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MEASUREMENT OF ASYMMETRIC FLUX IN THE GAP OF AN INDUCTION ACCELERATOR MODULE

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Summary

A unique transverse field probe is used to determine the effect of feed and load current asymmetries on the axial magnetic field symmetry in the acceleration gap of a linear induction accelerator module. The special probe was used to quantitatively measure transverse pulse magnetic fields down to one gauss in the presence of large common mode noise signals and 10^7V/M pulse electric fields. Module tests using the probe provided a direct measure of the asymmetric fields produced when unbalanced conditions occurred. It also verified that under normal balanced operation the on-axis transverse-field is less than one gauss.

Introduction

The flash X-ray machine (FXR) now under construction at Lawrence Livermore National Laboratory (LLNL) is a 54 module linear induction accelerator, designed to produce a 500 R burst of X rays from a 20 MeV, 4 kA, 60 ns pulsed electron beam [1].

In order to guide the intense 4 kA beam through the 146 mm bore of the 54 module beam pipe, magnetic field perturbations must be compensated for or minimized by careful design. Small (10-15 gauss maximum) fixed field perturbations, such as the earth's field or solenoid misalignment fields, can be compensated for using the normal arrangement of beam steering coils. The transient field perturbations caused by the acceleration pulse cannot be adequately compensated for using the fixed steering coil currents. In addition, transient asymmetric fields tend to cause early onset of beam instability and breakup.

To achieve the field symmetries required for the FXR accelerator, a core type accelerator module was developed using a balanced feed and ballast load configuration. Figure 1 shows a cross-section of the module in which two opposite-balanced feed-points are placed at 90° about the axis from two opposite-balanced load-points.

Flux Probe Design and Calibration

The flux probe sketched in Fig. 2 is designed to explore the transverse pulse magnetic field present on axis in the accelerator gap. It is a pickup loop similar to a shorted twin lead inside a cylindrical Faraday shield as shown. The Faraday shield, designed to minimize electric field pickup, is slit in the accel gap region to allow flux penetration through the active region of the loop. The "shielded twin lead" design has a nominal 180 ohm transmission line impedance which is balance terminated by a 90 ohm resistor on one leg as shown. A 90 ohm coaxial transmission line is used on the other leg. By using this matched "transmission line" type loop, unwanted signal reflections and common mode noise signals are greatly minimized. Since the cylindrical Faraday shield will allow pulse magnetic fields to penetrate only through the slit, the effective loop cross-section will be reduced depending on the size of the slit opening. To accurately calibrate the probe, including the slit attenuation factor σ, experimental measurements of the probe calibration factors were made using the test setup shown in Fig. 3. In this case, the pulse field could be closely calculated because of the coaxial geometry of the test fixture shown. With the pulser charged to V_0=2.0 kV, the calculated field B at the probe is 2.1 G. The integrator output V_B is 105 mV as shown in Fig. 4. This gives an overall calibration V_B/B of 50 mV/G. The relation between scope voltage and B field is:

$$V_B = \frac{\sigma A}{10^5 RC} B; \; V_B\text{-mV, RC-sec, A-C}_m^2\text{, B-Gauss.}$$

The integrator resistance including the 90 Ω probe terminator is 180 Ω. The active area A is 11.6 cm^2 (l=13.0 cm, W=.89 cm). The above results give a slit attenuation valve σ of 0.40.

Asymmetric Field Measurements

To evaluate the asymmetric effects caused by imbalance in feedline or ballast load currents, the transverse flux probe was inserted on axis in the acceleration gap end space of the accel cavity as shown in Fig. 5. In balanced operation, the transverse end space fields shown by the dashed lines in the figure are exactly nulled at the probe location. Any asymmetry or unbalance in the feedpoints, load-points or their respective currents will disturb the on axis null condition and show a transverse B field during the accel pulse. Artificial unbalance can be created by changing the $CuSO_4$ concentration in the aqueous solution used in the liquid load resistors of either the east or west load cell. By circulating only distilled water in a load resistor either east or west load can be essentially removed.

Balanced and unbalanced probe output signals are shown in Figs. 6A, B, and C. The signals shown are with the plane of the probe loop horizontal and are fed to the scope through a one microsecond integrator. In each case shown in Fig. 6, the Blumlein pulse source was charged to the same value. In Fig. 6A, balanced 40 Ω loads were used. In 6B the east load was infinite, the west load was 40 Ω, and in 6C the reverse was true. Figure 6A demonstrates module symmetry and also that the probe is not disturbed by the gap voltage for balanced conditions. Figures B and C show opposite transverse B field directions which confirm the probes transverse B field sensitivity and provide the magnitude of these fields.

In these initial cavity tests of the probe, the RC integrator (an early model) was noisy and not precisely calibrated. Since the axial length of cavity gap or end space is l_g=3.81 cm the active probe loop area is reduced from A=11.6 cm^2 to A=3.40 cm^2 (i.e., l=3.81 cm, W=.89 cm). The approximate

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signal calibration factor is $V_B/_B$=13.6 mV/gauss (σ=0.4, RC=1 μs, A=3.4 cm^2). At a peak signal of 450 mV, the transverse field is then approximately 33 gauss on the beam axis in the gap.

In a later series of cavity tests, the scope and the improved RC integrator, calibrated as previously described, are used to repeat the unbalanced load tests. Figure 7 shows the resulting integrated output signal when the east load is 40 Ω and the west load is open. The plane of the pickup loop is rotated 180° from the previous cases causing a negative deflection. The Blumlein charge voltage in this case is 253 kV and the east load current resistor band gave a peak current of 10.8 kA. The signal calibration factor when corrected for the active probe area in the gap is $V_B/_B$=14.66 mV/gauss (i.e., 50 x 3.4/11.6). For the peak signal shown in Fig. 6 of 610 mV, the peak transverse field is B=41.6 gauss.

Conclusion

The module test results shown in Figs. 6 and 7 show a direct correspondence between load current unbalance and the resulting transverse asymmetric field on the beam axis. A similar condition would also apply to feed current so that for each kilo-ampere of current imbalance, an additional 3.8 gauss transient field asymmetry can be expected. The probe test results also demonstrate the desired field symmetry attained under normal conditions using the balanced feed and load arrangement selected for the FXR accelerator modules.

Reference

[1] B. Kulke "Design of a MeV, 4 kA Linear Induction Accelerator for Flash Radiography," LLNL-UCID 18939, 1981.

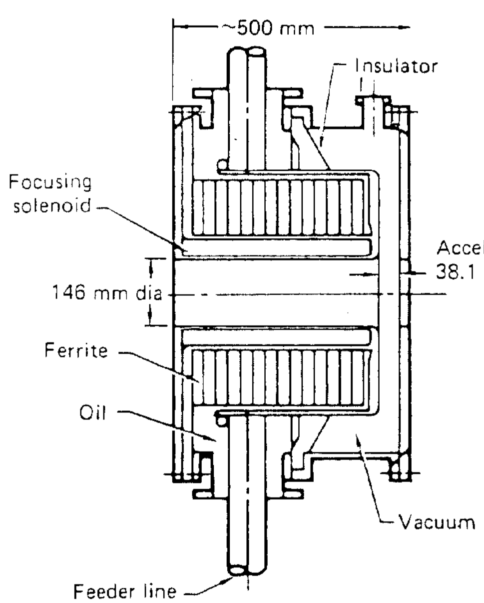


Figure 1. Standard accelerator module.

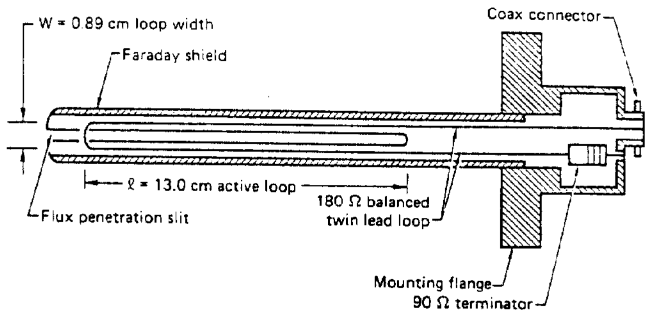


Figure 2. Transverse field flux probe.

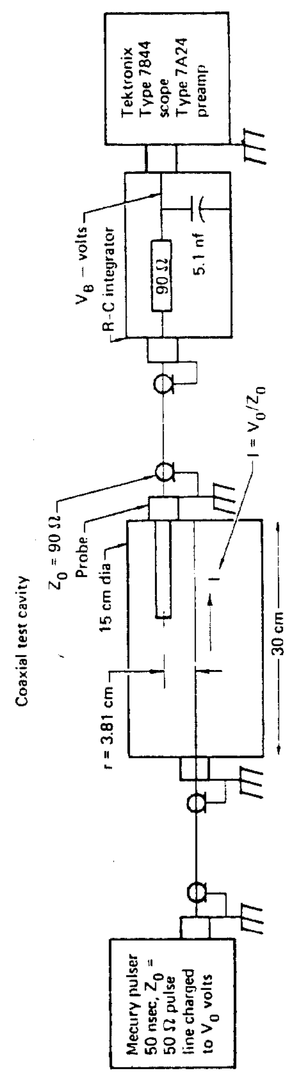


Figure 3. Probe calibration test setup.

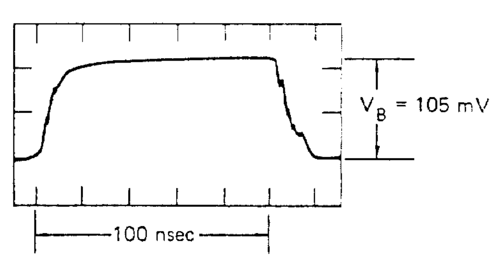


Figure 4. Calibration test results.

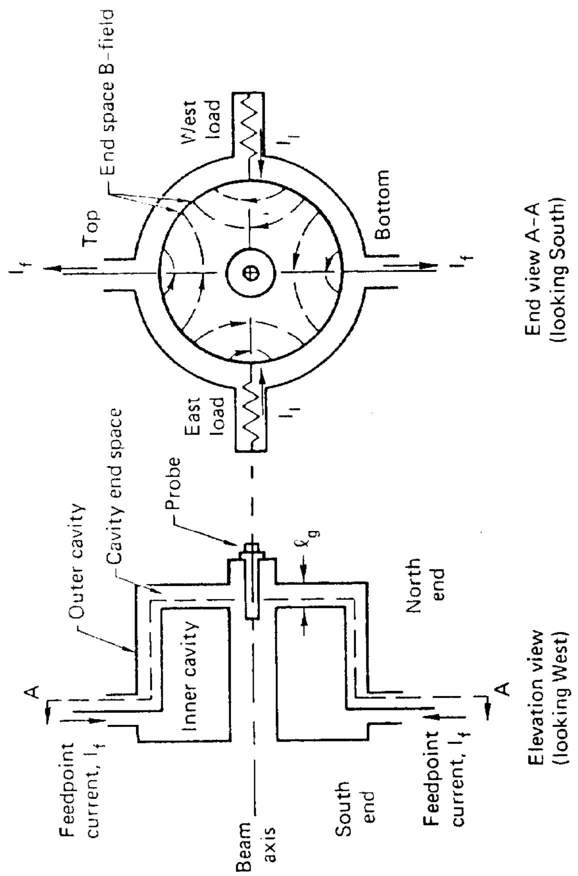


Figure 5. Accel cavity, feed and load geometry.

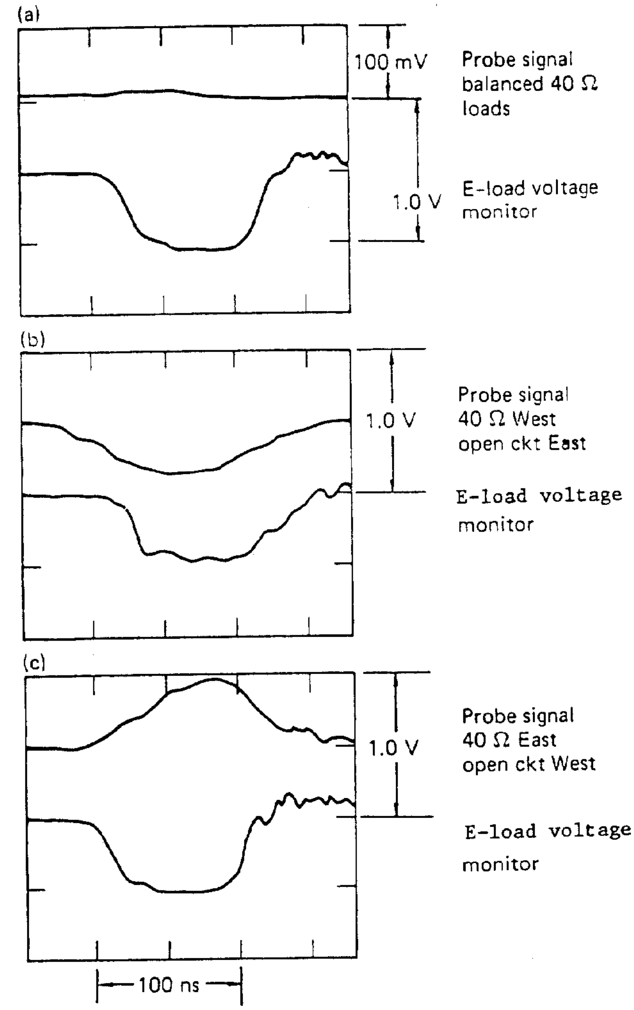
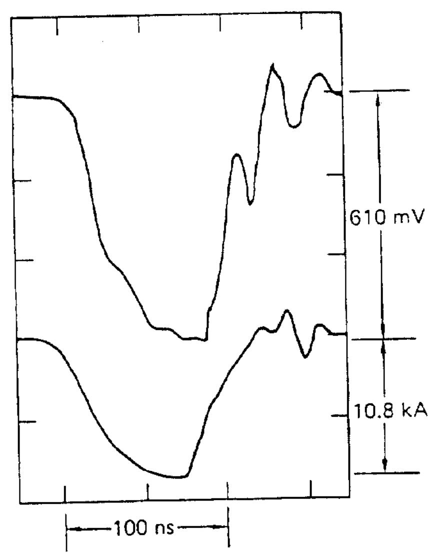


Figure 6. Transverse field measurements.



Upper trace
B-field probe with calibrated
R-C integrator and scope

Lower trace
Load can I-mon on east 40 Ω load
West load open

Figure 7. Transverse field measurements with calibrated probe.