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Synchrotron High Speed Magnetics Monitoring

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Synchrotron radiation is indispensable for scientific research, but reliable synchrotron operation requires extensive monitoring of magnetic fields. Instruments that interface to Ethernet data communication systems reduce the cost and improve accuracy of this important control task.

Wide-Ranging Applications

Since the 1930s, synchrotrons have become essential tools in widely diversified fields of scientific research and engineering development, including chemistry, biology, material science, and microelectronic engineering. Radiation produced in these particle accelerators provides unique insights into the fundamental properties of substances such as semiconductor crystals, viral proteins, molecular electronic structures, human cells, and a host of other organic, inorganic, and bioscience materials.

Synchrotron Light

Synchrotron radiation essentially is a form of light with a broad spectrum of electromagnetic wavelengths, ranging from radio frequencies through microwave, infrared, visible, ultraviolet, soft x-ray, hard x-ray, and on up to gamma rays. The intensity of this light can be up to a million times brighter than sunlight, and a billion times greater than radiation from a typical laboratory X-ray source. The radiation is emitted in extremely short pulses, typically 10–100 picoseconds in length.

Through the use of various synchrotron structures and optics, multiple beamlines can be created for different experiments. Typically, each beam has a high degree of time and space coherence. Time coherence results in photons that have very nearly the same energy (i.e., a beam that is nearly "monochromatic"). The energy of the photons produced can be from a fraction of an eV (electron volt) to 10^5eV.

Space coherence results in photons that are in phase, with very little divergence. Each beam is just a few thousandths of a millimeter across. A typical figure of merit for synchrotron radiation beams is low emittance (low particle scatter in phase space). These beams also exhibit polarization properties, which can be manipulated within the synchrotron.

Some electronic and related applications for synchrotron radiation include:

- Visible and infrared light for imaging and night vision device development
- Ultraviolet light for photolithography development in IC manufacturing, and for general investigations of molecular and material structures
- X-rays for characterizing material and crystal structures
- Gamma rays to explore the inner structure of atoms.

Generation of Synchrotron Radiation

To generate synchrotron radiation, electrons are injected by a linear accelerator (LINAC), and travel along a transport line into the synchrotron storage ring (***Figure 1***). The storage ring is an annular vacuum chamber that can be more than 100 meters in diameter. The electron beam is held in the storage ring by a series of high power bending magnets along the beam path, which keep electrons traveling around a 360° arc. These tightly focused, high-energy electrons travel near the speed of light. When electrons moving close to the speed of light are deflected by a magnetic field, they emit a thin beam of radiation tangential to their path.

The storage ring has many ports around it, through which synchrotron light emerges into beamlines, where it can be manipulated for experiments. Experimental workstations are located at the end of the beamlines. A researcher can specify the precise form of radiation that is delivered. Multiple beamlines can operate simultaneously, independent of each other.

The deflecting magnetic field that produces synchrotron radiation typically is created by insertion devices called wigglers or undulators. A wiggler/undulator is essentially a series of magnets with opposite polarity that force the electrons into a zigzag or undulating path. This action can be controlled to generate radiation of the type specified by a researcher. Wigglers and undulators also affect the flux, brightness, and pulse length of light bursts.

Storage Ring Magnets

Storage ring magnetic fields control the characteristics and quality of synchrotron beams. In a typical synchrotron there could

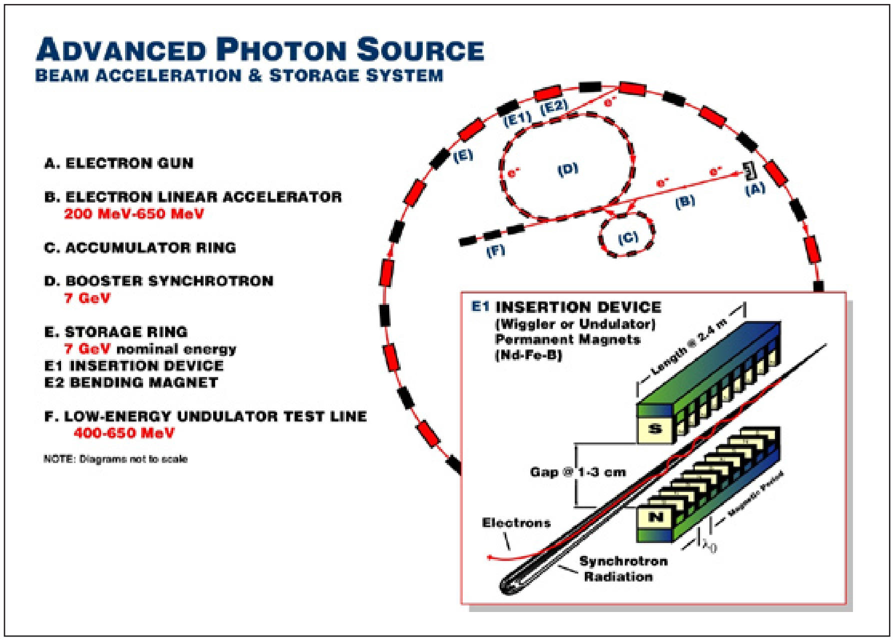

Figure 1. Synchrotron storage ring diagram (Courtesy of Argonne National Labs)

be 128 bending magnets in the main storage ring, plus 128 magnets to focus the electron beam. The quadrupole and sextrupole focusing magnets act in particle beam optics like lenses in light optics. Along the beam path, the magnet arrangement (bending, quadrupole, and sextrupole) is in a repetitive sequence called a periodic magnet lattice.

Loss of synchrotron light and shifts in wavelength are affected mainly by the quality of the magnet lattice fields. To provide the appropriate beam intensities and wavelengths to the maximum number of researchers, it is essential to control these magnets from a central location. Since magnets are located all around the storage ring, monitoring and control requires data communications covering distances up to hundreds of meters.

Monitoring Requirements

Magnetic fields are produced by passing high DC current through electromagnetic core windings. These fields can be measured directly, but it is impractical to set up a remote monitoring network based on this type of measurement. Instead, applied DC voltage is usually monitored. This data is collected and displayed at the central control station. The instrument measurement speed and data communications network should allow monitoring that is as close to real time as possible.

Two critical instrument requirements are high precision voltage measurements and high speed scanning across different magnets. However, there is a trade off between measurement quality and speed. For many instruments, high precision measurements require large measurement apertures or long integration periods. This reduces speed. To increase measurement speed, smaller apertures and shorter integration times could be used, but at the expense of data precision. For best results, the instrument should have a high speed data communications interface, high scan rate, short measurement settling time, and low internal noise.

Existing Monitoring Solutions. To satisfy high speed requirements, existing monitoring systems often use a data acquisition board. The board is installed in a local PC that also has an Ethernet interface. Collected data are sent through the network to the central workstation. This arrangement allows high data sampling rates and near-real-time monitoring.

On the other hand, most data acquisition boards have only 12 to 18 bit resolution. This results in limited measurement precision, typically less than 4 digit resolution. In addition, a large number of PCs are required for the local monitoring points. This drives up system costs (both hardware and software) significantly, and creates a major maintenance burden.

There are GPIB (General Purpose Interface Bus) based instruments that have higher speed and measurement precision. However, GPIB connections are limited to be less than 20m total cable distance. The data transfer rate is limited to about 1MB/s. Hence, GPIB based instruments are not a suitable solution.

Ethernet-Based High Speed Monitoring Network

To improve magnet monitoring and beam quality, high resolution Ethernet-based measurement systems can be installed (*Figure 2*). These systems combine digital multimeter (DMM) functions with a solid-state multiplexer for high speed multichannel measurements of magnet voltages. This instrumentation allows measurement resolutions as high as 6½ digits, and its multiplexer modules can be configured for up to 40 differential channels. With their Ethernet interface, instruments can be located up to 200 meters away from the central control room. (By using Ethernet hubs, the distance is virtually unlimited.) With a dedicated Ethernet network, data transfers can be controlled and moved at speed up to 100Mb/s.

Figure 2. Keithley Model 2701 Ethernet-based DMM/Data Acquisition System improves the quality of magnetic field measurements while its Model 7710 MUX modules with up to 40 channels reduce the number of instruments and PCs needed for monitoring.

Setting the DMM/MUX combination for a measurement integration period of 0.1 PLC (Power Line Cycle; 1PLC = 16.7ms at 60Hz), allows aggregate scan rates up to 500/s. For this setting, the RMS noise is less than 40μV on the 10V range.

With this type of monitoring, multiple DMM/MUX instruments are located around the storage ring and connected to the central workstation's 100BaseT network via TCP/IP Ethernet protocol. The test application utilizes the instruments' IVI Class Drivers, allowing full use of multiple analog I/O channels and channel lists to collect and transmit data to the central workstation for analysis and display.

Each instrument and each PC's network interface card has a unique TCP/IP address that identifies them for data collection. This makes the system very easy to use. Operators can communicate with the instruments without using external software by activating Internet Explorer and entering the TCP/IP address in the browser URL (Universal Resource Locator) line. The instruments also have a built-in web page that simplifies setup, troubleshooting, and data collection.

By combining the long distance, multi-box control capability of Ethernet with the instrument configuration described above, a more economical, near-real-time monitoring solution is created. It requires fewer PCs than earlier solutions, while providing superior measurement precision and control. KEITHLEY

About the Author

Mark Cejer is a Business Manager for Keithley Instruments, where he is responsible for developing Precision Electronic Test applications, markets, and products. Mark has been with Keithley for over 10 years and during that time has led the launch of the Keithley SourceMeter® Line, the Integra Series DMM/Data Acquisition System line, DMMs, and other precision instruments. He has a BSEE from the University of Akron and a MBA from Case Western Reserve University.

Ethernet-based Measurements Improve Accuracy While Increasing Speed and Lowering Test Costs

The Keithley Model 2701 Ethernet-Based DMM/Data Acquisition System provides distributed, remote data acquisition without a sacrifice in measurement accuracy. Its design fully integrates instrument-quality, 22-bit (6½-digit) resolution and sensitivity with Ethernet long-distance networking. The built-in, industry standard 10/100BaseTX fast Ethernet and TCP/IP protocol provide ease of use, high speed data transfers, and from having to use relatively slow, hard-to-configure GPIB legacy systems, and eliminates the need to purchase and install GPIB cards and software. Major advantages are fewer operators and fewer PCs per test station, while realizing higher productivity and lower testing costs.

The Model 2701 has two slots that accept a variety of switching and signal conditioning modules, allowing up to 40 differential measurement channels per instrument. This plug-in design helps reduce test time significantly, and eliminates triggering, timing, and processing issues that often complicate the building of systems from separate instruments and switches.

The design of the Model 2701 is based on Keithley's versatile Integra Series DMM/Data Acquisition/Switching platform. Each channel can be configured separately for any of 14 measurement functions, and provides built-in signal conditioning. Standard and optional measurement capabilities include AC and DC voltage and current, digital I/O signals, temperature (using thermocouples, RTDs, or thermistors), frequency, period, resistance (including continuity, two-wire, and four-wire ohms), and event counting/totalization. Multiple channels can be scanned at up to 500 channels/second. Mechanical switching modules allow higher voltage and isolation up to 1000V. Solid-state switching modules are available for long life and higher speed.

This flexibility allows the measurement of virtually any electrical or physical parameter with high speed and accuracy. The Model 2701's high channel count, broad expansion potential, free software, and built-in Ethernet provide the industry's lowest per-channel installed cost in a high performance data acquisition and control package.

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