# A scalable data acquisition system for superconducting coil experiment

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We developed a system for data acquisition and analysis, designed around VMEbus and UNIX workstations. The system is designed to be scalable: If we distribute it throughout the network, a thousand channels can be dealt with in the same way as a dozen channels. The issues of choosing and installing amplifiers are also discussed.

## 1. INTRODUCTION

The Large Helical Device project carried out by National Institute for Fusion Science (NIFS), Japan, necessitated research and development for world's largest superconducting coils.

In our typical experiment with short superconducting wires, we measure 32 to 64 channels of quantities such as voltages, temperatures, fluxes, and currents [1]. The sampling interval ranges from 100 $\mu$s to 2 ms. The graphs of the data must be displayed on computer screens and printed on paper whenever desired.

To this end, we developed a system for data acquisition and analysis, designed around VMEbus and UNIX workstations. The system also has basic data analysis facilities such as averaging, smoothing, and noise reduction. Most of the operations can be performed by pressing mouse buttons.

The whole system is designed to be "scalable " in the sense that a thousand channels can be dealt with in the same way by running multiple processes on networked workstations.

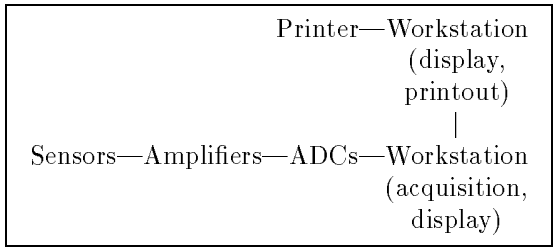


Figure 1. A small configuration.

## 2. DESCRIPTION OF THE SYSTEM

Fig. 1 shows a small configuration of the system, and Fig. 2 shows a scaled-up configuration. Signals from the sensors are amplified and fed to multichannel analog-to-digital converters (ADCs). The data acquisition processes on workstations set the sampling rates, trigger modes, and pre- or post-trigger times for the ADCs, which in turn send digital data to the workstations via VMEbus. The data acquisition processes transform the data to physical quantities

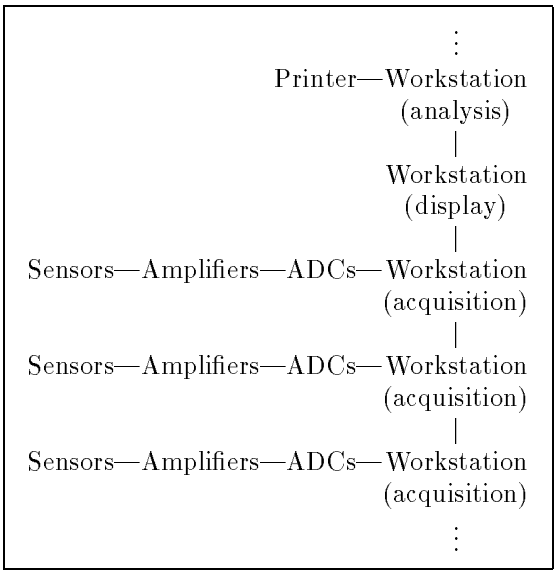


Figure 2. A scaled-up configuration.

such as temperature. These processes can also display graphs of the data on overlapping windows. Each window can display up to eight channels of data. Meanwhile, the data acquisition process creates two files for each run: a binary file containing raw data, and a text ("log") file describing experimental conditions and comments. Transformed data (in physical units) can also be written to text files to help further analyses by other software on workstations, PCs, and Macintoshes.

Data files are written on NFS (Network File System) servers so that any workstation on the network can examine the data and print out the graphs.

The system (Fig. 1) was used successfully in our helical coil experiments [2].

## 3. SCALABILITY AND RESPONSIVENESS ISSUES

In our future experiments, we will have to store and analyze more than one thousand channels of data. Some of the channels will have to be continuously displayed on computer screens (like pen recorders).

This can be achieved by distributing the processes throughout the network, each process dealing with 32 or 64 channels. Data will be stored on NFS file servers, from which any workstation connected to the network can acquire data. NFS is not suitable for fast data exchange, however. Alternatively, data may be sent to all processes on the network by multicasting or broadcasting. We have developed one such implementation where one process acquires data from ADCs and sends messages containing 32–64 channels of data to all processes on the network every tenth of a second, for example. Other processs listening to the multicast can display data on computer screens like multichannel pen recorders.

Plans are underway to extend this system to include part of the overall LHD control system. Though UNIX is not a "real-time" operating system, today's RISC-based workstations are so fast that, if properly designed, lack of real-time responsiveness can be made up for by ease of use and availability of popular tools.

## 4. NOISE REDUCTION

Because superconductor wires are stabilized by good conductors such as copper and aluminium, the typical normal-state signal level between two taps on a conductor specimen is very low (on the order of 1 mV). We therefore need a good noise reduction scheme.

We have developed two noise reduction schemes for our software. The first one is suitable for noise reduction on the fly. The second one, based on the least-squares method and moving averaging, is accurate but time consuming.

Note that almost all of the noise in our data is at 60 Hz and its multiples; see Figs. 3 and 4.

The first method is based on digital filtering in the time domain (see, e.g., [3]). Unlike filtering via fast Fourier transforms (FFT), this method can be applied on the fly. As is the case with FFT, however, this method removes the 60 Hz component of both noise and signal, and may result in ringing phenomena.

The second method is partly interactive, in that it first allows the user to specify the time

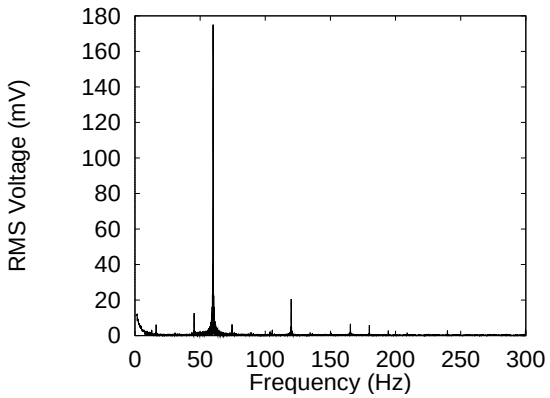


Figure 3. Typical spectrum of noisy data.

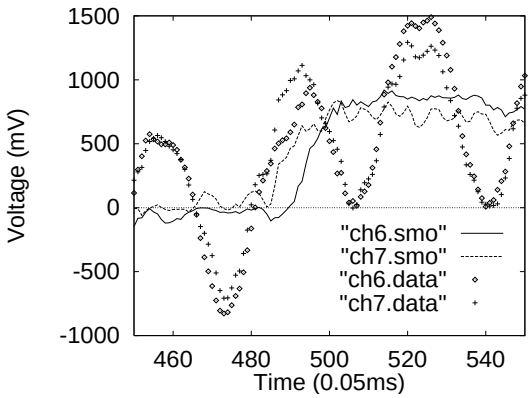


Figure 4. Typical noisy data before and after noise reduction.

region where there is no signal of interest. Next, in this region we determine $a_k$, $b_k$, $c_k$, and $\omega$ that minimizes the quantity

$$\sum_t \Bigg[ V(t) - \left( \sum_{k=1}^{m} (a_k \cos k\omega t + b_k \sin k\omega t) + c_0 + c_1 t \right) \Bigg]^2 .$$

Then we use these values of $a_k$, $b_k$, and $\omega$ to calculate in each data point the expected noise

$$\sum_{k=1}^{m} (a_k \cos k\omega t + b_k \sin k\omega t),$$

which is to be subtracted from the data $V(t)$ in the whole region. The number of harmonics $m$ is set between 6 and 10.

We used this noise reduction scheme to measure quench propagation speed. After the 60 Hz noise and its harmonics had been removed, we calculated the numerical derivative, $V'(t) = (V(t) - V(t - \Delta t))/\Delta t$, and repeatedly applied moving averaging, $V'(t) := (2V'(t) + V'(t + \Delta t) + V'(t - \Delta t))/4$, until a unique maximum emerged within the domain of interest. This maximum in the derivative $V'(t)$, i.e., the inflection point of the data $V(t)$, was our (almost) operational definition of the quench start time.

## 5. AMPLIFIERS

To decrease noise, we want to put the amplifiers as near as possible to the cryostat where the superconducting coils are mounted. When the helical coil is in full operation, the magnetic field near the cryostat is around 4 kG (0.4 T). We therefore need amplifiers (DC–10 kHz range) that work under high magnetic fields.

Amplifiers consist of semiconductor devices, resistors, and capacitors. Our measurements showed that 14 kG of magnetic field did not affect carbon and metal-film resistors, and ceramic and mylar capacitors. Chemical capacitors, especially old ones, were somewhat affected by the field: At 10 kG, the capacitances dropped by about one percent. There was a linear relationship between capacitance drop and the strength of the field. If we switched off the field, the capacitances resumed the normal values.

Since iron-core transformers cannot be used in magnetic fields, we must use batteries for power supply, and photocouplers or optical fibers for insulation between input and output circuits of the amplifiers.

We tested four types of amplifiers, assembled by three manufacturers. Noise, distortion, and frequency characteristics were not affected by up to 7 kG of field.

Optical-fiber-insulated amplifiers had higher insulation voltages between input and output circuits, but consumed more electric power, than photocoupler-insulated ones.

## 6. ACKNOWLEDGEMENT

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