Fast Ramping Measurements with a Slowly Rotating Coil

August 23 , *2007*

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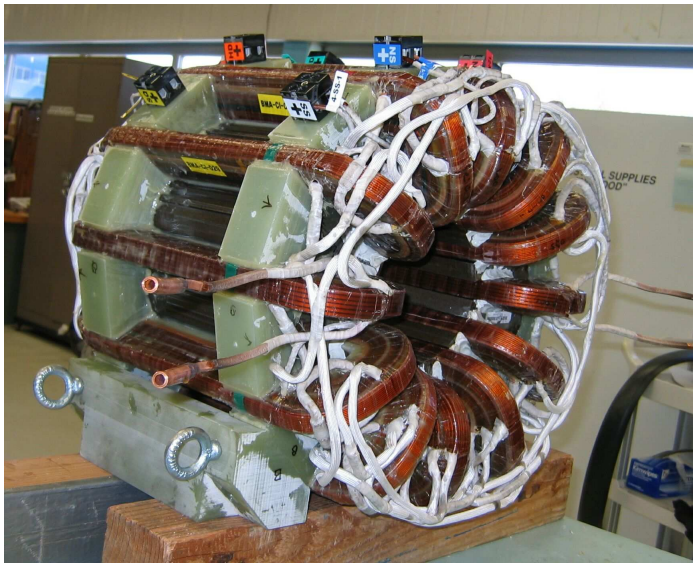
Motivation

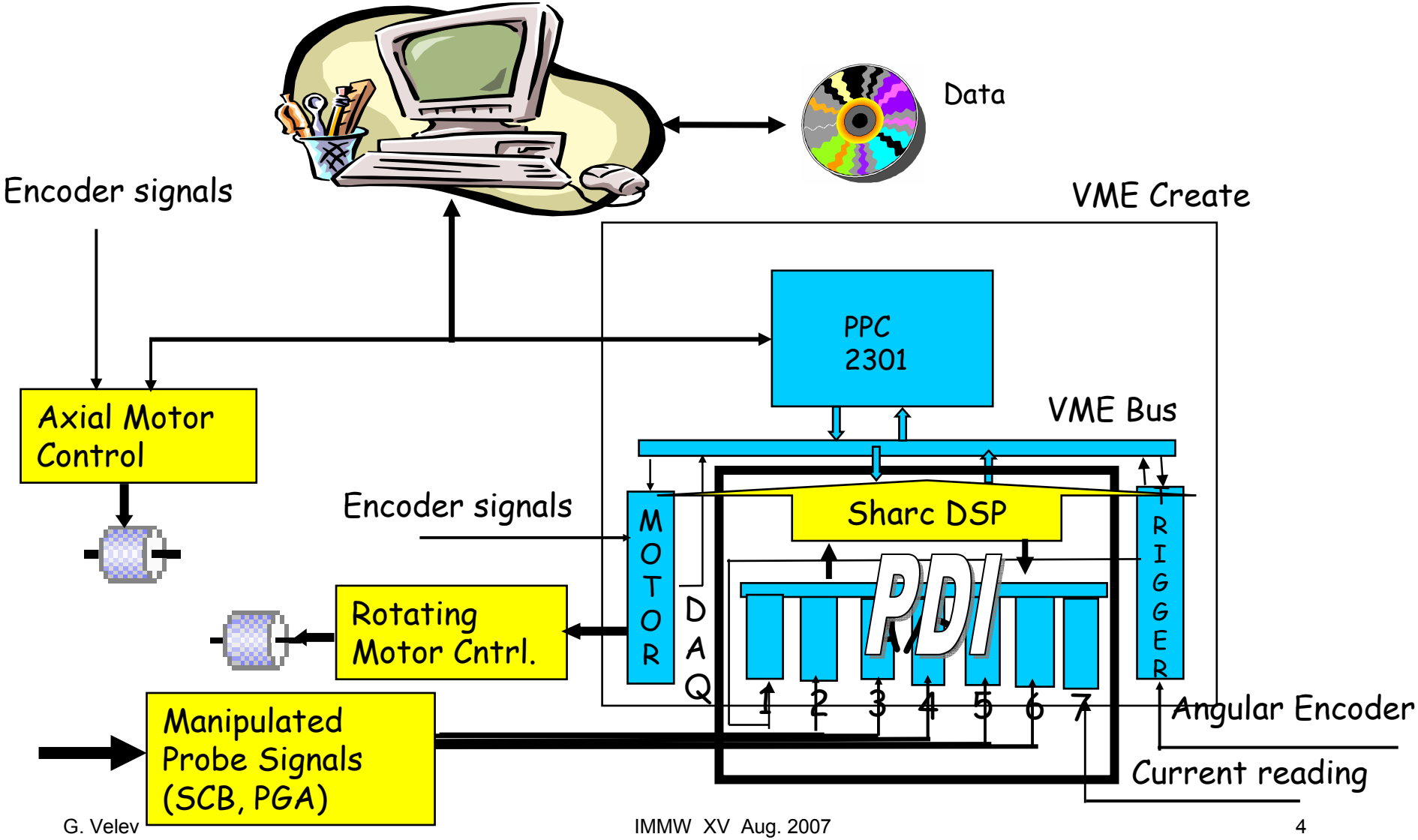
- The Booster Synchrotron started operation in beginning of 1970
  - Old corrector packages - limited by the ability to control the beam orbit
  - Need to increase the p beam intensity for neutrino experiments
- New new stronger, water-cooled corrector packages – Fermilab design
  - more orders, higher strength
  - including normal and skew dipoles, quadrupoles and sextupoles
  - the correctors are designed to provide full control over the orbit from 0.4 – 8.0 GeV
  - Booster is a rapid cycling machine, correctors track the 15 Hz cycle of the main Booster combined function magnets
  - slew rates: the quadrupole and sextupole elements should swing through the full current range in ~1 ms during the transition crossing



Production and Measurements

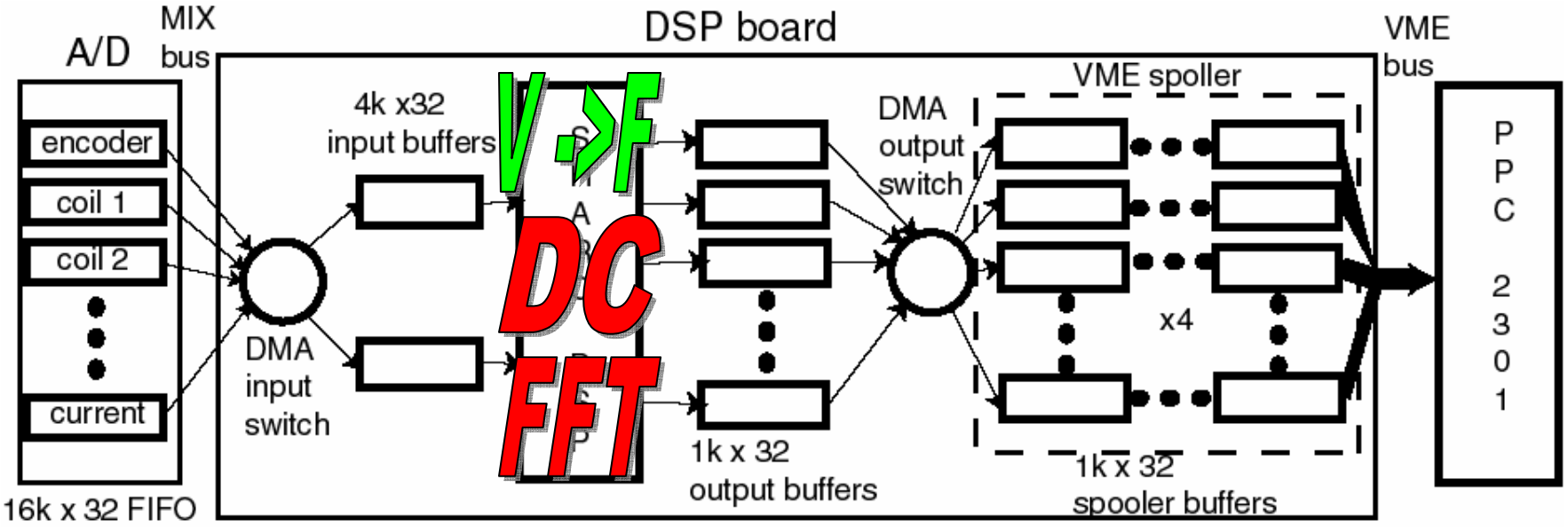
- 60 will be totally produced;
  - 48 will be installed in the Booster;
  - initially 24 were ordered for 2007 Shutdown
  - 12 is the final number going to the Booster this year
  - The production started at the beginning of this year;
  - two models were produced last fall '06 – to be tested
- A typical way to measure harmonics in AC powered magnets is to utilize an stationary array of multiple probes
- A new method, using a slowly rotating coil
  - To assemble measurement points for successive identical current cycles
  - Our fast Digital Signal Processor (DSP) measurement system is utilized in this measurements
  - DSP system + rotating coil: practically - no limitation in the data bandwidth
  - No new hardware was needed
  - Two major questions: eddy currents and slew rate or does the main field of the correctors follow the current ramp?

Diagram of the real time measurement system



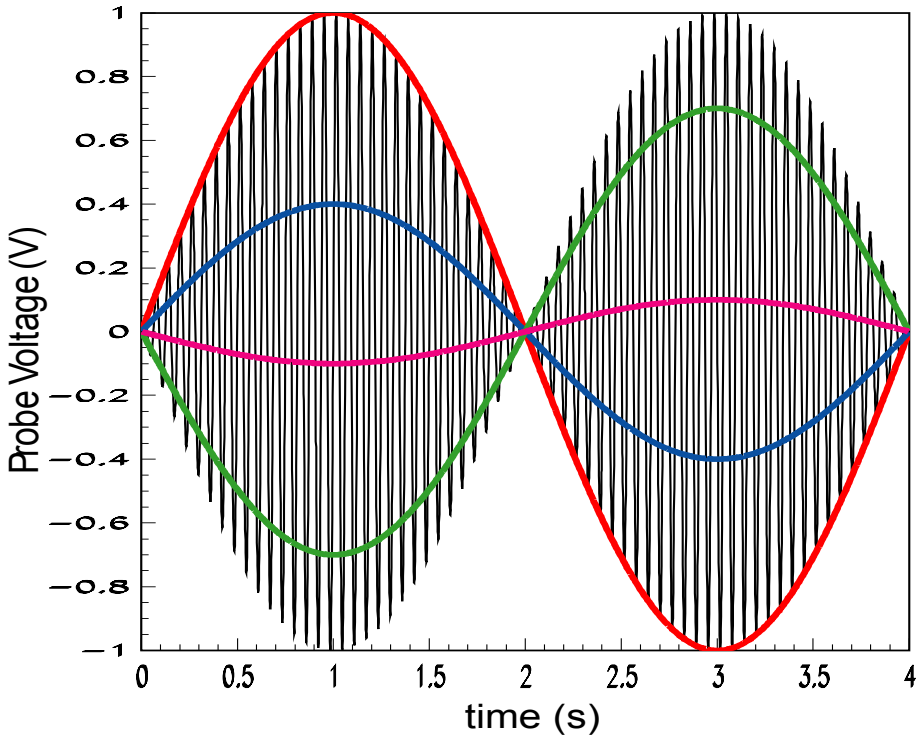
DSP Programming and Firmware

- The DSP firmware code was designed and written in-house
  - The major task for this code is to transfer on-line the information from A/D converter FIFO buffers into the processor memory,
  - integrate the input voltages to the fluxes and transfer the flux values to the VME accessible memory for reading by the control VME PPC computer
  - special treatment of the encoder pulses and current channel is performed.
  - it uses a DMA data transfer and processor interrupts for optimal data transfer
  - Details: *IEEE Trans. Appl. Supercond.*, Vol. 16, No. 2, June 2006, pp. 1374-1377



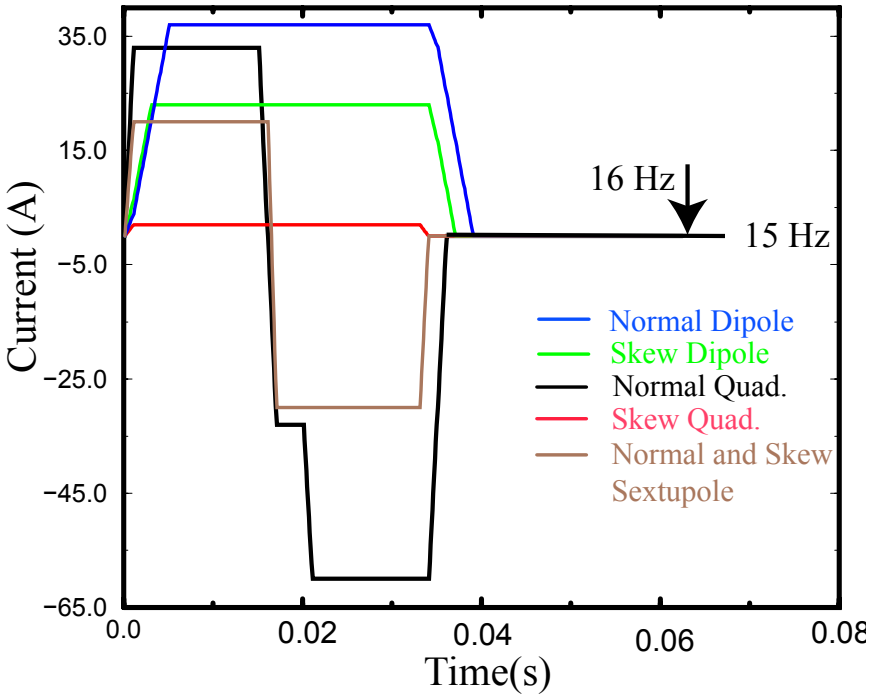
General Description of the Method

- A simulated signal of the probe dipole winding when the dipole corrector is excited with 16 Hz sinus AC.
- For this simulation:
  - the rotational speed of the probe is assumed to be 0.25 Hz with 16384 points per rotation.
  - for one full rotation of the probe, the current cycles 64 times per rotation and every cycle contains 256 points.
- If the points with the same phases from the current cycles are selected (these points correspond to being acquired the same magnet current but have different voltages due to the probe rotation) one may reconstruct the field harmonics
- The resolution is: 244.1 μs



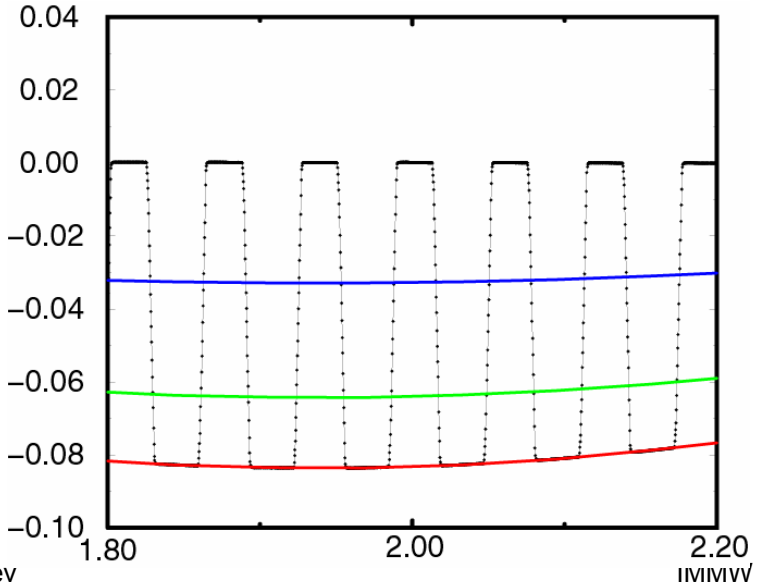
Booster Current Profiles

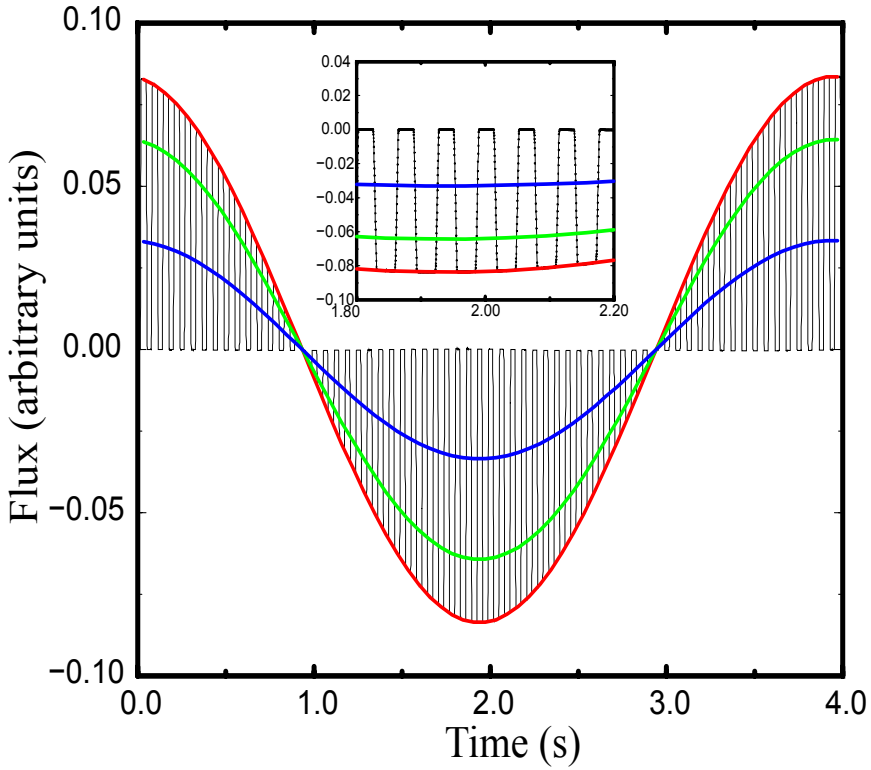
- Nominal Booster cycle – 15 Hz
- To synchronize the number of triggers per current cycle during the measurement, we modified the nominal Booster cycle
  - –frequency from 15 to 16 Hz, shortening the time at zero current.



Dipole DAQ signal

- The measured flux signal (black line) when the dipole corrector is excited.
- The nominal rotational probe speed is 0.25 Hz





Cycle synchronization

•During the initial tests, we found that we accumulate an error, in average, of ~20 μs after every 4 s rotation

• Precision of the control unit of our stepper motor.

•To compensate for this systematic effect, we applied a time correction based on the difference between the expected and measured current cycles.

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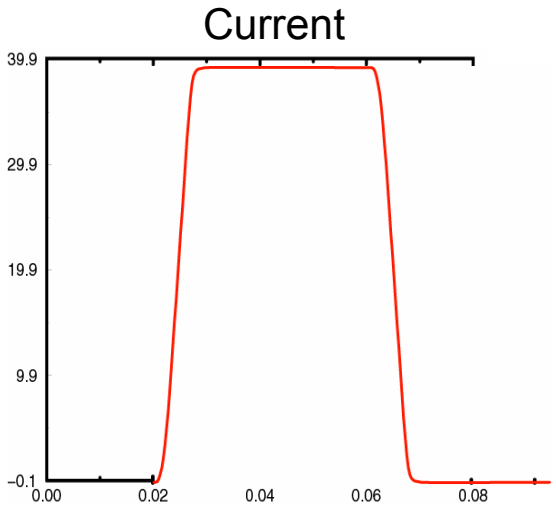
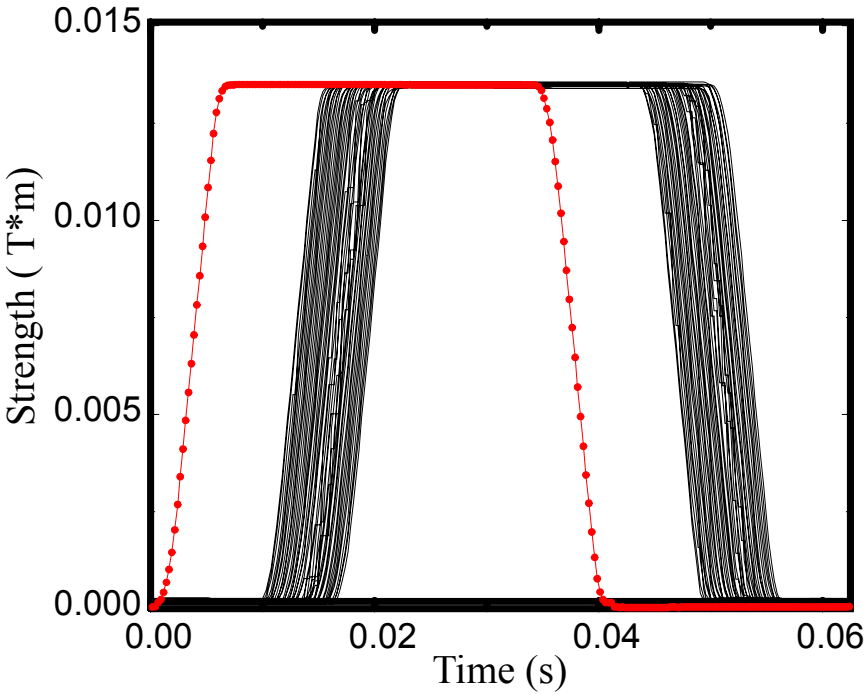
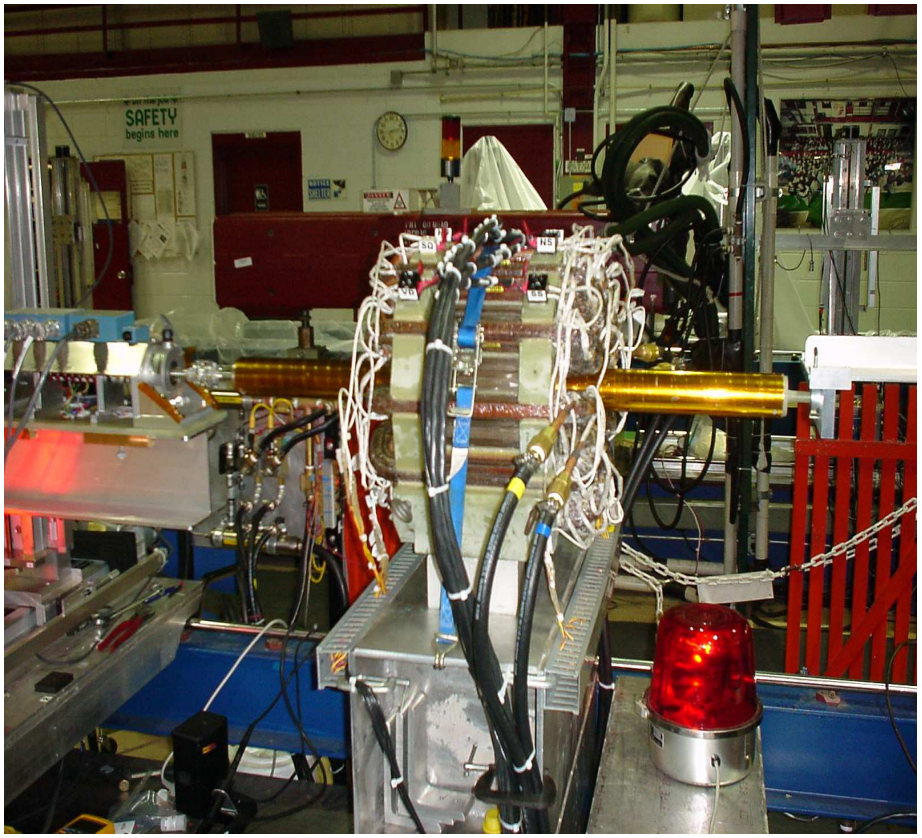
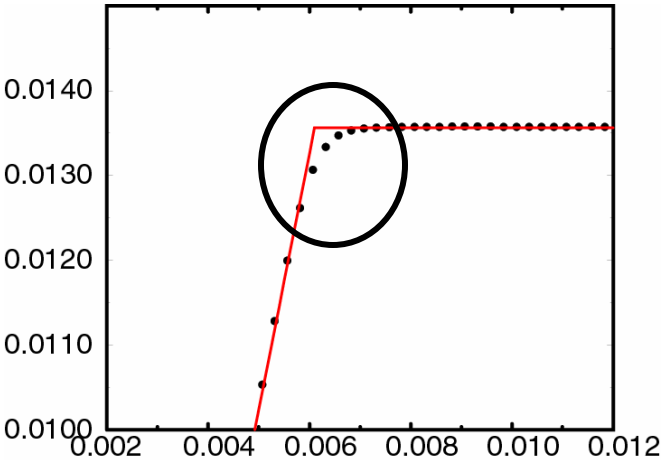


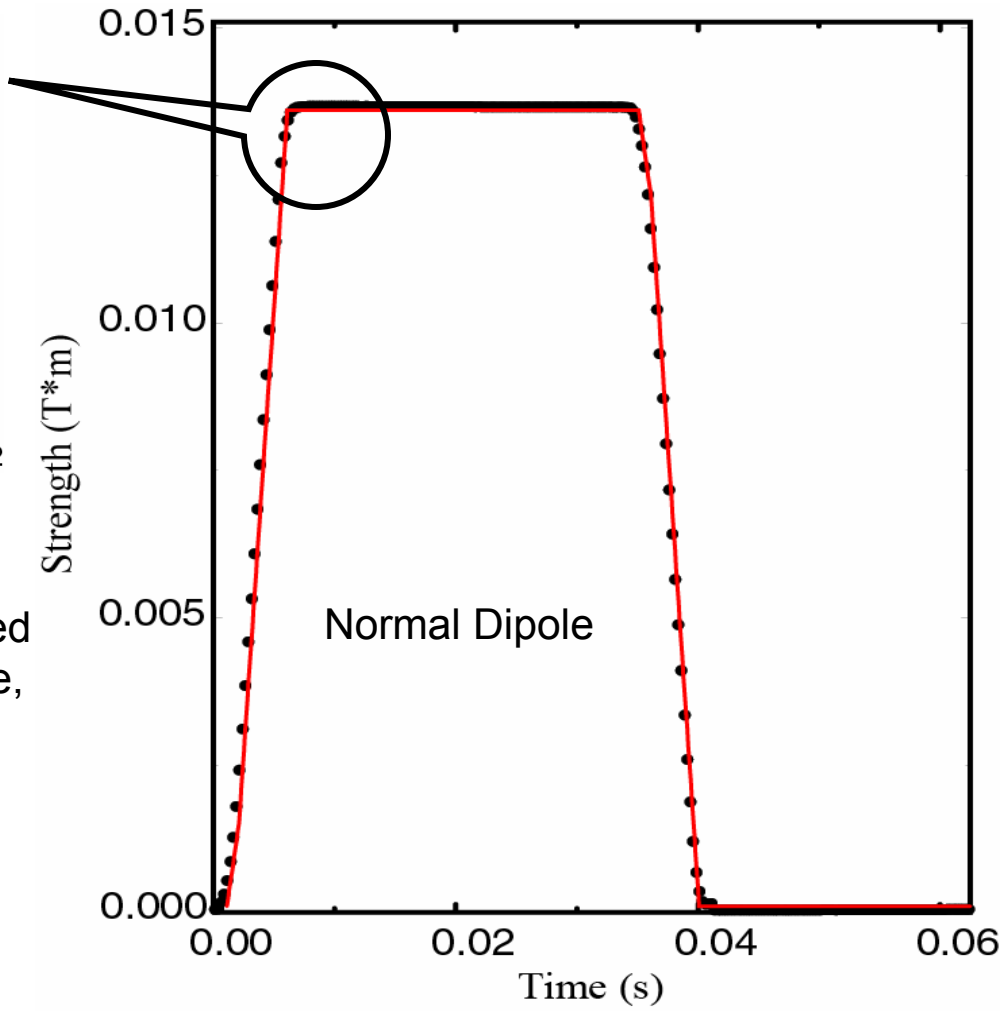


Corrector Measurement Setup



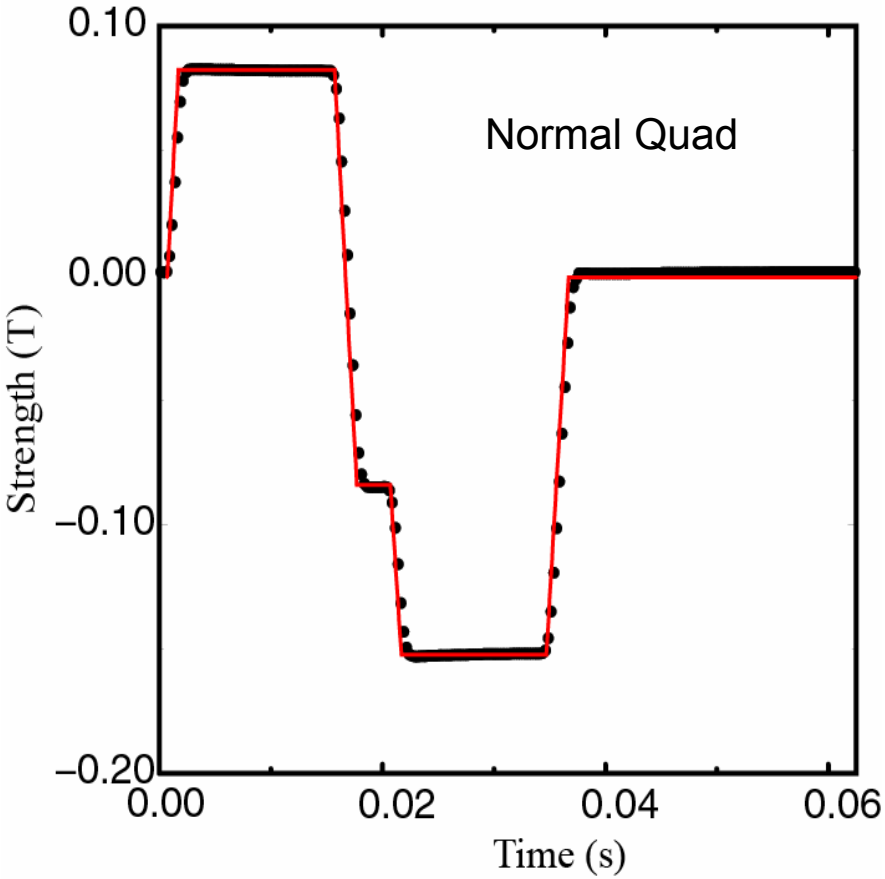
AC measurements – Strength – Dipole

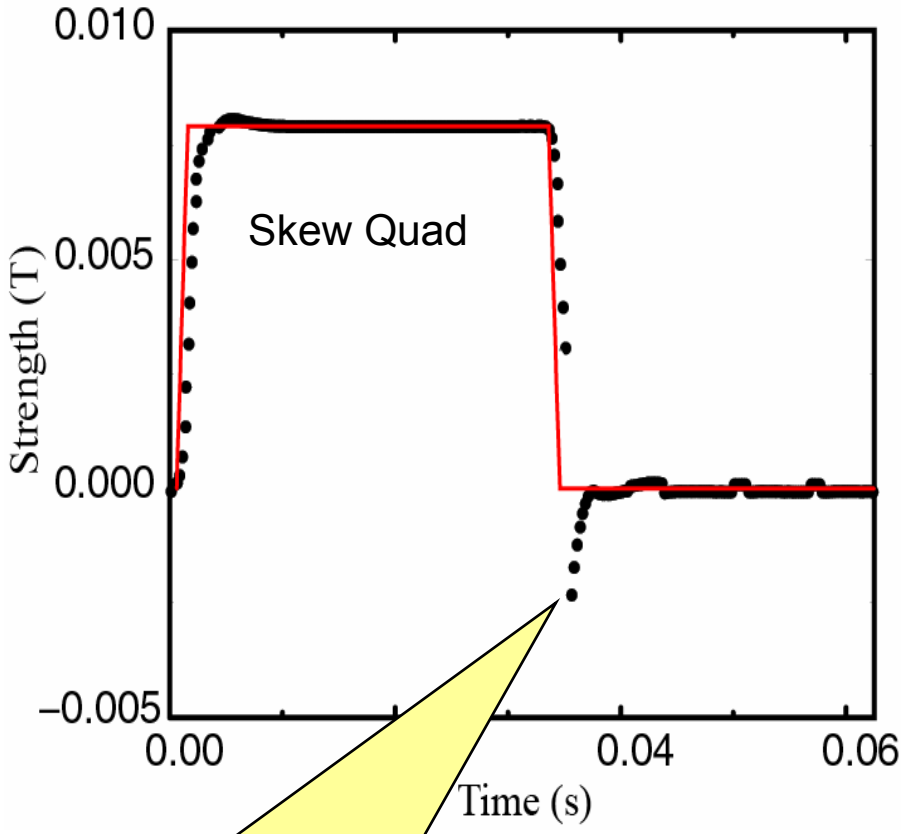




•A comparison between the AC measured and expected strengths for normal dipole,

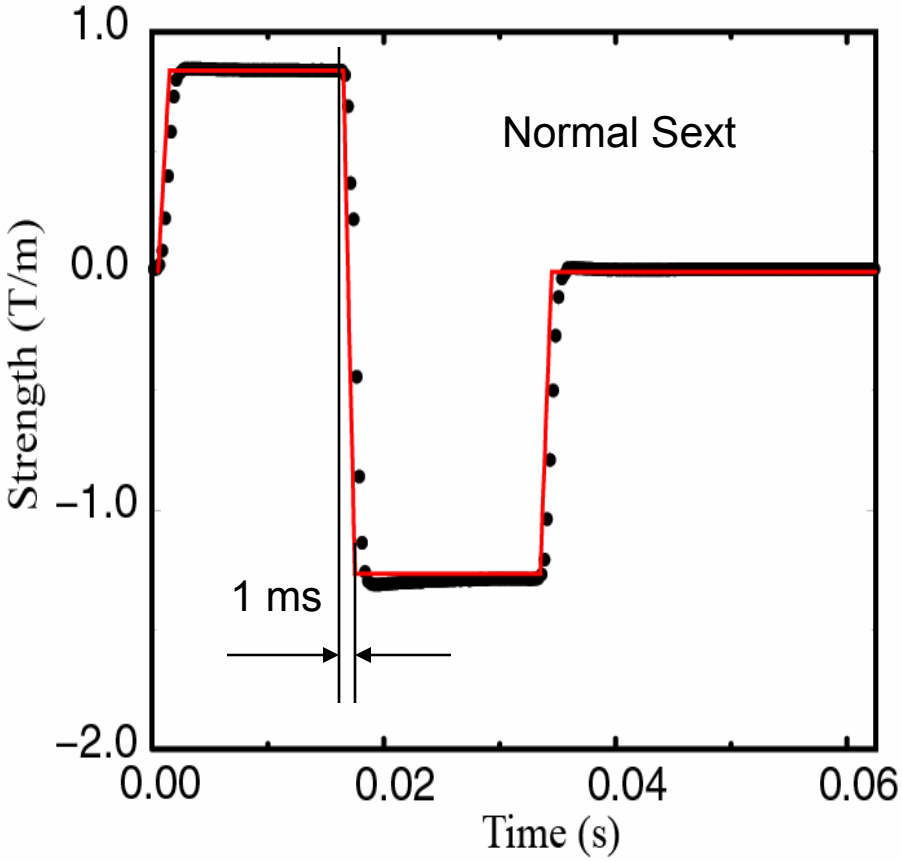
Strength - Quadrupoles

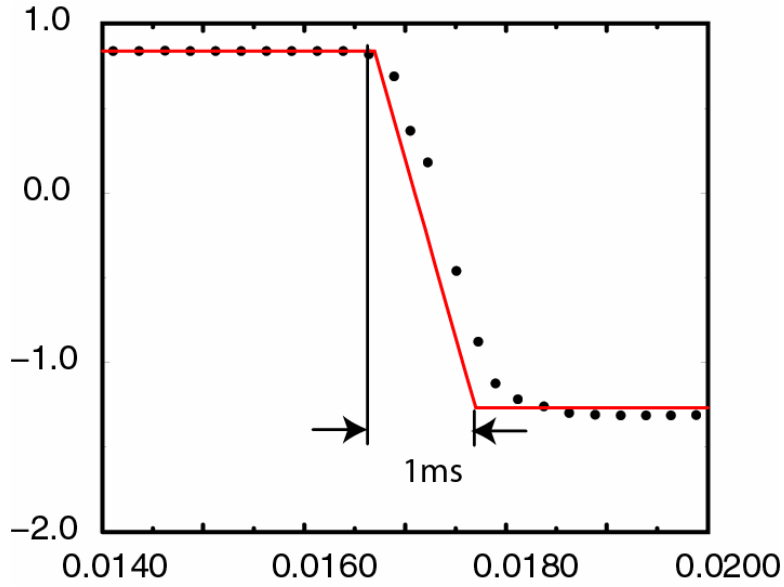




mismatch between the regulator setting and value of the inductance load

Strength – sextupole

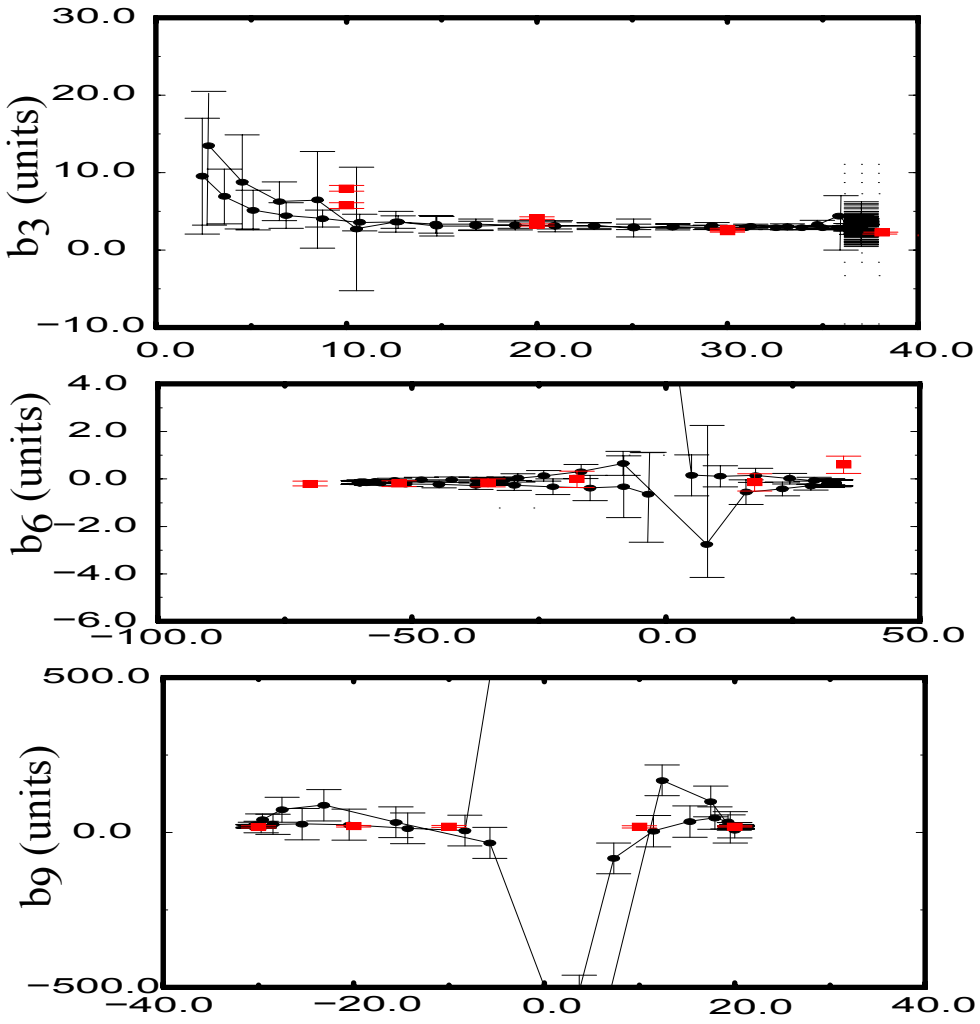




- Slew rate: the sextupole elements should swing through the full current range in ~1 ms during the transition crossing

Harmonics: Eddy currents

- To check for possible effects of eddy currents induced during fast ramping, we compared the first allowed harmonics of the corrector elements measured with AC and DC profiles.
- The DC measurements are performed with a stair-step current profile, where the ramp rate between the DC steps is ~0.5 A/s.
- Relativly small eddy current effect



Conclusion

- We proposed a method for AC field measurements for the corrector upgrade of Fermilab Booster.
- The method is based on the existing, in house made, fast continuous rotating coil measurement system.
- It uses the ability to synchronize the AC current period with the rotation of the measurement probe and obtain the field harmonics connecting the points from different AC cycles
- In addition, we measured four BMA corrector packages, excited with 16 Hz AC profiles, and found good consistency with DC measurements. The comparison between the first allowed harmonics pointed toward small eddy current effects in the corrector fields
- Results are reported on PAC2007

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