Electron gun based magnetic probe

Srinidhi Bheesette, Marcos Turqueti

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Existing magnetic probe technologies

Objectives:

● Accurate magnetic field measurements are fundamental to the construction, testing, and certification of magnetic systems.

● One such example is undulators for light sources. Undulators require several magnetic measurements at different stages during its construction.

● Every magnet block, composed of several magnetic poles, must be measured individually and sorted based on the magnetic moment results.

● The final process of fine-tuning the undulators requires the magnetic measurements of the whole assembly.
Existing measurement methods and limitations

Two existing technologies-

- **Hall probe:**
  - Widely used for local field mapping and are the sensor of the choice for most magnetic characterizations.
  - Have limitations such as DC offset, nonlinearity, temperature drift, sensor aging, and the planar Hall effect.
  - Their long-term gain and offset drift with time and temperature, requiring frequent re-calibrations.

- **Single Stretched Wire:**
  - This method is used for straight geometries and is not generally suited for local magnetic field measurements.

- **Nuclear Magnetic Resonance:**
  - This method of magnetic measurement is accurate for the main field but is seen to be unsuitable for field gradient measurements.
Electron Beam Magnetic Probe (eProbe)

- A novel technology that will provide - **local magnetic measurement capability**, along with **overlapping range** and **field accuracy** for several existing solutions.
- It will facilitate faster and simpler verification, construction, testing, and tuning complex magnetic systems such as undulators, wigglers, and magnets.
- The proposed eProbe is based on a very short micro Cathode Ray Tube (mCRT) integrated with an imaging sensor based on Charge-Coupled Devices (CCD).
- An electron gun fires a low energy electron beam into the image sensor, which is mounted perpendicularly to the beam and located at the opposite end of the probe.
- Electrostatic deflecting plates continually manipulate the electric field and thus project a pattern onto the imaging sensor.
eProbe prototype
Simulating the eProbe

- Each component of the eProbe was simulated in GEANT\(^1\), a toolkit for simulating particles' passage through matter.
- The CMOS digital image sensor was modeled as a 0.25 mm thick silicon layer with an active area of 2.46 mm by 1.85 mm.
- The active sensor area was divided into 1296 by 976 pixels, each of size 1.9 microns.
- The source used was an electron source of energy 100eV with a gaussian spread of 5eV dispersion placed at a 1 mm distance from the detector.
- The deviation in the centroid of the beam can be measured by introducing different magnetic fields in the x and y plane, considering the detector is on the z plane.

Introduction of magnetic field
Gaussian beam profile as seen on the detector

Particle hit map

Average energy hit map
Optimizing the eProbe parameters

- Simulations run for two different orientation (case A and B) for different magnetic and electric fields with the accelerating plates at 400, 2000, and 4000V.
- The deviation observed from the center of the detector was studied for different magnetic fields for both the cases.
- The intercept obtained from a relation between the derivation will help calibrate and measure various magnetic fields.
- The deviation would also give us an idea of the lowest magnetic field that could be measured by the electron gun.
Model orientation in Case A and Case B

**Case A:** Accelerating plates in front of the detector

**Case B:** Accelerating plates behind the detector
Vertical centroid deviation comparison for Case A and B

Delta Vertical centroid deviation for Case A

Delta Vertical centroid deviation for Case B
Vertical centroid peak deviation in Case A and B
Validation with previous measurements

- Real-time field measurements were carried with a magnetic probe placed at 10 mm from the source.
- For case C, the source-to-detector distance was changed, keeping the other parameters the same as case A.
- Simulations were run and the k-mean clustering algorithm was used to calculate the centroid at various magnetic fields.
- Results from measurement and simulations were compared and validated.
Simulating the measurement setup
Centroid determination using k-means clustering
Validating eProbe measurements

Graph 1: CGy (microns) vs. Magnetic field (Tesla)

- Trendline for series 1 $R^2 = 0.996$

Graph 2: B field in (uT) versus Electron Beam Centroid

Values range from 0 to 70 on the y-axis and 0 to 20 on the x-axis.
Vertical centroid deviation comparison for Case A, B and C
## Minimum magnetic field measurable

<table>
<thead>
<tr>
<th>Case</th>
<th>Source to detector distance</th>
<th>Position of the accelerating plate</th>
<th>Magnetic field until which no deflection is seen at different accelerating plate voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>1 mm</td>
<td>Front of the sensor</td>
<td>200uT, 900uT, 900uT</td>
</tr>
<tr>
<td>Case B</td>
<td>1 mm</td>
<td>Behind the sensor</td>
<td>100uT, 200uT, 200uT</td>
</tr>
<tr>
<td>Case C</td>
<td>10 mm</td>
<td>Front of the sensor</td>
<td>10uT, <strong>9uT</strong>, 70uT</td>
</tr>
</tbody>
</table>
Future tasks

- Calibrating the various sections of the CMOS detector using one beam deflected using the magnetic field.

![Diagram](image)

- Simulated and validate model for different source to detector distance eProbe configurations.

- Simulated the measurement using a custom made CCD to be designed at LBNL, so we can operate at even lower energies (~1-10 eV).
Conclusion

- Our studies indicate that an eProbe could be successfully simulated with various magnetic and electric fields using the GEANT4 simulation tool.
- Previously existing measurements were compared with the similar model simulated in GEANT4, and the results were seen to be consistent with those obtained from the actual measurements.
- The results from the simulations will allow us to develop different eProbe orientation by optimizing different parameters (distance, thickness, position of accelerating plate, etc.).
Thank You

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## Slope coefficient for the three cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Source to detector distance</th>
<th>Position of the accelerating plate</th>
<th>Vertical deflection vs Magnetic field slope at different accelerating plate voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>1 mm</td>
<td>Front of the sensor</td>
<td>0.584 0.841 1.103</td>
</tr>
<tr>
<td>Case B</td>
<td>1 mm</td>
<td>Behind the sensor</td>
<td>0.478 0.554 0.575</td>
</tr>
<tr>
<td>Case C</td>
<td>10 mm</td>
<td>Front of the sensor</td>
<td>0.308 0.353 0.347</td>
</tr>
</tbody>
</table>