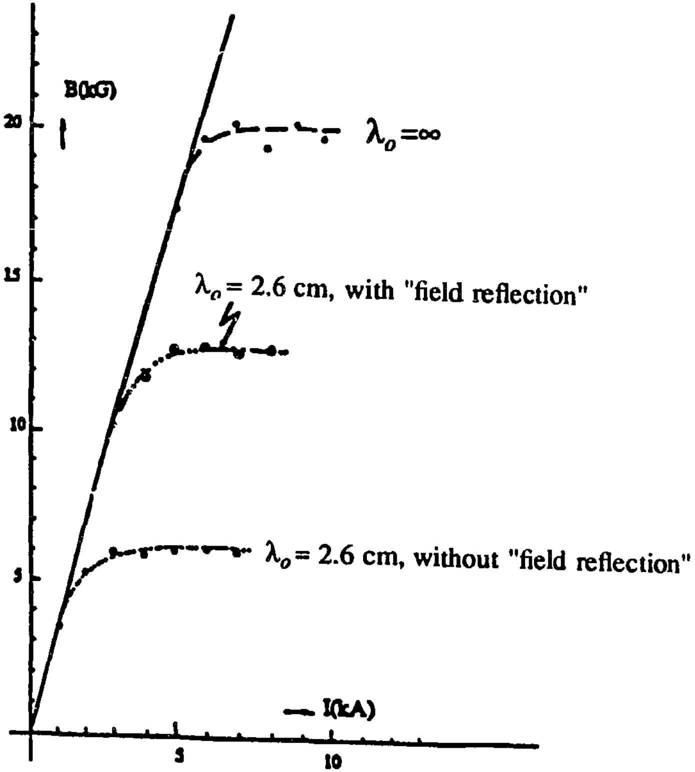


Fig.8
Pulsed Excitation Wiggler (Asymm.H)
B(max)

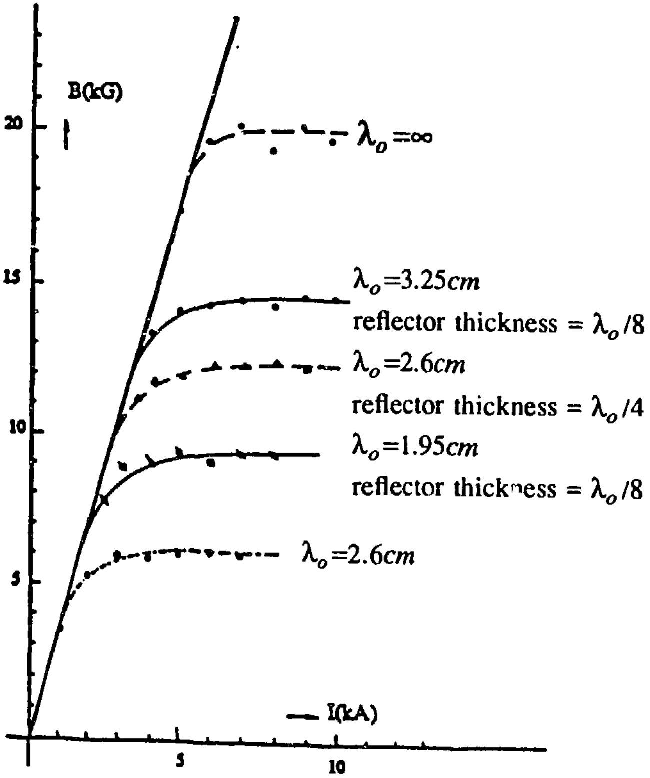
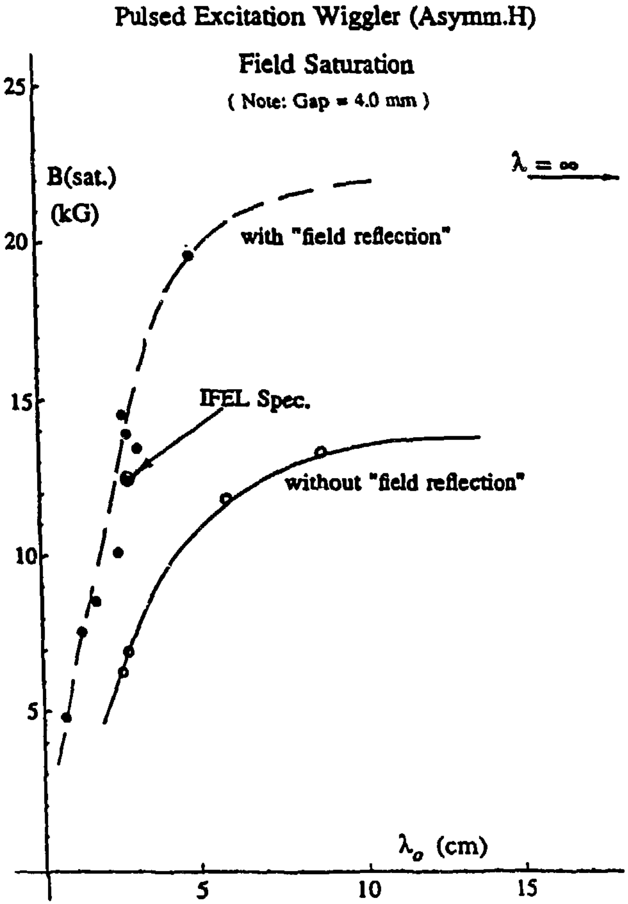
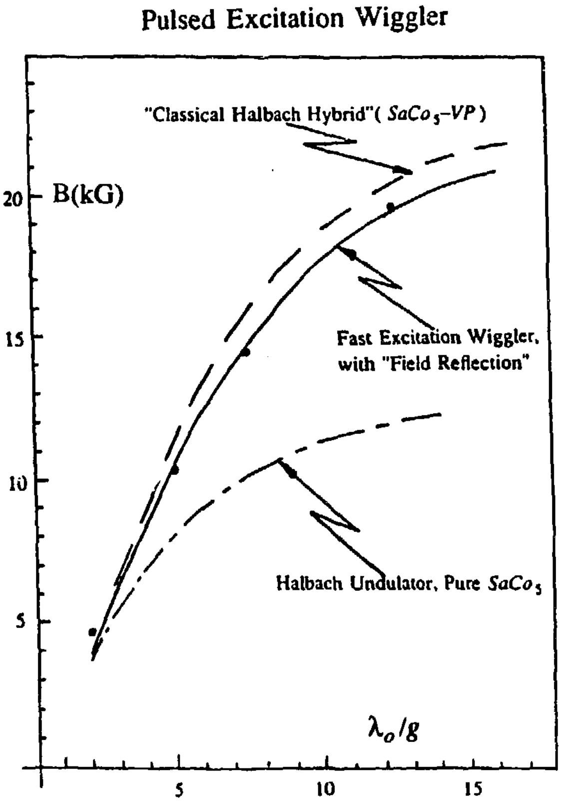


Fig.9



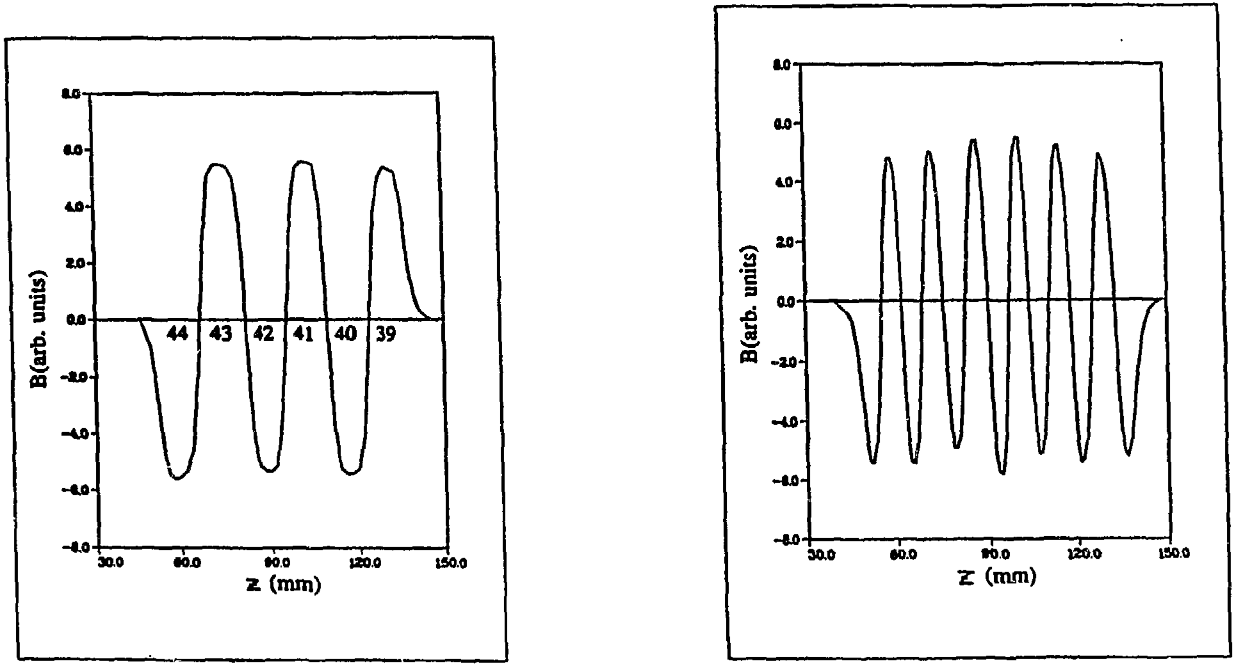


Relative "Performance" B(max) vs (λ_o/g) for a Permanent Magnet Hybrid ($SaCo_5$-VP), a "pure "$SaCo_5$ Undulator and the Fast Excitation Wiggler (Asymm.H), with Field Reflection

Fig.10

Fig.11

Pulsed Excitation Wiggler (Asymm.H), with Field Reflection; B vs z



Tapered Period Length Wiggler

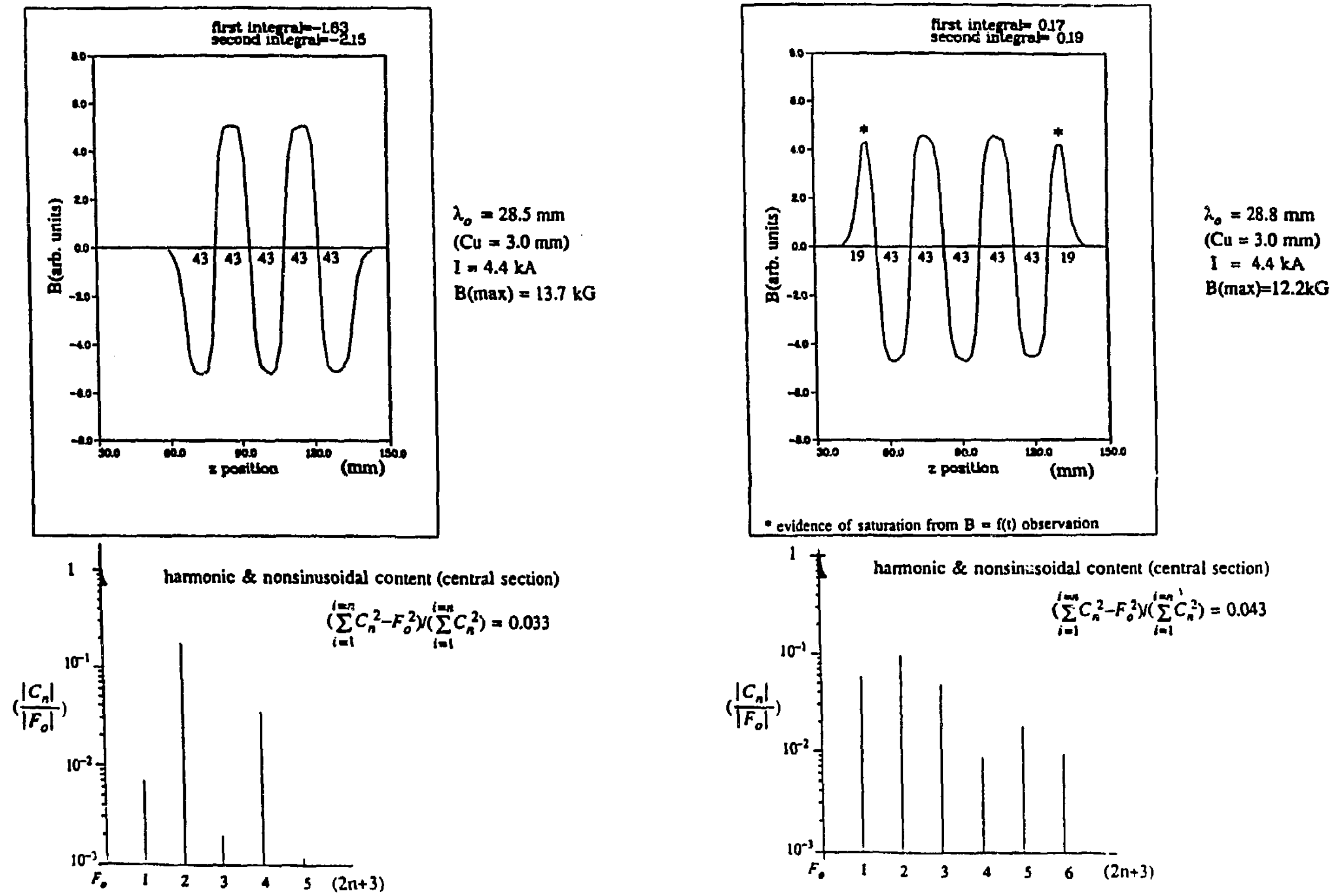
I = 4.8 kA; B(max) = 14.85 kG; K_W = 4.0

λ_o(42) = 28.5 mm, (Cu = 3.6 mm; $d_{lam.}$ = 0.254 mm)

λ_o = 13.8 mm; (Cu = 2.6 mm), I = 2.5 kA, B(max) = 7.8 kG

Fig.12

Pulsed Excitation Wiggler (Asymm.H), with Field Reflection; B vs z



first integral=-1.63
second integral=-2.15

λ_o = 28.5 mm
(Cu = 3.0 mm)
I = 4.4 kA
B(max) = 13.7 kG

harmonic & nonsinusoidal content (central section)

$(\sum_{i=1}^{i=n} C_n^2 - F_o^2)/(\sum_{i=1}^{i=n} C_n^2) = 0.033$

first integral= 0.17
second integral= 0.19

λ_o = 28.8 mm
(Cu = 3.0 mm)
I = 4.4 kA
B(max)=12.2kG

* evidence of saturation from B = f(t) observation

harmonic & nonsinusoidal content (central section)

$(\sum_{i=1}^{i=n} C_n^2 - F_o^2)/(\sum_{i=1}^{i=n} C_n^2) = 0.043$

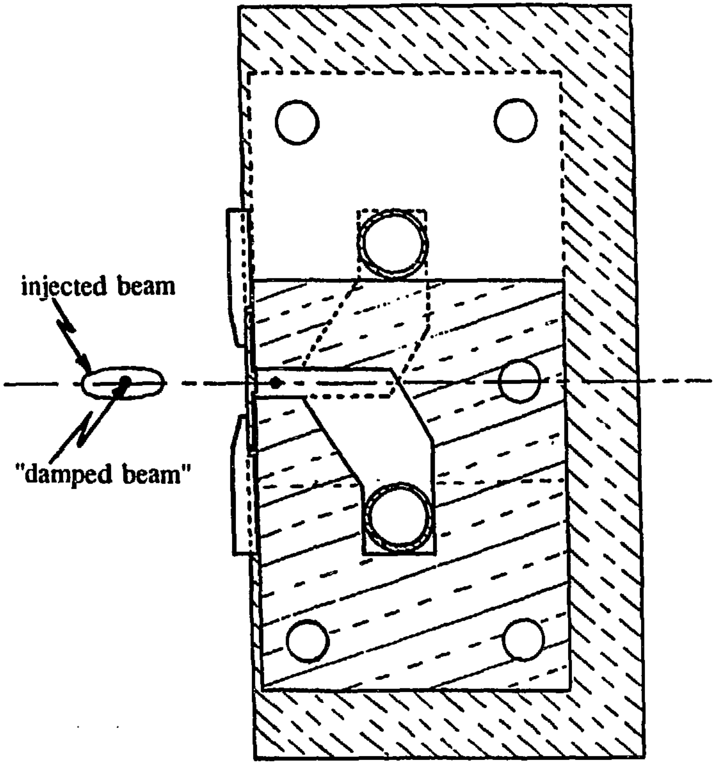


Fig.13a
Pulsed excitation Wiggler
Undulator/Septum Variant of the
Asymm.H Structure

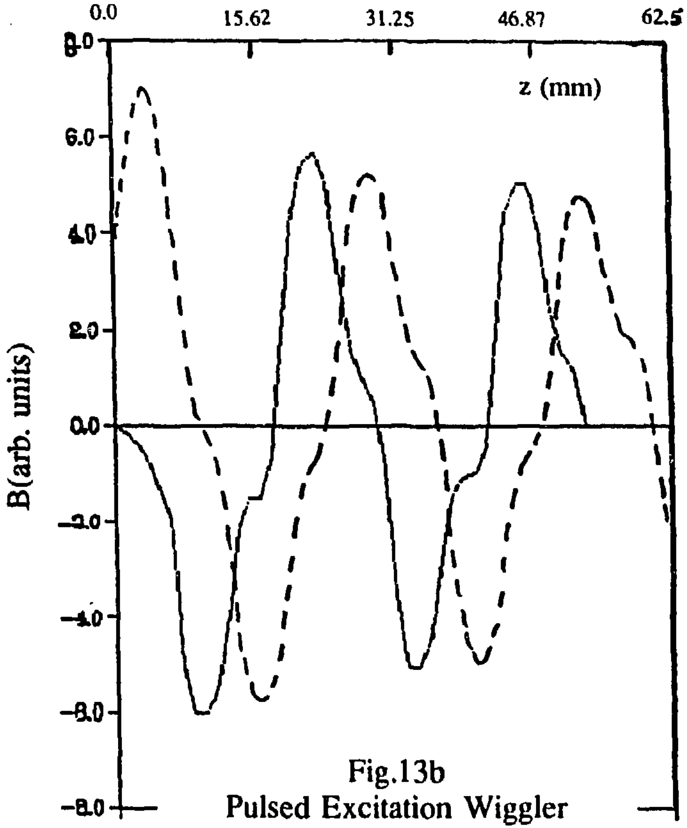


Fig.13b
Pulsed Excitation Wiggler
X-Y "Interlaced" Variant of the
Asymm.H Structure
($\lambda_{ox}=2.4cm$;$\lambda_{oy}=2.4cm$;$B_{\max}\approx 5kG$)
preliminary field data