

# A LABVIEW BASED CYCLOTRON MAGNETIC FIELD MAPPING SYSTEM

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This paper describes the application of National Instruments LabVIEW to the NSCL K500 magnet mapping, as part of the Coupled Cyclotron Upgrade. LabVIEW provides a fast development environment for hardware control from a PC running Windows NT. The PC and LabVIEW environment allow non-professional computer programmers to obtain a reliable and flexible system where modifications can be quickly implemented. This program supports the use of motor controllers, data acquisition cards, digital I/O modules and GPIB instruments. A complete map of 360 degrees is obtained in approximately 90 minutes, measuring 185000 field values with a spacing of 1.6 mm in radius every degree.

## 1 Introduction

As part of the refurbishing of the K500 superconducting cyclotron, it was necessary to remeasure the magnetic field after the cryostat and yoke had been modified. Due to staff limitations, we needed a mapping system that demanded less manpower than the system used for the K1200 mapping [1]. Hence, it was important to have a fast response time to software modification requests. Our previous electronics used standard nuclear instrumentation modules and low-level assembler programming, which limited the number of people able to modify the program. The use of LabVIEW [2] and low cost PC hardware proved an excellent choice to expand the pool of people able to program the data acquisition and motor control systems. This allowed immediate response from the programmers to problems arising from the experiment.

## 2 Mapping method

The central field in the median plane changes between 3 and 5 T across the operating region of the cyclotron. A search coil is displaced in the median plane of the magnetic field of the cyclotron along radial scans. The change in magnetic flux generates a voltage that is processed by a precision bipolar voltage to frequency converter that produces two pulse trains (see figure 1). One channel is active when the magnetic field increases and the other when the magnetic field decreases. These pulses are sent to counters in the PC where they are read synchronized by trigger pulses generated by an encoder (mounted on the same cart as the coil moving along a radial scale). The change in the magnetic field is proportional to the sum of positive and negative pulses. The advantage of this system versus a system that integrates the voltage is that we are independent of the velocity of the search coil. The voltage level will vary for a constant gradient, but the number of pulses will still be correct.

The calibration of the system is made with the help of two readings of the absolute field with NMR probes. The field at the center of the cyclotron ( $r=0$ ) and a second point (in our case this is measured through one of the holes for the dee RF conductor) determine the calibration of the search coil, and the center value determines the offset for each measurement.

## 3 Electronic components

Two brushless DC motors provide the motion for the angular and radial position. The motor controller is a two axes Animatics 5000 series with serial interface directly connected to the PC serial port.

The radial position is determined by a Hewlett-Packard HEDS-9200 encoder moving on a glass scale [3] with divisions each 0.2 mm. The pulses from the encoder are processed and one out of every eight pulses is used to trigger the accumulation counters. These 24 bit counters are included in the National Instruments I/O card (AT-MIO-16XE-50). These cards also provide DMA buffered operation for faster response. The angular encoder is an Inductosyn with 0.001 degree resolution [4].

The 10 V precision bipolar voltage to frequency converter was built by Lawrence Berkeley Laboratory [5] and used already in our previous system [1].

## 4 Software

We decided to use LabVIEW as an alternative to the low-level programming of nuclear instrumentation modules and CPUs. The limited amount of calculations involved during mapping allows the use of a possibly slower executable if easier maintenance of the code is obtained. The mapper program acquires the measurements and saves them to disk for later processing. The file saved has a header that describes the magnet parameters, time stamp, and comments. From each scan, we save the ini-

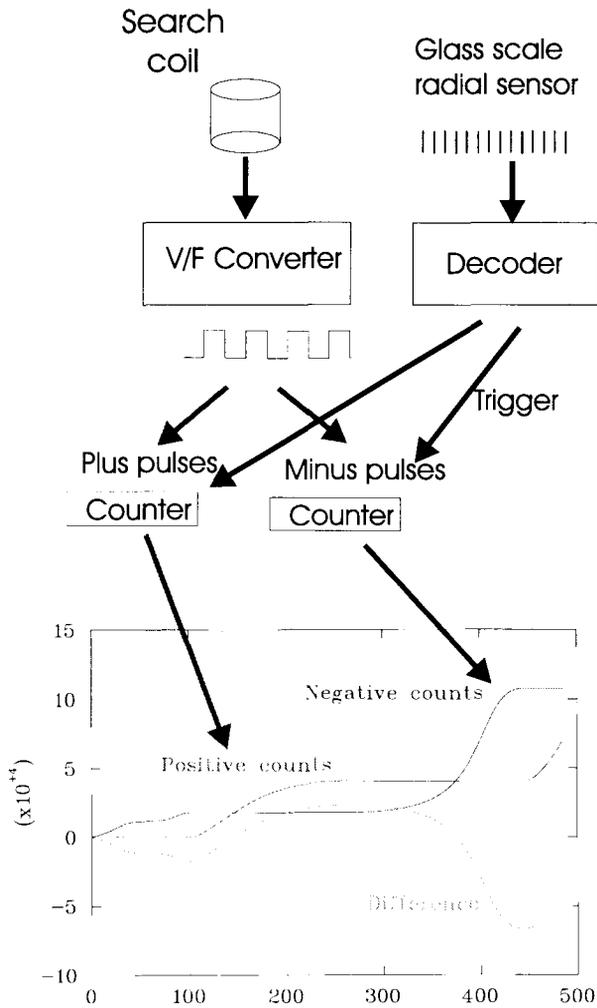


Figure 1: General overview of the mapper components.

tial and final readings of the angular encoder ( used to check for drifts during the scan) and a table with approximately 500 rows and three columns: the counts of the positive and negative pulse counters, as well as the time difference between trigger signals generated by the internal clock of the I/O card. This time difference (inverse of the velocity) gives an indication of how smooth the motion is. The program checks that the number of readings in one scan is compatible with the requested range of radii being scanned. We measure up to the maximum radius available at each angle determined by the presence of extraction system elements at each azimuth. By selecting values one sector away from the angle under consideration, we can later obtain a more complete field map during the final processing.

The I/O card is programmable with the drivers provided for LabVIEW and all its features are available without major effort. The values of the three counters are read when the trigger signal from the radial encoder

is received and stored in a DMA buffer. At the end of the radial scan the three buffers are written to disk. We also use the card digital output channels for various logic control tasks.

After the completion of the main field map measurements, we proceeded to measure the magnetic field along the extraction path. We used two Hall probes to determine the field and gradient at each point. The voltage from the Hall probes is measured with digital voltmeters with a GPIB interface. The probes move along a track that runs through the passive quadrupoles (focusing bars) in the extraction system allowing us to measure the field inside and in the fringe field region of each bar. The program used to move the Hall probes and take the data was written in just two days. The availability of public domain drivers for the GPIB instruments made it easy to incorporate them into the program. We have also used LabVIEW to write magnetic field mapping codes in simpler cases controlling gaussmeters with serial interfaces.

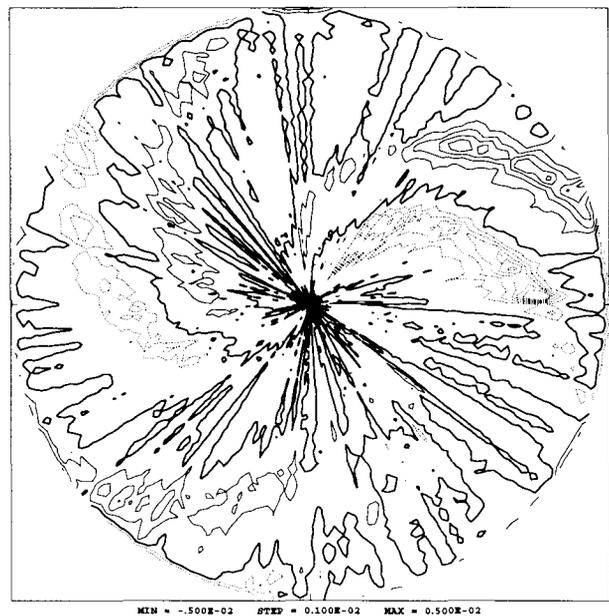


Figure 2: Countour plot of the difference between two maps at the same excitation. The polar grid has 180 values in azimuth and 53 in radius.

## 5 Accuracy of the measurements

To estimate the repeatability of the measurements we will compare two different maps made at the same excitation of the superconducting coils. A polar grid is created from each measurement with the characteristics needed for our orbit codes, a 360 degrees grid with a radius step of 0.5 inches and a 2 degree step in azimuth. A point by

point difference of these two grids was obtained. A polar countour plot is shown in figure 2 where the contours are plotted every gauss from -5 to +5. The thick line is the zero gauss contour, the solid thin line are positive and the dotted line are negative contours. We see that most of the points have differences of 0 or 1 gauss. A better estimate can be obtained from figure 3 where we show a histogram of the differences shown in figure 2. The average of the distribution is 0.033 gauss and  $\sigma=0.85$  gauss. The ion orbit simulations will not be affected by small

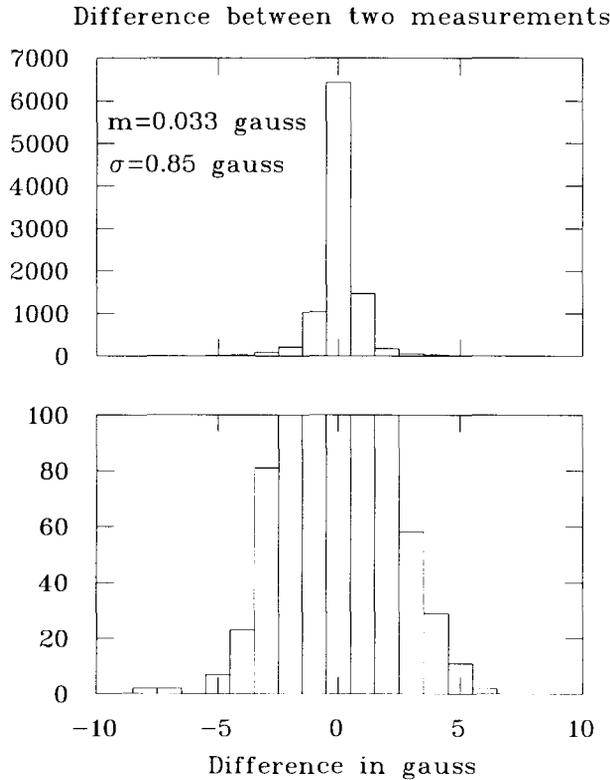


Figure 3: Histogram of the difference in field point by point (in gauss) between two maps at the same excitation shown in the previous figure.

localized magnetic field map errors. However, magnetic field map errors which affect the results for the average field and the third harmonic will produce incorrect simulations results. Figure 4 shows the difference in the average field and third harmonic between the two maps. We see that the average fields agree to better than 0.5 gauss. Except for the very last radius point the third harmonic also agree to better than 0.5 gauss. The corresponding differences for first and second harmonic are shown in figure 5.

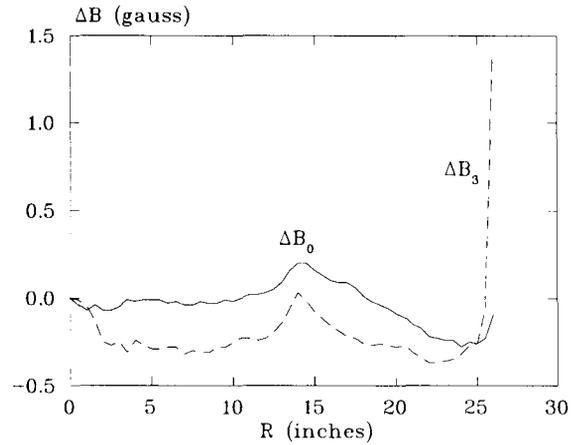


Figure 4: Difference in average field and third harmonic between two maps at the same excitation.

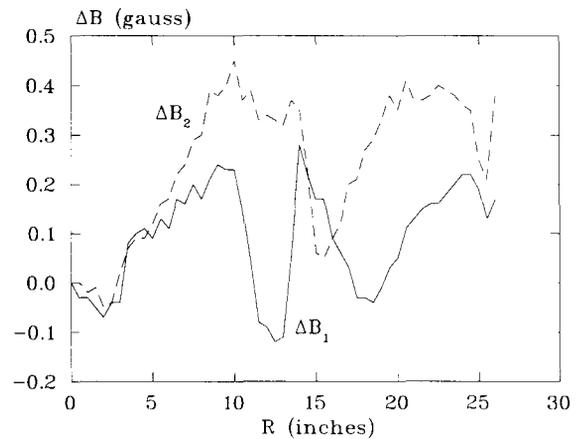


Figure 5: Difference in first and second harmonic imperfections between two maps at the same excitation.

## 6 Conclusions

We have had a positive experience in using LabVIEW as the programming language for several magnetic field mapping projects in our laboratory. It satisfied our expectations with respect to the reduced development time we desired. Several people in our operations group are now developing control programs based on LabVIEW.

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## References

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