Integrator qualification procedure.

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Short coil undulator measurements promise extra control over the undulator tuning accuracy. In contrast to the long coil procedure that requires hardware reconfiguring, short coils can be used together with the Hall probe scans. This allows for immediate Hall probe measurement correction, and thus reduces tuning time. The accuracy of the short coil measurement directly depends on the quality of the integrator that converts voltage across the coil to the flux change across it. The flux value in turn is used to calculate field integrals.

To test integrator we need to use the simplest procedure that avoids complicated data adjustment, and tracks only the integrator properties. We decided to use extended range of z-scans with the short coil starting at 0.5m before entering undulator and ending 0.5m behind the undulator as Figure 1 shows.

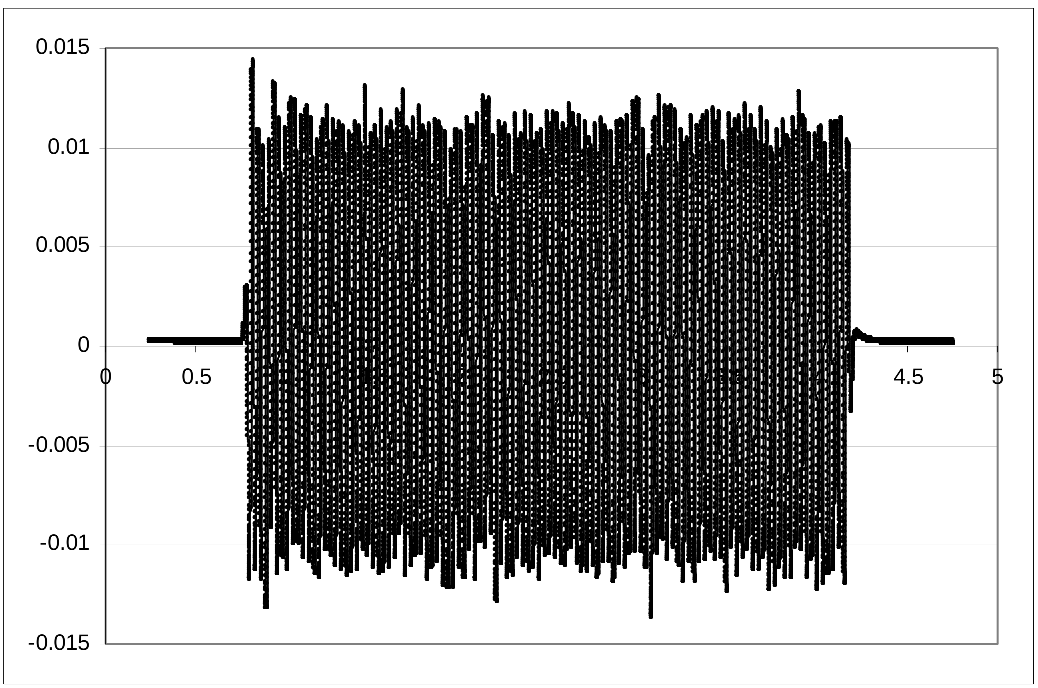

Figure 1.

Then we do large enough for the statistics number of short coil z-scans at the same coil X and Y position inside the undulator. The initial state of integrator (just before scan starts) may vary from scan to scan, so we do only one adjustment at the first data point (see Figure 2)

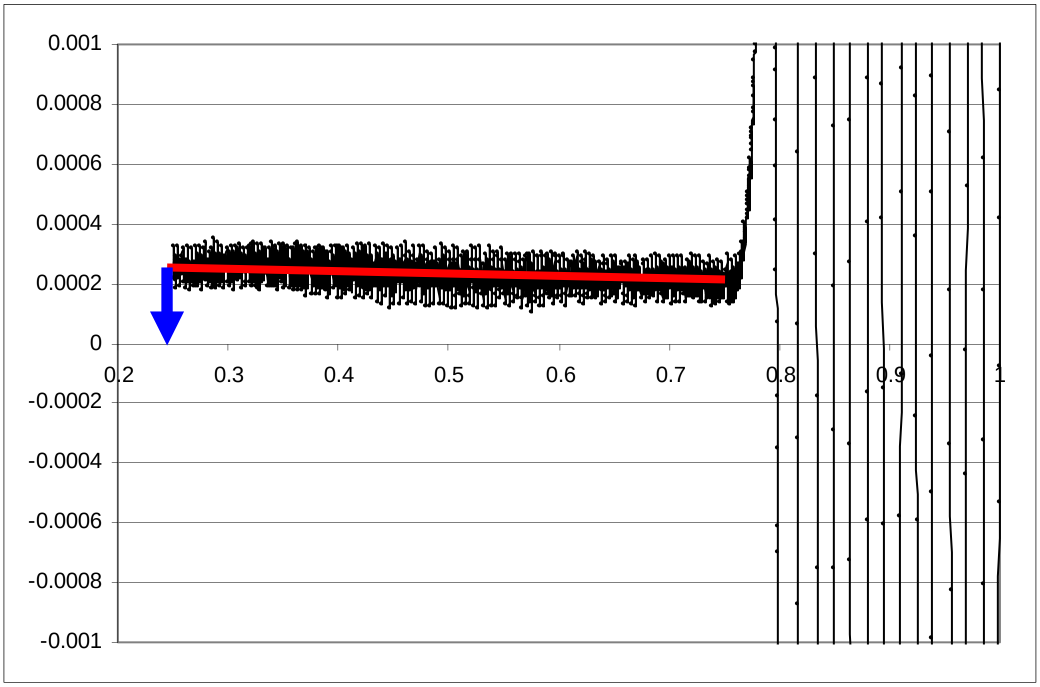

Figure 2.

To avoid measurement noise error we do linear approximation over the first 1700 points of the data (red line in Figure 2), and use it to find first data point offset. Then the whole curve was moved down by the offset value. Assuming that magnetic environment around the granite bench does not change over the time; we expect that ideal integrator must always produce same data. To compare results from different scans we were using Matlab based application ‘coil_anal.m’ to calculate field integrals and trajectories. Figures 3-6 shows measured field integrals for 100 identical scans obtained using LakeShore FM480 integrators.

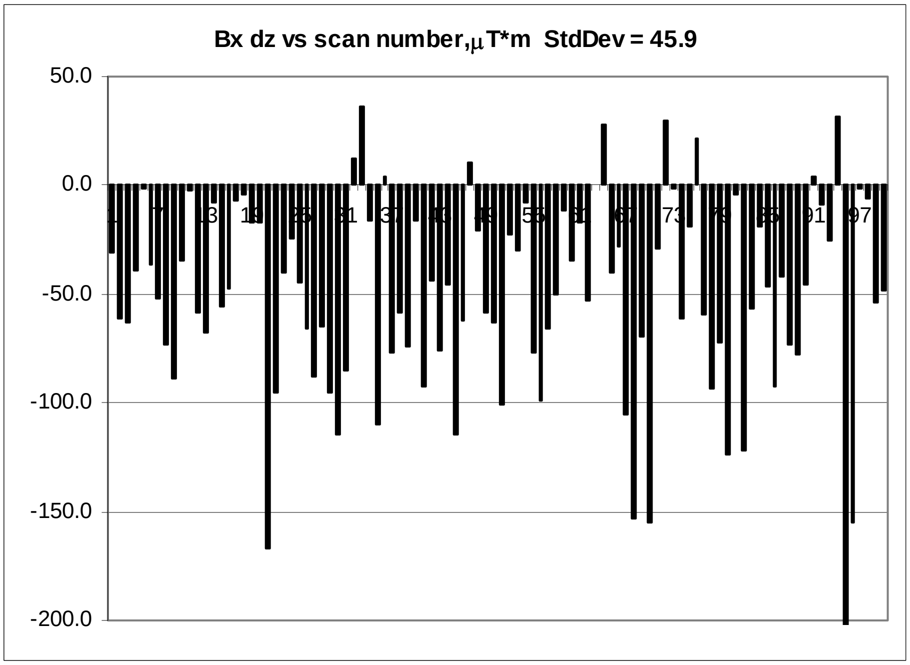

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Figure 3.

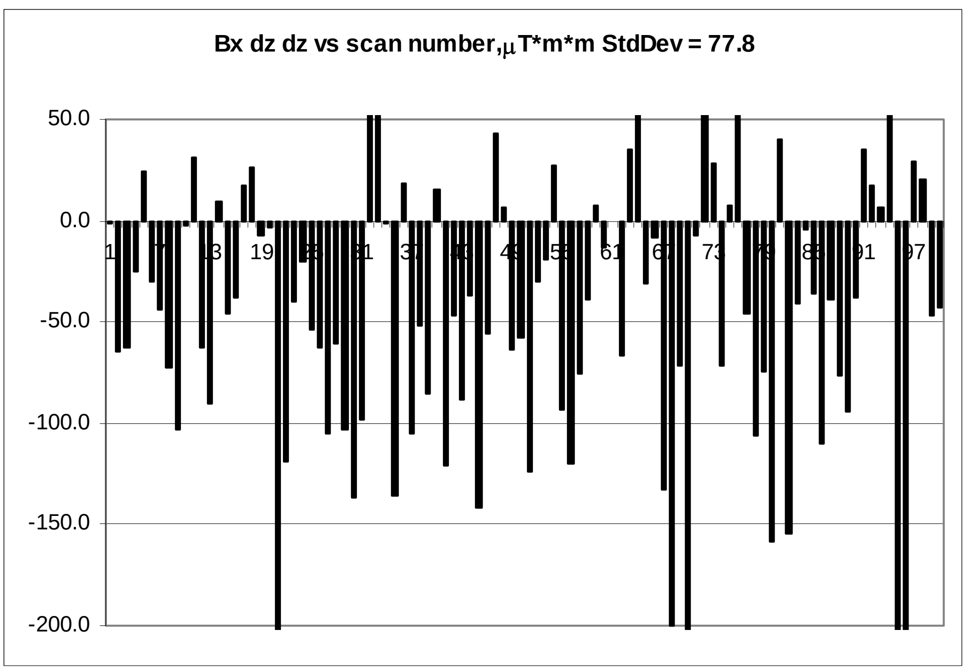

Figure 4

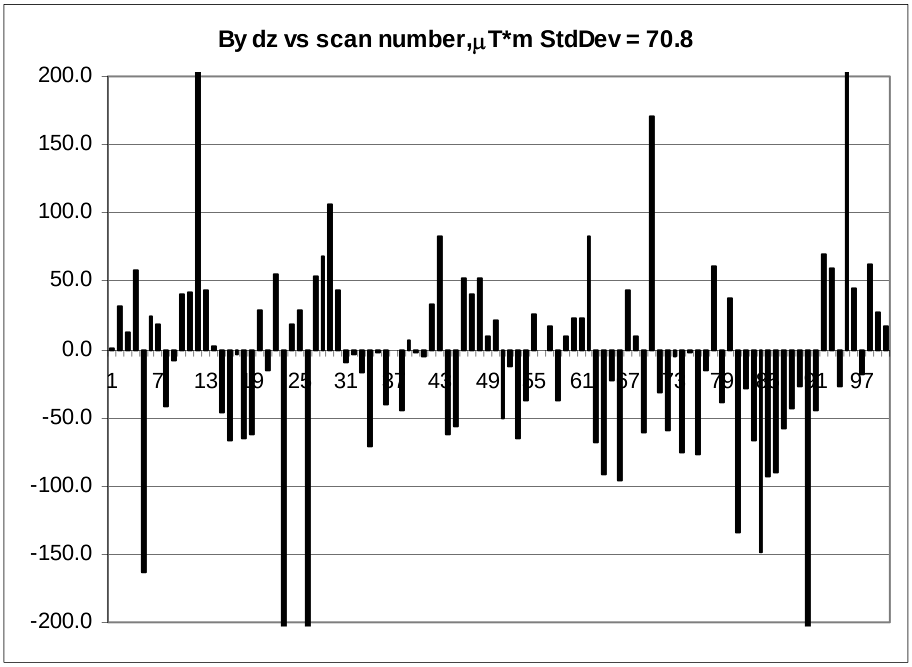

Figure 5.

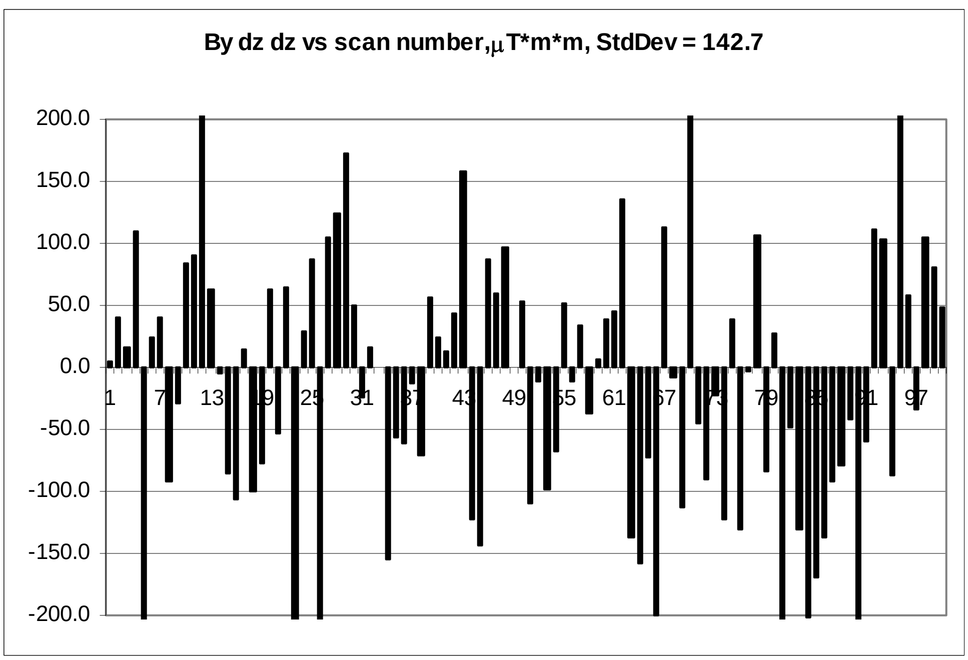

Figure 6

The standard deviation of the field integrals appears far higher than 30 μTm(m) that is the maximum allowed discrepancy between the Hall probe and Long coil measurements. It means that LakeShore integrators can not provide measurement accuracy neither for single scan Hall probe adjustment nor for long coil comparison (even using multiple short coil scans). This result is consistent with results obtained by Isaac Vasserman obtained independently at ANL.

To solve the problem we need to try different integrators. The first thing to do would be testing Walker Scientific MF-10D integrator that according to Isaac requires about ten scans averaged to get reasonable result. This might work well to verify long coil data, but can not be used to adjust Hall probe data in a single scan. Nevertheless if we can get reliable data out of the 10 scans it still will take less time and efforts then switching to long coil measurement and then back to the Hall probe ones. There are a few problems on that way. We have only one Walker integrator and it rather ancient version of it that recently took about few months to be repaired. The company is a small business that may disappear any time.

The last but not the list opportunity does exist by using passive integrator that is formed by short coil resistance, *R* and by low leakage capacitor, *C* connected in parallel to the coil. Since coil resistance is formed by wire it produces much less noise than any resistors used to build integrator from operational amplifier. The simple math shows that the time integral of the electric move force across the coil, *Iemf*, can be obtained from the voltage, *V* measured across the resistor using the following expression:

$$Iemf = \int_{t0}^{t} V dt + RC(V_t - V_{t0}),$$

where V_{t0} is the first voltage measured at the scan start, and V_t – voltage measured at time *t*.

The measurement can be accurately made by using National Instruments CompactRio controller that contains FPGA module, built-in DSP, and R series expansion slots that allows us to use same type of modules we are using with the pxi systems. Compact Rio module has small dimensions and powered by DC voltage. This makes easier to connect it directly to the short coil, and its small form factor definitely will reduce mechanical load on the bench carriage. FPGA module is capable to measure time with accuracy of 25ns that is important for the first part of the integral. On the other hand NI offers set of different low noise amplifiers we can choose from. The quality of amplifier is important for the second part of the integral. Definitely the value of capacitance *C* should be optimized to reduce overall integral calculation error. We suggest using NI9205 ADC module that offers reasonable parameters for suggested integration procedure. We have estimated that maximum voltage across the short coil moving at speed of 8 cm/s would be about 0.1 V. NI9205 module offers measurement range of 0.2 V with 16 bit resolution (6.57 microvolt/LSB), noise floor 10 microvolt, and absolute accuracy of 157 microvolt at over sampling rate of 100. We have estimated that at bench carriage speed of 8cm/s we can use over sampling rate of 3000 (by doing real time averaging over 3000 measurements), and may achieve accuracy better than 30 microvolt. This will give us a dynamic measurement range of 12 bits (1 bit is for sign, 2 bits for noise, and 1 bit due to using only half of measuring range).

The gallery of trajectories (*.ps files) as well as original data (*.dat files) can be found at:
v:\met\MagServe\MagData\LCLS\Undulator\L143-112000-13\DATASET0008\ShortCoilResults\