Application Briefs

Protecting a 1/8-Gigawatt Power Supply (8kA at 16kV) or How Do You Make a 2000A Fuse?

FAST DATA-ACQUISITION SYSTEM DETECTS ANOMALOUS WAVEFORMS AND SHUTS DOWN 2000-AMP IGNITRONS BEFORE THEY CAN MELT. PRINCIPLE APPLICABLE TO MANY OTHER SYSTEMS WHERE FAILURES MUST BE ANTICIPATED.

A new data-acquisition technique provides rapid acquisition, real-time threshold detection, and fast, multi-option response, for a large number of continuously-varying parameters. The concept was first employed in a multi-channel system recently installed in the main power supply for the Bevatron, a particle accelerator at the Lawrence Radiation Laboratory.*

In this application, a fast data-acquisition system samples waveforms at a large number of intervals during each cycle and compares them with stored threshold values (perhaps obtained by processing earlier data). Any significant disparities are noted, analyzed, and appropriate action is automatically taken, ranging from minor adjustments, to a "flag," to shutdown.

Since such anomalies can signal incipient breakdowns, this scheme can prevent the very expensive consequences of loosing large amounts of power under fault conditions, even for very short times. The method also allows observation of aging and so can effect parts replacement at appropriate – rather than arbitrary – intervals. It also provides rather obvious means of feedback of life data to parts manufacturers, who can use the information for product reliability improvement. (It's much more difficult to diagnose the source of failure by investigation of a hardened puddle of metal and glass, or after an explosion of suddenly-vaporized coolant!)

Although most of our readers are unlikely to be designers of control systems for Bevatrons, a little thought will show that the monitoring principles discussed in this practical example are useful for minimizing risks of failure and for failure analysis in any system where catastrophic failure should be unthinkable. Such situations can range through a wide gamut, limited only by the imagination, but are likely to include steel rolling mills, supertankers, intensive-care patients, power-distribution networks, etc.

This approach is facilitated by the increasing availability of memories, minicomputers, and conversion components, and the decreasing cost of building instrumentation networks.

THE PROBLEM

The power supply is a dual-motor-generator installation, feeding a 12-phase mercury ignitron rectifier network. The peak power output of the supply is *128 megawatts: 8,000 amperes dc at 16,000 volts!* There are 48 ignitrons, occupying 8 cubicles, each containing 6 tubes. Typical anode currents are 2,000A. Pairs of tubes, in parallel, share normal conduction currents.

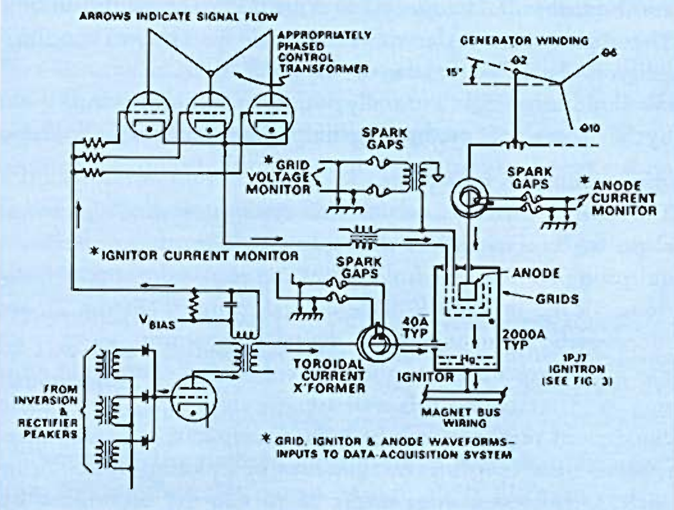

Figure 1. Ignitron Monitoring System

Unusual or spurious operation of elements of this system can result in improper sharing of current, which may result in catastrophic tube failure, due to excessive anode currents. Ignitrons require proper phasing of both grid waveforms and ignitor currents, with respect to the anode voltage. A failure in either of these control signals can prevent a tube from firing, thus creating excessive anode currents in its partner.

The data-acquisition system described here aids in the monitoring, detection, diagnosis, and correction of such occurrences.

Data acquisition, in this case, calls for quantitative measurement of the state of a series of parameters, and an immediate decision of the parameter's relationship to a threshold. This may be handled in a number of ways: by applying an analog comparator directly to the transducer, by applying

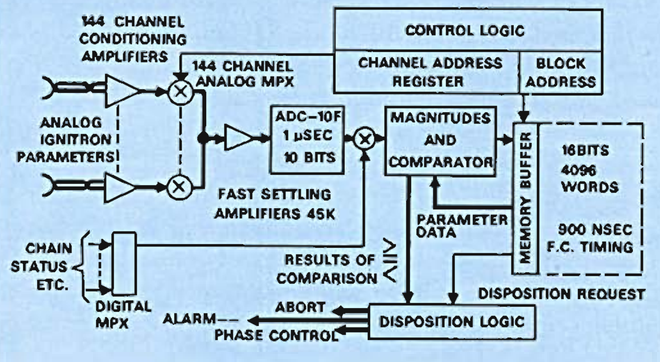

Figure 2. Data Acquisition System

THE AUTHOR

Don M. Evans, who has degrees in Electrical Engineering and Computer Science from the University of California at Berkeley, has been at the Lawrence Radiation Laboratory's Bevatron project for the past 10 years. The Digital Control Facility, for which he is responsible, includes four small computers in a "multi-processor" organization, which exercises control over the guide-field mentioned in this article, 42 200kW energy tracking magnets, a wide-band RF system for particle acceleration, and a Linac and Ion Source.

*Work performed under the auspices of the USAEC it to the output of the conditioning amplifier, or by using a digital processor, which analyzes the data after it has been acquired and entered into the processor's memory.

Analog comparators respond quickly, but a large number of separate comparators – and possibly even separate power supplies – are required. Also, unless many D/A's or sample-holds are used, threshold adjustment is manual and time-consuming. The digital case is far more desirable because of its flexibility – but the time-lag from acquisition to detection of threshold crossings is usually large. In addition, time spent by the processor in performing comparisons reduces the available on-line time for executing far more important control functions.

The new approach used for this system allows detection as close to "real time" as the repetition rate of parameter acquisition permits. Threshold values and required response functions, stored in a block of peripheral memory (Figure 2), are successively brought into a digital comparator, along with the proximate results of the A/D conversion. Threshold crossing is detected at this earliest possible time, and simple consequent responses can be immediately initiated (e.g., interruption of succeeding firing pulses or "phasing-back" firing angles). Other responses might be to flag the occurrence by incrementing a location in the peripheral core memory, or to interrupt a digital processor, which can then compare it with many earlier data points, stored in the peripheral memory.

FAST ACQUISITION REQUIRED

Forty-eight tubes under surveillance, with three parameters per tube (grid voltage, ignitor current, and anode current), require a total of 144 channels of analog multiplexing. A record of previous data for each of the parameters is maintained, in order to properly diagnose causes of failures and to provide a histogram of fault growth as follows: After comparison of the threshold with the converted parameter value, each value is inserted into its respective location in a block of the peripheral memory. Upon completion of one multiplex cycle of 144 channels, the block address is advanced to a new block. Because ten memory blocks are used, 10 successive values of each parameter are available, allowing reconstruction of the history of each tube in the system for that cycle prior to detection of an impending fault condition.

Since the rectifier system operates at a nominal frequency of 60Hz, a tube's conduction period is about 3ms. The magnitudes of the 144 parameters are sampled 10 times during one conduction cycle, allowing 10 blocks of core to be filled with data and the comparisons to be performed, all of which requires a maximum acquisition cycle duration of 300μs. This requirement establishes a maximum duration of 2μs for each individual sequence. During this time, a parameter must be addressed, the multiplexer settled, A/D conversion accomplished, digital comparison made, and parameter value written into memory. Also, the threshold to be compared is read out of core. While a parameter is being written into memory, the analog multiplexer seeks the address of the next parameter to be accessed. Further time-sharing takes place as the threshold value is read from core and rewritten while the A/D converter digitizes the analog value and provides the results to the

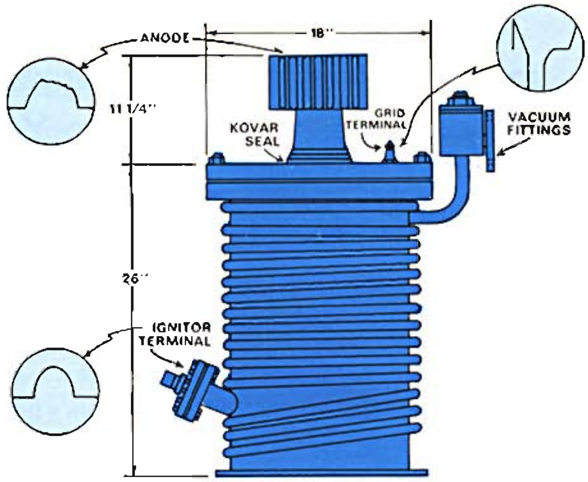

Figure 3. Mercury Ignitron 1PJ7 (One of 48)

comparator. All of these considerations determine the required operating characteristics of the modular devices. To meet the 0.1% system resolution requirement, the Analog Devices ADC-10FB*, a 10-bit successive-approximation converter with a conversion rate of 100ns/bit, is used.

DATA HANDLING

In order to accomplish the tasks required within the 2μs allowed, a core memory module with 900ns full cycle time is included, an Information Control Corporation 16-bit, 4*k*-word model. The parameter magnitude data occupies 10 bits of each word; the additional bits (6 most significant) are utilized as flag bits, counters for incrementing to keep track of the number of unusual occurrences, or as a code. These indicate the course of action to be taken, depending upon the results of the threshold comparison; i.e., >, =, or <. This flexibility provides for polarity and allows appropriate threshold action, whether an increase or a decrease signals a fault condition.

The net result of these design considerations is a peripheral memory bank synchronized to the conduction periods of mercury ignitrons, address-keyed to sequence through significant parameters in step with the conversions occurring in real time. Rapid cycling through a number of parameters during each repetition cycle, with occasional "side-trips" to acquire static data with no "real-time significance," allows one to obtain a histogram of data by successively inserting each block of data points into adjacent blocks of peripheral memory. Continuing this process over 10 blocks of data provides a rotating list of blocks, each with data from the present cycle of data-taking and the 9 prior readings for comparison.

OTHER ASPECTS

In addition to handling the analog data, the system also includes provisions for status monitoring for safety and control logic chains. This provides a "software" capability for alteration of chains, since all chain points are collected and assembled in parallel words of 10-bits each and then presented to a digital multiplexer. This output is scanned occasionally instead of the converter output. The "threshold" words used to compare against the digital status words allow simple logical decisions to be made, depending on the status of the collected chain data.

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* For information on Model ADC-10F, use reply card. Circle C11

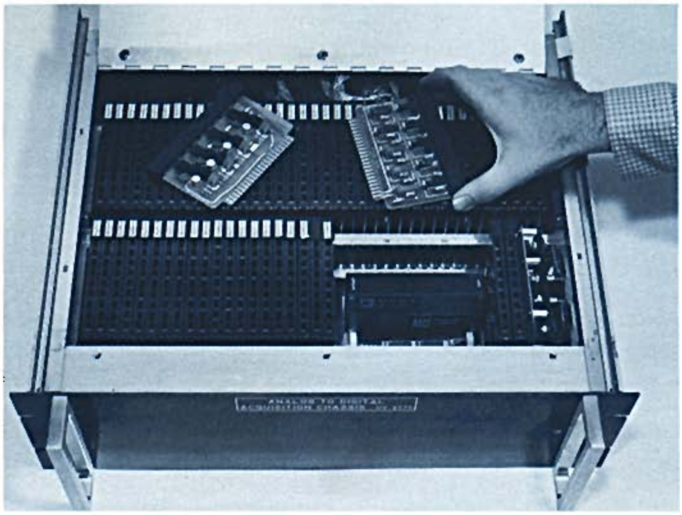

Figure 4. Data Acquisition Chassis. Converter is in Foreground

Low-cost (modest-speed) IC differential-input operational amplifiers are used for signal conditioning. MOS analog switches with internal chip address decoding simplify logic and switch-driver design. Because of the fast transient response required by the buffer amplifier between the multiplexer and the converter, an Analog Devices Model 45K* fast-settling op amp is used.

Communication with the memory is available through both keyboard and digital processor direct-memory-access channel. The system has a capability for set-point control and closed-loop regulation: One may include in the system, as a portion of its cycle, an *output* mode, such that certain address blocks supply digital words to control external devices. By manipulating the feedback element in each of those devices included, (in the control mode) the results of threshold comparison can be utilized to increase or decrease voltages or currents or gains, as a digitally-operated servomechanism.

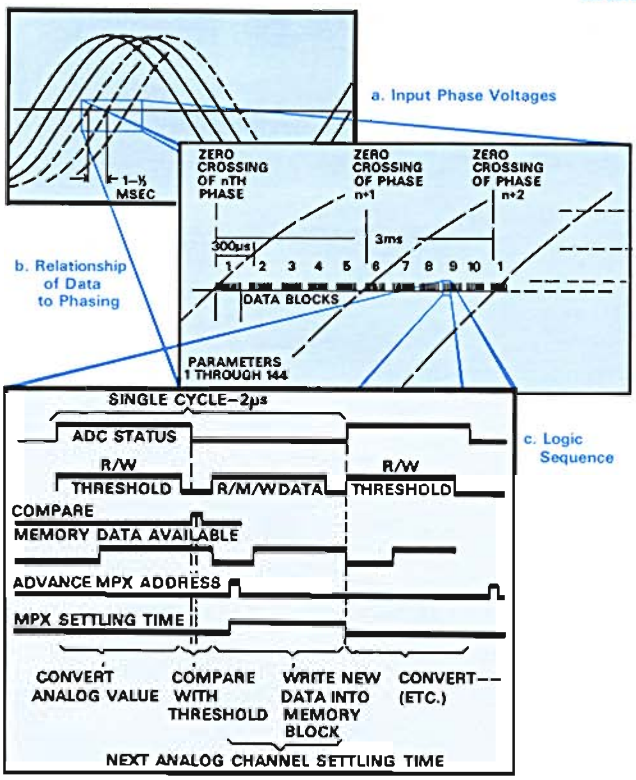

Figure 5. System Timing

*For information on Model 45, use reply card. Circle C12

Worth Reading

The following items should be of interest to readers whose especial interest is in solving problems of input instrumentation in the presence of common-mode signals. They form a logical supplement to the Model 272 bibliography, started in Vol. 5, No. 2, of *Dialogue*. Although not all new, they are relevant.

√*Signal Conditioning*, Applications bulletin No. 101, published by Brush Instruments Division of Gould, Inc., Cleveland, Ohio, a 16-page easy-to-read discussion of how-to-marry a given source configuration (e.g., single-ended—grounded, balanced—floating, etc.) to the appropriate preamp input configuration. Includes a useful "Amplifier Compatibility Summary" matrix.

√*Input Connection Practices for Differential Amplifiers, published by* Neff Instrument Corporation, Duarte, California, a practical discussion that ends with a summary of 6 "Input Connection Rules."

√*Techniques to Analyze and Optimize Noise Rejection Ratio of Low-Level Differential Data Systems*, published by Dana Laboratories, Inc., Irvine, California, includes numerical examples of CMRR calculations.

√"Protecting Hospitalized Patients from Electrical Hazards," from *Hewlett-Packard Journal*, March, 1970, discusses various approaches to isolation, including a floating-input scheme used in some h-p products. Also includes a table listing 9 steps to "Maintaining safe patient electrical environments."

√"Micropower Through the Heart is a Killer," from *EDN*, April 1, 1971 (cover story), a review of the problems of patient isolation and a solution (viz., the 272). **For reprint, Circle C13**

NOTED BRIEFLY

"Putting D-A Converters to Work: 10 Examples Show Versatility," by Rick Spofford, from *Electronics*, October 26, 1970, Uses of fixed-reference and multiplying DAC's in display, radar, servo, and other applications. **For reprint, Circle C14**

"Solid-State Voltage References," from *Instruments and Control Systems*, March, 1971, Compares standard cells and zener diode references, discusses tradeoffs for selection as primary and transfer standards.

Sample-and-Hold module, technical data SHA-1A. **Circle C15**

Isolation Amplifiers for Medical and Industrial Applications, technical data Models 272/273. **Circle C16**