Undulator Line Developments Update

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APS/ANL

LCLS TAC Meeting, SLAC, Stanford

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Undulator Prototype

- Magnetic characterization of magnets
- Mechanical certification of poles
- Design, construction and testing of undulator movers
- Assembly of magnetic structure

Quadrupole Lens Prototype

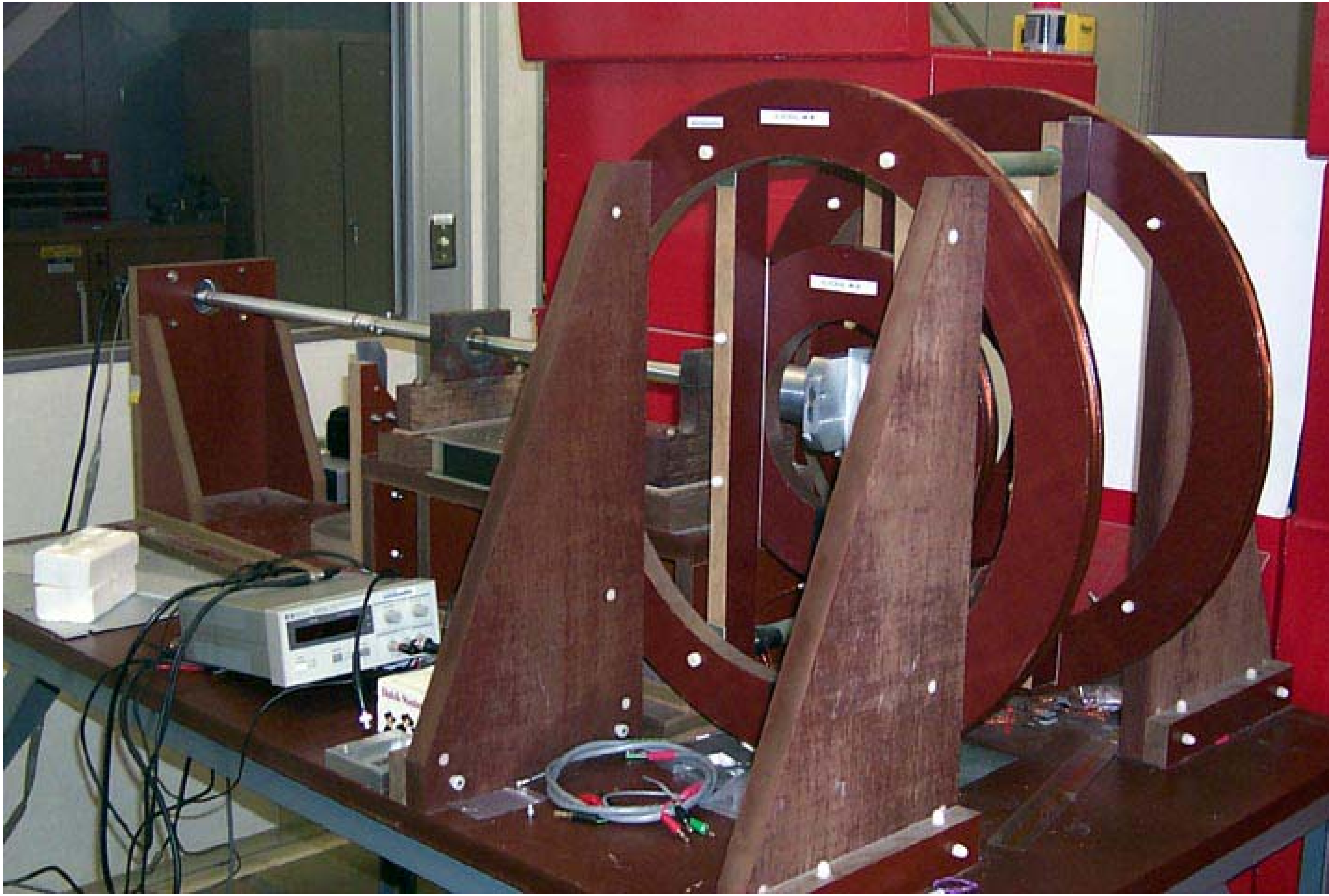
- Mechanical and magnetic charaterization
- Conceptual design of the retractable lens

Electron Beam Diagnostics

- Design of the button-type BPM
- Conceptual design of the electronics

X-ray Beam Diagnostics

- Conceptual design of the mechanical assembly
- Universal diagnostics for high- and low-energy



- Helmholtz coils measure all three components of the total moment of the magnet block.

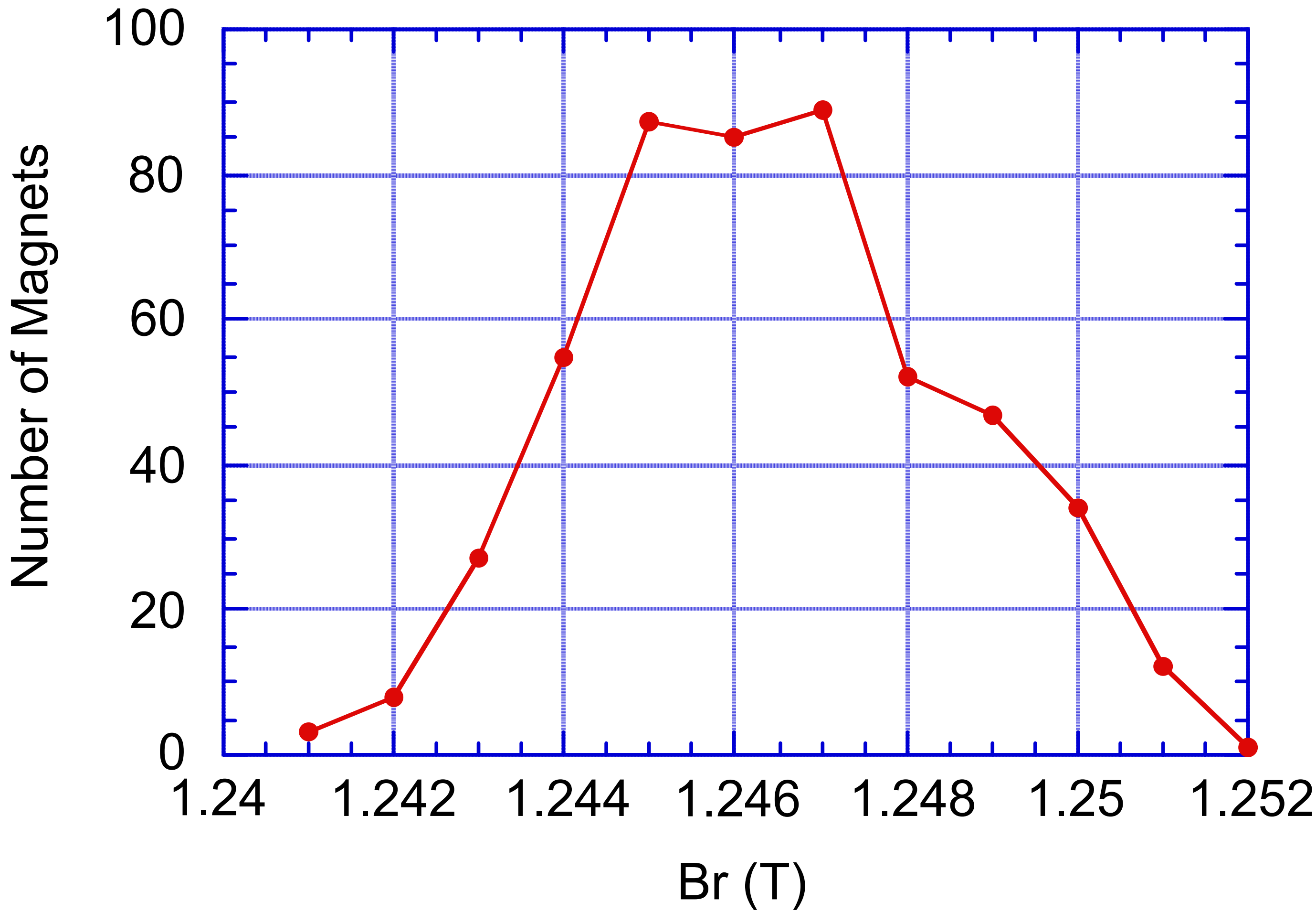
- Helmholtz coil measurements were made by vendor and delivered with the magnets.

- Comparison measurements made at APS agree so closely with vendor's measurements that repeating all the measurements is unnecessary.

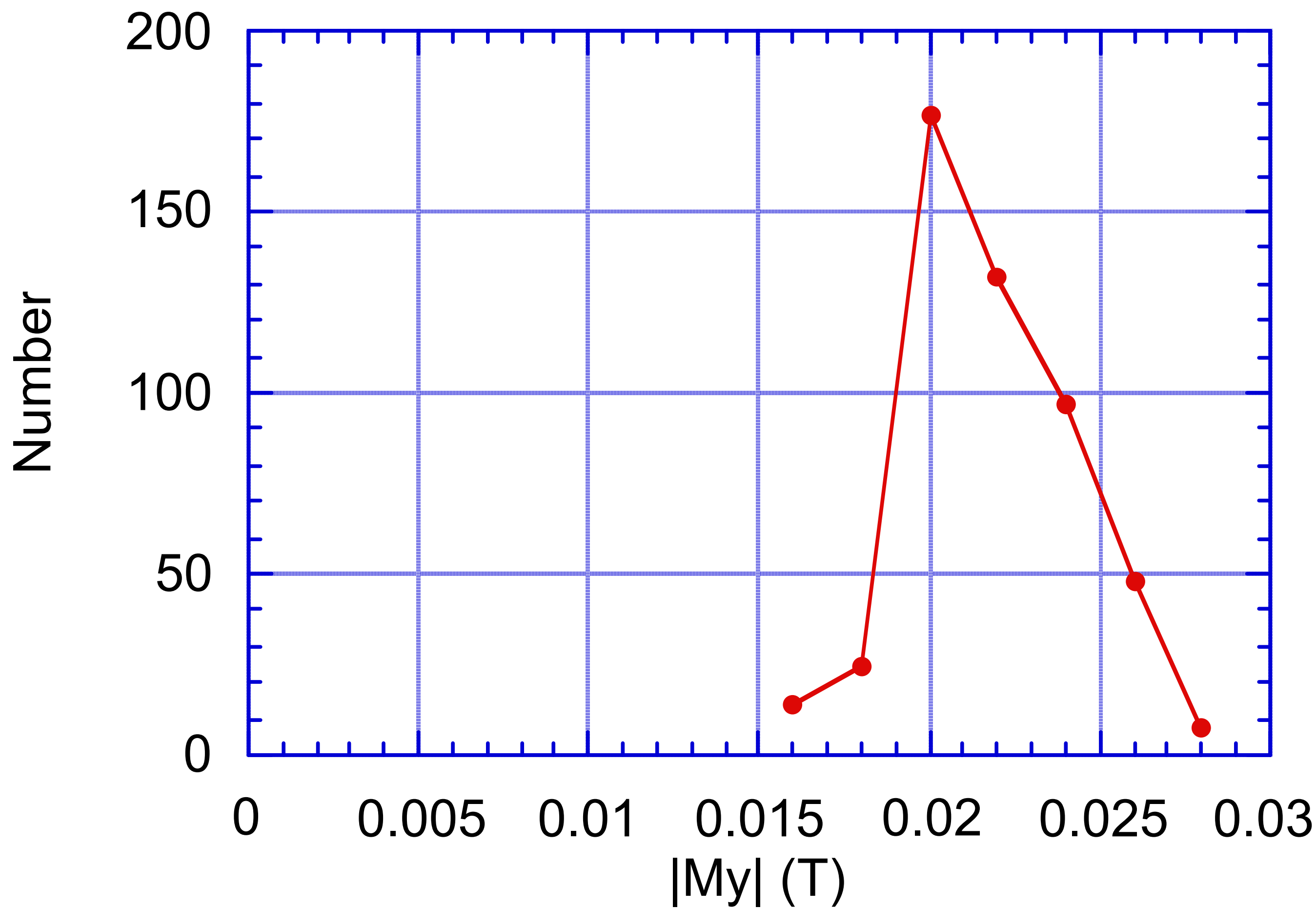
Requirements for the magnet blocks were:

- All the same strength within ±1%
- Angle of magnetization parallel to geometric axis within ±2°

These requirements were exceeded.



Distribution of total magnetic moments in the population of magnet blocks.
Note that all the magnets fall within a variation of ±0.5%.



Distribution of vertical magnetic moments in the overall magnet population. All the magnets have some vertical moment - the range is from 0.7° to 1.3°, with an average of 1.0°. The magnets are symmetric so that the vertical moment can be oriented in either direction during assembly.

The blocks have no horizontal transverse moment.

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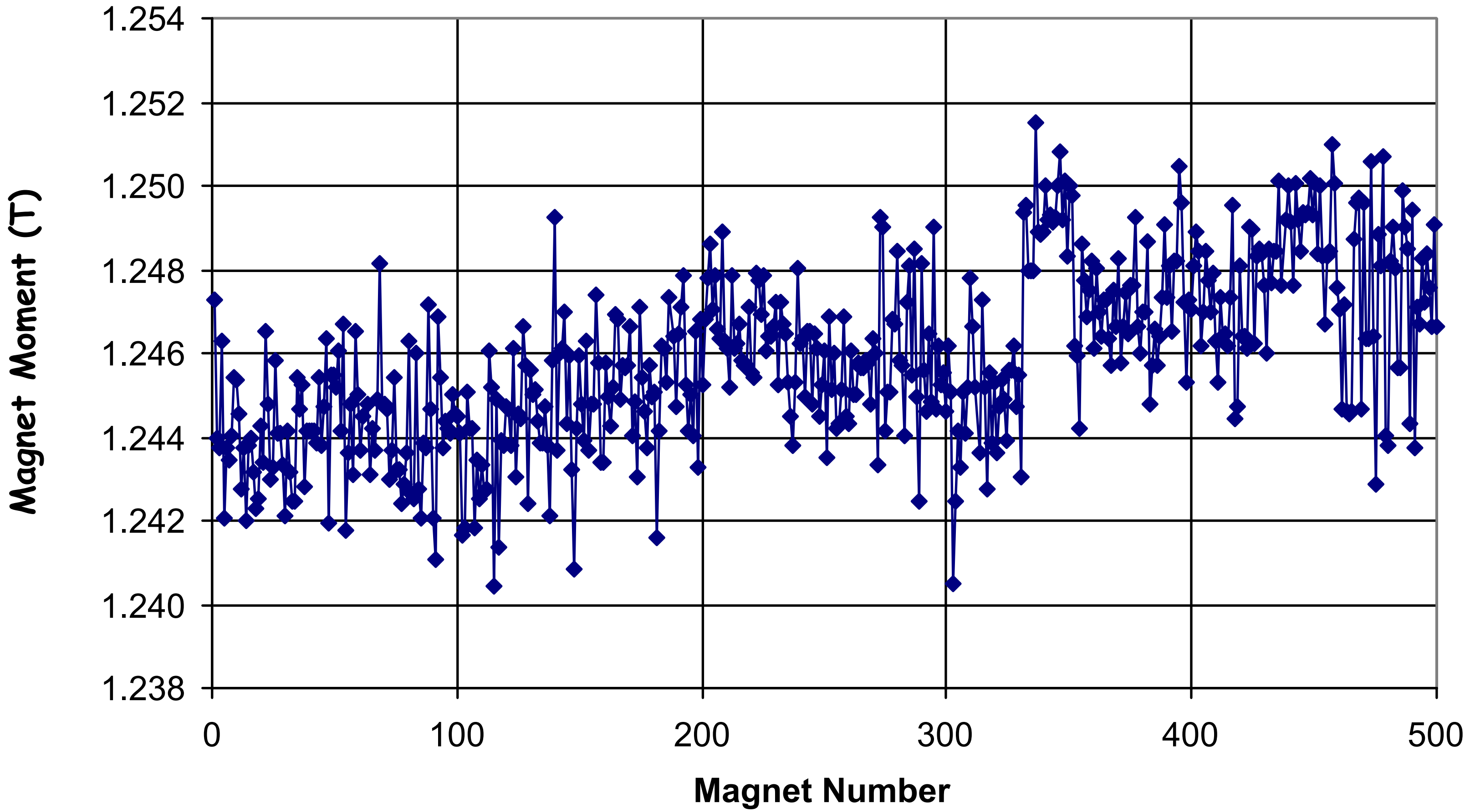
Sorting considerations:

-> Main component of the total moment of the block

First integral of the field through a half-period test fixture



Total magnetic moment of the magnet blocks for the LCLS prototype, ordered by magnet serial number.

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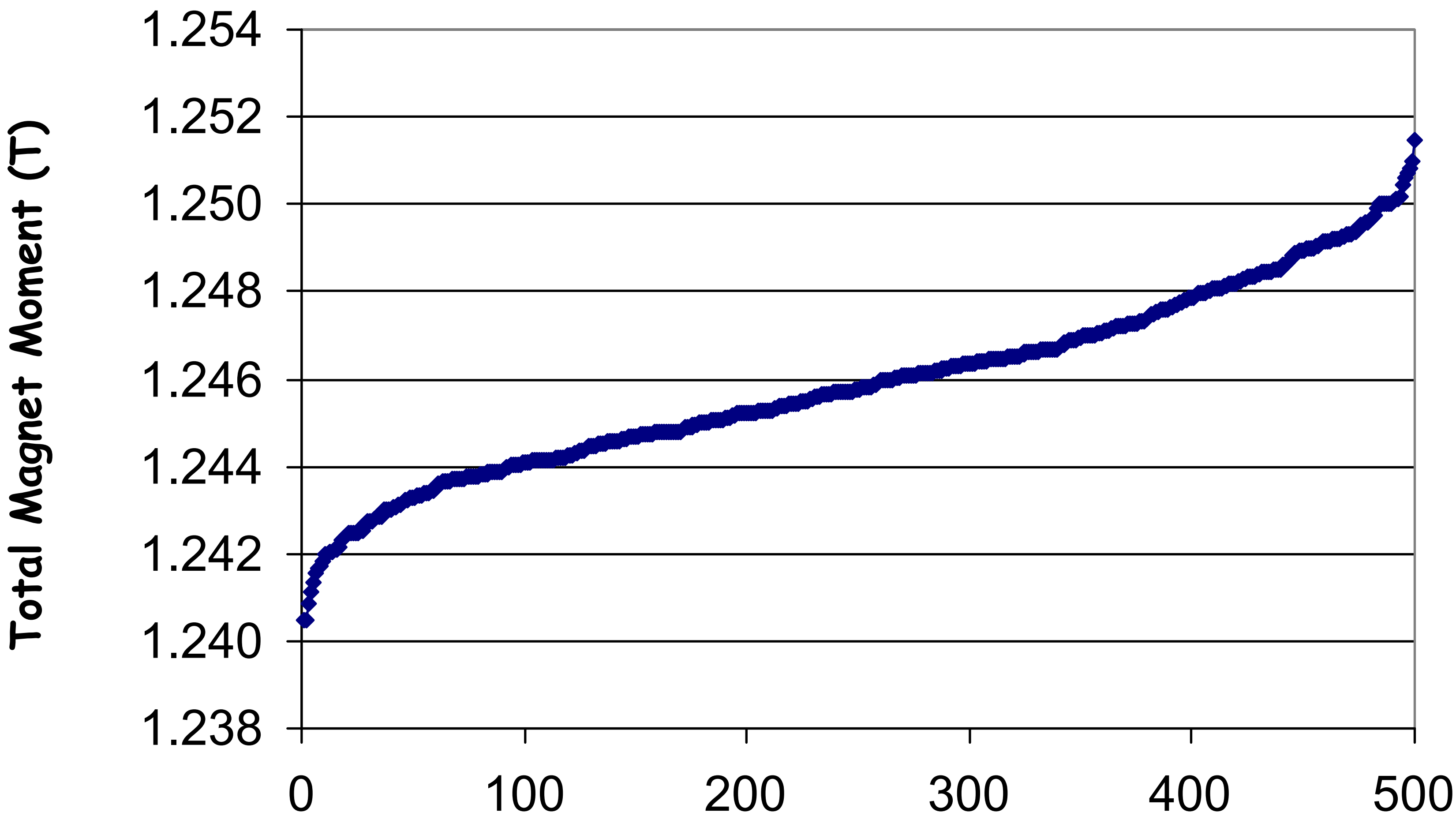

Magnet block strength, with the magnets in order of increasing magnetic moment.

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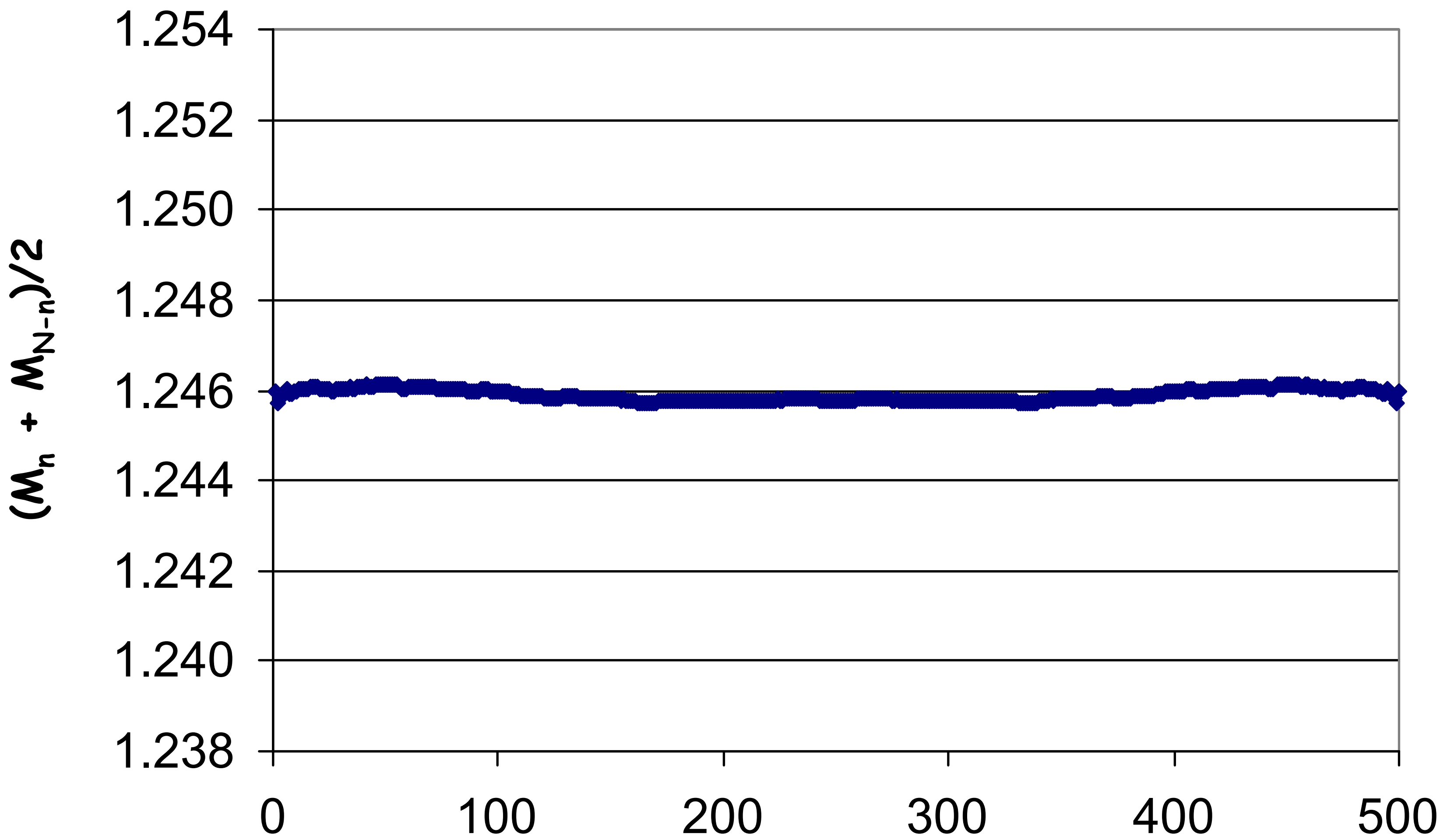
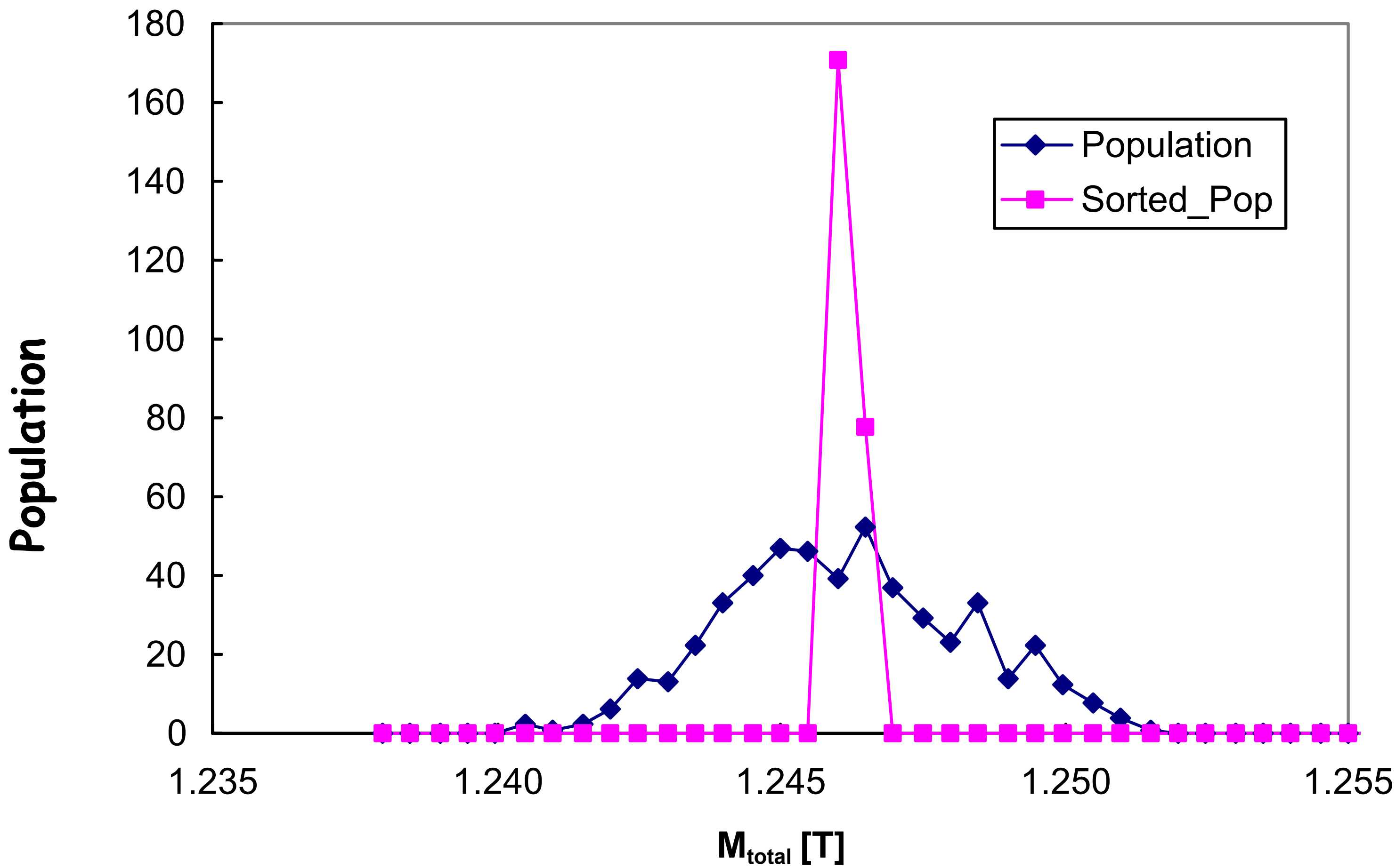


After pairing the magnets by matching strong to weak, to even out the distribution.

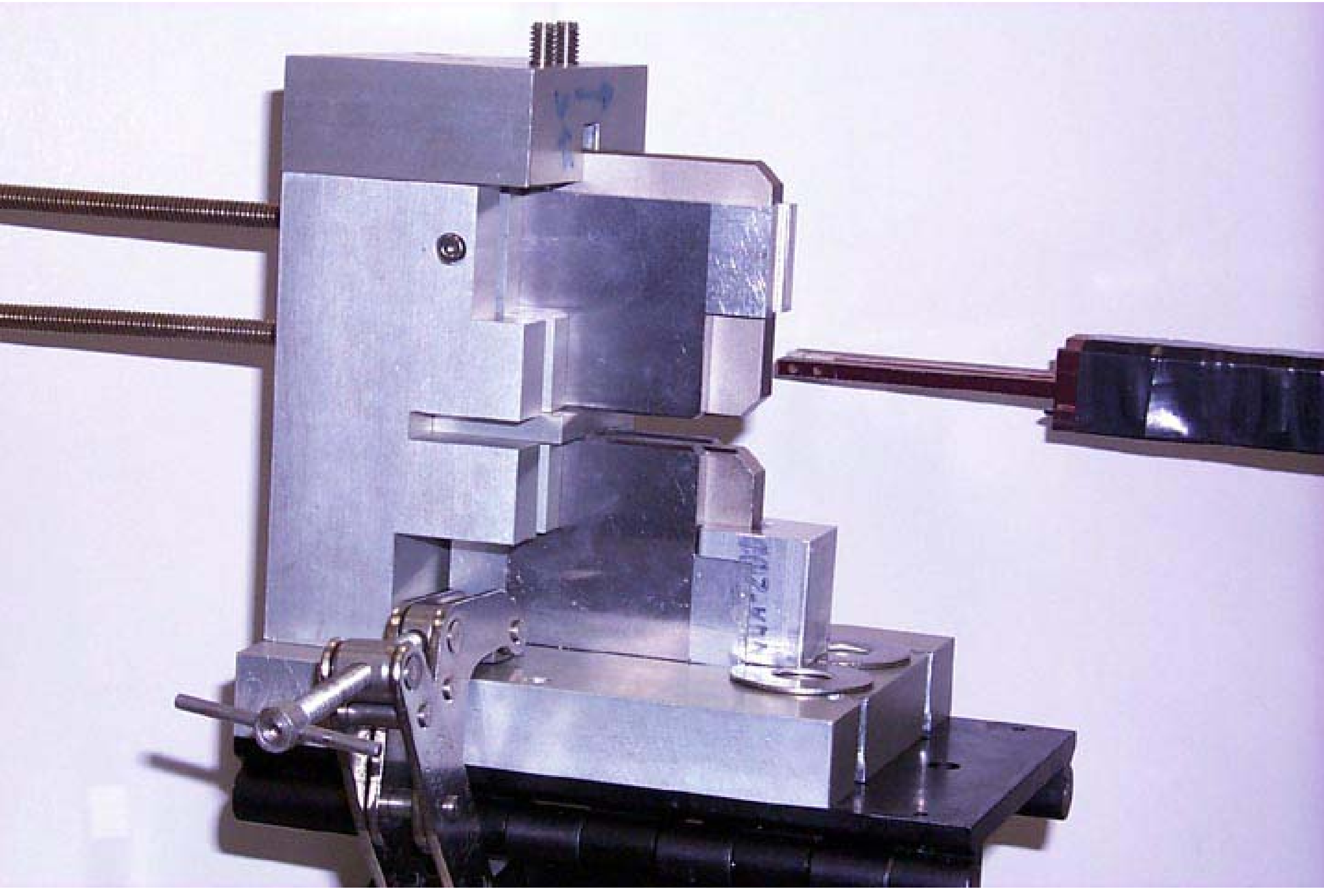


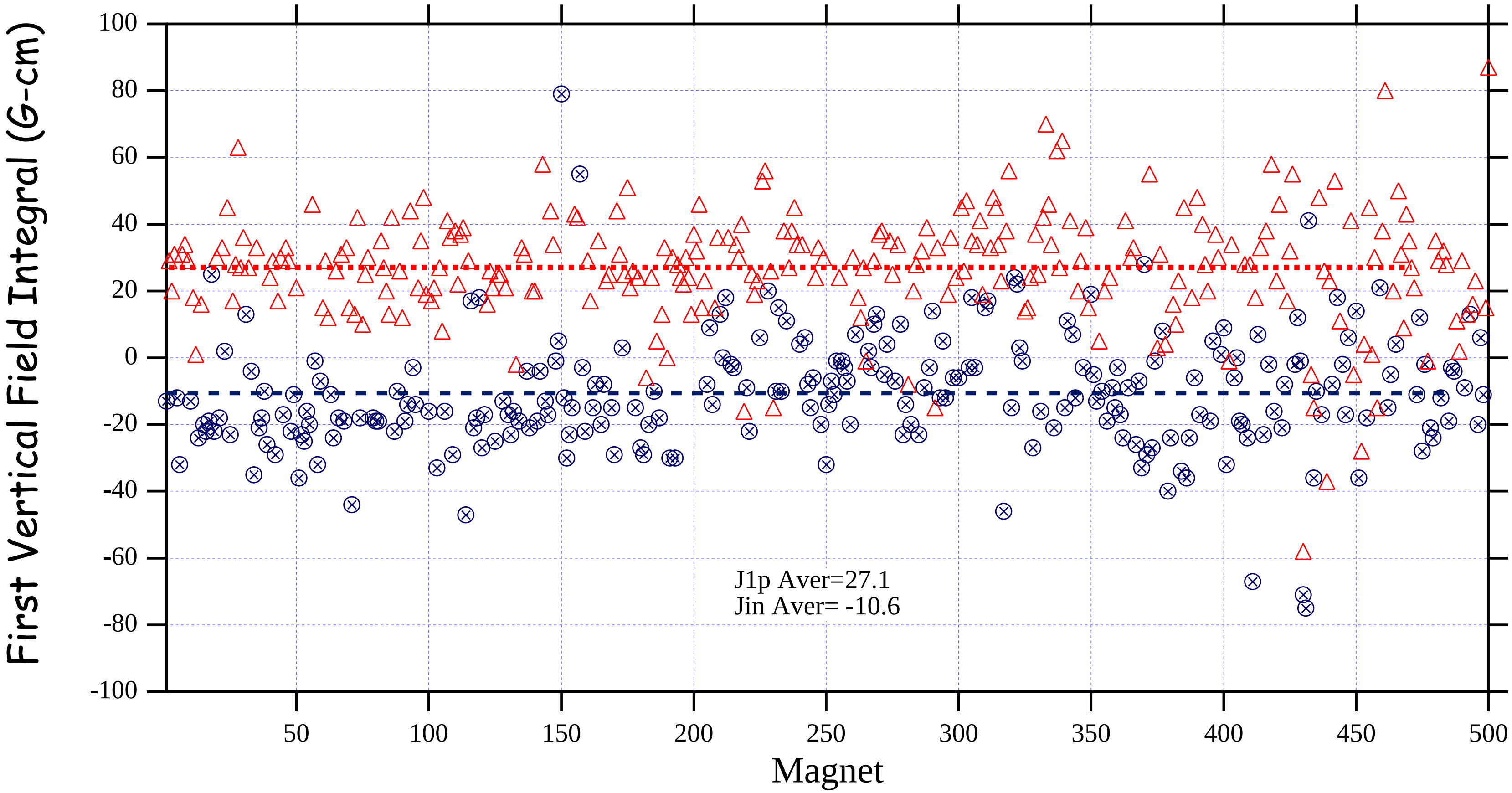
Histogram showing frequency vs. total magnetic moment. The pink squares show the result after pairing the magnets.

Sorting considerations:

Main component of the total moment of the block

->First integral of the field through a half-period test fixture





First field integral through the half-period test fixture. Red triangles are for magnets with a positive vertical component of the top magnet's total moment (i.e., same as bottom magnet); circles are for a negative vertical component (i.e., opposite moments for top and bottom magnets). The vertical component of the moment makes a clear difference, though there are some oddball magnets.

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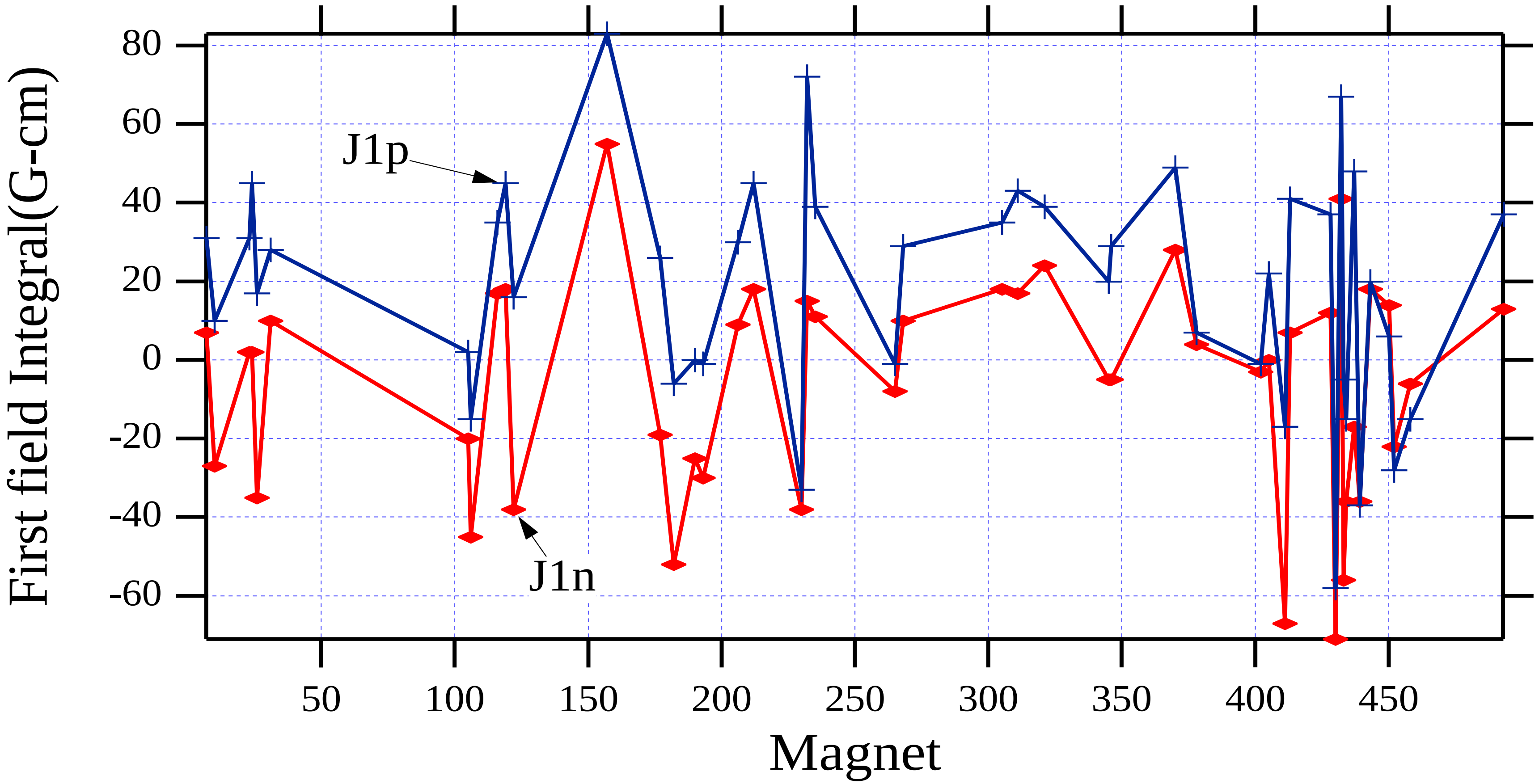
Sorting considerations:

Main component of the total moment of the block

First integral of the field through a half-period test fixture

-> Distribution of moment within the magnet block



First field integral through the half-period test fixture when the same magnet is oriented with its vertical moment positive (blue +) and negative (red -), for a few of the magnets. The positive orientation usually gives a higher integral, but not always.

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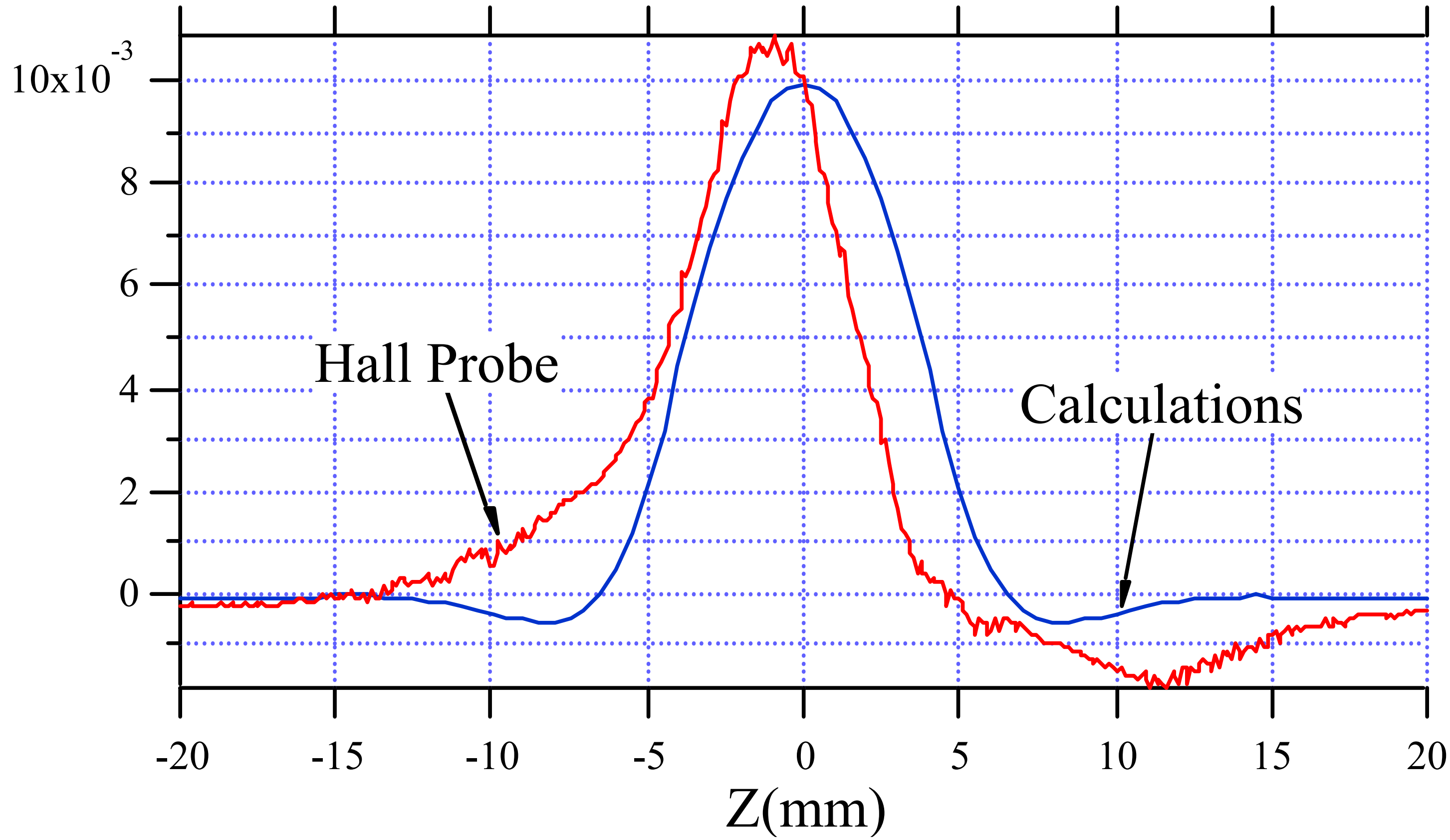

Difference in vertical on-axis field when magnet block is rotated to change the vertical component its field, plotted vs. z. The measured effect may differ from the calculation if the distribution of the vertical magnetization in the magnet block is not uniform; this can affect the phase errors.

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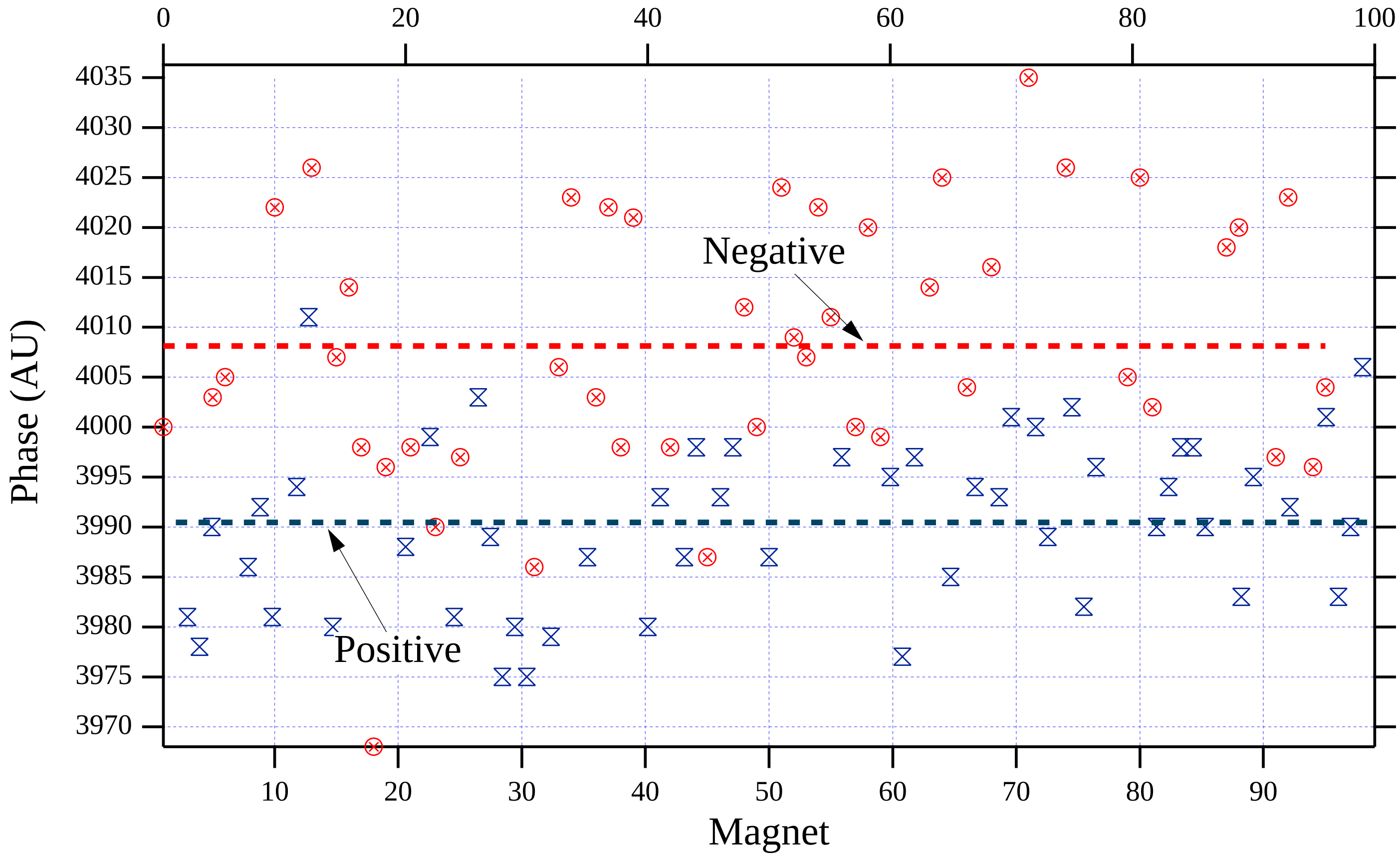


Measurements of phase for LCLS prototype magnets. Red circles and blue x's are for negative and positive orientations of the vertical moment component. The RMS variation among the negative points is 0.6°, and 0.4° among the positive.

Other factors that affect the half-period measurements have been attributed to:

- which pole the magnet is up against
- non-parallel sides of the magnet block

For the initial assembly of the first section of the undulator, not all these will be taken into consideration in the magnet arrangement.

Instead, the pairs of top and bottom magnets will be selected by matching strongest total moment to weakest. The top magnet position will alternate between the stronger and the weaker of the magnet pair. Rotations will be as the magnets were originally measured, i.e., random.

The result will be compared to the half-period test measurements. The effect of rotations will be compared to measurements, too, to determine whether all magnets need to be measured in both rotations, and we will go from there.

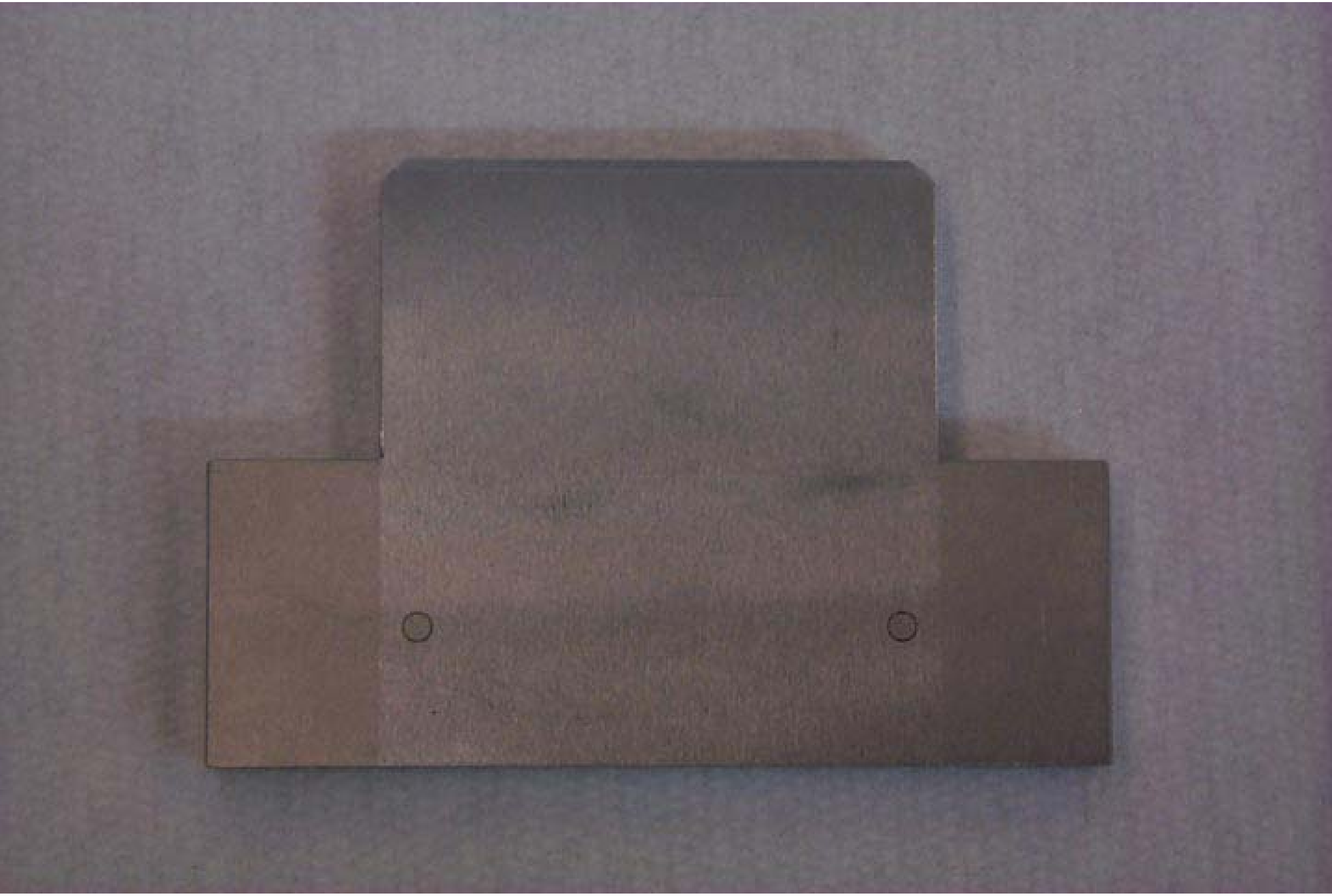
The Poles

All the poles have been manufactured and assembled to their titanium ears.

Most have completed the magnetic anneal.

A few poles cracked during the anneal, at the location of the pins.
Replacements have been manufactured and await annealing.

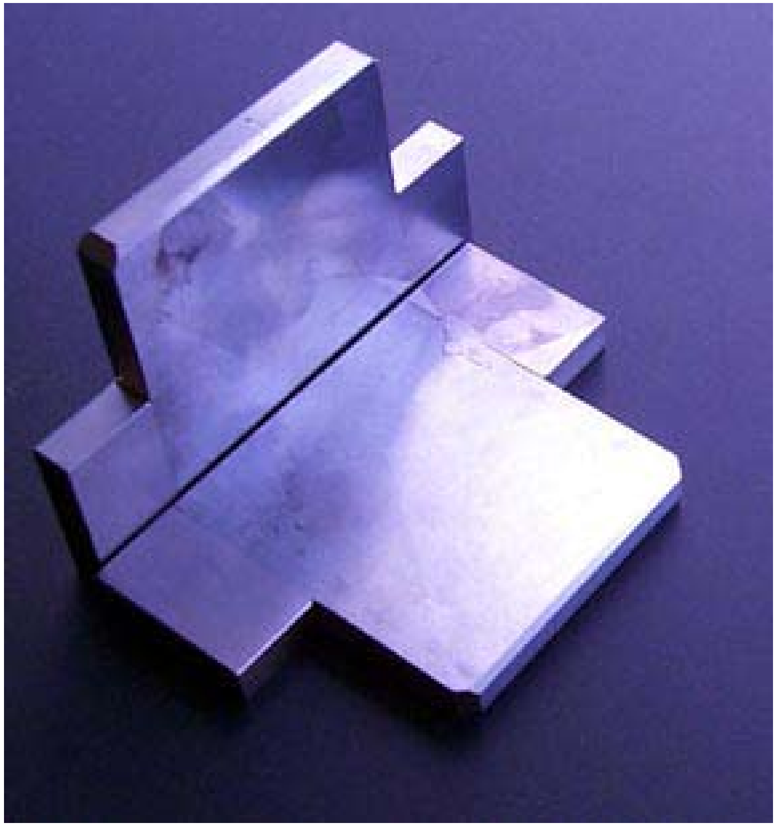
Dimensional checking found that the poles are very uniform: the same height to ~10 μm, and thicknesses are good.



There are two small problems with the poles, however:

- Pole chamfer is 1 mm instead of the 0.5 mm chosen from the magnetic modeling. This should reduce the undulator effective field by ~1.7% (no change in the peak field), equivalent to a gap change of ~0.16 mm. This is a small problem.

- There are flaws in some poles, due, we believe, to the EDM wire breaking when the pole blanks were sliced off the vanadium permendur bar.



Lines on pole face may be 1 or 2 mm wide (where several are close together), and the deepest are ~0.2 mm.

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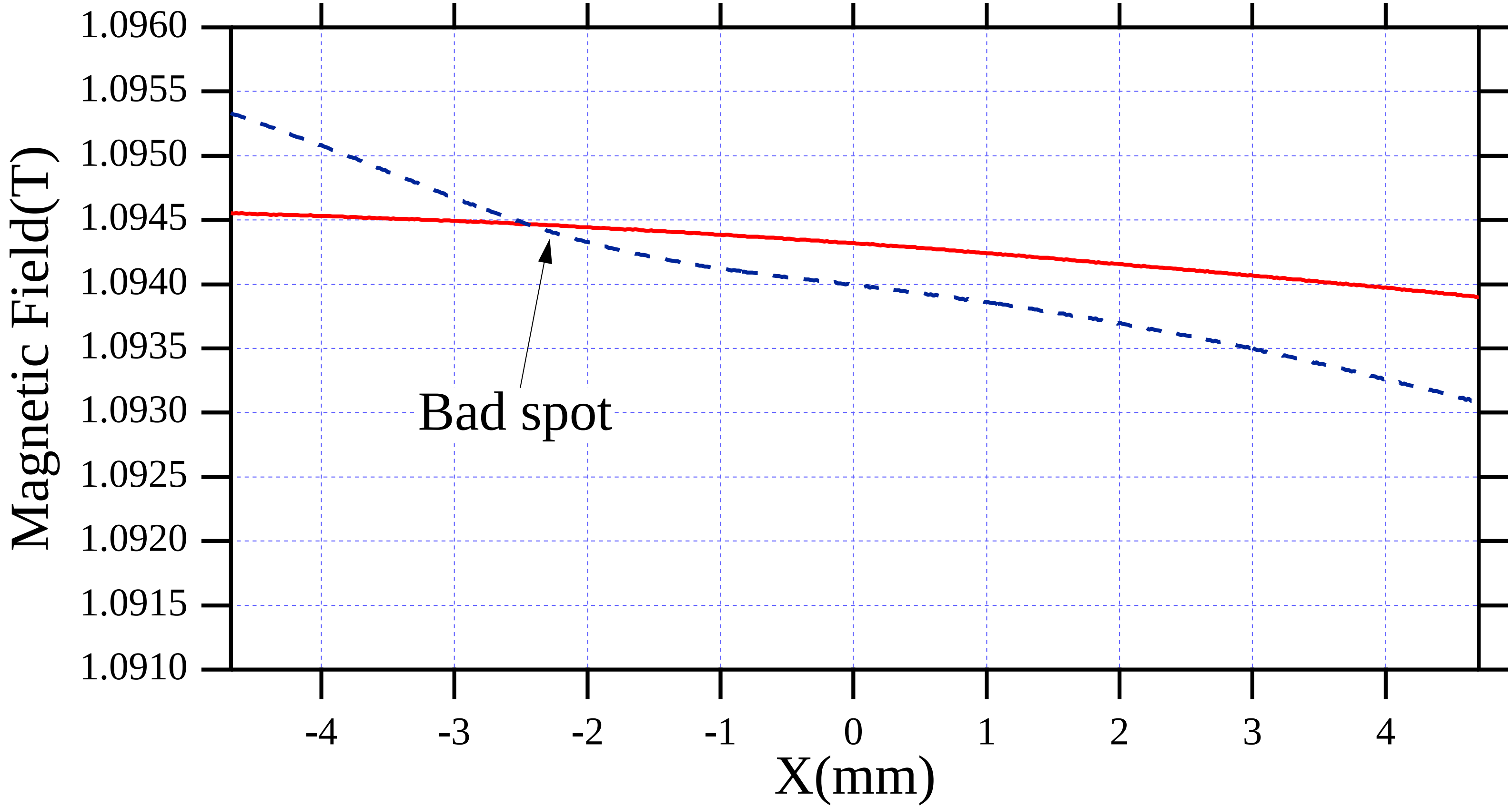

Magnetic field vs. x, with a 'bad' pole. Solid line corresponds to field between two good poles, dashed line corresponds to field between a good and a bad pole. Sign of the field is reversed. Location of scratches is indicated. Overall slope is due to a slight cant in the pole mounting.

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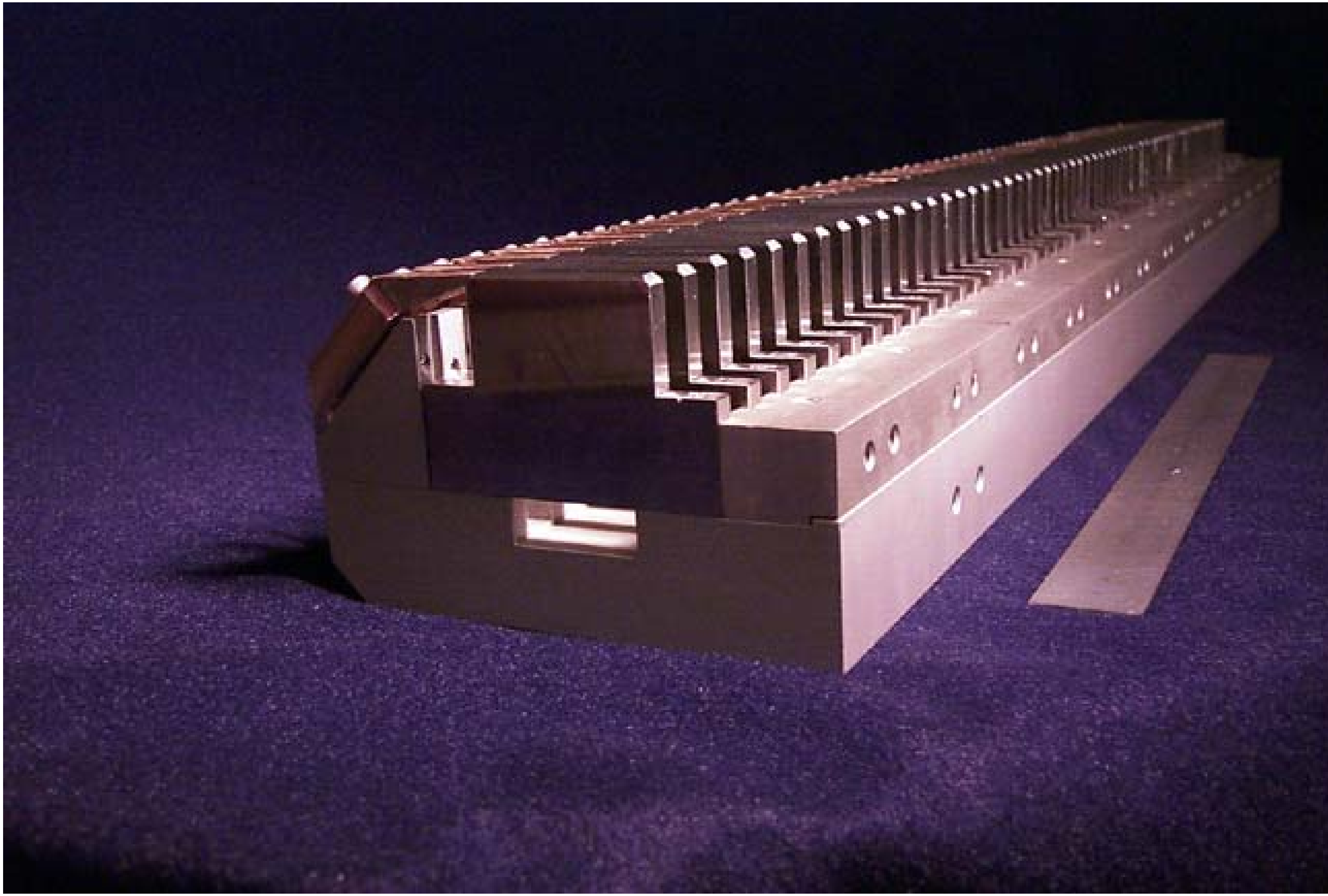

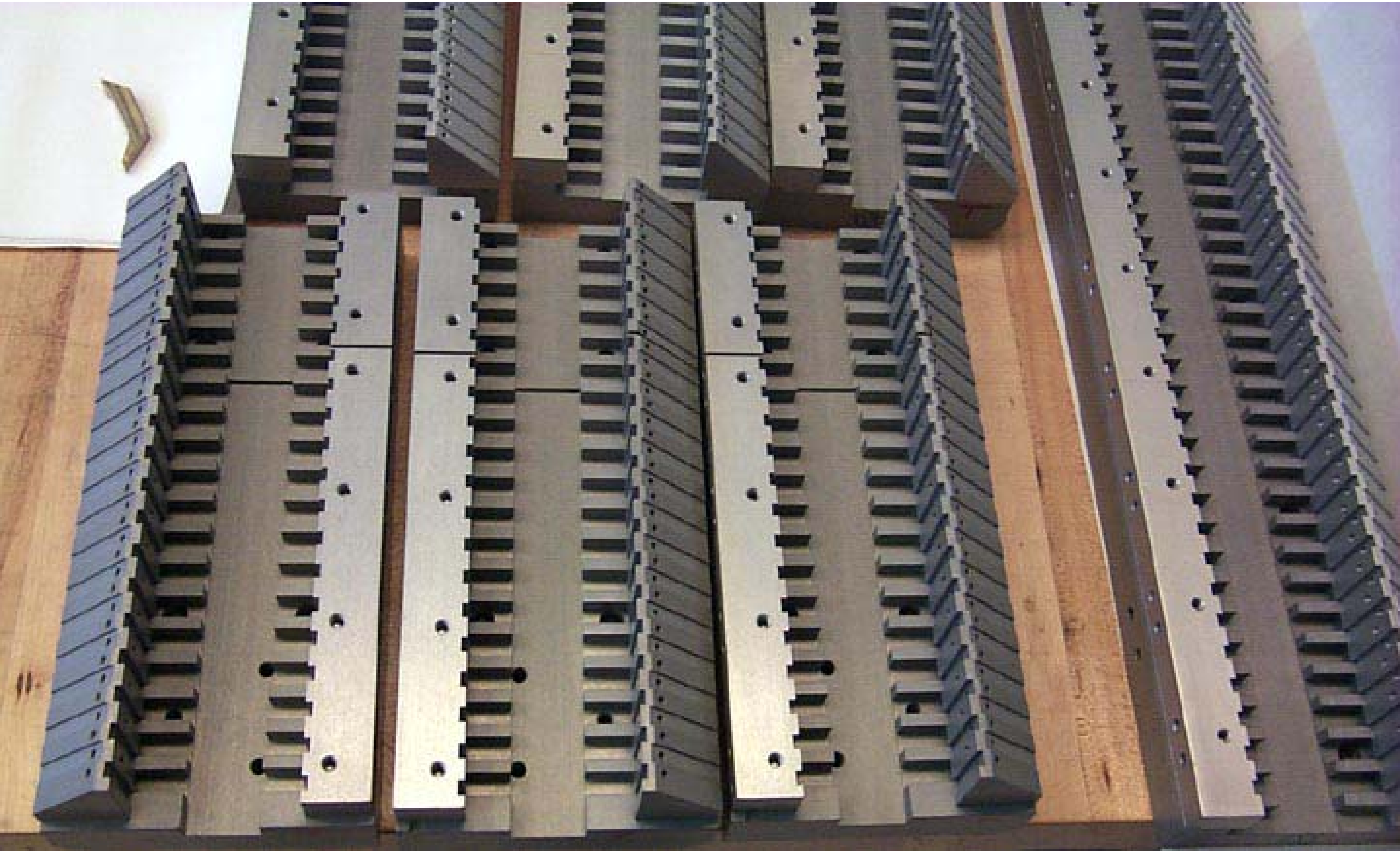

Phase Tuning

$$\frac{1}{L}\int_{-L/2}^{L/2}\cos\left(\Delta k\frac{1+K^2/2}{2\gamma^2}z\right)dz=\frac{\sin\left(\frac{\Delta k}{k_0}\pi N\right)}{\frac{\Delta k}{k_0}\pi N}$$

Where, $k_0 = 2k_u\gamma^2/\left(1+K^2/2\right)$
is the synchronous wave vector

$k_0 + \Delta k$	detuned wave vector
k_u	undulator wave vector
γ	relativistic factor
K	undulator deflection parameter
N	number of periods of the undulator section

The specified maximum of the allowed energy gain reduction is 2%.

It results $\left|\Delta k/k_0\right| < .14\%$

Temperature variation compensation : up to ±1.5°c

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Tests of the eccentric cam positioning system for the undulators

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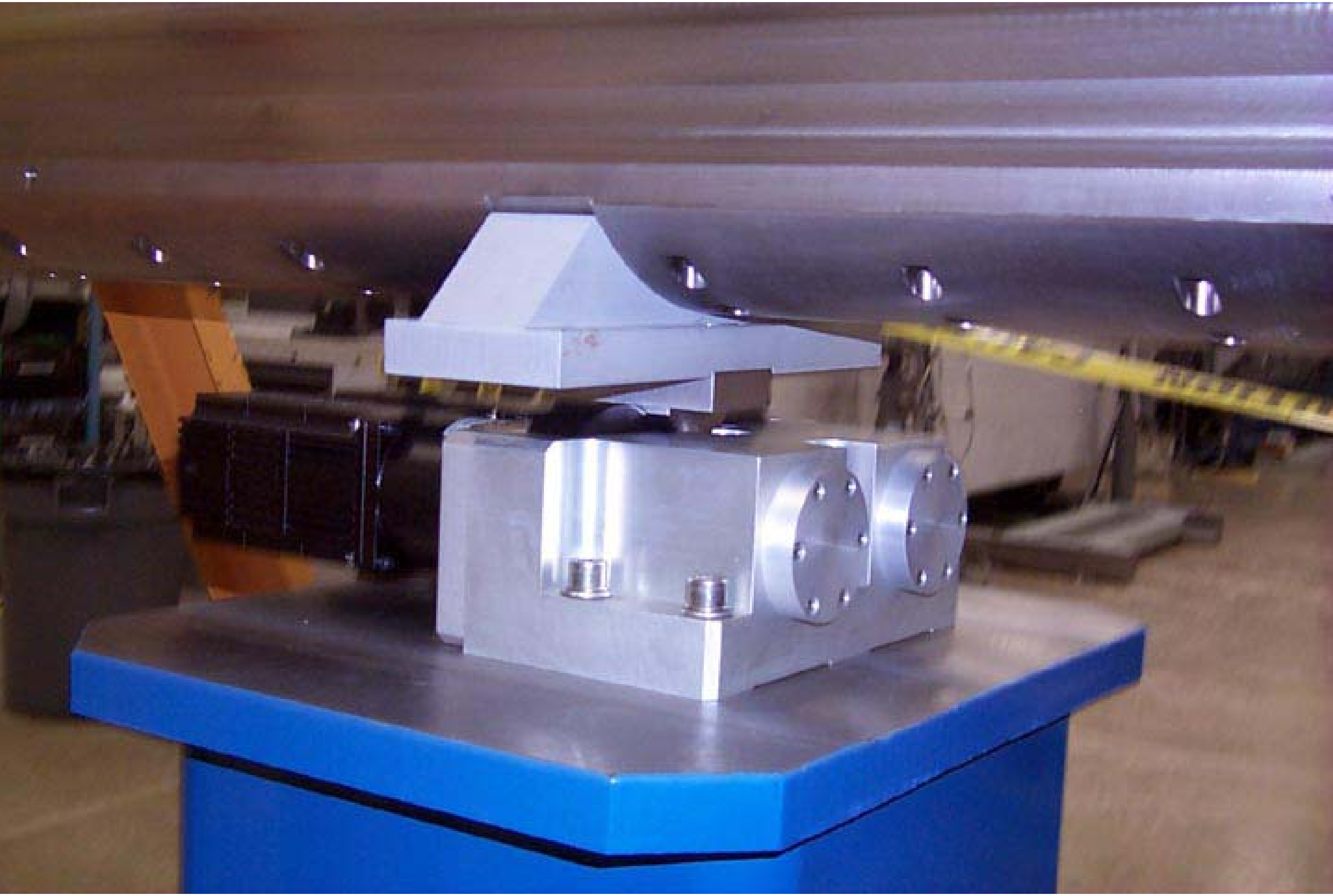
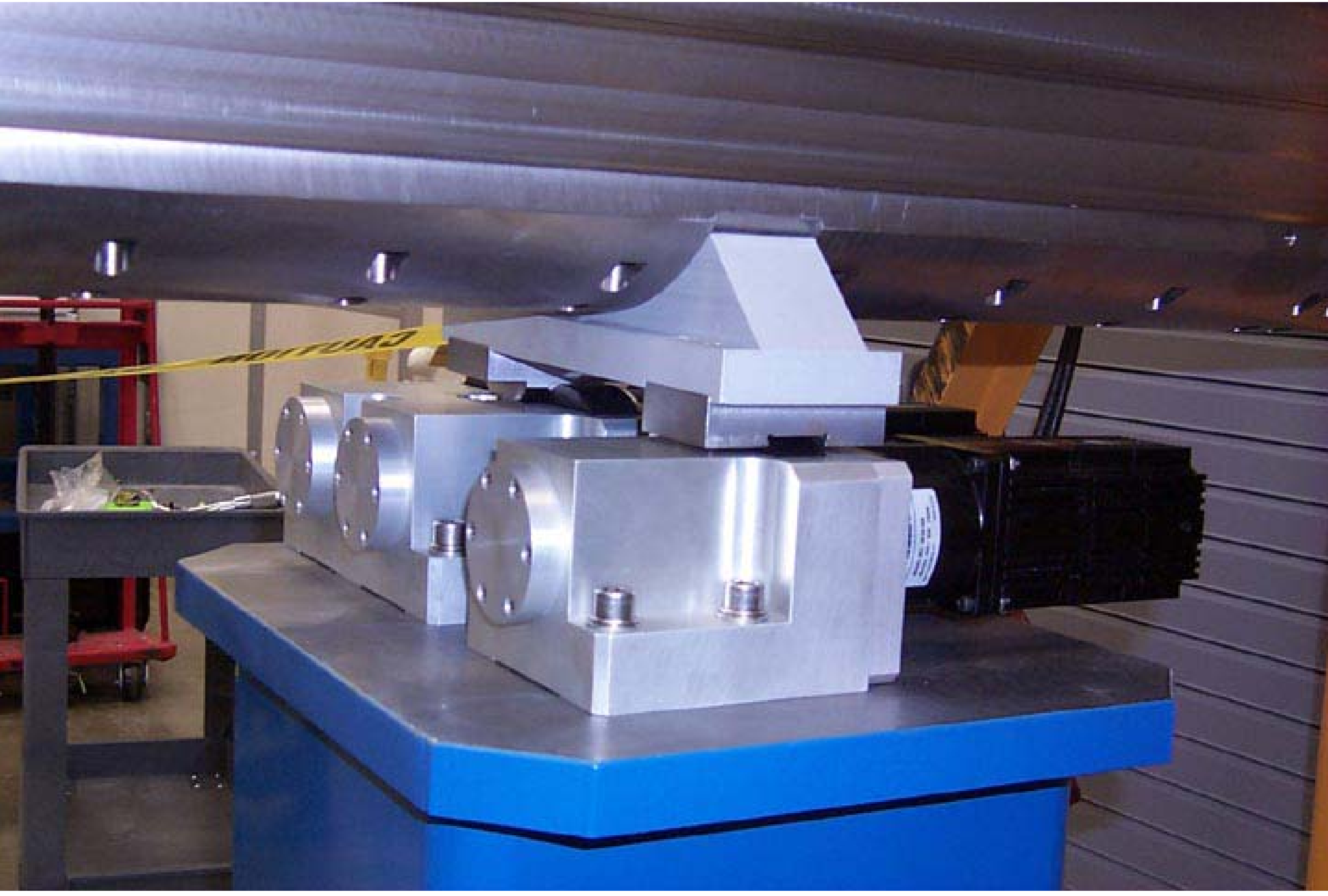
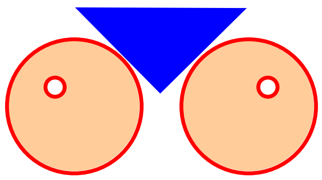
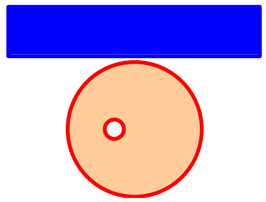




Alignment of the LCLS undulators:

- No alignment in longitudinal direction
- Each undulator is supported by three alignment stages:
    - first and second alignment stages move undulator in two transverse directions,
    - third stage moves in vertical direction only.





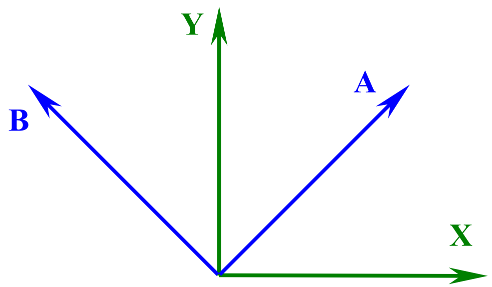
- Alignment range is 6mm, resolution is:

  $3\text{mm} * 2\pi / 4000 / 100 = 47\ \text{nm}$

- Coordinate relations:

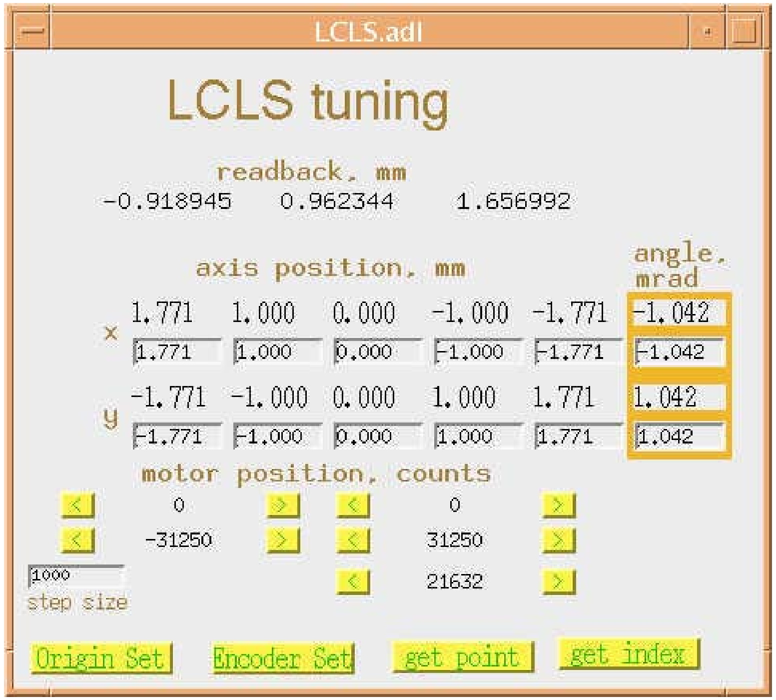
  $X = (A - B) / \sqrt{2}$

  $Y = (A + B) / \sqrt{2}$

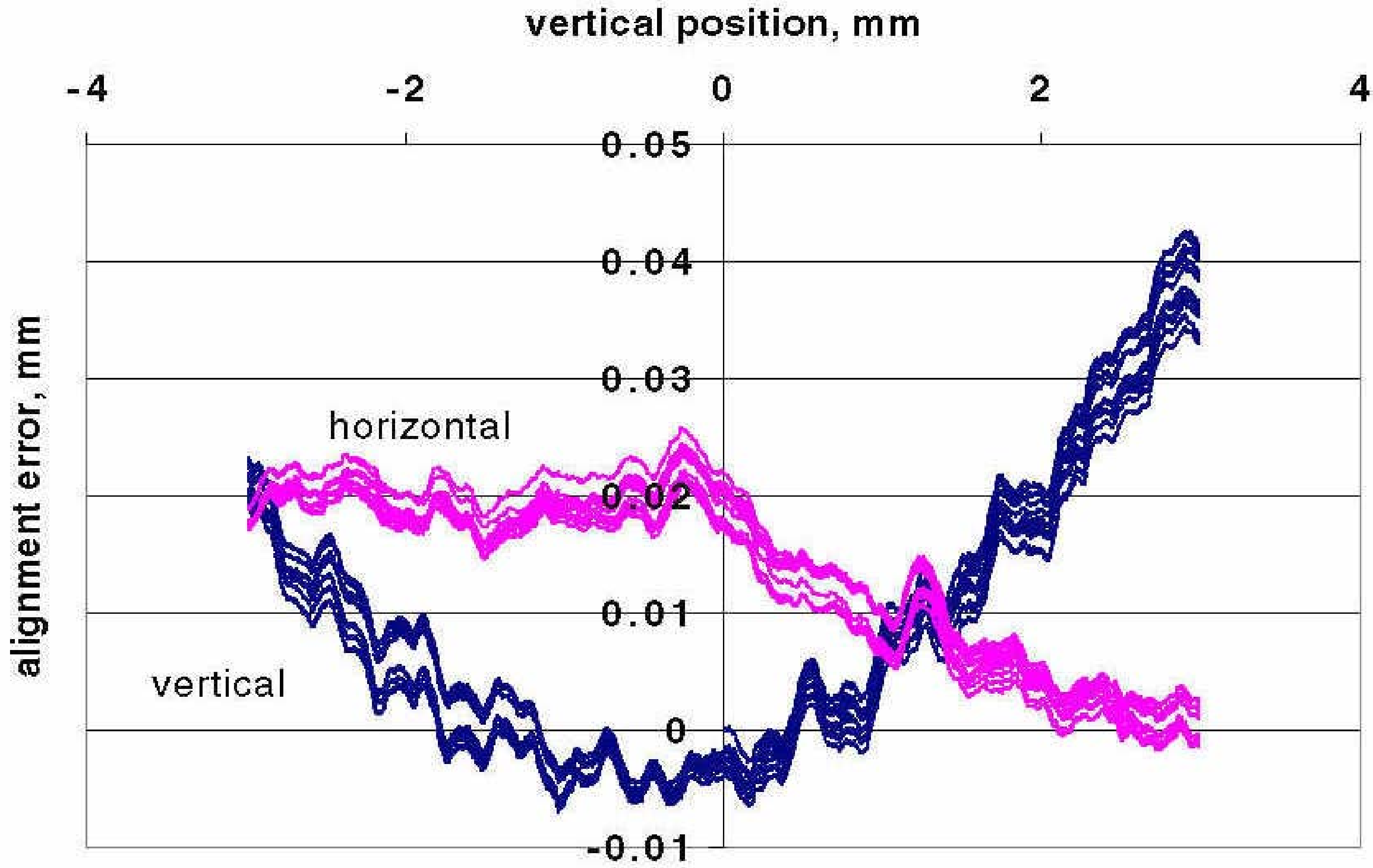


Testing software:

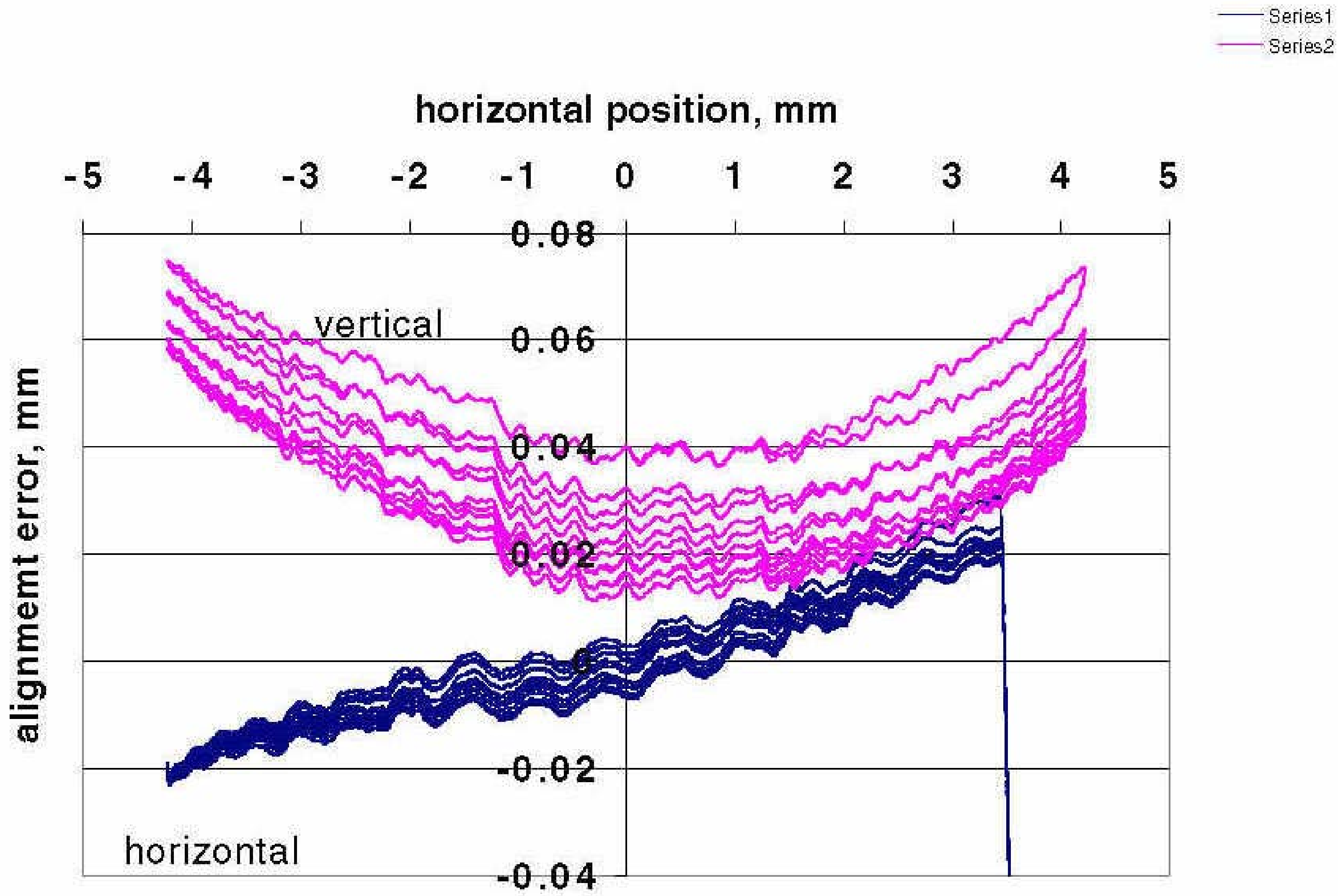
- EPICS based
- Program features:
  - **adjustment in horizontal (X) and vertical (Y) directions:**
    - upstream end only
    - downstream end only
    - upstream stage only
    - downstream stages only
    - parallel shift of the device
    - rotation of the device around X and Y axes.
  - **individual tweaking of each motor**
- Readback channels:
  - **Five incremental rotary encoders integrated in servomotors**
    - resolution 4000 counts / turn



- Testing of the stages is done by Heidenhain MT25 incremental linear encoders
  - -measuring range 25 mm
  - - accuracy ± 0.5 μm
  - - resolution 40nm



Positioning error during vertical adjustment



Positioning error during horizontal adjustment

Discussion and future developments:

• Positioning reproducibility is about 5 μm for both horizontal and vertical coordinates.

It is well within required alignment accuracy:
- -100 μm in horizontal direction
- -50 μm in vertical direction

• Lack of rigidity in the gear boxes appears as a non-linear positioning error.

Simulation shows that an error of 50 μm can be reduced to less than 1 μm by appropriate shift of a cam shaft phase

• Precise linear encoders are required for proper tuning of the positioning system

• Cam eccentricity in two-coordinate stages has to be reduced by a √2 factor to get the same vertical travel range with one-coordinate stage.

• Absolute position readback is required:
- wire wound potentiometers will be used as cam shaft position sensors.

FY2002 Plans and Schedules

- Magnetic measurements of the undulator prototype
- Constructing the BPM prototype
- Engineering design of the spectrograph/ monochromator mechanical system