HIGH LEVEL PHYSICS APPLICATIONS MAGNETS & BEAMS

Magnets

Accelerator View from the Physicist

Why Use a Magnet to Guide a Charged Particle Beam ?

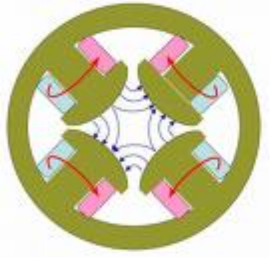
$$\frac{dp}{dt} = e\left(E + v \times B\right)$$

For Charged particles, you can use Electric or Magnetic particles to modify a trajectory.

As β increases, the required electric field to provide a comparable bend as a given magnetic field gets larger

Practical limits on electric fields are 10 kV over mm, typical magnetic fields are 10 kG. Electric fields usually not used for β>~0.01 * - homework: why ??

Magnets In Accelerators



- The modern approach is to use separate function magnets: each magnet provides an independent multipole:
  - Dipole – steer
  - Quadrupole - focus
  - Sextupole – correct chromaticity
- Offers independent control of diff functions

Magnet Nodes

- Magnets are the primary means on beam manipulation in the transverse plane in accelerators
- Some issues concerning magnet organization / class structure
  - Permanent magnets, electro magnets
  - Dipoles for bending, quadrupoles for focusing, sextupoles for chromaticity correction
  - Main magnets, corrector or trim magnets
  - Several magnets may be on a common power supply, magnets on a single power supply

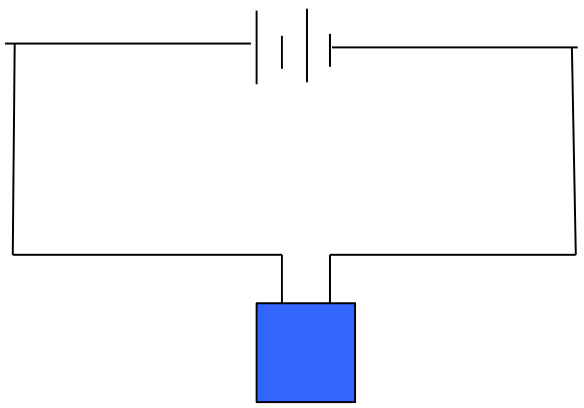
Magnet Nodes

- Many different types of magnets:
  - Permanent Magnets
  - Electro Magnets
    - Dipoles, Quadrupoles, Sextupoles, …
    - Correctors – dipole, quadrupole, …
- See gov.sns.xal.smf.impl.magnet + other sub-classes
- Multiple "magnet devices" can exist at the same location: e.g. quadrupole with dipole corrector trim windings

Some Magnet / Power Supply Properties / Interfaces

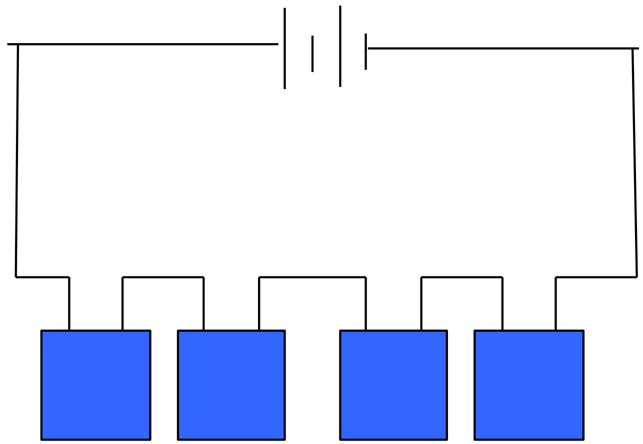
- As a beam physicist, controlling and knowing the magnetic field is critical for an interface to a beam model
- Methods such as getField() and setField() are necessary
- Need to know the effective magnetic length to get the effect of the field on the beam
- Need to know the parent power supply that controls it.

Independently Powered Magnets vs. Multiply Powered Magnets



- Individual power supply –
  - Expensive
  - Common for lattice transitions where matching is required
  - Power Supply B(I) is uniquely determined by the magnet properties

Independently Powered Magnets vs. Multiply Powered Magnets



- Multiple magnets / power supply
  - Common practice for long stretches of a lattice structure, often independent control for the horizontal and vertical planes
  - Power Supply B(I) is determined by the average of the involved magnet properties
  - Setting the field of one magnet affects the field in others

Power Supply / Magnet Control in XAL

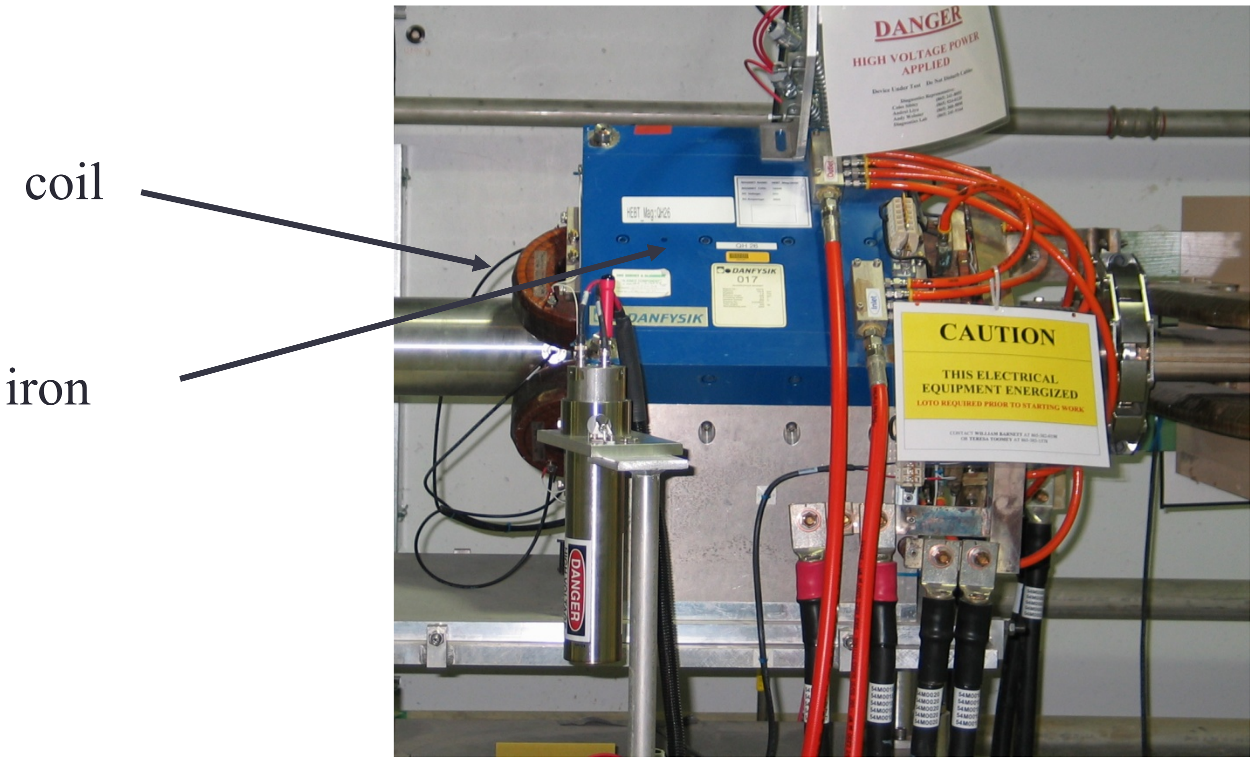
- Magnet Interfaces
  - Readback – for each specific magnet: getField()
  - Setting – interface to the power supply, affects other magnets if it's a multiple power supply
- Power Interfaces
  - Readback – provides the average field of all the magnets on this power supply
  - Setpoint – provides a setting for the average of all magnets on a power supply

- Note – power supplies driving multiple magnets generally control magnets of the same type. The variations of B(I) from magnet to magnet are generally < 1%

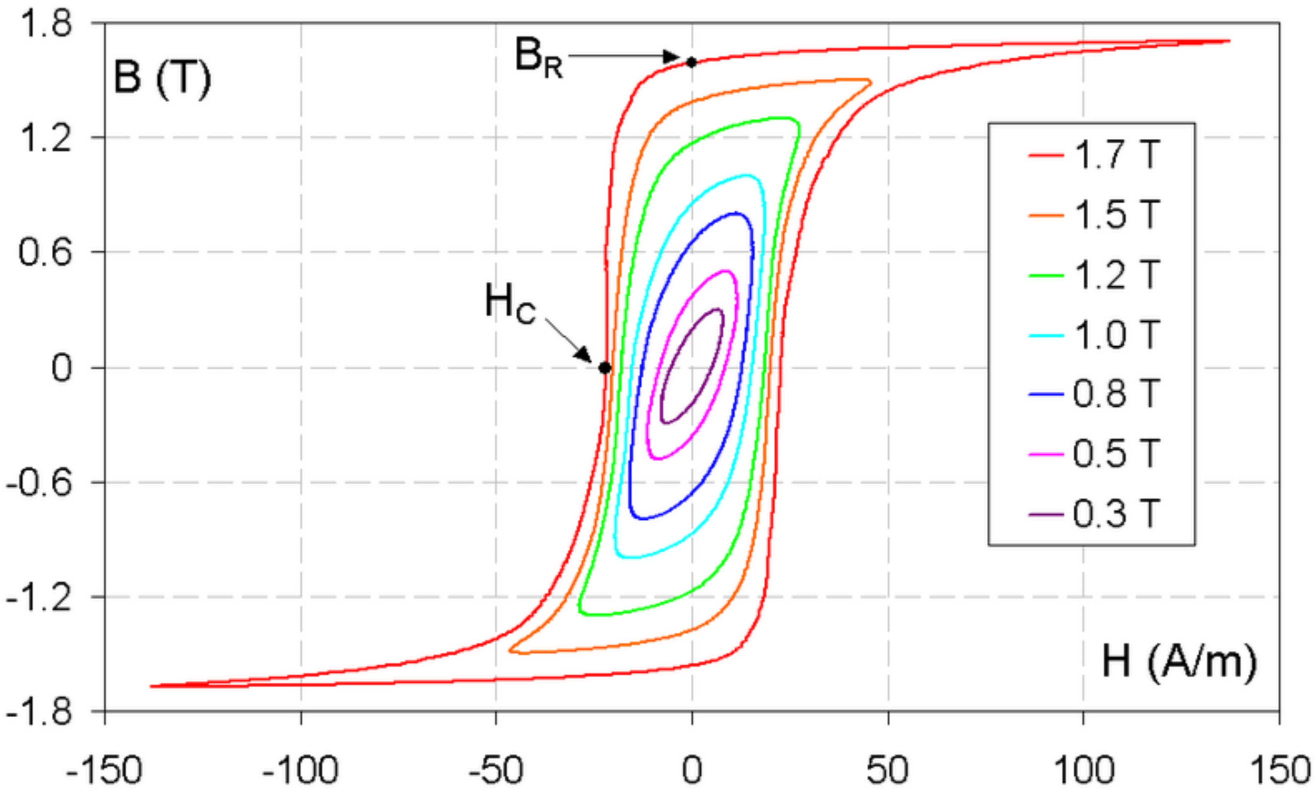
Magnetic Hysteresis – Path dependence of the magnetic field

- Magnets are controlled by specifying the amount of current in the driving power supply
- Most accelerator magnets contain ferro-magentic material (iron) to increase the flux density in the region where the beam is
- The iron has a
- Atomic dipoles align themselves and produce a magnetic field component themselves
- The magnitude of the magnetic field in the magnet – for a fixed current – depends how these dipole moments are lined up.
  - This depends on the history of the current in the magnet

Typical Accelerator Magnet



- Blue part is iron
- Note color code on the leads – polarity counts too.



The magnets are composed of conventional grain-oriented electrical steel. B_R denotes the remanence and H_C is the coercive field. A hysteresis loop shows the relationship between the induced magnetic flux density (B) and the magnetizing force (H(I)).

$B \neq F(H(I))$ – result depends on the history.
B saturates at high current

Repeatability Studies

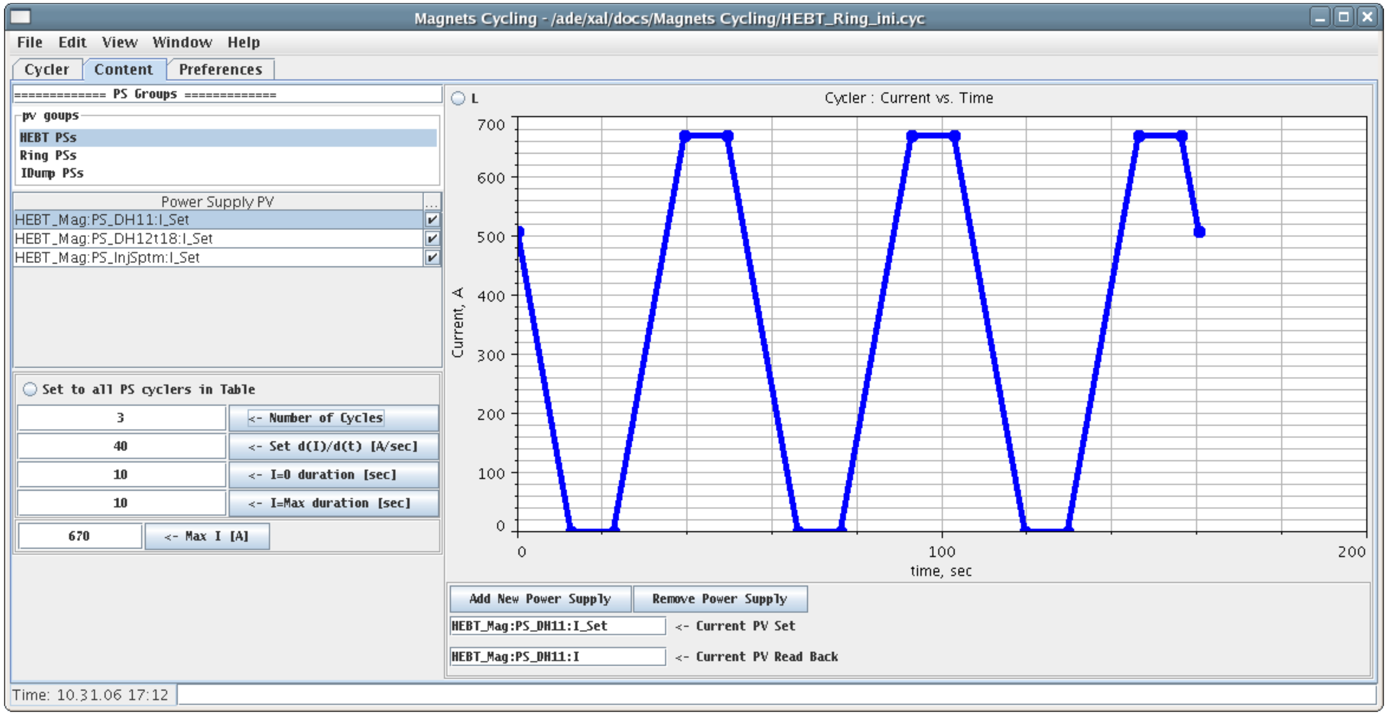
We want to obtain a certain value of magnetic field (B) and we can manipulate only the current (I). The solution is to use a defined, slow, repeatable procedure to set the current I_0. By specifying the history, the magnetic flux density B will always be the same.

Theoretically this is a complicated problem, but we have the accelerator as a gauge to estimate the reproducibility of the B-value. We can study this procedure experimentally.

If we repeatedly get the same tuning state for the accelerator, we are satisfied. The accelerator state tuning characteristics:

- Losses (BLM signals)
- Beam trajectories (BPM signals)
- Brightness (light source)

Magnet Cycling Approach (A. Shishlo)



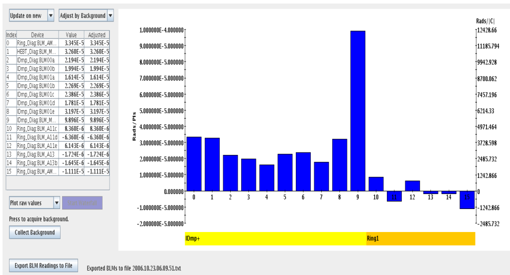
- We have to choose parameters of cycling to provide the same final "B" value every time.
  - Number of cycles, wait time, and ramp rate

Magnets Cycling Procedure

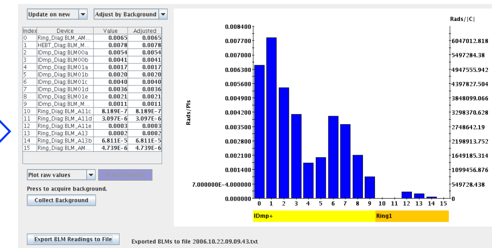
Plan:

1. Cycle using conservative ramp parameters
2. Tweak to get a good tune
3. Cycle again and see that the tune is still good
4. Move I up and down to destroy the good tune
5. Cycle again and return to the good tune
6. Change parameters to reduce the cycling time and repeat 4,5 again, as long as the cycling is working.

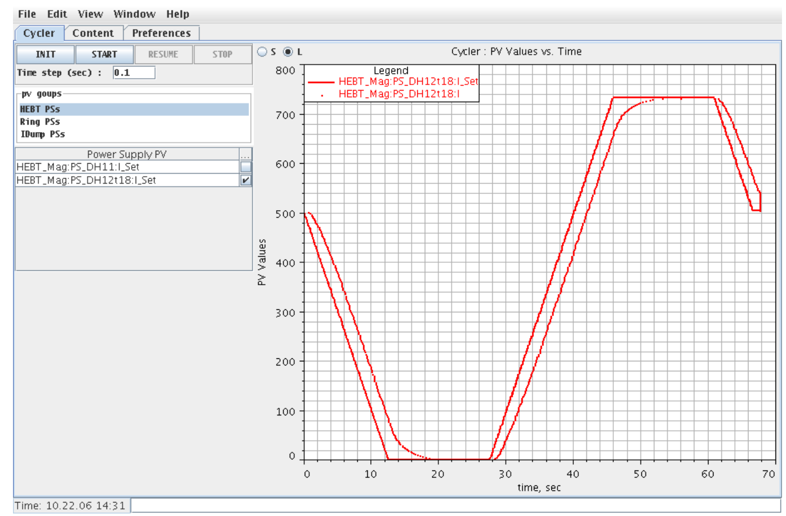
Example using the SNS HEBT Dipoles

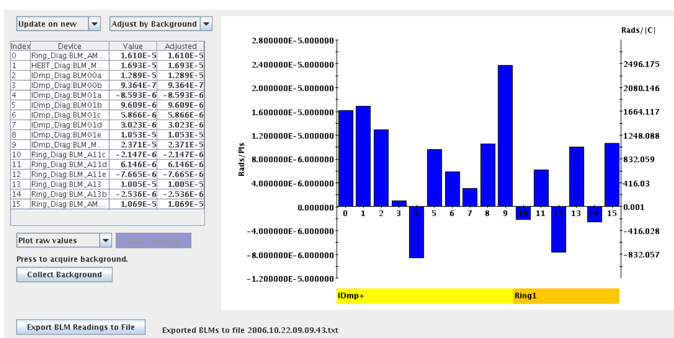


I from 504.7 A -> 404.4 A
Losses > x 100 times,
no beam in Ring



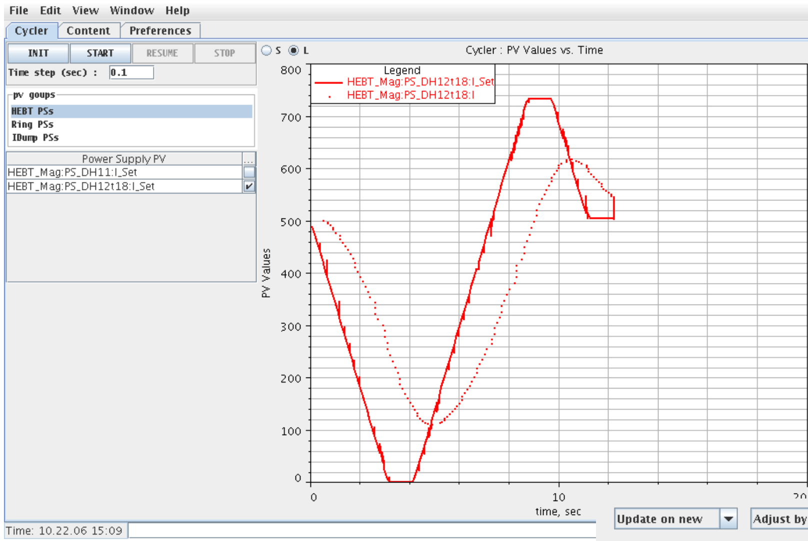
After cycling
With 40 A/sec change rate
The good tune is restored!
It takes 67 sec.



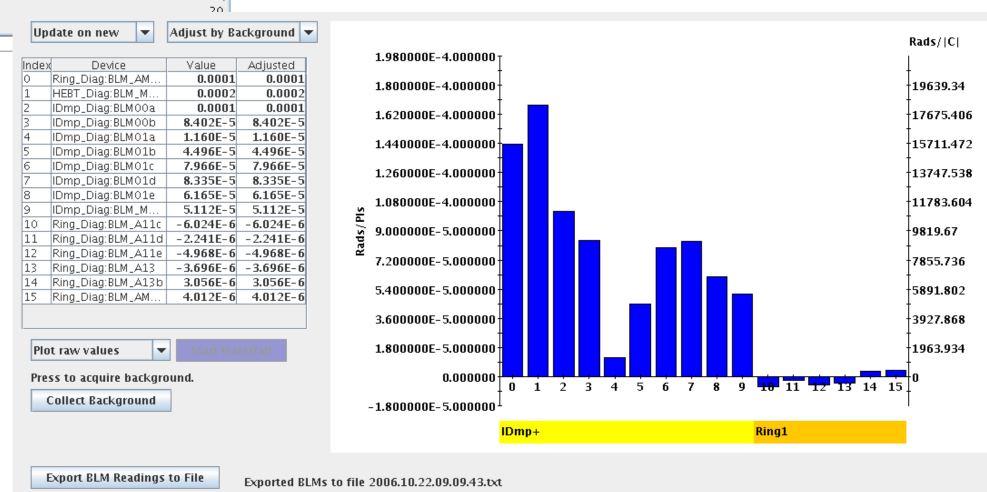


Then we pushed the cycling to the limit until it stopped working.

SNS HEBT Dipole Results (2)

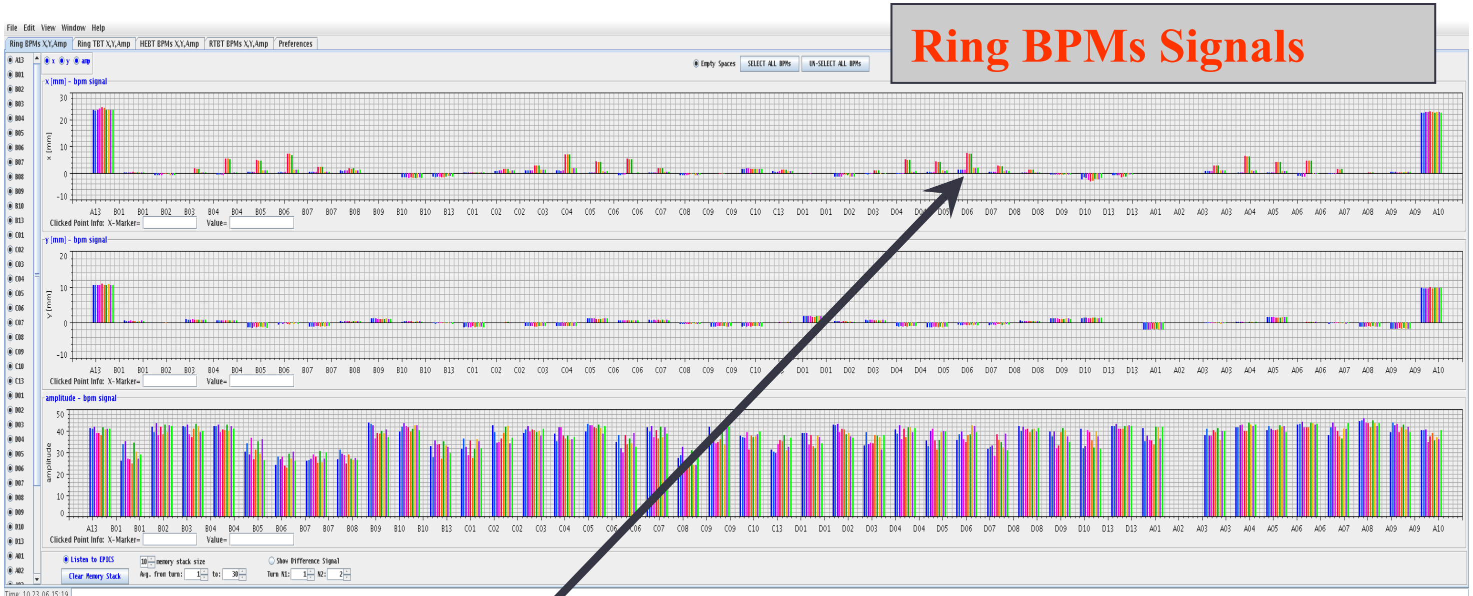


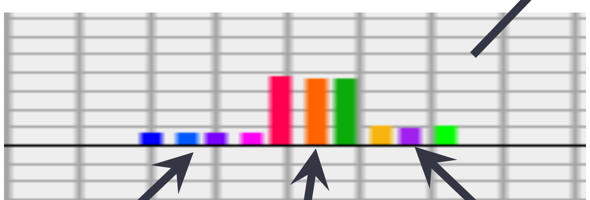
At 12 seconds, the cycling doesn't work too well. The losses are 10 times bigger after such fast cycling.



SNS Main Ring Dipole Example

Ring BPMs Signals





Initial

After cycling

After moving I around

Main Ring Dipole Cycling:
40 A/sec
250 seconds total time

Characterizing the Magnet Strength

- In accelerator physics, the magnet strength is often given by the field index k_n:

$$k_n = \frac{\partial^n B / \partial x^n}{B\rho} \qquad B\rho = \frac{\beta E}{e}$$

Where n=0 for dipole, n=1 for quad, …

•This requires knowledge of the beam energy at the magnet to a priori convert a magnet measurement into a focusing strength.

•The field can be provided, and focusing strength calculated as needed in a model configuration

B vs. k, this is the question

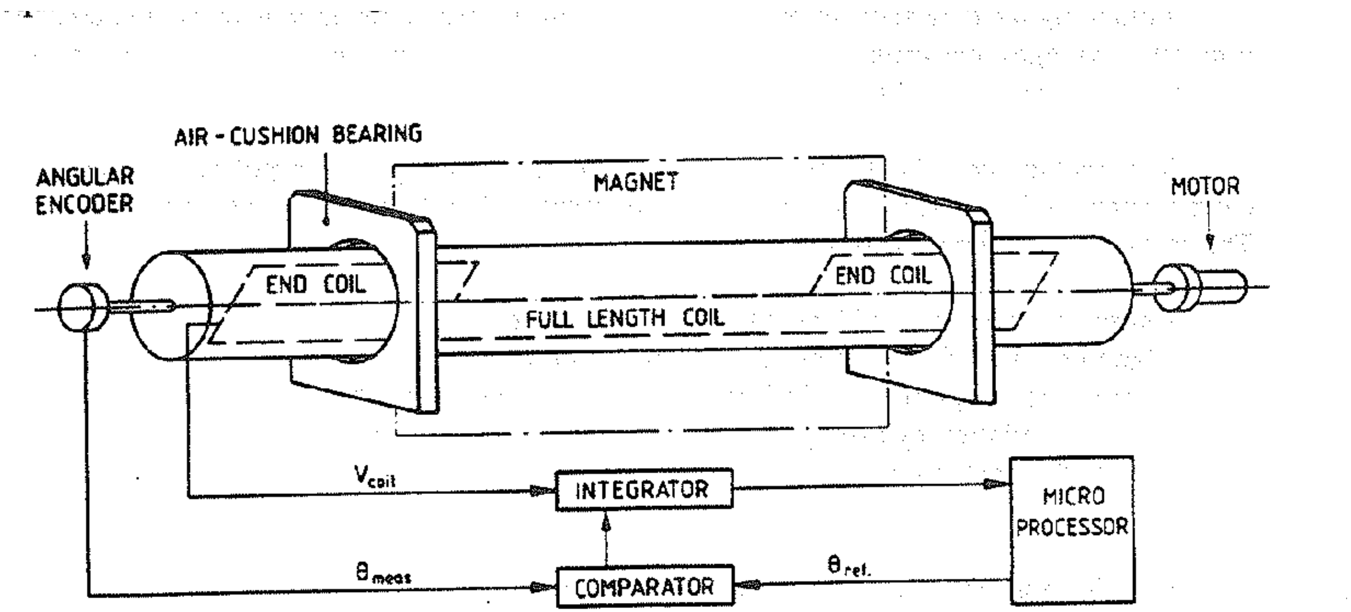
- For an Accelerator Physics model, you need to characterize the field as either "B" or normalized field strength "k"
- B(I) is measured – you must convert to k with the proper beam energy information
  - This is OK if the energy is known and static at a given magnet
- Otherwise just use B and calculate "k" internal to the model
  - XAL is setup this way

Where should the Field / Current Translation Occur ?

- Engineers deal with magnet current – not field
- Typically Accelerator Physics provides the translation which is done in an IOC
  - Advantage - physics units for magnets are available to the entire control system
  - Disadvantage – requires modification / reboots of IOC to update
- Could be done at a higher level (e.g. XAL)
  - Advantage: direct control without IOC reboots etc.
  - Disadvantage: not avaialable to all channel access clients
- Transformation from B-> I and I->B should be consistent, or one can walk away from a desired setpoint
  - Spline fits – be careful
  - Interpolation between measured points

Magnet Measurement

- Rotating Coils (harmonic coils)
  - Provide information on the magnitude of each pole of the field (dipole, quad, sextupole,…) in the normal and skew directions.



Magnetic Measurement

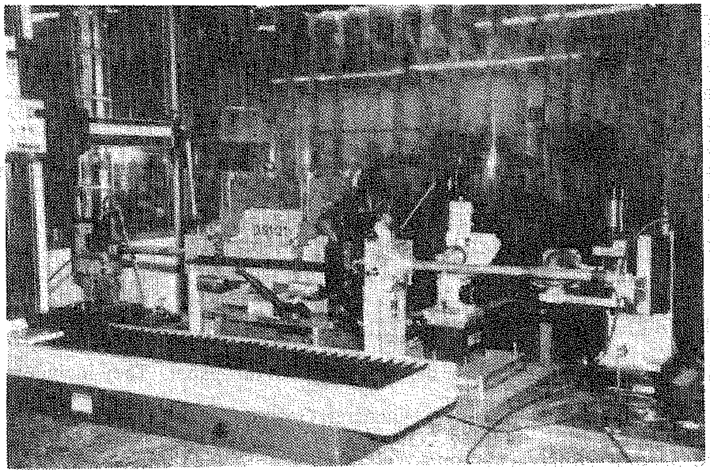


Fig. 9 SLAC stretched-wire equipment

- Vibrating wire / taut wire
  - Useful to find magnetic centers

- Hall Probe –find the field at a point (size of the detector)
  - Complex variants with 3-D measurements

- Flip Coil
  - Useful for measuring the effective field along non-straight beam paths (e.g. dipoles)

Magnets in Accelerators

- Prediction of the exact field a beam will feel is difficult
  - Hysteresis effects
  - Magnet mapping uncertainties
  - Positioning uncertainties
  - Differences in mapping power supplies vs. production
- Reproducibility is critical
- Use of beam measurements is needed to provide the actual field calibration (better than 1%)