Detector And Front-End Electronics Of A Fissile Mass Flow Monitoring System


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Abstract

A detector and front-end electronics unit with secure data transmission has been designed and implemented for a fissile mass flow monitoring system for monitoring fissile mass flow of gasses and liquids in a pipe. The detector/electronics unit consists of four bismuth germanate (BGO) scintillation detectors, pulse-shaping and counting electronics, local temperature sensors and onboard local area network nodes which locally acquire data and report to the master computer via a secure network link. The signal gain of the pulse-shaping circuitry and energy windows of the pulse-counting circuitry are periodically self calibrated and self adjusted in situ using a characteristic line in the fissile material pulse height spectrum as a reference point to compensate for drift such as that in the detector gain due to photomultiplier tube aging. The temperature-dependent signal amplitude variations due to the intrinsic temperature coefficients of the photomultiplier tube gain and BGO scintillation efficiency have been experimentally characterized and real-time gain corrections have been introduced. The detector and electronics design, measured intrinsic performance of the detectors and electronics and the performance of the detector and electronics units within the fissile mass flow monitoring system are described.

Introduction

A new system has been developed to measure and record the fissile mass flow (FMF) of a gas or liquid flowing in a pipe and is designed for long periods of continuous operation in a somewhat harsh environment without operator intervention. Shown schematically in Figure 1, the FMF monitor consists of a moderated CF-252 source with a shutter permitting pulsed exposures of the pipe to a neutron flux, an array of four gamma ray detectors and a host computer. The pulsed neutron flux induces fission in the fissile liquid or gas and the downstream gamma-ray detector/electronics modules measure waves of delayed gamma rays emitted by the resulting fission fragments. The detected gamma rays are counted and reported to the host computer which correlates the time at which the shutter is opened with the detector output to determine the fissile mass flow. The

Figure 1. Schematic Diagram of the Fissile Mass Flow monitor.
FMF detector, read-out electronics and network configuration are described here, and other sub-systems of the FMF monitor are presented in companion papers.

The FMF monitor operates in two modes. In calibration mode the system measures the pulse height spectrum of the fissile gas or liquid under study, identifies a characteristic energy peak and adjusts the electronic gain to set the centroid of the energy peak to a predetermined voltage. In measurement mode two energy windows are defined in the pulse height spectrum and the pulse count rate in each window is recorded as a function of time and reported to the host computer each time the Cf-252 source shutter is opened. The count-rate data acquired in measurement mode is used to determine the fissile mass flow rate.

Shown in Figure 2, each monitor point consists of four detector/electronics modules mounted around the fissile gas or liquid pipe. Each module includes a bismuth germanate (BGO)/photomultiplier tube (PMT) scintillation detectors, pulse shaping and counting electronics, local temperature sensor and an on board local area network node. Each of these subcircuits are described below.

**Detectors and Preamplifiers**

The gamma-ray detectors (Figure 3) are commercially available units consisting of four-inch diameter BGO crystals coupled to three-inch diameter PMTs. A resistive bias network and integrating preamplifier is also included in the module. BGO was selected for its high density (7.3 g/cm³) and the high atomic number of its bismuth component (83) which give the scintillator excellent stopping power for high energy gamma rays. A second advantage of BGO is its low neutron cross section which minimizes the effects of the near-by Cf-252 source on the measurement and reduces the potential for damage to the scintillator due to neutron interactions.

The BGO/PMT detector has two limitations, however, which require compensation in the circuitry. First, both BGO and PMTs have large temperature components; BGO detection efficiency decreases by approximately 2% per degree C near room temperature [1] and PMT gains typically decrease by up to 1% per degree C depending on the anode composition and tube
structure [2]. Correction for temperature variations are accomplished by monitoring the temperature with an on-board temperature sensor and adjusting the system gain based upon a polynomial expression for the measured system temperature dependent response. Second, PMT gains are known to drift, typically to a lower value, with aging. Compensation for PMT aging is accomplished with periodic self calibration of the amplifier shaping electronics using a characteristic peak in the pulse height spectrum as described above. The shaping electronics have a 5:1 gain range, permitting normal operation in the presence of PMT gain shifts from 44% to 220% of nominal value.

**Pulse Shaping and Counting Electronics**

A custom read-out electronics board was designed to process and count the gamma-ray pulses from the detector/preamplifier module which appear within two operator-defined energy ranges. The measured count-rates are reported to the host computer over a secure local area network. Shown schematically in Figure 4 and photographically in Figure 5, each custom electronics card consists of a CR$^2$-RC$^3$ bipolar shaping amplifier, two single channel analyzers (SCAs), and an on-board local area network node. The SCA windows and shaping amplifier gains are controlled by the host computer via the local area network. The main SCA is used to count the fission fragments in the measurement mode while the lower SCA is used to calibrate the system. When in calibration mode the electronics card is configured as a simple multi-channel analyzer by setting the lower SCA window to a minimum width and sweeping the window over the entire SCA dynamic range. A representative Cs-137 (662 keV) pulse height spectrum obtained by sweeping the lower SCA is shown in Figure 6.

![Figure 4. Block diagram of the detector/electronics module.](image-url)
Figure 5. Custom electronics card (a) and daughter network node (b).

Figure 6. Cs-137 (662 keV) pulse height spectrum obtained by sweeping the SCA. The characteristic ~90 keV and 186 keV peaks from a near-by U-235 source are also visible in the spectrum.
Network

The control and data communication between the master computer and the sensor nodes is provided by a peer-to-peer network over a twisted pair cable with a 78Kbits bandwidth capability. The network is connected in a free form topology, i.e. it does not matter which network branch the nodes are connected to. The network is used for two main functions: control of the sensor node parameters and transfer of count data collected by the node.

Each of the sensor nodes has a specialized microcontroller that performs network communication as well as sensor electronics setup and data collection. The master computer also has a network card capable of handling the sensor node microcontroller network protocol. The master computer sends control and setup commands over the network to which each node always respond with an acknowledgment (thus showing the health of the node). These commands are used by the node microcontroller to set present and default gain parameter values in electronic potentiometers on the sensor board, data collecting periods, to respond to request data transfer requests and to know when to start each data collection cycle. While the master computer sends control and setup command to the individual nodes, it provides the start signal simultaneously to all nodes, so that data collection begins at approximately the same instant in all nodes on the network.

Once the data collection cycle is started, every 100 milliseconds the node microcontroller reads the two internal counters, to which the detector signals are connected, and stores the count in internal memory. Every 5 seconds the data collected since the last transmission is formed into a packet and sent to the master computer. Between data collection cycles, the microcontroller also reads the temperature sensor (0.5 °C accuracy) to put temperature data in all the packets. To minimize data collisions, and subsequent retries, with data from other sensor nodes on the network, the data transmission from each node is staggered according to the node address in the network. The master computer counts the packets received by each sensor node, and at the end of normal transmission, if it misses any of the packets, it automatically sends a request to the appropriate node for the particular packet to be re-transmitted. Data packets from the nodes to the master computer are transmitted with authentication keys, so that the data is guaranteed to be the one sent from the particular node.

Conclusions

A detector and front-end electronics unit with secure data transmission has been designed and implemented in a fissile mass flow monitoring system. Because the system is designed to operate continuously for months in an industrial environment without operator intervention, self calibration and temperature compensation capabilities are built into the system. The detectors will be field deployed along with the rest of the fissile mass flow system in 1997.

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