CAP

BNL - 63617
CAP-151-CK-96C

CONF-9604147--3

SOLENOID FRINGE FIELD COMPENSATION FOR THE CLUSTER KLYSTRON

H. Wang, R.C. Fernow, H.G. Kirk, R.B. Palmer and Y. Zhao

Brookhaven National Laboratory
Physics Department, Bldg. 901A
Upton, NY 11973

April 1966

MASTER

CENTER FOR ACCELERATOR PHYSICS

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Un

**BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.**

Under Contract No. DE-AC02-76CH00016 with the

UNITED STATES DEPARTMENT OF ENERGY

Submitted to the "Pulsed RF Sources for Linear Collider Workshop (RF96)", Shonan Village, Japan, April 8-12, 1996

bnl
cul

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Solenoid Fringe Field Compensation for the Cluster Klystron

H. Wang, R. C. Fernow, H. G. Kirk, R. B. Palmer, and Y. Zhao

*Brookhaven National Laboratory, Bldg. 901A, Physics Department,
P. O. Box 5000, Upton, New York 11973-5000*

Abstract. Optimization of the solenoid pancake currents so as to have a uniform axial magnetic field over an extended volume, is very important for the successful operation of the Cluster Klystron. By boosting the first and the last pancake currents by 35%, a uniform field $B_r/B_z \leq 0.1\%$ at radius $R \leq 2$ cm can be extended from ± 7 cm to ± 16 cm. The result confirms simulations and the requirements for a 3-beam Cluster Klystron Experiment are achieved.

INTRODUCTION

The main features of Cluster Klystron includes using Magnetron-Injection-Guns (MIGs) deeply immersed in a focusing solenoid and running multiple beams off the axis of the solenoid [1, 2]. This requires that the axial magnetic field B_z is long and uniform, while radial magnetic field B_r is small, in order to avoid beam aberrations and misalignment problems [3]. With a finite length of solenoid, the uniform field length can be maximized by boosting the end pancake currents up to a higher percentage than the main current. Simulation studies [4, 5] have showed that a 35% extra current on the two end pancakes of our solenoid (nine pancakes in total) produces an optimum compensation on the fringe field. A uniform field $B_r/B_z \leq 0.1\%$ within the radius of $R \leq 2$ cm is obtained in a central length ± 16 cm (total 32 cm), that is $B_r \leq 4$ Gauss at $B_z = 4$ kGauss. Based on this solenoid field, the current Cluster Klystron demonstration experiment [6] is designed for a 3-beam structure running beams off-axis at $R = 1.5$ cm. A modification on the connection and supply to the pancake coils of solenoid was done in order to carry out this field measurement. A further Cluster Klystron MIG beam test is going to place the section from MIGs to beam diagnostic screens within this central area.

MEASUREMENT SETUP

The fringe field measurement was done only for the bottom half of the solenoid since the upper portion of the bore was occupied by a vacuum chamber. The solenoid top flange supports the high voltage fixture through the footage of the

vacuum chamber. The Hall probe could only reach to 4 cm far to the center of the solenoid in axial direction. We know from the simulation that the field within this distance is uniform.

One Magnetics 150-1 and two E/M 20-250-0218 power supplies were used to drive the main pancake coils and to shunt the top and bottom pancake coils separately. Both types of power supplies can be electrically floating from the ground, but may not be over their own voltage capability. If we used the original coil feeds, i.e. currents are fed from top to bottom or from bottom to top, it will give us a problem that at least one E/M power supply had to be floated on a voltage about 140 Volts. The actual modification was done by rearranging the copper lead connections to the pancake coils, so that we can just float the main power supply (Magnetics 150-1) on a maximum 20 Volts. Figure 1 shows this electrical floating scheme. The $5\ \Omega$ resistor is for ground-fault protection.

FIGURE 1. Electrical wiring diagram of solenoid pancake coils.

An axial Hall probe with a F. W. Bell Gaussmeter(model 9200) was used for the axial field measurement. The probe was contained in a brass-pipe holder, and the holder was clamped in a cylindrical-hole standoff which is fixed on a flange. The flange is concentrically mounted on the solenoid bottom flange. The holder can be placed on axis or off axis at $R=1, 2$ or 4 cm.

A transverse Hall probe was also available. It could be mounted on same fixture to directly measure the B_r , like the data presented in reference (4), but alignment

accuracy in holding became very important. The probe actually measures the magnetic flux perpendicular to the flat area of the tip. $B_p = B_r + \alpha B_z$, here α is the angle in radian between two axes of holder and solenoid. Since the B_z/B_r is around 1000, an angle of a few milliradian can cause the B_r up to 50% in error. There was a way to reduce this error by rotating the holder around itself 360°, so the B_p will be changing between $B_r - \alpha B_z$ and $B_r + \alpha B_z$. Using the mean value of the B_p , we could get B_r in minimum error, but that requires maintaining the angle α the same during the rotation. It was very difficult to do so at an up-side-down position by this simple fixture. The actual way to measure the B_r in this experiment is to derive $B_r(z)$ from the measured $B_z(z)$ data. From $\nabla \cdot \vec{B} = 0$, we can get a first order approximation

$$B_r(r_0, z) \cong -\frac{1}{2} r_0 \left. \frac{\partial B_z}{\partial z} \right|_{r_0} \quad (1).$$

By numerically fitting the experimental curve, or $B_z(z)$ data at 60 points into a 6-order polynomial form, the $\partial B_z / \partial z$ can be analytically obtained. The fitting error normally can be controlled within $\pm 0.02\%$.

MEASUREMENT RESULTS

An on-axis field measurement was done from $B_z = 3.5$ kGauss to 5 kGauss. Figure 2 shows the result at $B_z = 4$ kGauss level. In general from the measurement, the B_z curve becomes more flat as the additional current increases. At about 35%, the curve reaches maximum length on flat top without overshoot. At a certain power level, the top E/M power supply could not deliver more power to reach a desired percentage current due to its own failure. For example, at $B_z = 4$ kGauss level, the balanced currents could only go up to 35%. This unbalance did not affect the bottom field from the inspection of INTMAG simulation.

An off-axis field measurement was done at $R = 2$ cm on $B_z = 4$ kGauss level. Figure 3 presents the similar B_z curves to Figure 2 from 0% to 50%. Figure 4 picks up 0%, 35% and 50% curves from Figure 3 and compares with INTMAG simulations. Figure 5 shows B_r curves derived by Equation (1) from the B_z data in Figure 3. This plot clearly shows the tendency of optimization as the percentage of extra current changes. Figure 5 picks up 0%, 35% and 50% curves and compares with INTMAG simulations. It shows that 35% curve is the optimum curve which approximates the $B_r = 0$ line over the longest length. Figure 6 just picks up this optimum B_r curve and compares with two different types of simulations, INTMAG and POISSON. The experimental data also shows the error bars. Those error bars include errors from three sources. First is the reading error on the Gaussmeter, depending on how many digits are on the meter. Second is the

FIGURE 2. Solenoid bottom half, axial and on-axis field measurement.

FIGURE 3. Solenoid bottom half, axial and off-axis field measurement.

FIGURE 4. Solenoid bottom half, axial and off-axis field measurement and comparison with simulation.

FIGURE 5. Solenoid bottom half, radial and off-axis field measurement.

FIGURE 6. Solenoid bottom half, radial and off-axis field measurement and comparison with simulation.

FIGURE 7. Solenoid bottom half, radial and off-axis field measurement and comparison with simulation.

theoretical error (second order error) when we use first order approximation (Equation 1) to calculate Br. Third is the polynomial fitting error. We used a 3 1/2 digits meter with a typical reading error of 10 Gauss. An error analysis indicated that the theoretical error gave about 3.5 Gauss, and the fitting error contributed about 0.5 Gauss to this set of error bars.

CONCLUSION

Our experiment and simulation have demonstrated that by boosting the end pancake coils to a higher percentage current than the main coils in a solenoid, one can get good fringe field compensation without a complex magnetic field design. This kind of compensated solenoid is feasible for our 3-beam Cluster Klystron application.

REFERENCES

1. Palmer, R. B., Herrmannsfeldt, W. B., and Epley, K. R., "An Immersed Field Cluster Klystron", SLAC-PUB-5026, May, 1989.
2. Palmer, R. B., et al., "Introduction to the Cluster Klystron", in *Proceedings of International Workshop on Pulsed RF Power Sources for Linear Colliders (RF' 93)* at Dubna-Protvino, Russia, July 5-9, 1993, pp. 28-42.
3. Wang, H., Palmer, R. B., et al., "Beam Aberration Considerations and Simulations for the Cluster Klystron", in *AIP Conference Proceedings 337 of Pulsed RF Sources for Linear Colliders (RF' 94)* at Montauk, New York, October 2-7, 1994, pp. 103-117.
4. Kirk, H., "The BNL-SLAC Cluster Klystron Experiment", in *Proceedings of International Workshop on Pulsed RF Power Sources for Linear Colliders (RF' 93)* at Dubna-Protvino, Russia, July 5-9, 1993, pp. 67-72.
5. Palmer, R. B., ..., Wang, H., et al., "Status of the BNL-MIT-SLAC Cluster Klystron Project", in *AIP Conference Proceedings 337 of Pulsed RF Sources for Linear Colliders (RF' 94)* at Montauk, New York, October 2-7, 1994, pp. 94-102.
6. Palmer, R. B., Fernow, R. C., et al., "The Cluster Klystron Demonstration Experiment", NIM in Physics Research (Section A) Vol. 366 (1995) No. 1, pp. 1-16.