IMPLEMENTATION OF A COMPUTER-CONTROLLED MONITORING SYSTEM AT THE PRINCETON AVF CYCLOTRON

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Stability in the parameters of the beams from our cyclotrons is often crucial to the experiments our laboratories perform. For example, when running a high-resolution experiment with Princeton's QDDD Spectrograph, there are 42 magnetic elements between the ion source and the detector. Instability or drift in any of these elements can easily nullify the sophisticated dispersion matching and kinematic correction that make such experiments possible with our machines. At the Princeton Cyclotron we have purchased a commercial computer-controlled measurement system and interfaced it to 20 elements of our beamline. While this project is still far from complete, we have satisfied two of the conditions that must be met for such a system to be useful. These are, firstly that measurements can be made under the conditions of a working laboratory to 1 part in 100,000, and secondly that the results can be presented in a form useful both to the experimenter concerned with the quality of his data and to the technical staff who must maintain and develop the equipment.

OVERALL PROJECT STEPS

Although the following steps may overlap somewhat, they represent the plan of attack at Princeton.

1) Initial acquisition of a computer-controlled measurement and control system. We have purchased the Analog Devices (R) model 350 system containing a 256k, MP/M-86 based control computer with a compiled extended Basic language that supports an instruction set for their measurement cards and a remote intelligent measurement cage with 16 card slots that features an excellent 12-bit, 30 kHz ADC that can also simulate a 16-bit, 60 Hz ADC by a noise-added signal averaging technique. With this initial system we also purchased two 16-differential/32-unbalanced input cards and a 4-channel output card for the measurement cage, a dual-port RS-232-C card that occupies 1 of 6 slots in the control computer, a single floppy-disk drive and a backplane with two input and two output signal isolation and conditioning amplifiers. Including monitor and cables, the system cost was approximately $53,000.

2) Interfacing to 20 beamline elements. These included 12 quadrupoles, 6 steering magnets and 2 dipoles.

3) Development of software and hardware strategies. Particular points investigated were the extent to which signal conditioning was necessary, the level of performance that could be expected in both time and accuracy, and the development of ways of extracting, processing and presenting the data that would be useful to all concerned.

4) Expansion of the system to 48 input and 12 output channels, with signal conditioning where needed. At a cost of about $5,300 this allows:

5) Expansion of the interface to 42 magnet currents plus 3 voltages, or everything between the ion source and the QDDD detector.

6) Control of selected parameters by an experiment via RS-232-C port. The two most interesting to our experimenters are the QDDD setting and the DEE voltage, which can be reduced to quench the beam.

7) Additions to the system and interface for further parameters, such as fluxmeters. This will allow:

8) Updating of critical parameters to better standards for drift control by modulating current settings.

At the present time we have accomplished the first three of these steps and are proceeding on the fourth. In the process, we have not only gained much valuable information about this system and its possibilities, but we have also pinpointed a number of specific problems with our beamline elements. The results already appear in our data from high-resolution experiments.

SOFTWARE: THE ERGONOMICS OF DATA PRESENTATION

With the experimenter concentrating on his experiment and a small technical staff focussed on development and problems already identified, the periodic checking of the basic equipment in the laboratory that would keep it in top condition is often the task that is put off or ignored. Even if it were practical to retain all of the raw data that could be collected by such a system as this, it would simply be ignored for want of someone with the time to review it. For this reason, we felt it important from the outset to design the software for usefulness rather than completeness.

There are four tasks for the software that serve four different levels of attention. The first is the need to monitor the system to ensure that nothing has gone wrong: that no elements have become unstable or changed their values appreciably. This is accomplished by a graphic CRT display that shows the present value of each element relative to the initial reading it had when the monitor was set up, on a scale appropriate to the sensitivity of an experiment to changes in that element. Thus full screen deflection would correspond to a change of about 1% of full current for a quadrupole, but a change of 0.02% for an analyzing dipole. Past history for each element is also presented visually at the same abscissa as two vertical stripes of different texture, one representing the total range of variation seen and one the RMS variation from the original value. At a glance, one can assure oneself that nothing has changed appreciably or, if it has, what has changed and by how much. The unit displayed is in all cases programmed to be the same as the least significant digit in the setting potentiometer or divider.

The second software task provides more precise information in numerical form as an alternate CRT display. For each element the present setting, the rms variation from the initial setting and the variation from the average over the last ten 1-minute cycles is listed in tabular form. This provides quantitative information for evaluating a problem, but clearly requires that one have his attention on the beamline.

The third task is to provide even more detailed information on any particular element as a diagnostic aid once a problem has been identified. The software provides this by a scan mode that behaves much like a sampling storage oscilloscope. One hundred samples are taken, each averaged over a number of measurements that correspond to 1/60 second to as long as you would like. These are plotted as differences from the first sample vs. time. At the conclusion of the scan, the average value of the samples and the RMS variation of the samples from their average are presented numerically. This allows study of the perfomance of a regulator over time scales that vary from well below the response time of any iron magnet to drift studies that can last hours or even days.

The fourth task has been to provide long-term memory and record-keeping. This was done by sending information in a similar format as the three CRT displays described above to an alphanumeric printer as time-stamped records. Although the graphics are somewhat cruder than those on the CRT, use of the same format makes it easy to compare a past record with a present display.

As a final note on software, the author, except for a brief fling with a PDP-8 in the early 70's and some more recent experience with a VIC-20, has succeeded in avoiding computers almost completely. This system is programmed in a compiled extended Basic that can handle the measurement tasks quite efficiently. The services of a system-level programmer are not required.

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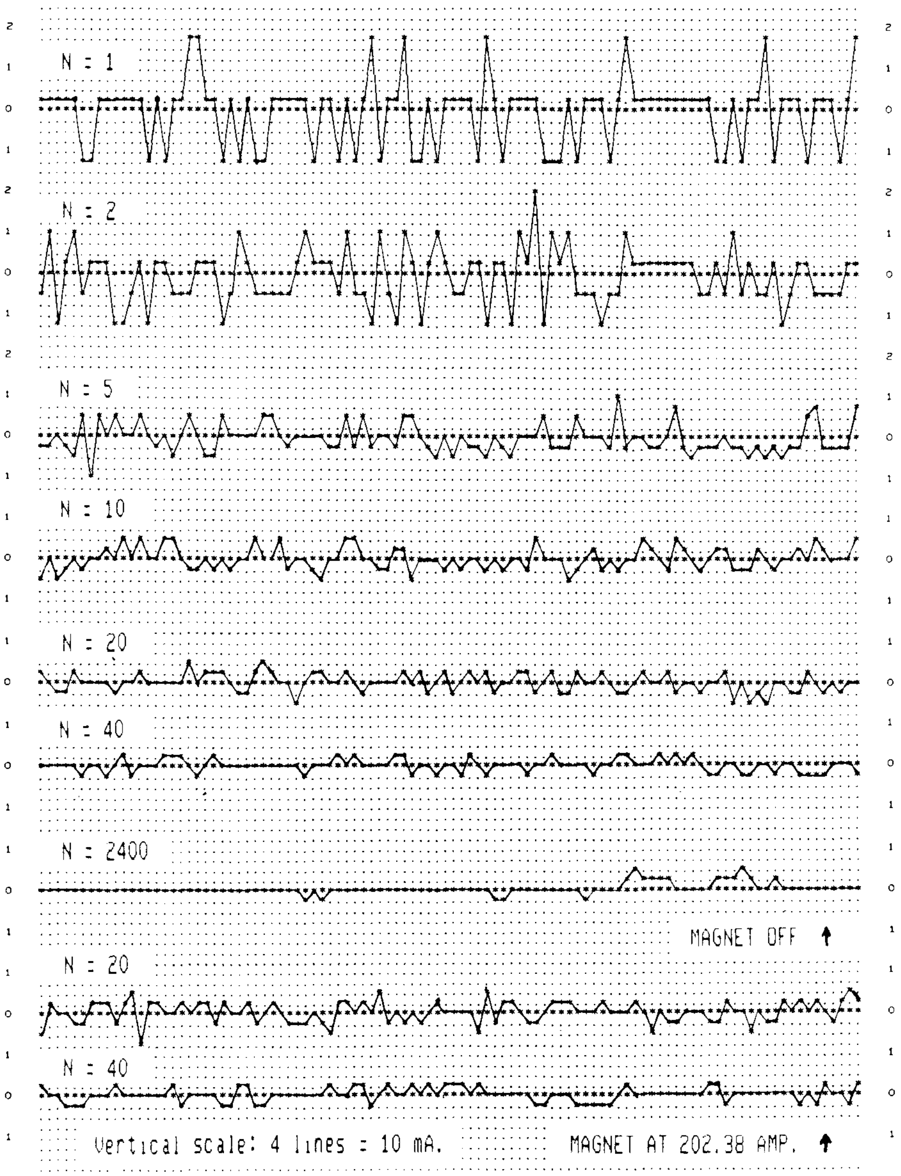

Figure 1. Typical data from scan routine for various numbers of measurements in each sample. Each graph represents 100 Successive samples.

NOISE AND STABILITY CHECKS

TEST SYSTEM

Noise and stability were checked using the following arrangement. The regulator for our analyzing magnet, which was recently revamped for increased stability and freedom from ground loops, features a shunt designed to drop 2.5 Volts at 350 Amperes of magnet current. This shunt was connected to a bipolar isolating conditioning amplifier that mapped the 2.5 V span into 7.17 V. This in turn fed the ±10 V ADC input to the measuring system, with a 2kΩ isolating resistor added to the return line. A 10 V output channel from the system was connected to the output side of this resistor through a 50 MegΩ resistor. Driven by a quasi-random number routine, this provided the 0.4 mV peak-to-peak noise source required for the averaging technique described below. The multiplexed differential ADC input used was adjusted in software to ±10 V span and 16 bit resolution. This input therefore had a resolution of 0.305 mV.

Referring all parameters to the magnet current, then gives the following: the full-scale current span is 350 Ampere, the ADC resolution is 15.39 mA. and the flat-spectrum noise source has a peak to peak amplitude of 20.18 mA., or RMS variation of 7.13 mA..

THE MEASUREMENTS

Using the "storage oscilloscope", or scan, mode in the software, a series of measurements was made consisting of 100 samples each for the average value of a number, N, of individual ADC readouts. The program calculated the average value for all the samples and, in the usual approximation that confuses sample with population statistics, the RMS variation of the samples about their mean. Runs were made with the magnet turned off for N = 1, 2, 5, 10, 20, 40 and 2400 and with the magnet turned on at 202.38 A. for N = 20, 20, 40, and 40. This sample data is shown graphically in Figure 1. (note: the printer routine used to prepare the figure quantizes the data at 2.5 mA., but the CRT display and numerical data are not so restricted). The vertical scale is 10 mA. per numbered interval of 4 lines. Quantization of the data at the expected level can clearly be seen in the low-N runs; in particular the distribution of points over three levels in the N = 1 run shows that the quasi-random noise amply bridges the ADC step size so that the high-N samples can be treated as statistical. To the eye, the data appear to be statistically distributed for all but the N = 2400 run. This run, with 40 second sample time, took about two hours to complete and shows time correlations more characteristic of drift.

RESULTS

Statistical summaries of these data are shown in Figure 2., which plots the RMS variations of the samples against the number of measurements in each sample. The straight line in the figure is approximately the variation expected from the quasi-random noise source alone. The curved line is this contribution added in the square to a constant 1.1 mA. contribution that matches the variation observed in the long N = 2400 run.

Except for the first two points, the data are well represented by the curved line. Deviations for N = 1 and 2 are expected both because the statistical approximations break down, and because the loop gain of a regulator for a magnet that has L/R ~ 3 sec. has rolled off considerably on this time scale. Of particular interest are the runs for N = 20 and N = 40 as these have short enough sample times (0.33 and 0.67 sec.) to be used in routines that, even with software overhead times, can sample 40 to 50 elements at 1 to 2 minute intervals. The precision of these measurements (1/92,000 and 1/125,000 of the measured current, 1/160,000 and 1/218,000 of the maximum current) is especially good for a configuration that waives nearly a factor of 3 for range mismatch and bipolar capability. The variations seen for these two values are smaller than the ADC step size by factors of 6 and 10 respectively. It is also worth noting that these measurements were made with the system interfaced to a number of other elements, and that the magnet-on data were taken with our cyclotron delivering an alpha beam to an experiment, so that all the usual noise sources in our laboratory were in operation at the time.

CONCLUSION

With some care in interfacing, a modern computer-controlled measurement system can be pushed beyond its normal resolution by signal averaging to provide as many as 50 measurements per minute at the 1/100,000 level, with the data presented in forms convenient to both experimenters and technical personel. We therefore now have a tool that provides a precision that, until recently, used to demand balanced bridges to achieve but which is far more convenient to operate and to interpret.

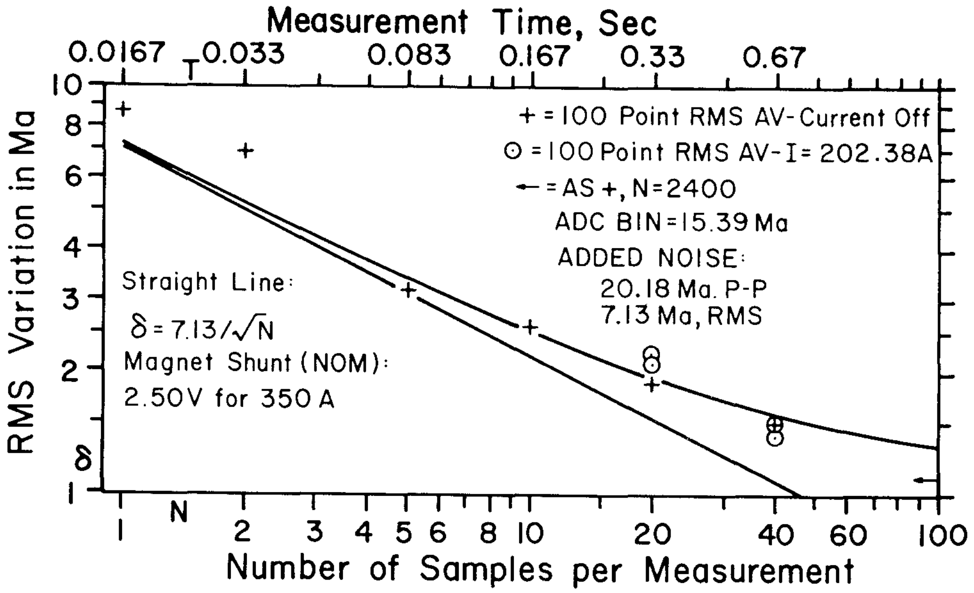

Figure 2. Summary of data for noise and stability check

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