LOCATING THE MAGNETIC CENTERLINE WITH A LOW ENERGY ELECTRON PROBE

Flux Line Mapping in a Linear Induction Accelerator

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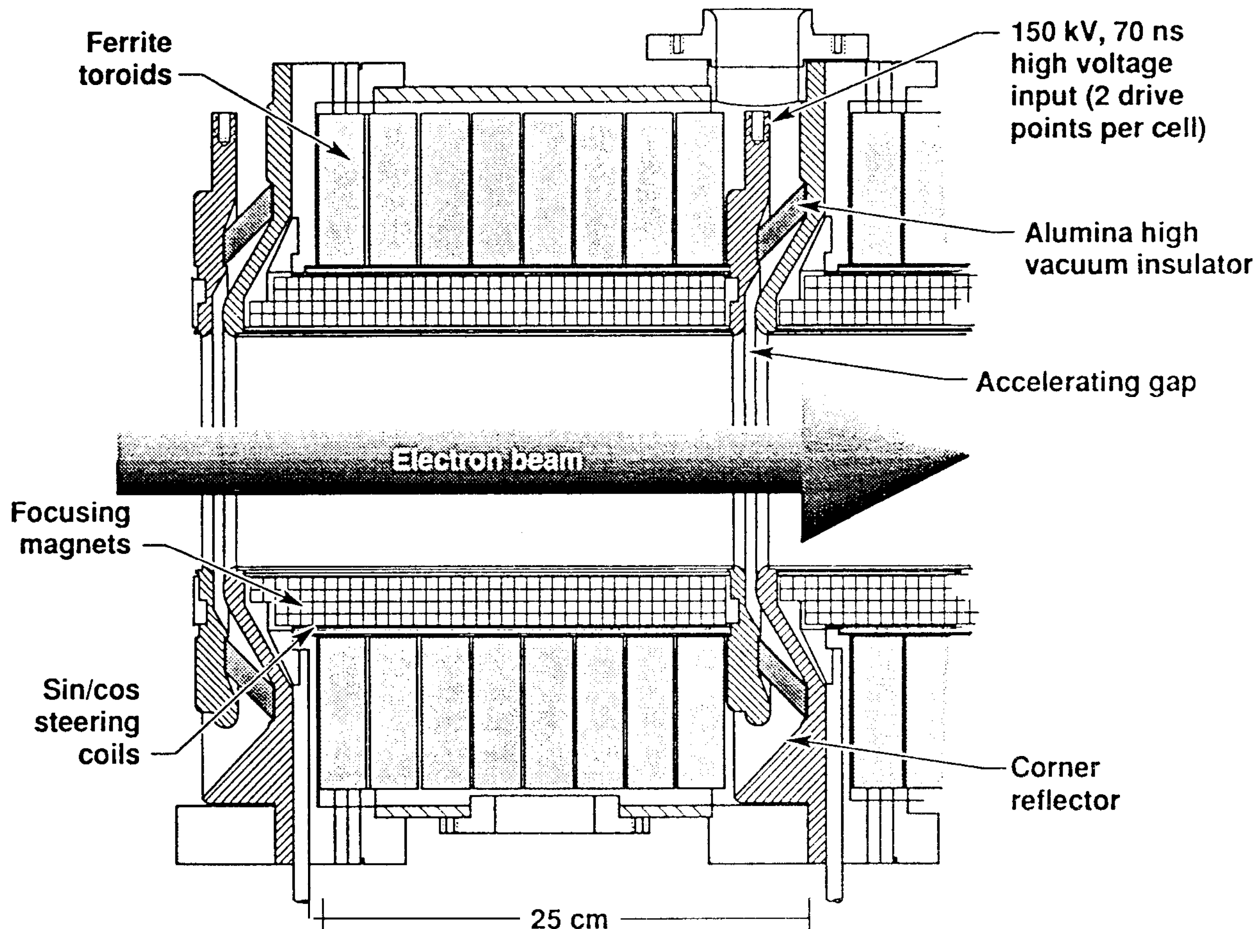
Summary

The following is a narrative of the oral report on "Locating the Magnetic Centerline with a Low Energy Electron Probe" presented at the First International Workshop of Accelerator Alignment. The low energy electron probe (LEEP) was originally developed at LLNL by Gene Lauer and has seen many modifications to improve accuracy and resolution. The technique is specifically designed to map the transverse position of a field line vs. its axial position in a solenoidal coil. The diagnostic uses a low energy (~4keV) electron beam, which is propagated from within the focusing field of the first accelerator cell. Due to the low energy of the electron beam, it will remain on the same flux potential that it is launched on, ie. it will follow a flux line (this statement can be in error if the electron beam is launched several mm from the solenoid axis, but for paraxial measurements the errors remain below the resolution of our detectors, < 10 µm). A phosphor screen has been used, in the past, to intercept the electron beam and convert it to a light spot which can be located in X and Y. The axial position of the phosphor screen is recorded with the X-Y location to produce a flux line map (for a single flux line) through the entire accelerator.

The linear induction accelerators at LLNL employ solenoidal coils to maintain electron beam focus throughout the accelerator. The coils are surrounded with ferrite toroids which increase the inductance in the high voltage accelerating gaps. Sin/Cos coils also surround the focusing magnets to “trim” the magnetic field. The Sin/Cos coils produce less than 1% of the field strength of the focusing coils but are nevertheless essential for producing a straight paraxial field line.

ETA II cell



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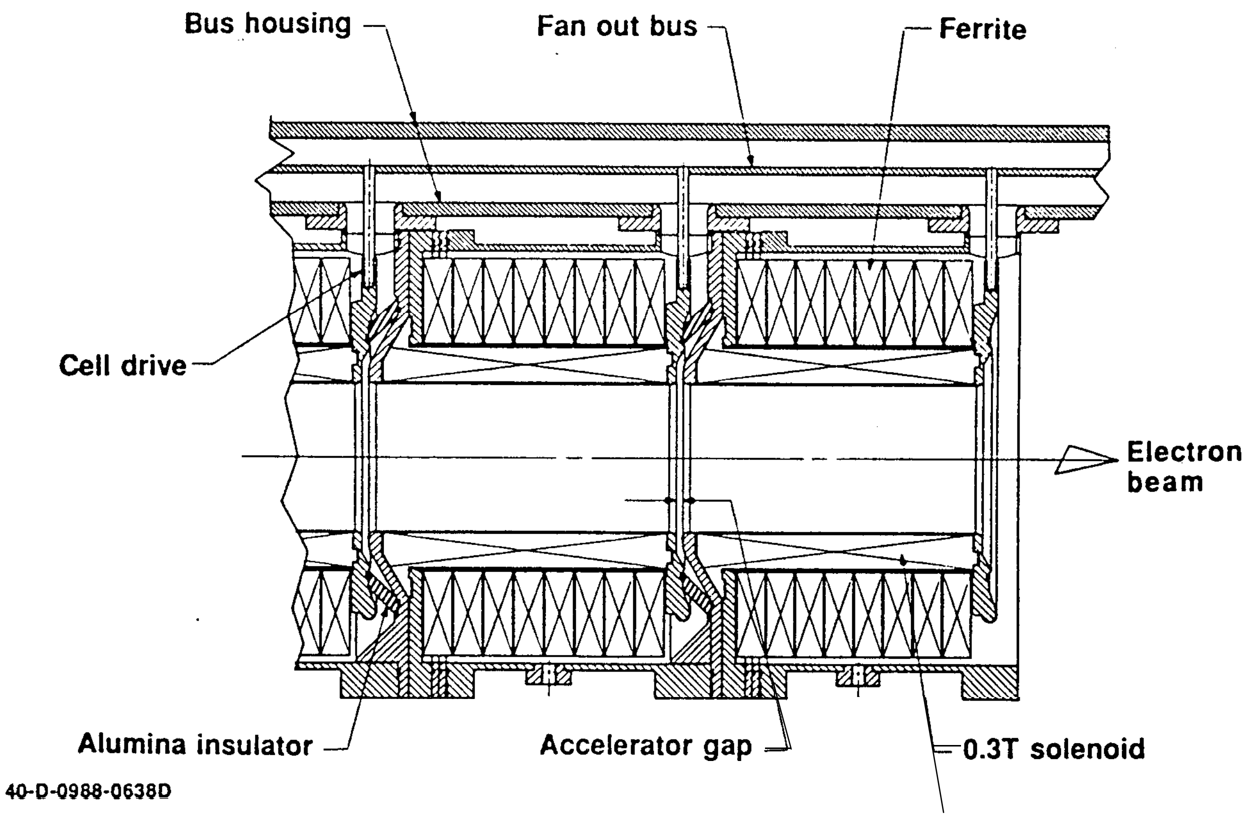
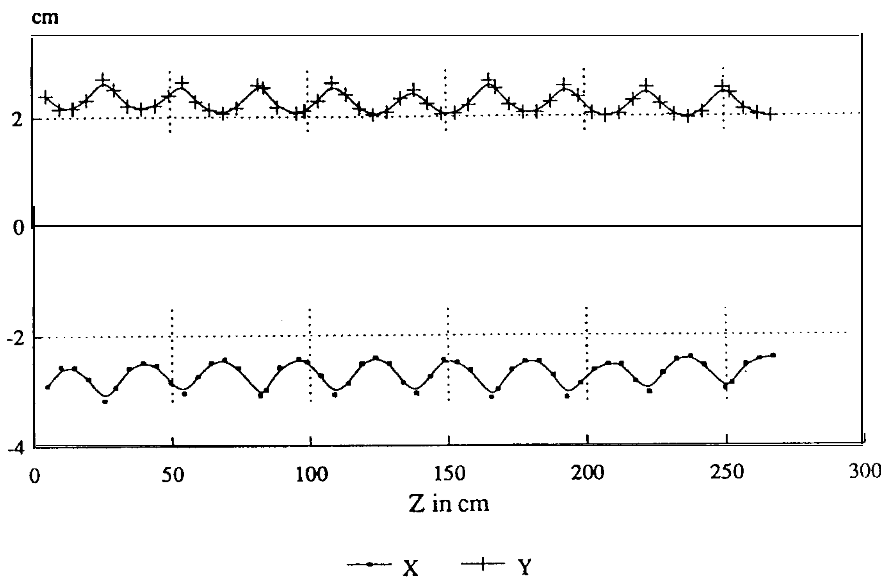
The solenoidal cells are linked together into 10-cell blocks. There is precise mechanical adjustment of each 10-cell block, via a five-axis geared lead screw system (commercially available jacks). The 10-cell blocks are installed to form an accelerator, for example the Advanced Test Accelerator has 20 10-cell blocks or 200 cells. By measuring the linearity of the field throughout the installed accelerator, a linear least squares fit can be generated to show how to adjust the mechanical position of each 10-cell block to minimize the field nonlinearity. Now, after mechanically aligning the accelerator, the LEEP diagnostic can be used to produce real time feedback on how to set the current of the Sin/Cos (trim) coils, and thus provide the final touch in straighting the magnetic field.

ETA II individual cell



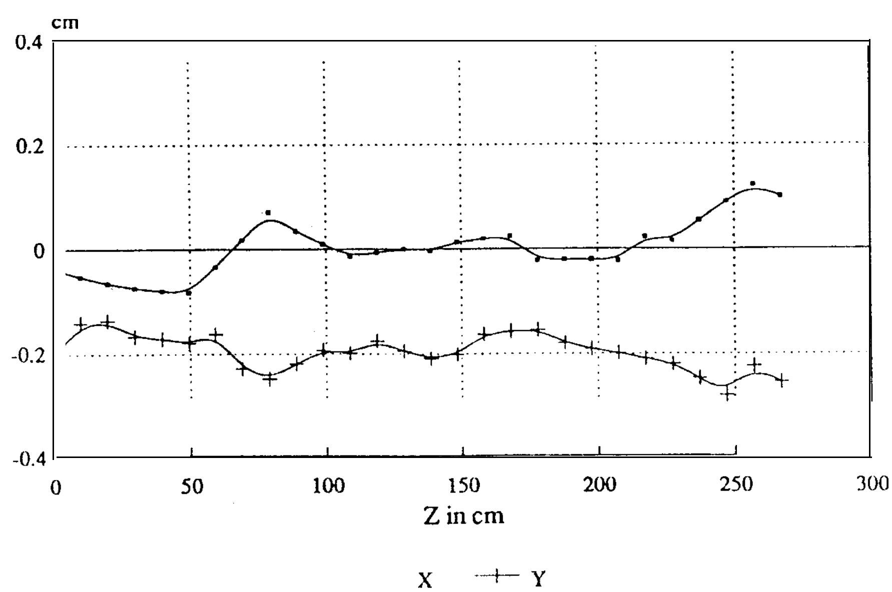
Measuring the linearity of the magnetic field off-axis reveals the field line deviations that occur at each accelerating gap. The electron beam does not follow these large field deviations exactly. However, near the accelerator axis there is relatively little field deviation and the electron beam will follow a flux line with negligable error.

4.6 cm off axis, 90 deg. CC from leads



10-cell at 500 A, Aux. coil at 200 V
e-gun 3 kV, 2.3 V, 260 V screen

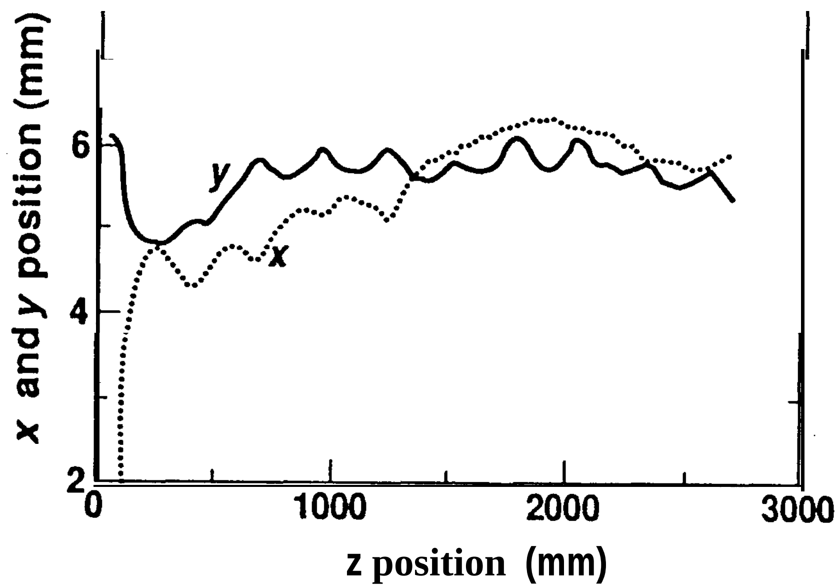
On axis



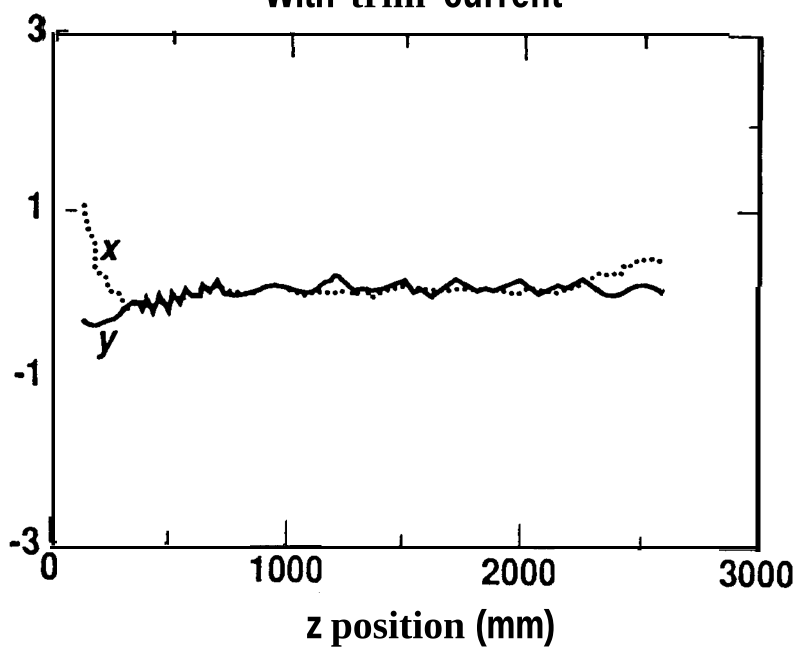
10-cell at 500 A, Aux. coil at 100 V
e-gun 2 kV, 2.4 V, 260 V screen, (rp3)

The electron beam does not have to be exactly on axis to be a useful diagnostic in determining the proper trim for the Sin/Cos (trim) coils.

Without trim current

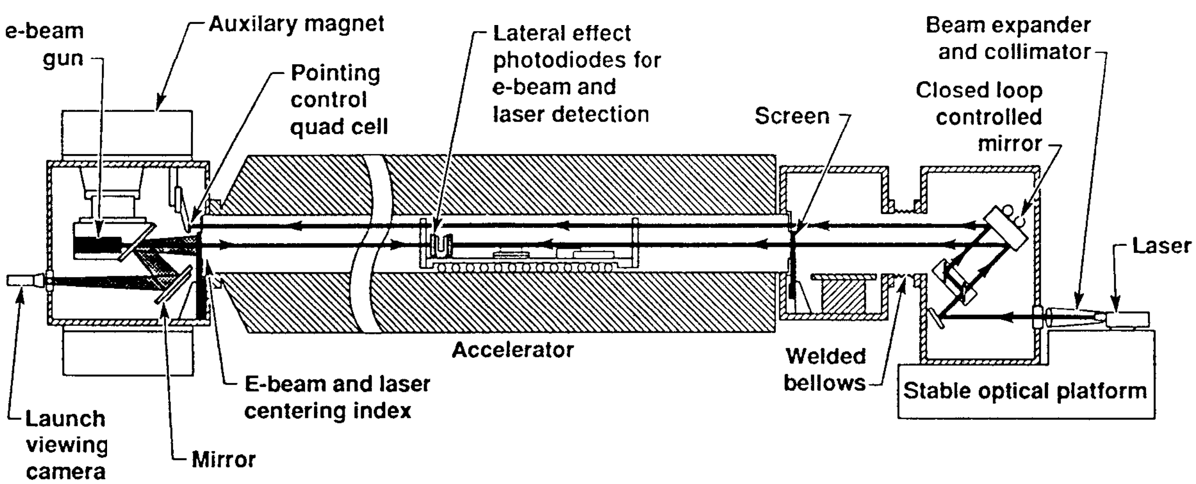


With trim current



The latest version of the LEEP diagnostic is aimed at solving several systematic problems or uncertainties that have existed with previous versions. The transverse position of the electron beam has, in the past, been determined by first converting it to a light spot on a phosphor screen. The phosphor screen was moved through the accelerator on a carriage, that also carried a TV camera to observe the spot. To know the true position of the electron beam required tracking the carriage with a laser beam and another camera. The cameras produced several problems such as; slow operation due to image processing requirements, camera failure in high magnetic fields (> 500 kG), and finally the cameras effected the field. These problems were solved by replacing the cameras with lateral effect photodiodes, which provide a direct analog determination of the X-Y position of either the electron beam or the laser beam. The photodiodes were specially built to eliminate magnetic materials. Another advantage of using the lateral effect photodiodes was that the carriage could be completely exposed to vacuum, so the laser beam could propagate past the carriage. By splitting the reference laser beam and propagating one half of the beam past the carriage, to a detector at the far end of the accelerator, the pointing direction of the laser could be stabilized to a couple of microns over the roughly 4 hour scan time.

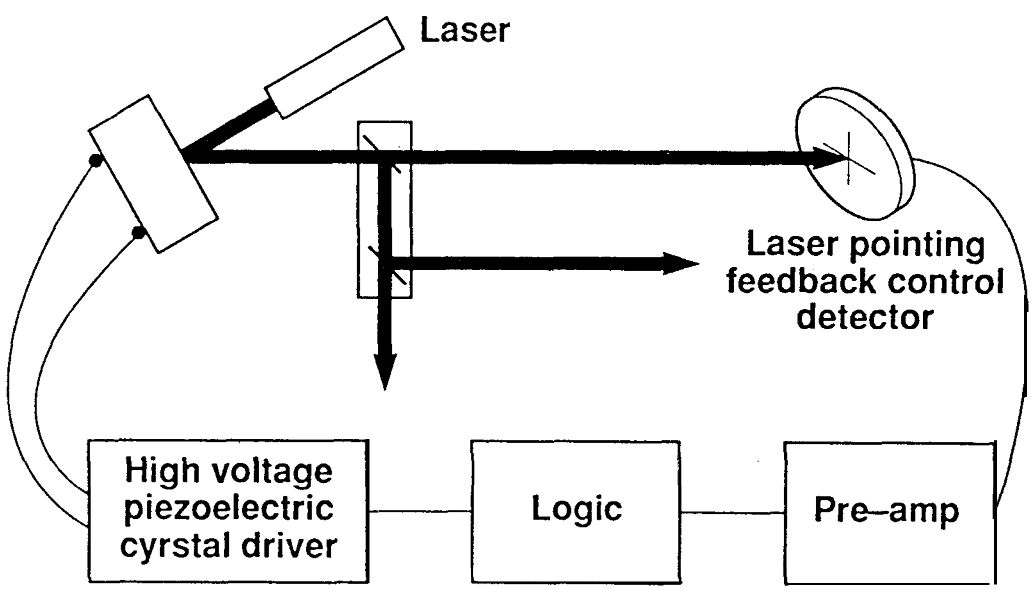
LEEP II provides several essential advances in accelerator alignment



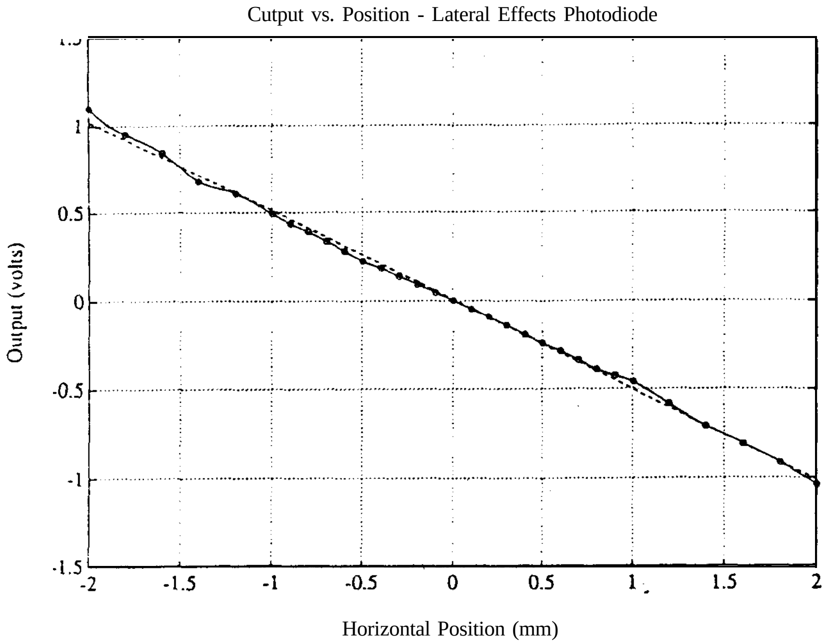
- Two point stabilized laser tracking
- Higher resolution and higher accuracy
- Correlation of magnetic axis to mechanical axis
- Elimination of magnetic effects on sensors and vice versa
- Higher speed of operation
- Capability to scan up to 80 meters
- Reduced risk to intrabeam-tube diagnostics

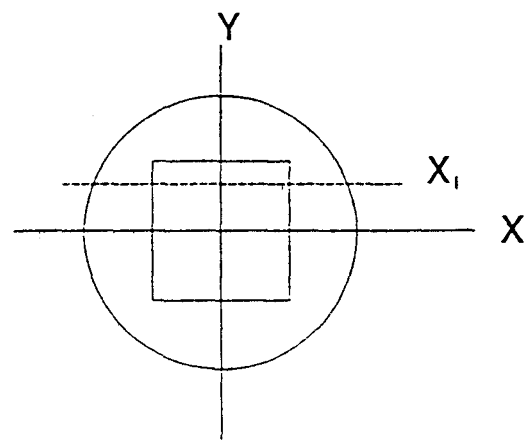
The reference laser beam is split with two cemented cube beam splitters. It is not necessary that the beams emerge from the beam splitter exactly parallel (10^{-4} radians is adequate). However, it is essential that the movement of one beam is matched by the movement of the other beam. One of the two emerging beams is intercepted by the carriage to determine the transverse position of the carriage. The other beam propagates past the carriage to a quad-cell detector at the far end of the accelerator. The quad-cell produces an error signal that is used to control a pointing mirror, and thus assure that the laser beam is held in a constant position.

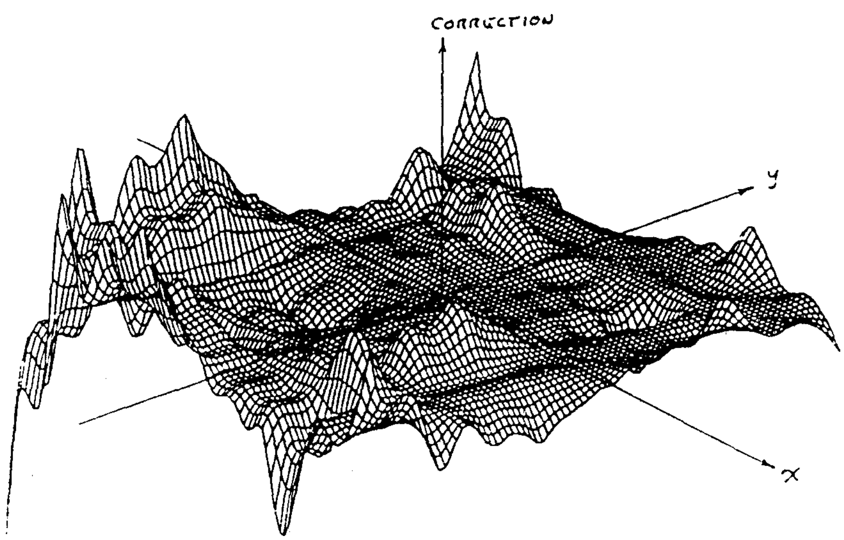
The feedback control loop has sufficient bandwidth to actively damp out laser jitter due to normal environmental vibrations



Although the lateral effect photodiodes will provide high resolution over their entire surface, their accuracy may be inadequate for our purposes. Each photodiode will be calibrated to produce a response for its entire surface, to address this issue. The correction surface below is for illustration only.







The Low Energy Electron Probe (LEEP) Diagnostic

A diagnostic for mapping flux lines through an accelerator

Review

The LEEP diagnostic provides a precise measurement of the linearity of the magnetic field through a solenoidal magnet or more cogently through a series of such magnets in an accelerator. The LEEP diagnostic provides information necessary for both mechanical alignment and for fine tuning the trim current of the Sin/Cos coils, which are the final adjustment of the field linearity. The essence of the system is as follows:

- The first and last cells of the accelerator are positioned using conventional computer aided theodolite techniques.
- Lateral effect photodiodes are indexed to the first and last cells to serve as an alignment target for a reference laser.
- The reference laser is split into two beams, one of which is used to stabilize the laser pointing and the other is used to track the position of the flux line diagnostics carriage.
- A low energy electron beam is launched along a flux line near the beam tube center at one end of the accelerator.
- The transverse position of the electron beam (and thus the flux line) is determined with a lateral effect photodiode on the diagnostics carriage.
- The diagnostics carriage is moved from one end of the accelerator to the other. As it moves, the transverse position of the electron beam is recorded as a function of carriage position, thus producing a flux line map.